UNITED NATIONS
OFFICE FOR OUTER SPACE AFFAIRS

Highlights in Space 2006

Prepared in cooperation with the International Astronautical Federation, the Committee on Space Research and the International Institute of Space Law

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UNITED NATIONS OFFICE AT VIENNA

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Progress in space science, technology and applications,
international cooperation and space law

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INTRODUCTION

This publication has been compiled from reports prepared for the United Nations Committee on the Peaceful Uses of Outer Space. It was first published in 1992 as part of the United Nations activities undertaken for the International Space Year, with the objective of making all countries aware of the benefits of sound space activities.

The first part of the report on space technology, space applications, international cooperation and space law, was prepared by the International Astronautical Federation (IAF) and covers the period from 1 November 2005 to 31 October 2006. In addition, the International Institute of Space Law (IISL) provided information for the section on international cooperation and space law. The second part, focusing on space science and recent progress made regarding space research, was prepared by the Committee on Space Research (COSPAR) of the International Council for Science (ICSU) and covers the period from 1 November 2004 to 31 October 2006. Many international experts from various specialized fields have contributed to the drafting of this comprehensive report. The information contained therein indicates a wide variety of ongoing space activities in national as well as international space programmes. A list of coordinators and contributors can also be found at the end of the report. This publication is available in English only.

This 2006 review of latest developments in space science, technology, space applications, international collaboration and space law has the aim to inform a broad worldwide audience of recent advancements in the manifold field of outer space.

We hope that “Highlights in Space 2006” can significantly contribute to all the efforts undertaken by the United Nations family, in particular the Office for Outer Space Affairs, in attempting to disseminate information on space activities and on the benefits involved to all nations of the world.

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PART ONE

HIGHLIGHTS IN SPACE TECHNOLOGY AND APPLICATIONS FOR 2006

I. OVERVIEW

Space Transportation. The second and final demonstration launch and the first commercial launch of the enhanced Ariane 5 Evolution Cryotechnique Type A (ECA) were both successful, with the vehicle lifting the heaviest commercial payload ever carried to the geostationary orbit, over 8 tonnes. That payload was exceeded by the ECA's next launch, which orbited 8.2 tonnes.

NASA announced major revisions in its next-generation launch infrastructure. Instead of using a Space Shuttle main engine (SSME) for the upper stage, the Crew Launch Vehicle (CLV), now named Ares-1, will employ the same updated J-2X engine that is planned for the heavy-lift cargo launch vehicle, and will use a more powerful 5-segment solid-propellant booster instead of the previously planned 4-segment rocket used on the Shuttle. The cluster of five redesigned space shuttle main engines, originally slated to boost the heavy-lift launch vehicle, named Ares-5, was replaced by the RS-68 engine that boosts the Delta-IV launcher. The first phase of the $8.15-billion contract for development of the Crew Exploration Vehicle (CEV), now renamed Orion, was awarded to Lockheed Martin on 31 August.

The U.S. State of New Mexico announced its intention to create a 5,500 hectare spaceport named Spaceport America, with $225 million worth of funds. The Virgin Galactic (a US company with a UK investor) selected the New Mexico spaceport as its base of operations for 6-passenger space tourist flights. Commercial flying is scheduled to start in 2009, using Scaled Composites-designed SpaceShipTwo vehicles, launched by White Knight Two aircraft, both owned and operated by the Virgin Galactic. The transition to New Mexico will occur as soon as the spaceport is ready, forecast as 2010.

Satellite Communications. Successful launch of the second Inmarsat-4 satellite increased coverage by the two Inmarsat-4 spacecraft to 86% of the Earth's land-mass, permitting Inmarsat (UK) to begin commercial operations of its next-generation two-way Broadband Global Area Network (BGAN). The U.S. Federal Communications Commission (FCC) subsequently granted Inmarsat the 60-day Special Temporary Authorizations (STAs) for five resellers, to market BGAN services in the U.S.

Satellite Navigation. The first of the two test satellites for Europe's Galileo navigation and position-location system, Giove-A, was launched and began its mission of demonstrating several key Galileo technologies. ESA subsequently signed a $1.1 billion contract with Galileo Industries to develop and build the four In-Orbit Validation (IOV) Galileo satellites, which are to be launched in 2008, on a six-month mission to confirm and demonstrate the Galileo system capabilities. The IOV obtained the commitment for full funding in August. On 1 December 2005 Ukraine joined the Europe's Galileo

programme.

Japan and India undertook first steps toward creating their own national navigation and position-location satellite systems. Japan's plans call for a three-spacecraft constellation to be launched in the beginning of 2009 and India announced a seven-satellite system, their first launch planned for 2008.

Earth Observations. European Space Agency (ESA) decided to proceed with development of the first three satellites in the Global Monitoring for Environment and Security (GMES) initiative, despite the commitment of only $850 million of the total $2.9 billion needed to build and launch them and to build the ground segment.

Studies of atmospheric data collected over the past 25 years by five different satellites and other instruments, reported in September, indicate a halt, and in some parts of the stratosphere a reversal, of the depletion of stratospheric ozone. The research team attributed this highly favourable and wholly unexpected phenomenon to the actions taken by the world's governments restricting the use of ozone-depleting chemicals following the 1987 Montreal Protocol.

The first in the new series of three U.S. weather satellites, the Geostationary Operational Environmental Satellite (GOES) N, was launched. It was the first payload, orbited by a Boeing Delta-4 rocket in 17 months.

The International Space Station (ISS). Space agency leaders announced a new schedule for completing the assembly of the ISS. The U.S. agreed to operate 16 Shuttle flights to launch the major elements of the station before retiring the Shuttle fleet. Europe's Columbus module is to be launched in 2007, and the three flights needed to launch Japan's Kibo Experiment Module are planned for 2007 and 2008. The crew of the ISS will increase to six, beginning in 2009.

Following the long hiatus after the loss of Shuttle Columbia in February 2003, assembly of the station resumed in September when Shuttle Atlantis delivered an 18-tonne segment of the main truss and 66 additional kW of solar power arrays. As reported by the United States National Aeronautics and Space Administration (NASA), it was for the first time since the Columbia failure, that the agency and its contractors had a technically sound foundation to continue the Shuttle operations needed to complete the ISS.

ESA's 10.3-tonne Columbus space laboratory for the ISS was handed over to the agency and shipped to the Kennedy Space Centre on 30 May, where it was pressure-tested for four months and then placed in storage, awaiting its planned launch in September 2007.

The first female space tourist, Iranian-born Anousheh Ansari traveled to the ISS in September aboard a Russian Soyuz vehicle for a one-week tour, during which she conducted a series of experiments for ESA.

Space Science Studies. On 31 October NASA Administrator Michael Griffin approved the Shuttle mission to repair and upgrade the Hubble space telescope, and initiated plans to conduct the mission in May 2008.

The Japan Aerospace Exploration Agency (JAXA) launched Japan's first infrared astronomy telescope Astro-F. Renamed Akari ("Light"), the spacecraft is studying protogalaxies, searching for as-yet undiscovered comets, and penetrating cosmic dust to study star formation. ESA collaborates with JAXA on the mission by providing ground and data-processing support. JAXA's Solar-B spacecraft began studies of the Sun following its launch in September.

Space Exploration. NASA's Mars Reconnaissance Orbiter (MRO), launched in August 2005, arrived on Mars on 10 March, was successfully inserted into an elliptical orbit, and was then aerobraked into its final operating orbit in September. The goals of this 2-year mission are to seek more evidence of current or past water or ice occurrences on the red planet and to identify the best locations for future landers or rovers to hunt for such evidence. MRO carries the most powerful camera ever to leave the Earth orbit.

The NASA/ESA Cassini spacecraft discovered what appears to be a subsurface reservoir or reservoirs of liquid water on Saturn's tiny moon Enceladus. The water, which may be only a few tens of meters below the surface, is apparently being heated by an as-yet unknown internal source within the satellite.

NASA's long-planned New Horizons mission to Pluto, its moon Charon, the two newly discovered satellites of Pluto, and several objects in the far-distant Kuiper Belt just outside the Solar System, left the Earth this year. As the fastest spacecraft ever launched, at over 56,000 km/hr, it passed the Moon just nine hours after launch. Its trip to Jupiter, where it will get a gravity assist in February 2007, will take only one year.

NASA's $212-million Stardust mission, launched in February 1999, returned its collection of cometary and interstellar dust particles to Earth following the highest-speed re-entry ever of any man-made object: 12.8 km/sec. The sample contained over a million particles bigger than a micron, many large enough to be visible to the naked eye, and hundreds of particle tracks left in the aerogel collector medium. The first analyses of the samples indicated that the particles had been formed at extremely high temperatures, such as might be found close to a star, and not in the frigid cold of the solar system's outer reaches where most short-term comets are born.

Russia announced an ambitious programme for resuming its robotic exploration of the Moon in June. Planned for its launch in 2009, the new Luna orbiting spacecraft will carry three separate lunar surface systems, which should be able to characterize Moonquakes caused by Earth's gravitational pull.

ESA's Venus Express mission was launched successfully and injected into a 9-day elliptical orbit around Venus. Following checkout of the spacecraft's seven

instruments, its science mission began on 4 June.

The ESA government ministers approved a five-year (2006 – 2010) budget package totaling $9.67 billion for the agency, including $708 million for the 2011 ExoMars project to explore Mars with a rover vehicle.

Japan's Hayabusa spacecraft, launched to the asteroid Itokawa in May 2003, landed on the asteroid twice to collect samples and will return to Earth in June 2010. Data from the encounter suggest that Itokawa is one of the youngest Solar System objects ever seen, made up of pebble-sized rocks packed solidly together.

Technology Advancement. Bigelow Aerospace (USA) launched a privately funded Genesis-1 expandable space module demonstration prototype into the orbit on 12 July, aboard a Russian/Ukrainian Dnepr rocket and successfully inflated it. Genesis-1 is a one-quarter-scale prototype for the full-scale 18-22 tonne manned Nautilus module, that Bigelow expects to employ as the first private-sector space station.

International Cooperation. The International Space Exploration Strategy Workshop, held in Washington, D.C., was the first in a series planned to develop a global exploration strategy for the Moon, Mars, and other destinations. Attended by over 200 representatives of space industries and 12 national space agencies, its focus was to generate ideas for activities on the surface of the Moon. This event in the series was followed in May by a workshop in Italy, sponsored by ESA and the Italian Space Agency.

Global Space Markets. Civil, military, and commercial organizations worldwide conducted a total of 56 orbital launches of payloads in 2005, compared to 54 in 2004. On the top of the list was Russia, with 18 government launches made, of which 3 failed to deliver their payloads to the planned orbits. Commercial companies operated a total of 28 launches, including one failure.

The $6.4-billion acquisition of PanAmSat by Intelsat received all necessary government approvals and was consummated on 3 July. The combined 2005 revenues of the merged companies, $2.031 billion in total, makes the new entity the largest fixed satellite service operator in the world, overtaking the former leader SES Global. The combined Intelsat-PanAmSat backlog amounted to $8.3 billion as of 31 March. The merger is claimed to offer the companies over $400 million in savings over the next five years.

The two winners of NASA's competition for the $500-million Commercial Orbital Transportation Services (COTS) contract to demonstrate systems for the delivery of cargo and, possibly crew members to the International Space Station, were Rocketplane Kistler and Space-X.

On 7 September Lockheed Martin (USA) sold its majority share of International Launch Services (ILS) to Mario Lemme, a member of the ILS Board of Directors.

Lockheed Martin will now take over commercial launch marketing and operations of the U.S. Atlas-V.

Russian president Vladimir Putin announced in June the merger of a number of Russian space enterprises into a new umbrella company, the Information Satellite Systems Company (ISS), owned by the government. ISS is expected to be formed at the end of 2006 or in the beginning of 2007. The Russian cabinet endorsed the action in July.

Virgin Galactic reported in August that nearly 200 people made deposits for reservations to fly two-hour suborbital missions on the company's SpaceShipTwo vehicles and that the company received $20 million of deposits in the region. Virgin Galactic is investing between $200 million and $240 million in developing the new venture. First commercial flight is planned for 2009, with the New Mexico spaceport (see section A above) expected to be ready for transition of operations in 2010.

II. SPACE TRANSPORTATION

A. Current Launch Activities

The Lockheed Martin Atlas-V that launched NASA's New Horizons spacecraft to Pluto on 19 January (see below) was the first of the Atlas V-500 series to employ five Aerojet (USA) 1.1-MN solid-propellant boosters and an oversized 5.4-m x 20-m fairing built by Contraves (Switzerland). It also carried a Boeing/ATK-Thiokol (USA) Delta-2 spin table with a third stage powered by a Star-48 solid-propellant motor, converting the normally two-stage Atlas-V into a three-stage vehicle for this mission.

The second and last demonstration launch of Arianespace's enhanced Ariane 5 Evolution Cryotechnique Type A (ECA) took place successfully on 16 November 2005, placing into geosynchronous transfer orbits the 6,116-kg Ka-band Spaceway-2 satellite, built for DirecTV (USA) by Boeing Satellite Systems International on its 702 bus, and the 1.975-kg Telkom-2, built for Indonesia's PT Telkom by Orbital Sciences on its Star-2 bus. The Ariane ECA model can carry 9,500 kg to a geosynchronous transfer orbit, considerably more than the total payload mass of 8,091 kg launched on 16 November, which was up to then the heaviest mass ever launched commercially into a geosynchronous transfer orbit.

The ECA's first commercial launch was conducted on 11 March, successfully orbiting the Spainsat X-band and Ka-band satellite and Eutelsat's Hot Bird 7A. The two spacecraft had a combined mass of 7.8 tonnes. The next launch of the ECA version, on 27 May, broke the payload-mass record the rocket had just established by orbiting the 5.5-tonne Satmex-6 (see below) and the 2.6-tonne Thaicom-5 for a total mass to a geosynchronous transfer orbit of 8.2 tonnes. On 11 August another ECA orbited the French military communications satellite Syracuse-3B, built by Acatel Alenia Space (France), and JSAT Corporation's (Japan) JCSAT-10, built by Lockheed Martin (USA). On 13 October an Ariane 5-ECA launched Optus D-1, built by Orbital Sciences

Corporation (OSC, USA) for Optus Networks Pty Ltd (Australia), and DirecTV-9S, built by Space Systems/Loral (USA) for DirecTV (USA).

Optus D-1, which replaces Optus B-1 in a geostationary-orbit slot at 160 degrees east longitude, is the first spacecraft to be built on OSC's new line of Star 2.4 platforms. It weighs 2.35 tonnes, carries 24 Ku-band transponders, and has 5 kW of onboard power. DirecTV-9S was built by Space Systems/Loral on the company's 1300 satellite bus. Weighing 5.53 tonnes and carrying 52 high-power Ku-band and two Ka-band transponders, it will deliver direct-to-home broadcast television to U.S. customers for 15 years from its geostationary-orbit slot at 101 degrees west longitude.

On 28 February a Proton-M/Breeze-M vehicle launched from the Baikonur Cosmodrome by International Launch Services (ILS) failed to deliver its Arabsat-4A payload into a proper orbit due to early shutdown of the vehicle's Breeze-M upper stage during its second firing. The satellite was separated from the stage and its solar panels were opened, but it was unable to be raised from its useless 500-km x 14,700-km orbit. It subsequently had to be declared a total loss, and was sent into a destructive atmospheric entry in March. It was the first failure of the Breeze-M stage, which was built by Proton prime contractor Khrunichev State Research and Production Space Center (Russia).

Cause of the loss was investigated by two teams, an ILS failure review board and a Russian State Commission, the latter of whom concluded that foreign object debris had blocked the flow of oxidizer to the vehicle's booster hydraulic pump, causing premature shutdown of the Breeze-M engine during the second of four planned burns. Corrective action to preclude a recurrence was taken in May, allowing Proton launches to resume on 5 August, with the launch of Eutelsat's Hot Bird-8 communication satellite (see below) by an International Launch Services (ILS) Proton-M from the Baikonur Cosmodrome.

A Sineva ballistic missile converted to space use was used to launch Russia's Kompas-2 Earth-observation satellite from the nuclear submarine Ekaterinberg in the Barents Sea on 27 May. Kompas-2 was intended for ionosphere analysis in earthquake forecasting, but its stabilization system malfunctioned shortly after it reached orbit, rendering the payload useless.

On 26 July the first stage of a Dnepr rocket launched from the Baikonur Cosmodrome failed 74 seconds after launch, destroying Ukraine's first Earth surveillance satellite and 17 other small payloads, which included Belarus's first satellite, the 750-kg BelKA; Russia's 87-kg Baumenets, developed by students at Bauman State Technical University; UniSat-4 and PiCPoT from Italy; and five P-Pod containers loaded with a total of 14 1-kg, 10-cm CubeSat spacecraft developed by 10 universities worldwide and including one from the Aerospace Corporation (USA). Dnepr and the SS-18 missile (also known as the RS-20, from which the Dnepr was derived), have a combined success rate of 97% over 165 launches. Root cause of the Dnepr failure was subsequently identified by launch service company ISC Kosmotras (Russia) as a malfunctioning hydraulic drive in the thrust-vectoring system on the first-stage combustion chamber, caused by failure of defective thermal insulation resulting from a manufacturing error.

The first launch of India's Geosynchronous Satellite Launch Vehicle (GSLV) from ISRO's new launch pad at the Satish Dhawan Space Center on Sriharikota Island ended in failure on 10 July. The third mission of the GSLV, designated GSLV F02, was carrying India's 2,200-kg Insat-4C direct-to-home broadcast satellite. The $54-million failure was caused by a complete loss of pressure in one of the GSLV's four liquid-propellant strap-on boosters, resulting in an asymmetric thrust that necessitated destruction of the vehicle by the range safety officer. The report of a 15-member team investigating the failure, issued on 6 September, indicated that the its root cause was a faulty fuel regulator in the booster, apparently due to an "inadvertent error in manufacturing which escaped the subsequent inspection and acceptance test procedures." Insat-4C was India's heaviest payload to date, with 12 Ku-band transponders and a planned service life of 10 years. The next GSLV launch, of the Insat-4CR (an identical replacement for the lost spacecraft), is scheduled for June 2007.

B. Development Activity

On 11 January NASA issued a "Call for Improvements" on proposals submitted for the Crew Exploration Vehicle (CEV; see Highlights 2005), now named Orion. Issued to the two bidding teams, headed by Lockheed Martin and Boeing/Northrop-Grumman, the Call specified anew for Orion to be a blunt-nosed capsule and dropped previous requirement for a liquid-oxygen/methane service-module engine. It also omitted the requirement for an Orion version able to deliver unpressurized cargo to the International Space Station, and reduced the Orion diameter from 5.5 m to 5 m.

On 8 September NASA awarded Lockheed Martin the $3.9 billion design, development, construction, testing, and evaluation contract for the first two Orion spacecraft. Production of additional vehicles is covered by a set of options worth up to $3.5 billion through 7 September 2019 that have yet to be negotiated. A further $750 million in engineering work, which NASA is expected to assign Lockheed Martin over the life of the contract, could bring its total value to $8.15 billion. The Lockheed Martin design for Orion features a main 33-kN-thrust engine burning hydrazine and nitrogen tetroxide, that will be derived from the Space Shuttle's Orbital Maneuvering System (OMS); a solid-propellant rocket for the launch abort system that would pull the crew to safety at any point on the way to orbit, and circular solar arrays instead of the customary rectangular shape. Orion's capsule-type crew module, which is designed to carry 6 crewmembers to the ISS and 4 to the lunar surface, is 5 m in diameter and has a total pressurized volume of 19 cubic meters.

Orion will have an expendable heat shield whose design and fabrication for the lunar re-entry mission will come from a two-phase development programme. Five teams were awarded Phase-1 development contracts in November 2005: Applied Research Associates, for phenolic-carbon materials; Boeing, for phenolic-impregnated carbon ablators; Lockheed Martin, for advanced carbon-carbon with calcium carbonate materials; and two Textron teams. On 21 September Boeing was awarded a 16-month phase-2 contract worth up to $14 million to support the design and development of the

Orion heat shield by the lead organization, NASA's Ames Research Center. Micrometeoroid and debris protection were to be provided by Nextel and Kevlar blankets. NASA was concerned, however, that the single Boeing programme was too risky for this critical component, so a draft request for proposals for alternative Phase-2 heat-shield approaches was issued by the agency on 1 November.

NASA announced on 20 January the reorientation of the Crew Launch Vehicle (CLV) configuration. Instead of using the Space Shuttle main engine (SSME) for the upper stage (see Highlights 2005), the CLV will employ the same updated J-2X engine that is planned for the heavy-lift cargo launch vehicle (CaLV). Because the J-2X's thrust (1.02 MN) is considerably lower than that of the SSME (2.28 MN), NASA also decided to use a more powerful 5-segment solid-propellant booster for the CLV, the same version to be used for the cargo launcher, instead of the previously planned 4-segment rocket used on the Shuttle. The 5-segment booster has already been ground-tested. The cost and development-time savings, promised by the common engine use on the two launch vehicles, was the main motivation for the changes. NASA subsequently also replaced the cluster of five redesigned SSMEs to boost the heavy-lift Cargo Launch Vehicle (CaLV) planned for Moon and Mars exploration missions by the RS-68 engine that boosts the Delta-IV launcher. The final decision was based by choosing between the options of high cost and proven reliability of the SSME on over 100 missions on one side and the much lower cost but fewer missions flown by the RS-68 on the other. As a consequence of these changes, on 27 March NASA extended the delivery date for CEV (Orion) proposals from 31 March to 31 August, adding $17.5 million to each of the two contractor teams' $60 million Phase-1 design contracts.

On 5 July NASA renamed the CLV Ares-1 and the CaLV Ares-5. Lockheed Martin announced on 13 September, following finalization of the company's contract for Orion, that it had teamed up with the Alliant Techsystems (ATK) and Pratt & Whitney Rocketdyne (PWR) to bid on developing and building the human-rated upper stage for Ares-1 following the expected issuing of a formal Request for Proposals by NASA in February 2007. ATK, which will be the team leader on the upper-stage development, has already been assigned responsibility for the Ares-1 booster, and PWR is developing the upper stage's J-2X engine.

On 9 May NASA announced six finalists in the competition for the $500-million Commercial Orbital Transportation Services (COTS) contract to demonstrate systems for delivery of cargo and possibly crew members to the International Space Station (see Highlights 2005). The companies selected were Andrews Space, Rocketplane Kistler, SpaceDev, Space Exploration Technologies (Space-X), SpaceHab, and Transformational Space Corporation (t-Space). The two winners, announced in August, were Rocketplane Kistler and Space-X.

The U.S. Federal Trade Commission (FTC) on 3 October approved Boeing's and Lockheed Martin's new joint venture United Launch Alliance (see Highlights 2005). As rationale for its decision, the FTD cited the benefits to U.S. national security by the merger of Boeing Delta-IV and Atlas-V production and sales to the U.S. government,

despite expectations that it will limit the competition and yield little or no savings to the government in the long run. The FTD approval is contingent on the two companies signing a consent decree, pledging them to cooperate with other providers and not freeze them out of spacecraft and launch competitions. Specifically, ULA must (1) cooperate on equivalent terms with all providers of U.S. government launch vehicles; (2) provide equal consideration and support to all launch service providers when seeking any U.S. government delivery-on-orbit contract, and (3) safeguard competitively sensitive information obtained from other space vehicle and launch service providers. Formal creation of the new venture by the two companies awaits the finalization and signing of over 100 closing documents.

The U.S. State of New Mexico's Economic Development Department, on 11 January 2006, granted a "right of entry" permit for 5,500 hectares of state land to New Mexico's Spaceport Authority for the Southwest Regional Spaceport, now renamed Spaceport America. The state's Governor Richardson Investment Programme for local New Mexico transportation projects was announced on 9 January, which called for $25 million to support roads at the new spaceport, as part of an overall spaceport appropriation of $110 million, approved by the state legislature and signed by Governor Richardson on 1 March. Funding committed to the spaceport during the design and construction period totaled $225 million, including grants from the U.S. government and contributions from industry as well as the abovementioned state appropriation. The first launch from the new spaceport, a UP Aerospace Spaceloft XL single-stage solid-propellant sounding rocket, carrying multiple student payloads took place on 24 September. Virgin Galactic selected the New Mexico spaceport as its base of operations for 6-passenger space tourist flights. Commercial flying is scheduled to start in 2009, using Scaled Composites-designed SpaceShipTwo vehicles, launched by White Knight Two aircraft, both owned and operated by Virgin Galactic, and transition to New Mexico as soon as the spaceport is ready is forecasted for 2010.

The second inland U.S. spaceport was approved by the Federal Aviation Administration's Office of Space Transportation on 12 June, with the granting of an FAA Launch Site Operator's license to the Oklahoma Space Industry Development Authority. The Oklahoma Spaceport is located at the Clinton-Sherman Industrial Airpark near Burns Flat, Oklahoma, along with a corridor defined within the U.S. National Airspace for space flight operations. It was the first overland space launch corridor outside of restricted military airspace ever to be approved by the FAA. Rocketplane Limited, which merged with Kistler to form Rocketplane Kistler (RpK), is planning to conduct its space tourism operations from the new spaceport.

On 5 January the U.S. Federal Aviation Administration (FAA) issued proposed rules for suborbital space tourist operations. The proposed rules include specifications for pilot licensing, medical standards for the crew, vehicle flight testing, and training for emergency operations by space tourists, whom the FAA now officially designate as "space flight participants."

The maiden launch of Space Exploration Technologies' (Space-X's) Falcon-1 rocket from Omelek Island in the Kwajalein Atoll was scrubbed on 19 December 2005 due to the damage, that occurred to the first-stage fuel tank while the fuel was being pumped out during a launch hold, imposed by high winds. The mishap was caused by failure of an electronic component in a tank pressurization system valve, creating a vacuum that deformed the tank. After several additional delays, the Falcon-1 launch finally took place on 24 March, but failed shortly after liftoff. Its 20-kg payload, the experimental FalconSAT-2 built by students at the U.S. Air Force academy (see below), was lost.

The failure was apparently caused by a fuel leak that started on the ground four minutes before liftoff. The subsequent fire, clearly visible around the top of the engine, started 25 seconds after launch and damaged the helium fuel-tank pressurizing system, causing the main engine to shut down 29 seconds after liftoff. Root cause of the failure, investigated by a Pentagon team of two former U.S. Air Force officers and a Space-X team, was first thought to have been due to a ground-processing error: improper tightening of a nut on a pipe fitting that had been loosened for a pre-launch avionics test. However, it was later determined that the nut had cracked due to subsurface intergranular corrosion, not detectable by visual inspection. The corrosion was most likely due to long exposure of the vehicle to the sea air at Omelek Island from November 2005 until the actual launch date. Future Falcon-1 vehicles will use stainless steel nuts instead of aluminum ones, cover the engine with a shroud while on the pad awaiting launch, fireproof all sensitive plumbing, purge the engine bay with nitrogen, and cover all engine-bay openings with fireproof blankets. Space-X will also incorporate additional automation of their health-monitoring systems, increasing by an order of magnitude the software anomalies that can trigger a launch abort.

A drop and landing test of Boeing's X-37 Approach and Landing Test Vehicle (ALTV) was conducted on 7 April. After release from its White Knight carrier plane at 11.3 km altitude, the ALTV conducted its autonomous approach and landing sequence flawlessly, but then exceeded the expected distance to be traveled on the runway, rolling off its end and damaging the craft's nosewheel. The programme is sponsored by the U.S. Defense Advanced Research Projects Agency (DARPA), with support from NASA.

On 14 June AirLaunch LLC drop-tested a 30-tonne surrogate for the company's QuickReach rocket from a U.S. Air Force C-17 cargo aircraft based at Edwards Air Force Base. It was the heaviest single object ever dropped from a C-17. A month later AirLaunch drop-tested an even heavier full-scale simulated rocket weighing 32.7 tonnes from an altitude of 9.7 km at a C-17A carrier aircraft speed of 370 km/hr. The tests were part of a series in the U.S. Defense Advanced Research Projects Agency's (DARPA's) Falcon small-launcher programme, to develop a vehicle which is able to carry a 450-kg payload to low Earth orbit within a day's notice for under $5 million.

Blue Origin (USA) filed an Environmental Impact Statement with the U.S. Federal Aviation Administration on 26 July, outlining its plans for space tourism operations from its Culbertson County launch site in the U.S. state of Texas. The 15-m

tall New Shepard rocket, powered by a 1-MN-thrust peroxide-kerosene engine, would carry three paying passengers to an altitude of 98 km beginning in 2010 after a two-year series of test flights.

The Jules Verne, the first flight model of Europe's Automated Transfer Vehicle (ATV) for servicing the International Space Station (ISS), successfully completed three 30-second acoustical tests at ESA's Estec technology center in Noordwijk, Netherlands during the first week of July. The tests were conducted on the 11-tonne ATV, which will weigh 20.5 tonnes when loaded with fuel and supplies, using over 400 sensors to measure the ATV's response to the simulated acoustic environment of an Ariane-5 launch.

Following several abortive attempts to involve ESA in its winged Klipper project for transportation of human crew, Russia secured ESA participation on 22 June, after modifying its approach to a more modest programme using an enlarged Soyuz capsule. The new Advanced Crew Transportation System (ACTS) gained the support of the ESA members France and Germany to cooperate with Russia in an 18-month long effort to address outstanding ACTS issues, primarily the division of development activities between Russia and the European countries and the issues of technology transfer. On 21 July ESA approved a total funding envelope of $23 - $28 million for the study, which is expected to be spearheaded by France and Germany. Japan and Italy have also indicated interest in joining ACTS. Initial plans suggest the use of both the ESA launch site in Kourou and the Baikonur Cosmodrome in Kazakhstan, both of which could be compatible with Soyuz-derived launchers.

On 16 May ESA approved development of the Intermediate Experimental Vehicle (IXV), to demonstrate thermal protection, flight control, and other systems needed for a next-generation reusable or partly reusable vehicle. The agency's Future Launcher Preparatory Programme (FLPP) committed up to $71 million of its $380-million budget on the IXV through 2008. Launch by a Vega rocket is planned for 2010.

Another FLPP project, initiated in 2001, was launched this year by Italy's CIRA aerospace research centre, with the rollout in late April of its Unmanned Space Vehicle (USV-1) demonstrator. USV-1 drop tests from the L. Broglio air base in Sicily were conducted from mid-June through August. On its first flight, the 1,250-kg unpowered demonstrator was dropped from a 200-m x 300-m balloon at an altitude of 25 km. During its two-minute glide, it attained transonic speed and conducted several manoeuvres, before parachuting into the sea near Sicily. An all-Italian team, composed of Alcatel Alenia Space Italia, Carlo Gavazzi Space, Space Software Italia, Technosystems Developers,and Vitrociset was involved into building of the two USV flight-test articles (the second is under construction).

Italy's USV programme, which is planned to run until 2012 at a total cost of about $225 million, is being followed up by the USV-X Unmanned Space Vehicle Experimental project, which will entail two reusable test vehicles to be launched from Kourou into 200-km orbits by Vega rockets beginning in 2011. Design of the 900-kg USV-X began in September.

III. ROBOTIC EARTH ORBITAL ACTIVITIES

A. Telecommunications

(1) Fixed-Base Communication Systems

PanAmSat's 43rd satellite, the last prior to the company's acquisition by Intelsat, was launched by a Sea Launch Zenit-3SL from Sea Launch's equatorial Pacific Ocean Odyssey platform on 18 June. The 4.64-tonne Galaxy 16, built by Space Systems/Loral (USA), carries 24 C-band and 24 Ku-band transponders to provide high-definition and Internet-protocol television and broadband Internet access from its geostationary-orbit slot at 99 degrees west longitude, where it has replaced PanAmSat's Galaxy-4R. There were two unique characteristics of the launch: its accuracy of orbital placement was sufficiently high to allow an expected 20-year service life (in comparison to the contract-specified 15 years), moreover, the satellite and launch were insured for the lowest premium in the past five years. Total cost of the spacecraft, launch, and insurance was $172 million.

On 21 June the U.S. Federal Communications Commission (FCC) issued a Notice of Proposed Rulemaking that would open additional spectrum in the 17.3 – 17.7 GHz and 24.75 – 55.35 GHz bands for Direct Broadcast Services (DBS). If adopted, the allocation will become effective on 1 April 2007. Four companies subsequently filed applications for licensing in the new bands: Echostar (USA), DirecTV (USA), Intelsat (Bermuda), and Pegasus (USA), a reseller of DirecTV services.

On 21 September Intelsat's IS-802 satellite, serving Africa and the Indian Ocean region from a geostationary-orbit slot at 33 degrees east longitude, suffered a power failure similar to the January 2005 failure of an Intelsat predecessor spacecraft of the same design, IS-804, launched in 1997, the same year as IS-802. Both spacecraft were built by Lockheed Martin on the company's 7000 bus, the same platform as two other Intelsat satellites currently operating satisfactorily in orbit, IS-801 and IS-805. Unlike IS-804, whose failure was sudden and total, controllers have been able to maintain communication with IS-802, which is under control and accepting commands. The January 2005 failure was concluded in November 2005 to have been caused by an electrostatic discharge that impacted the high-voltage power system.

Eutelsat's Hot Bird 3 also suffered an anomaly on 3 October that caused substantial damage to a solar array and reduced power to the spacecraft, which was built by EADS Astrium and launched in 1997. It was subsequently moved from its geostationary-orbit slot at 13 degrees east longitude to one at 10 degrees and renamed Eurobird-10. With 6 years of design life still remaining, the satellite will continue to operate using a reduced number of its 20 Ku-band transponders. Another anomaly, occurring on Eutelsat's W-3A satellite (also built by EADS Astrium), caused the spacecraft to switch to a Sun-pointing "safe" mode following a routine maneuver on 9 October. W-3A's 44 Ku-band and two Ka-band transponders were off line for 11-1/2 hours but were then restored to normal control. Launched in 2004, the satellite serves

Europe, sub-Saharan Africa and western Asia from its geostationary-orbit slot at 7 degrees east longitude.

Ciel Satellite Communications Inc. (Canada) placed an order with Alcatel Alenia Space (France) on 17 March for the all-Ku-band Ciel-2 satellite, the bulk of whose transponders Ciel has agreed to lease to EchoStar (USA) for direct-broadcast television service in the U.S. The 6-tonne Ciel-2, planned for launch in 2008 to Ciel's geostationary-orbit slot at 129 degrees west longitude, will also provide service to Canada. Bids to build the 11 – 12 kW satellite had also been received by Ciel from Lockheed Martin Commercial Space Systems and Space Systems/Loral, both USA. EchoStar also plans to be the anchor customer for Mexico's new QuetzSat satellite, expected to be ordered later this year. QuetzSat is currently using EchoStar-4 in a Mexican geostationary-orbit slot at 77 degrees west longitude, having received U.S. Federal Communications Commission approval on 19 April to take title to the satellite and lease it to EchoStar for direct-broadcast television service to U.S. customers.

Comsat International (USA) signed a lease agreement on 20 April to provide 6,000 Brazilian lottery outlets and banks with very small aperture terminal (VSAT) broadband network services via Loral Skynet do Brasil's Estrela do Sul-1 (Telstar-14) satellite. The network is being operated by Comsat subsidiary Visat for Brazil's government-owned Caixa Economica Federal.

On 23 February Turkey placed an order for Turksat-3A with Alcatel Alenia Space (France). The contract, for a Spacebus 4000-B2 platform carrying 24 Ku-band transponders, also includes modernization by Alcatel of Turkey's existing ground network. Scheduled for launch early in 2008 to a geostationary-orbit slot at 42 degrees east longitude, the 8-kW satellite will be used by operator Turksat SA for telecommunications and television broadcast services to customers in southern Europe and central Asia.

The 3,680-kg Spainsat X-band and Ka-band satellite was launched by the first commercial flight of the Ariane 5 ECA on 11 March into a geostationary-orbit slot at 30 degrees west longitude. Owned by the government-industry consortium Hisdesat, it is being used by the Spanish Ministry of Defense for secure communications in conjunction with the Xtar-Eur satellite launched in February, and also by Xtar-LLC (Spain and the U.S.) for government customers outside of Spain. The 5.7-kW satellite carries 13 X-band transponders and one Ka-band transponder, and is expected to operate for 15 years. It and Xtar-Eur together cost Hisdesat $500 million, including their launches.

Satmex-6 was launched from Kourou on 27 May by an Ariane 5 ECA rocket along with Shin Satellite's Thaicom-5. The 5.5-tonne spacecraft, built by Space Systems/Loral on the FS-1300 bus, carries 36 C-band and 24 Ku-band transponders and is being used by owner/operator Satmex (Mexico) to deliver switchable telecommunications and broadcast services to Mexico, the U.S., and Central America from its geostationary-orbit slot at 113 degrees west longitude. Satmex's last satellite, Satmex-5, was launched over 8 years ago, but an $880-million debt restructuring of the company on 13 April, allowed Satmex to

finance the $270-million cost of Satmex-6.

Eutelsat's 4,100-kg Hot Bird 7A, orbited on 11 March by the same launcher that lifted Spainsat, carries 38 Ku-band transponders and is providing direct-broadcast television from a geostationary-orbit slot at 13 degrees east longitude, where it replaced Eutelsat's Hot Bird 1. The spacecraft was built by Alcatel Alenia Space (France), and has a projected operating life of 15 years. Hot Bird 8, launched from the Baikonur Cosmodrome by the Proton-M return-to-flight mission on 5 August (see above), was subsequently placed in Eutelsat's geostationary-orbit slot at 13 degrees east longitude to provide Eutelsat with additional capacity and redundancy, allowing Eutelsat to move the older Hot Bird 3 to a new location. The 4.9-tonne Hot Bird 8 carries 64 Ku-band transponders.

SES Global's Astra-1KR satellite was launched from Cape Canaveral aboard an International Launch Services (ILS) Atlas-5 on 20 April. The 4.33-tonne spacecraft, built by Lockheed Martin Commercial Space Systems (USA), was placed in SES Global's geostationary-orbit slot at 19.2 degrees east longitude, where it replaced Astra-1B and Astra-1C and is now co-located with seven other satellites. It began direct-broadcast television service to customers in Europe in mid-June via its 32 Ku-band transponders. Astra-1KR's design service life is 15 years. The launch marked the Atlas rocket series' 79th straight success and the 100th launch by ILS.

A new player in the satellite communications industry, Avanti Screenmedia (UK), completed financing early in May for a small Ka-band satellite to distribute high-speed internet service in areas not covered by cable or digital service lines (DSL), a customer niche not served by the established satellite companies. Avanti ordered the Hylas satellite from Astrium Satellites (formerly EADS Astrium) on 15 May; it is planned to be launched into the British geostationary-orbit slot at 33.5 degrees west longitude late in 2008. British regulatory approval was granted in August 2005. Astrium will provide the telecommunications payload; the bus for the spacecraft, which is expected to weigh less than 3 tonnes, is being built by the Indian Space Research Organization (ISRO). Total cost of the project is estimated at $137 million. Hylas will carry 24 54-MHz Ka-band transponders for broadband transmissions and four 54-MHz Ku-band transponders for television service. Astrium plans to use the satellite for in-orbit validation of technologies applicable to flexible, reconfigurable payloads, derived from company-funded research.

On 24 April Alcatel Alenia Space (France) and Orbital Sciences Corporation (OSC, USA) signed a contract to build the AMC-21 communications satellite for SES Americom. The contract was notable since it facilitates the first project that the two companies, who have up to now been competitors, are conducting jointly. Alcatel will supply the payload and serve as prime contractor; OSC will provide the Star-2 platform and will be responsible for integration and testing. The 2,500-kg AMC-21 will carry 24 Ku-band transponders to provide broadcast television for the U.S. Public Broadcasting Service. It is scheduled for launch in mid-2008 into a geostationary-orbit slot at 125 degrees west longitude, and has a design lifetime of 16 years.

Alcatel (France) announced on 3 October that the company has joined with Maroc Connect (Morocco) to deploy a next-generation satellite communications network in Morocco, covering five major regions of the country beginning in early 2007. Total investment in the system is $32 million.

The growing European interest in small satellites was reflected in a 29 – 30 June workshop on the Small Geo concept, originated by Germany as a platform for future small geostationary-orbit commercial communication satellites. Initial development funding of $125 million for Small Geo was committed by several ESA governments in December 2005 to a team led by OHB-System AG (Germany). Another $125 million is to be committed by industry partners. Small Geo would involve satellites in the 2 – 2.5-tonne class with up to 300 kg of payload, up to 3 kW of power, and a 15-year service life, a category which has been dominated by Orbital Sciences Corporation (USA). Launch of the first flight model is envisioned in 2010. Participants in the workshop, which was organized by DLR (Germany), were operators Eutelsat, SES Global (Luxembourg), Avanti Screen Media Group (UK), Telenor Satellite Services (Norway), and Hispasat (Spain).

Following the loss of Arabsat-4A in February's Proton-M launch failure, Arabsat ordered on 6 June a replacement satellite, Badr-6, from Astrium Satellites (formerly EADS Astrium). The 3.4-tonne Badr-6 (also called Arabsat-4AR), to be built on Astrium's Eurostar-3000 platform with an Alcatel Alenia Space electronics payload, will carry 24 C-band and 20 Ku-band transponders to Arabsat's geostationary-orbit slot at 26 degrees east longitude. A contract with Arianespace was signed on 6 July for launch aboard an Ariane-5 in the first half of 2008, along with a contract for launching Arabsat-5A in 2009 or 2010.

Kazakhstan's first commercial satellite, the 1,380-kg KazSat-1, was launched from the Baikonur Cosmodrome into Russia's geostationary-orbit slot at 103 degrees east longitude on 18 June by a Russian Proton-K rocket. Designed by the Russian Satellite Communications Company and built by the Khrunichev State Research and Production Space Center (Russia), KazSat-1 carries twelve 72-MHz Ku-band transponders to provide television and communications services in Kazakhstan, central Russia, and surrounding central Asia areas. Kazakhstan's new national; satellite operator KazSat assumed control of the spacecraft on 18 October.

JCSAT-9, a 4.4-tonne satellite owned by JSat Corporation (Japan), was launched into a near-perfect geosynchronous transfer orbit on 12 April by a Sea Launch Zenit-3SL rocket. The spacecraft, built by Lockheed Martin Commercial Launch Systems, carries 20 Ku-band and 20 C-band transponders for fixed communication services and one S-band transponder for mobile communications. The precise launch should enable JSAT-9 to exceed its contract lifetime of 12 years by 50%, to 18 years, from its geostationary-orbit slot at 132 degrees east longitude. It will replace N-STARa, which had been launched in 1995 and was at the end of its 10-year service life. JCSAT-9 was originally scheduled to be launched by an Ariane-5, but was switched to Sea Launch because the Ariane manifest was full. The switch was facilitated by the agreement between Sea

Launch and Ariane.

Venezuela ordered its Simon Bolivar communications satellite from China's Great Wall Corporation on 10 November 2005. The 6-tonne spacecraft, the second Chinese satellite export, is to carry 24 transponders and is planned for launch in 2008. Nigeria announced that services from the first Chinese satellite sold for export, NigComSat-1, will be marketed by a new company, NigComSat Ltd., created on 31 August. NigComSat-1 was ordered in December 2004 and is planned for launch aboard a Chinese Long March 3B in January 2007. Contract terms finalized in January call for the Nigerian Space Research and Development Agency to pay 20% of the satellite's cost and launch, with the Chinese Export Import Bank financing the balance.

On 20 February the joint European – Indian venture, which was formed last year by EADS Astrium and ANTRIX, the commercial arm of the Indian Space Research Organization (ISRO), won its first contract to build a 3-tonne communications satellite, Eutelsat's W2M, planned for launch in 2008 to Eutelsat's geostationary-orbit slot at 10 degrees east longitude. The spacecraft, which is to be built on a bus, based on the flight-proven I-3K model used for ISRO's Insat 4A, will carry up to 32 Ku-band transponders. Insat-4A was launched by an Ariane-5 launch vehicle from Kourou on 22 December 2005 and was fully commissioned in January. It carries 12 high-power Ku-band and 12 C-band transponders to deliver direct-to-home television services from its geostationary-orbit slot at 83 degree east longitude, where it is co-located with Insat-2E and Insat-3B.

Subsequently, this joint European – Indian venture also received an order to build the 2-tonne HYLAS (Highly Adaptable satellite) for Avanti Screen Multimedia PLC (UK), which is to deliver broadcasting, multimedia and broadband services. For both of these projects, EADS Astrium will construct the communications payload, while the Antrix Corporation will build the bus, integrate and test the spacecraft, and will be in charge of early in-orbit operations.

On 17 April the Indian Space Research Organization (ISRO) opened a new satellite integration and test facility at ISRO's Satellite Centre in Bangalore. The new $66-million Satellite Integration and Testing Establishment is equipped with an antenna test facility, a thermal vacuum test chamber and an assembly facility. It is expected to enable ISRO to reach its goal of processing six satellites simultaneously: two for communications, two for remote sensing, and two for foreign clients. ISRO's Insat-4B communications satellite, scheduled for launch by an Ariane-5 rocket in 2007, is being assembled and integrated at the new facility.

India approved plans on 29 September to invest $133 million in an all-Ku-band direct-to-home (DTH) television broadcast satellite, Insat-4G. This satellite, which will be designed and built by ISRO in 24 months, will carry 18 high-power Ku-band transponders for DTH service along with a navigation payload to serve as a backup to one scheduled for launch in 2007 on the GSat-4 satellite. ISRO has been authorized to spend up to 62% of the project's budget on imported components. Insat-4G is planned for launch in 2008 or 2009.

Shin Satellite (Thailand) signed a cooperative agreement with China Satellite Communications Corporation (China Satcom) on 24 April to deliver broadband service to Chinese corporations via Shin's IPSTAR/Thaicom-4 satellite, which was launched last year to provide broadband communications in Asian rural areas. The two organizations also opened a new broadband satellite gateway in Beijing on 24 May to service northern China. Additional gateways in Shanghai and Guangzhou were opened later in the year. China Satcom's affiliates include China Telecommunications Broadband Satellite Corporation, China Space Mobile Satellite Communication Company, and China Telecom (Hong Kong) Chinasat Corporation.

China's latest and largest communication satellite, a third-generation DFH-4 model, was launched in late October by a Long March 3B rocket from the Xichang Satellite Launch Center into a geostationary-orbit slot at 92.2 degrees east longitude. Built by the China Academy of Space Technology (CAST) for direct-broadcast television provider Sinosat (China), Sinosat-2 weighed 5.3 tonnes at launch and carries 18 36-MHz Ku-band and four 54-MHz Ku-band transponders in its 800-kg payload. The spacecraft generates 10 kW end-of-life power and has a design service life of 15 years, twice that of the predecessor DFH-3 platforms. The DFH-4 bus design can grow to 5.6 tonnes, carry 38 Ku-band and 16 C-band transponders, and generate 14 kW of power.

On 21 June Vietnam announced that its first communications satellite, Vinasat-1, is being built by Lockheed Martin Commercial Space Systems (USA) on Lockheed Martin's A-2100 bus at a total cost of $270 million, including launch, insurance and two ground control centers. The 2,800-kg satellite, to be launched by an Ariane-5 rocket to Vietnam's geostationary-orbit slot at 123 degrees east longitude, will carry both C-band and Ku-band transponders. Its design service life is 15 years.

Koreasat-5 was launched to a geostationary-orbit slot at 113 degrees east longitude over the Asia-Pacific region on 21 August by a Sea Launch Zenit-3SL rocket from Sea Launch's Odyssey sea-based platform. The 4.5-tonne satellite carries 24 Ku-band transponders, among them 12 providing digital television broadband multimedia services and 12 to replace Koreasat-2's civil services; the 12 Ka-band transponders are being used by the South Korean military. The satellite was built by Alcatel Alenia Space (France) on the company's Spacebus 4000 C1 platform for South Korea's KT Corporation and South Korea's Agency for Defense Development. It will join South Korea's new high-capacity Spacecom System over the Asia-Pacific region.

SingTelOptus (Australia) announced on 8 August the signing of a new agreement with Gilat Satellite Network (Israel) to extend the broadband services of Gilat's SkyEdge division to rural Australia and New Zealand, as the first stage in Australia's Rural Broadband Subsidy plan. Gilat will provide Optus with several thousand Very Small Aperture Terminals (VSATs) and other SkyEdge hub infrastructure for the rural customers to have access to satellite-based voice, data and video broadband service. This development is supplementary to over 12,000 Gilat VSATs and several hubs, which have been delivered to Australia by Gilat since 2004.

(2) Mobile Communication Systems

The second Inmarsat-4 satellite was launched successfully on 8 November 2005 by a Sea Launch Zenit-3SL to its geostationary-orbit slot over the Americas at 53 degrees west longitude. The 5.96-tonne Inmarsat-4 F2 was built by EADS Astrium (France), which also built Inmarsat-4 F1, launched last year to a slot over the Indian Ocean at 64 degrees east longitude. The F2 launch increased coverage by the two Inmarsat-4 spacecraft to 86% of the Earth's land-mass, permitting Inmarsat (UK) to begin commercial operations of its next-generation two-way Broadband Global Area Network (BGAN) in December 2005, with full operational capability available in March. 14,000 BGAN terminals built by vendors Hughes Network Systems (USA), Nera AS (Norway), and Thrane & Thrane (Denmark) were delivered in June. The third and final Astrium-built Inmarsat-4 was launched by an International Launch Services Atlas-5 rocket from Cape Canaveral late in 2006.

On 15 May Inmarsat was granted 60-day Special Temporary Authorizations (STAs) by the U.S. Federal Communications Commission (FCC) for five resellers to market BGAN service in the U.S. The STAs went to BT Americas, Inc; France Telecom Mobile Satellite Communications; MVS USA; Stratos Global; and Telenor Satellite Services.

The U.S. Federal Aviation Administration approved on 4 January the Worldspace's second Afristar digital audio service (UARS) satellite, planned to service European customers following its 2008 launch. Afristar-2 will add 150 channels to the 50 now available from Afristar-1. Worldspace has yet to receive terrestrial repeater licenses and agreements with automobile manufacturers. Afristar-2 will cost Worldspace no more then $100 million if a unit stored at the manufacturer EADS's Toulouse facility can be used. An all-new satellite would cost $200 - $250 million, plus a-like amount for the ground segment and new receivers. Worldspace projects 4.7 million subscribers by 2014.

On 9 May the company obtained a license to deliver a 50-channel subscription radio service in Italy beginning in 2007, using Worldspace's AfriStar-1 satellite and a terrestrial gapfiller network in cooperation with New Satellite Radio. The license for 12.5 MHz of radio spectrum, issued to Worldspace Italia by Italy's Ministry of Communications, provides Worldspace with an all-important regulatory foothold in Europe. As of 31 March, the company had about 150,000 subscribers, most of them in India.

On 11 January Mobile Satellite Ventures (MSV; USA) ordered three large satellites from Boeing Satellite Systems International (BSSI, USA). The satellites are going to be built on the Boeing's 702 bus and expected to weigh 5.5 tonnes each, delivering 11 kWe end-of-life power and carrying 22-m diameter L-band mesh antennas. The contract, valued at $500 million to $1 billion depending on options, was BSSI's first commercial satellite order in three years. The first satellite is planned for launch in late 2009, with the second and third to follow 5 and 10 months later. They will each provide

10,000 cellular-telephone-type voice links to customers in North and South America, with handsets priced at no more than $7 higher than standard cellular telephones. Total system cost, which covers the three satellites, their launches, insurance, and the ground segment (including the ground tower network called the "ancillary terrestrial component" – ATC), is expected to be within the $500-million – $1 billion range. Under a $57-million contract with BSSI, Viasat (USA) will provide the ground-based hardware to form spot beams that will enable hand-held telephones to communicate with the satellites.

Intelsat and Connexion by Boeing signed two multiyear service agreements on 2 February for mobile information services to ships at sea in the mid-Atlantic and Indian Oceans using Intelsat 705 and 706 satellites, beginning in the first quarter of this year. Boeing however announced on 24 June that it was seeking a buyer for Connexion, because the market for airborne internet services had not developed satisfactorily. Since no buyers emerged, Boeing announced in mid-August to write down all Connexion assets and terminate the business at the end of the third quarter, paying SES Global $70 million on 3 October for early termination of its satellite leases.

Two weeks after the announcement from Boeing, on 30 August, Ryanair (UK) announced that they will adopt the onboard mobile communications system of OnAir (Switzerland) to provide passenger use of satellite-linked mobile telephones and hand-held data devices on their entire short-haul fleet of aircraft. Fifty Boeing 737 aircraft are to be fitted with Mobil OnAir equipment in the second half of 2007 and the balance of the Ryanair fleet (150 aircrafts) will be fitted out in 2008. OnAir employs Inmarsat (UK) L-band satellite capacity for the services.

Passengers on United Airlines (USA) flights began receiving up to 19 channels of XM Satellite Radio music in March under an agreement between the companies announced on 2 March.

As a measure to ameliorate the interoperability issues encountered during the hurricanes of 2005, Iridium Satellite LLC (USA) announced on 2 May that deployable emergency communications packages, designed for first responders, will be available for the forthcoming hurricane season. These packages can include satellite telephones, voice and data transceivers, solar-powered chargers, docking stations and other tools that can be used for asset tracking, directing equipment suppliers and other needs. The hardware and services of these packages can be customized by first responders to meet their individual needs; they can also overcome interoperability issues by using their Iridium telephones to communicate with the existing radios, satellites and mobile telephones operated by Iridium's partners.

Globalstar (USA) placed a $9.7-million deposit with Alcatel Alenia Space (France) on 10 October to begin work on replacement spacecraft for its 48-satellite low-Earth-orbit constellation. The company is seeking initial public offering of $100 million to finance the new fleet, which is planned for its first launch in 2009. An additional $100 million in bank credit has been arranged, plus a commitment of $200 million from Globalstar's current owner, Thermo Capital Partners (USA), who brought the company out of

bankruptcy in 2003. Total cost of the replacement system, including construction of the 650-kg satellites, their launches, and insurance, was estimated by Globalstar at $1 billion to $1.2 billion between 2007 and 2014. The balance of financing needed for the new fleet is expected to come from $600 million in operating revenues of the current and new fleets between 2007 and 2014. Eight first-generation Globalstar satellites, built by Space Systems/Loral (USA), are planned for launch aboard two Russian Soyuz rockets in 2007 at a cost of $110 million. Service life of the new-generation spacecraft is expected to be 15 years, double that of the original satellites, whose approaching end-of-life constituted the primary rationale for proceeding with the replacement fleet. They are expected to cost about $15 million each. Forty of the original forty-nine 450-kg Globalstar satellites are still operational. Globalstar prices its service at $0.55/minute, in comparison with $0.65 by Thuraya (Abu Dhabi), $0.85 by Iridium (USA) and $1.25 by Inmarsat (UK).

On 23 March testing was conducted at France's national fire-fighters' school ENSOSP on a prototype of a 400-kg "humanitarian toolbox" called Emergesat. A French industry consortium led by Alcatel Alenia Space designed and built the prototype, which uses terrestrial wireless and high-speed satellite links to transmit video and data communications to disaster areas. It will be transported by helicopter or aircraft to the centers of crisis areas where existing communications links are either nonexistent or have been destroyed. It carries its own gasoline-powered electric generator, a satellite dish and antennas, able to communicate with standard cellular telephones within a 2-km radius. Operational-unit data rates will be up to 2 MB/sec upload and 10 MB/sec download, sufficient for videoconferencing and downloading of maps to crisis-area worker teams.

A consortium led by Alcatel (France) received a $47-million package of grants and loans on 25 April from France's Industrial Innovation Agency (AII) to develop and deploy a hybrid satellite-terrestrial S-band (2.2 GHz) mobile television system. The Unlimited Mobile TV (TVMSL) project will provide television service to cellular telephones and other mobile devices in France. AII expects the system to expand throughout Europe and elsewhere. The goal of the initial effort, whose total cost is expected to be about $120 million, is to validate the basic system architecture and the technologies needed for the ancillary terrestrial component (ATC). The ATC infrastructure is expected to be in place in 2007, with the full hybrid system to become operational in 2009.

On 21 April Telespazio SpA (Italy) announced the signing of an agreement to deploy and operate a mobile communications network for Italy's Fire Brigade. Expanding the system used during the Turin winter Olympics last year, Telespazio is outfitting a fleet of emergency vehicles able to communicate via broadband links with the Interior Ministry's operations center. They will use the SkyplexNet capability of Eutelsat's Hotbird-6 direct-broadcast satellite.

Under an agreement between the United Nations' International Telecommunications Union (ITU) and Thuraya Satellite Telecommunications Company (UAE), signed on 10 July, Thuraya will provide hand-held satellite terminals to be distributed by the ITU to first responders for disaster response, as well as discounts on

service time to humanitarian and government agencies responding to disasters. The dual-mode handsets will be able to use both ground-based cellular networks and the Thuraya satellite, which covers most of Europe, the Middle East, central and south Asia and all of Africa but the southern tip.

(3) Navigation and Position Location

A report by the U.S. Defense Science Board (DSB), titled "The Future of the Global Positioning System", which was released on 22 November 2005 recommends major changes in the U.S. GPS satellite constellation. The new GPS-3 system, planned for its first launch in 2013, will increase size of the constellation to 30 spacecraft deployed in three orbital planes, each containing 10 satellites, instead of the present system of 24 satellites and 4 spares in six orbital planes. This is the configuration to be employed by Europe's Galileo system. The DSB also makes the following recommendations: a change to a three-plane configuration is to be made before launching any more satellites; future spacecrafts should be launched two at a time on a medium-class launcher to keep the costs down, and the civil interoperability with Europe's Galileo System should be promoted.

The first of the two test satellites for Europe's Galileo navigation and position-location system, Giove-A, was launched by Starsem aboard a Russian Soyuz-Fregat rocket from the Baikonur Cosmodrome on 28 December 2005. Built by Surrey Satellite Technology Ltd (UK) under a $33.6-million ESA contract, the 602-kg, 660-W spacecraft began its mission on 18 January, demonstrating several key Galileo technologies, including rubidium clocks and the simultaneous use of two signal-transmission channels from its 23,600-km circular orbit inclined at 56 degrees. Giove-B, built by Galileo Industries SA (Belgium) and planned for launch in 2007, will duplicate Giove-A's functions and demonstrate a passive hydrogen maser clock and three-channel transmissions, using a second-source signal generator.

On 19 January European Space Agency (ESA) signed a $1.1-billion contract with Galileo Industries, a consortium led by EADS Astrium (Germany), which is building the spacecraft buses, and Alcatel Alenia Space (France), responsible for the ground segment, for developing and building the four In-Orbit Validation (IOV) Galileo satellites. Astrium UK is providing the payloads. The four satellites are to be launched in late 2008 by two Arianespace/Starsem Soyuz Fregat rockets on a six-month mission to confirm and demonstrate the Galileo system capabilities**.**

On 1 December 2005 Ukraine joined the Galileo programme. Ukraine's agreement with the European Commission covers satellite navigation cooperation in science and technology, industrial manufacturing, services and market development, including access to European Geostationary Navigation Overlay Service (EGNOS), to be deployed in 2007, which enhances the performance of the U.S. Global Positioning System.

On 12 July ESA announced the transition of EGNOS from the agency's EGNOS

System Test Bed (ESTB) to the "production" EGNOS system for provision of GPS augmentation services over Europe. EGNOS, the first European satellite navigation system, is a joint project of ESA, the European Commission and Eurocontrol. It is now providing signals to the European user community for navigation, positioning, and timing, with an improved utilization of the GPS system, in a multitude of fields such as farming, aviation and maritime tests, road applications, and many others. EGNOS will be fully cooperative with the Galileo system when the latter becomes operational.

Grupo GMV (Spain) announced on 29 June the creation of a 10-company consortium to study the use of satellite navigation systems in Europe for humanitarian assistance, emergency management, and law enforcement. Named Harmless, the 20-month study has a budget of $2.5 million, some of which has been committed by the European Commission. Overseen by the Galileo Joint Undertaking, it will assess how best to use Europe's Galileo and Egnos systems.

Qinetiq (UK) and C&N Inc. (Japan) signed an agreement on 3 July to provide satellite tracking using Qinetiq's Q20 Global Positioning System (GPS) chip in portable electronic devices such as mobile telephones, personal organizers, hand-held and vehicle-mounted navigation devices, cameras, and watches. The Qinetiq chip enables satellite tracking in low-signal areas such as inside buildings.

Intelsat announced on 29 March the signing of a multi-million-dollar agreement with the Agency for the Safety of Aerial Navigation in Africa and Madagascar to provide satellite capacity for Africa's civil aviation network. The Intelsat 10-02 satellite will transmit position-location, weather, technical, and air-traffic information between aircraft and airports in 17 countries.

On 14 April Japanese government agencies signed an agreement with an industry consortium, Advanced Space Business Corporation, clearing the path for development and launch of the first satellite in the Quasi Zenith Satellite System (QZSS), which will enhance Japan's navigation and communication services nationwide. The Japan Aerospace Exploration Agency (JAXA) is funding this first of the three-satellite constellations. It is being built by Mitsubishi Electric and planned for launch in the first quarter of 2009, to demonstrate enhanced position-location service, which will then be sold commercially. Funding shares for the other two satellites have yet to be decided.

India approved the development of an independent Indian Regional Navigation Satellite System (INRSS) on 16 May. The seven-satellite constellation (four geostationary-orbit spacecraft and three in highly elliptical orbits) is budgeted at $311-million and will be built by the Indian Space Research Organization's (ISRO's) Satellite Centre in Bangalore. Launch is planned via ISRO's Polar Satellite Launch Vehicles in the beginning of 2008. Ground facilities will be funded by a separate budget. The complete system, including development and deployment of the satellite constellation, ground infrastructure, and the system verification and testing, is expected to be complete by 2011. This system is separate from India's prospective plans to participate in the Russian Glonass and the European Galileo navigation systems.

India plans to use the new system for air traffic control via its indigenous GeoAided GPS Augmented Navigation (Gagan) system, designed to accommodate India's burgeoning air traffic movements (17% growth in the past five years). The $155-million project, a joint effort by the Airports Authority of India (AAI) and the Indian Space Research Organization (ISRO), is modeled after the U.S. Wide Area Augmentation System (WAAS). The system, designed to overlay Africa, Asia, Australia, and the western half of the Pacific Ocean, is expected to be implemented in stages and to become fully operational by 2012 – 2014. Preliminary tests conducted by Raytheon (USA) indicated an aircraft-location baseline accuracy of about 1 meter, both horizontally and vertically well within the specified 7.6-m requirement.

B. Remote Sensing

(1) Earth Observations

On 23 December 2005 the U.S. Presidential Science Adviser ordered NASA and the U.S. Geological Survey to develop a new Earth-observing satellite to continue Landsat-type data observations instead of the previous plan, which involved transferring this function to the new U.S. National Polar-Orbiting Earth Satellite System (NPOESS). On 22 February NASA's Goddard Space Flight Center issued a pre-solicitation notice for the development and construction of Landsat-8; a draft Request for Proposals was released in June; and the final solicitation followed in September. Responders are being asked to include a thermal-band capability as an option in their proposals.

Landsat-5 was returned to service on 21-22 January, following the repair of its solar array drive that began malfunctioning in November 2005. The repair was implemented by ground controllers, who increased the speed at which the drive changes the array position, thereby allowing the arrays to deliver sufficient power to recharge the batteries.

The U.S. National Geospatial–Intelligence Agency (NGA) on 6 January issued its first option on the $500-million Clearview programme contracts awarded in January 2003. Space Imaging and DigitalGlobe each received $24-million awards and Orbimage was awarded $12 million. Space Imaging and Orbimage subsequently completed their merger into a new company, GeoEye, on 12 January. DigitalGlobe received a second increment of $12 million on 16 March, and GeoEye obtained its first Clearview contract award of $13 million on 20 March.

On 15 February NASA announced that data from the agency's Earth observation satellites Terra, Aqua, And Earth-Observing-1, along with data from Landsat, are being used to predict the growth patterns of invasive plant species in the U.S. First use of the Invasive Species Forecasting System was to track and help combat the growth of tamarisk (saltcedar) in the western U.S.

The mass of the Antarctic ice sheet decreased by over 150 cubic km between April 2002 and August 2005, according to a NASA announcement on 2 March. The finding, by the NASA-DLR (Germany) Gravity Recovery and Climate Experiment (GRACE) satellites corresponds to a global sea-level rise of 1.2 mm. Data from GRACE, analyzed in June also suggest the presence of a large mass under Wilkes Land in the East Antarctic Ice Sheet, believed to be the residue of a meteor that could have been as big as 48m in diameter and had impacted Earth about 250 million years ago, leaving a 500-km crater. GRACE data released on 20 December 2005 also suggest that Greenland's fresh-water ice sheet is melting at a higher rate than previously believed. The sheet shrank by 162 cubic km between 2002 and 2005, which would cause a rise in global sea level of about 0.4 mm/year.

NASA announced on 13 June that its satellite image-processing technology was adapted by scientists at George Washington University and Cornell University for use in diabetes research. Image processing of electron photomicrographs of beta cells in the pancreas of rats is helping them to better identify and understand production of the insulin granules which regulate blood glucose levels, a key factor in controlling diabetes.

DigitalGlobe (USA) announced on 14 June that the nonprofit humanitarian organization Healing Hands International will use imagery from the company's Quickbird satellite for agricultural development and disaster relief in Africa and Central America. The data will be provided by a DigitalGlobe partner, Native Communities Development Corporation (USA).

On 15 March the Canadian Space Agency awarded McDonald Detwiler Associates a $6.7-million contract to design a fleet of small satellites that will complement the existing Radarsat C-band family early in the next decade. The Radarsat Constellation of three satellites will undertake coastal surveillance, track ice in shipping lanes, conduct other ocean surveillance tasks and ensure future continuity of data for Radarsat users.

Russia launched its 5.9-tonne Resurs-DK1 satellite aboard a Starsem Soyuz-U rocket from the Baikonur Cosmodrome on 15 June. The high-resolution civilian spacecraft is transmitting digital images to Russian ground stations from its 71-degree, 200 x 360-km elliptical orbit. Owned and operated by the Russian space agency Roskosmos, Resurs-DK1 provides 1-m panchromatic resolution and 2-3 m resolution in multispectral bands, and can cover up to 700,000 km per 24 hours in swath widths, ranging from 4.7 km to 28.3 km. Images are being marketed commercially to European and Asiatic customers by Roskosmos' commercial affiliate Sovinformsputnik. Resurs-DK1 also carries a 470-kg international Payload for Antimatter Exploration and Light-nuclei Astrophysics (PAMELA) to study antimatter and dark matter in space for institutes in Italy, Russia, Germany and Sweden.

ESA signed a multi-year bulk-purchase agreement with SpotImage (France), announced on 18 January. The contract gives ESA the right to order 12,000 images from Spot-2 and Spot-4, which offer 10-m black-and-white resolution and 20-m colour

resolution, but no images from higher-resolution Spot-5. It also includes an ESA commitment to take over the operation of Spot ground stations in Sweden and in Spain's Canary Islands.

On 20 March ESA decided to proceed with development of the first three satellites in the 5-spacecraft Global Monitoring for Environment and Security (GMES) initiative, despite the commitment of only $850 million of the $2.9 billion needed to build and launch them and to build the ground segment. Sentinel-1, a follow-on for the radar instruments aboard ERS-2 and Envisat, is planned for launch in 2010 or 2011 at a cost of $277 million, not including the launch. Sentinel-2, carrying a super-spectral land-monitoring sensor that will complement data from the U.S. Landsat, is planned for launch in 2011 – 2012. Sentinel-3, also expected to launch in 2011 – 2012, will carry an ocean-measuring altimeter and optical and infrared radiometers, that will serve as follow-ons to the Medium Resolution Imaging Spectrometer Instrument (MERIS) on Envisat. At least three of the five planned Sentinels, those dealing with ocean altimetry and atmospheric mnonitoring, will be operated by EUMETSAT. The GMES system will also include other European radar and optical imaging satellites already on orbit or in development, such as Germany's TanDem-X.

On 17 July LogicaCMG (UK) announced the creation of a five-nation consortium to study the data security policy for GMES, with the goal of protecting GMES against unauthorized access and threats. This follows the ESA contract with Logica, signed on 8 May for $30 million to develop the Galileo security management facilities.

Farmstar (France) announced on 27 February that it had delivered satellite-based crop data directly to its 10,000-farmer subscriber base, who collectively have over 250,000 hectares under cultivation in France. Farmstar, which is financed by EADS Astrium's Infoterra Global and the French agricultural research cooperative Arvalis, and is expected to book about $3 million in sales by the end of this year, began to deliver its services to the UK and Spain and is planning to expand to the U.S., Canada, and South America. The company's service includes delivering satellite-based crop status maps to its subscribers three to five times during the growing season and prescribing irrigation, fertilization and other soil treatments. Data for these services are obtained by Farmstar from three French Spot satellites and from India's IRS spacecraft.

On 10 July Astrium Ltd. (UK) and Surrey Satellite Technology Ltd. (SSTL, UK) agreed to jointly develop a small radar Earth observation satellite, using an SSTL bus and an Astrium payload. The AstroSAR-UK satellite, weighing less than 500 kg, will use an X-band phased-array radar. Once the spacecraft's capabilities have been demonstrated and prices established, its services will be used by the UK government and other commercial customers.

On 8 July the regional government of the Alpes-Maritimes on the French Riviera concluded a contract to purchase two images per day from radar surveillance spacecrafts, Canada's Radarsat and Europe's Envisat, in its coastal monitoring programme. The goal

is to detect oil spills in time and to permit cleanup vessels to deal with them before they contaminate the 120 km of the area's beaches. Spot Image (France) will obtain the images, which will then be analyzed by Boost Technologies (France) and tracked by Groupe Acri of Sophia Antipolis, who will direct local officials where to send the cleanup vessels.

Algeria ordered two small high-resolution satellites from EADS Astrium (France) on 1 February. The contract includes a 32-month training programme for 25 Algerian engineers at EADS' Toulouse facility. The 130-kg Alsat-2 spacecraft, being built for the Algerian National Space Centre on EADS' Myriade small-satellite platform, will have 2.5-m black-and-white resolution. Planned for launch in 2008, the first Alsat-2 will enable collection of data on a 64-GB recorder from regions out of line-of-sight contact with its ground station in Algeria. EADS is providing the Myriade bus and payload components to Algeria for the second spacecraft, which will be assembled at a new satellite development facility in Oran, Algeria. EADS won the contract in competition with Surrey Satellite Technology Ltd. (UK), who built the 32-m resolution Alsat-1.

On 22 February ESA approved the construction of a second CryoSat polar ice-monitoring spacecraft to replace the one lost after a launch failure in October 2005. CryoSat-2, which will be built by a consortium led by EADS Astrium (France) is planned for launch in March 2009 on a three-year mission in low polar orbit.

The German aerospace agency DLR approved two new Earth-observation missions on 8 March. The TanDem-X satellite, planned for launch in early 2009, will carry an X-band synthetic-aperture radar with three imaging modes, with swath widths of 10, 30, and 300 km and corresponding resolutions of 1, 3, and 16 m. It will operate from a 514-km orbit with the TerraSAR-X satellite scheduled for launch late this year, which carries an X-band radar with the same performance features. The two satellites will provide operator Infoterra (Germany) with the ability to market three-dimensional images. The $110-million manufacturing contract for TanDem-X was signed by DLR and Astrium Satellites (France) on 30 August. Total cost of the TanDem-X mission, including launch and ground support facilities, will be about $185 million. The second new mission is the EnMAP hyperspectral imager, planned for launch in 2009 or 2010 to study environmental phenomena worldwide. The 770-kg satellite will operate in 200 channels with a ground resolution of 30 m.

Spain's Center for Industrial Technology Development (CDTI) announced on 29 June that the Spanish government, as part of the country's 2006 – 2011 space funding programme, allocated a budget of $240 million for a new small optical Earth observation satellite, whose development is to be managed by ESA. The 600-kg satellite, with 2.5-m black-and-white resolution, is planned for launch in 2010. It will be used by the government for territorial surveillance and by a commercial operator, which will be selected by CDTI.

On 24 January an H-2A rocket launched Japan's Advanced Land Observing Satellite (ALOS) from the Tanegashima space center into a Sun-synchronous 700-km

orbit. The $404-million satellite, named Daichi ("Mother Earth"), was built by NEC Toshiba Space Systems. Weighing 3.35 tonnes and generating 7 kW of power from its 22-m solar array (the largest ever built for a Japanese spacecraft), Daichi's three main instruments, which have a combined output data-rate of 1.36 GB/sec, are an optical imager for three-dimensional stereoscopic mapping at 2.5-m resolution over a 70-km swath, named PRISM (Panchromatic Remote-Sensing Instrument for Stereo Mapping); a visible and near-infrared sounder to characterize vegetation and land-use changes, called AVNIR-2 (Advanced Visible and Near-Infrared Radiometer-2); and PALSAR (Phased-Array L-Band Synthetic Aperture radar), for all-weather day and night mapping in four frequencies. The primary mission of Daichi is to make 1/25,000-scale maps of Japan's territory and to support global disaster-monitoring programmes. Checkout was completed in April, and following instrument calibration during the summer, Daichi began its operations in mid-September. Under an agreement with ESA, approved in December 2005, the data from Daichi will be made available to commercial distributors and the scientific community in Europe and Africa as well as to Europe's Global Monitoring for Environment and Security (GMES) network.

ImageSat International's (Israel) Eros-B1 imaging satellite was launched from Svobodny, Siberia into a 508-km orbit by a Russian Start-1 converted missile launcher on 25 April. The 290-kg spacecraft, built by the MBT Division of Israel Aircraft Industries Ltd (Israel), has a black-and-white resolution of 0.7 m, as compared with Eros A's 1.9-m resolution. Its payload was manufactured by Elbit Systems Ltd's Elop Electro-Optics Industries subsidiary (Israel).

China launched Remote Sensing Satellite No. 1 into a 600-km near-polar orbit on 26 April aboard a Long March 4B rocket from the Taiyun Satellite Launch Center. The 2,700-kg satellite is being used for land and agricultural surveys. It is the first of 18 remote-sensing satellites China plans to launch during the next decade.

On 30 June a commercial Chinese company, Beijing Landview Mapping Information Technology Company obtained the 166-kg Beijing-1 Earth observation satellite, built by Surrey Satellite Technology LTD (UK) and launched by a Russian Kosmos rocket in October 2005. The $19-million Beijing-1, with 4-m black-and-white image resolution and 32-m colour resolution, is conducting a 6-month project to map all of China. Beijing-1 operates on a commercial basis for both government and private-sector customers.

South Korea's KOMPSAT-2 (Korea Multi-Purpose Satellite-2) satellite was launched by a Eurockot Launch Services Rockot from the Plesetsk Cosmodrome on 28 July. Also known as Arirang-2, the satellite carries an optical imager with 1-m black-and-white resolution and a multispectral imager with 4-m resolution. The 800-kg spacecraft, owned and operated by the Korea Aerospace Research Institute (KARI), costs around $200 million, including the launch. Its imager was built by Elop Electro-Optical Industries Ltd. (Israel), while payload subsystems as well as technical expertise and training were provided by EADS Astrium (France). Kompsat-2 was placed in a 685-km Sun-synchronous orbit for use as a commercial and environmental monitoring satellite,

also serving Korea's Geographic Information System for optical monitoring and mapping. SpotImage (France) is marketing its images commercially. KARI is also working on a follow-on X-band radar imaging satellite, Kompsat-5, for which Alcatel Alenia Space (France) will supply the synthetic aperture radar, data link, and ground image processor. Kompsat-5 is planned for launch in 2008.

(2) Atmosphere and Ocean Observations

On 4 January the U.S.- French Topex/Poseidon ocean surveillance mission was terminated after 13 years and 62,000 orbits, due to a stalled pitch reaction wheel that could not be restarted. The satellite's data were used for over 2,100 scientific publications.

The U.S. Cloudsat and the French-U.S. Calipso satellites were launched on 28 April by a Boeing Delta-2 rocket from Vandenberg Air Force Base. CloudSat, built by the Jet Propulsion Laboratory, is leading Calipso by 135 seconds in the A-train's 705-km Sun-synchronous orbit, allowing the two spacecraft to study the same column of atmosphere with different instruments. Calipso, which cost NASA and CNES $285 million and was built by Alcatel Alenia Space on their Proteus bus, can detect aerosols within clouds and distinguish them from cloud particles. The $217-million CloudSat, built by Ball Aerospace (USA) in cooperation with the Canadian Space Agency, measures the amount and size of water drops and ice particles in clouds.

The two satellites complement each other: Calipso observes thin clouds, while CloudSat's lower-resolution lidar (500 m vertically) is able to profile through thick clouds, that block Calipso's 30-m resolution lidar. The two thereby provide, for the first time, a picture of the distribution of all the clouds in the atmosphere. This knowledge improves scientists' ability not only to understand weather but also to predict future climate changes and human impacts on them. The $2.3-billion A-train constellation now comprises Aqua (USA), followed by Cloudsat (USA) 1 minute later, Parasol (France) two minutes later, then Calipso (France and USA) 15 seconds later, and finally, 4 minutes and 45 seconds later, Aura (USA).

On 14 April an Orbital Sciences Corporation Minotaur-1 launched the six 62-kg satellites of NASA's Constellation Observing System for Meteorology, Ionosphere, and Climate (COSMIC) mission into a 500-km 72-degree orbit from Vandenberg Air Force Base. The $100-million mission, sponsored jointly by the Taiwan Province of China's National Space Programme Office under the designation Formosat-3, is using radio occultation techniques to measure variations in electron and air density, temperature and moisture in the Earth's atmosphere. The methodology involves measuring the bending of radio signals from the U.S. Global Positioning System (GPS) satellites as they pass through the atmosphere, a technique that can be used to track hurricanes and climate changes, and to monitor the effects of space weather on the atmosphere.

The first of a new series of U.S. weather satellites, the Geostationary Operational Environmental Satellite (GOES)-N, was launched by a Boeing Delta-4 rocket from Cape

Canaveral on 24 May. It began its operational service from a geostationary-orbit slot at 90 degrees west longitude, it will then be moved to a slot at 75 degrees west longitude to monitor Atlantic hurricanes in 2008 and after 2011, it will serve as an on-orbit spare. This is the first of three new GOES satellites, built by Boeing Satellite Systems (USA). The two earlier-generation GOES satellites, which are still in the orbit, are the last two of the five earlier-generation GOES satellites, built by Space Systems/Loral (USA). The $480-million GOES-N has new batteries that allow it to operate during solar-panel eclipses and is equipped with the first operational version of the Solar X-Ray Imager, which can monitor solar flares and other solar events that disrupt satellite operations and disable power grids on Earth. It also has four times better image resolution (1.5 km) and atmospheric-sounder capability then previous GOES satellites. It was the first payload launched by a Delta-4 rocket in 17 months. The first visible and infrared images from GOES-N, now named GOES-13, were transmitted on 16 August.

On 22 February EUMETSAT and the U.S. National Oceanic and Atmospheric Administration (NOAA) signed an agreement allowing the U.S. government to restrict the dissemination of data from U.S. instruments flying on European weather spacecraft during a war or other emergency. The restriction will apply only to data less than three hours old, and only to specific limited geographical areas, not on a global basis. The agreement also protects European national weather services against any cutoff of short-term weather forecasts from Europe's Metop satellites.

Raytheon (USA) and Lockheed Martin (USA) announced on 26 March their receipt of six-month contracts from the U.S. National Oceanic and Atmospheric Administration (NOAA) to develop conceptual designs, cost estimates and viability analyses for an Integrated Ocean Observing System (IOOS). The system will consist of buoys, ships, underwater vehicles, satellites and other platforms, and will provide data that can help NOAA to better predict weather and climate change, mitigate natural hazards, oversee coastal resources as well as to assist in the U.S. homeland security. The IOOS represents the U.S. contribution to the 10-year Global Earth Observation System of Systems (GEOSS) project, that over 60 countries signed up to at the Third Earth Observation Summit in Brussels in 2005.

On 30 June the U.S. NOAA's Deep Ocean Assessment and Reporting of Tsunamis (DART-2) system was announced to employ Iridium Satellite LLC (USA) data links to transmit information relayed from sea-floor sensors by the system's 31 ocean buoys to NOAA tsunami warning centers.

From 15 August through 15 September NASA conducted the African Monsoon Multidisciplinary Analyses 2006, using combined data from satellites, airborne remote-sensing instruments, GPS-equipped dropsondes and other sources, in order to determine the cause of some winds from Africa developing into tropical storms and eventually into Atlantic hurricanes. The $5-million study also included scientists from Howard University (USA) and the U.S. NOAA. The study focused on low-pressure waves, that originate in the Cape Verde islands, 400 km off the Senegal coast, where these waves presage about 60% of Atlantic hurricanes. About 10% of the 60 to 70 waves, that occur

annually, turn into tropical cyclones. Satellites, that were used in the study, included NASA's Aqua, the Tropical Rainfall Measurement Mission satellite, QuikSCAT, Cloudsat, and Calipso.

NASA announced on 31 August that data on phytoplankton from the agency's Seaviewing Wide-Field-of-View Sensor (SeaWiFS) aboard the OrbView-2 satellite could motivate major changes in climate modelling. Comparisons with the ground-truth algae samples, that were collected from ships, revealed that algae which exhibit a healthy green colour to the satellite sensor could actually be unhealthy, with the fluorescent green color resulting from a lack of iron. Since the healthy phytoplankton represents a major source of carbon dioxide absorption from the atmosphere, this discovery could mean that estimates of the amount of carbon consumed annually by phytoplankton might have to be reduced by about 2 million tons.

On 9 September a NASA-funded team of scientists from NASA's Jet Propulsion Laboratory, NOAA, Georgia Tech and Hampton University reported that studies of atmospheric data, collected over the past 25 years by five different satellites and other airborne and ground-based instruments indicate a reversal of the depletion of ozone in the stratosphere layer between 11 and 18 km in altitude, and a cessation of ozone depletion in the layer between 18 and 25 km. This highly favourable and wholly unexpected trend in ozone concentrations was attributed to the actions taken by the world's governments restricting the use of ozone-depleting chemicals, following the 1987 Montreal Protocol on Substances that Deplete the Ozone Layer.

Findings based on data from the U.S. - French Jason and Topex/Poseidon satellites and a phalanx of sea-based sensors, released on 21 September revealed that the average temperature of the water near the surface of the Earth's oceans has been cooling significantly since 2003, reversing a warming trend over the previous decade. The average temperature of the upper ocean increased by 0.09 degrees Celsius between 1993 to 2003, but then decreased by 0.03 degrees Celsius between 2003 and 2005. This drop reflected a loss of about 20% of the heat gained by the oceans since 1955. The scientists at NASA's Jet Propulsion Laboratory, who analyzed the results, concluded that global warming trends do not always have a steady, predictable effect on ocean temperatures, but are affected by natural variations in the climate.

EUMETSAT's MSG-2 second-generation weather satellite was launched on 21 December 2005 by an Ariane-5 to a geostationary-orbit slot at zero degrees longitude. The 2-tonne satellite, designated Meteosat-9, carries SEVIRI (Spinning Enhanced Visible and Infrared Imager) that provides 1-km resolution on clouds and the atmosphere in the visible and infrared spectra, enabling the tracking of tropical storms and very-short-range weather phenomena. The $176-million spacecraft also carries GERB (Geostationary Earth Radiation Budget), an experimental radiation budget instrument which is a forerunner of future climate-prediction capabilities.

Alcatel Alenia Space (France) completed installation of 51 meteorological satellite data-reception centers in 47 African nations early in November 2005. As part of

the EUMETSAT's overall programme, the project allows local forecasters in Africa to access Europe's second-generation Meteosat-8 and Meteosat-9 weather satellites with modern image-processing technology. The project was funded by the European Commission with $18 million and is managed by Kenya's Meteorological Department,.

EUMETSAT's Metop-1 polar-orbiting meteorological satellite, Europe's first, was shipped to the Baikonur Cosmodrome on 18 April for launch by a Starsem Soyuz 2-1a rocket. Built by EADS Astrium (France), the 4.1-tonne Metop-1 carries 12 instruments funded by ESA, the French space agency CNES and the U.S. NOAA. The launch was originally planned for 30 June but was delayed to 19 July for verification of ground facilities. The launch was aborted three minutes before liftoff due to error readings on the rocket's fuel-tank purge lines. Another launch attempt was planned for 7 October and Metop-1 was finally launched into its 837-km polar orbit on 19 October. EUMETSAT took over control of the spacecraft from ESA's ESOC operations center on 23 October. Metop-1 is the first of three Metop satellites to be launched as part of the joint U.S. - European polar-orbiting weather satellite system. The other two spacecraft in the constellation, Metop-2 and Metop-3, are also being built by EADS Astrium and will fly in 2010 and 2014 respectively.

One of the contributing factors to the Metop-1 launch delay was an anomaly in the ball-bearing lubrication system on the U.S.-supplied Advanced Microwave Sounding Unit (AMSU-A), discovered after the spacecraft arrived at the landing site, which required returning it to the U.S. for replacement. EUMETSAT financed $2.3 billion of the Eumetsat Polar System (EPS/Metop), with ESA contributing $700 million and the French space agency CNES $190 million. The total system cost of $3.2 billion covers three spacecrafts and 14 years of operation.

The main weather instrument of Metop-1 (out of eight in total) is a $330-million Infrared Atmospheric Sounding Interferometer (IASI), designed and developed by CNES and built by Alcatel Alenia Space (France). It can measure atmospheric temperatures to within 1 degree Celsius and humidity to within 5%, with a vertical resolution in the lower atmosphere of 1 km. It has 8,400 spectral channels and an accuracy 400 times that of the high infrared sounder (HIRS) carried on U.S. NOAA satellites. The other instruments of Metop-1 are the NOAA's AMSU-A; a HIRS as backup to the IASI; an advanced very high resolution radiometer for global cloud imagery; a microwave humidity sounder; a limb-viewing radio occultation sounder and a global ozone monitor. Metop-1 also carries Argos global data location/collection equipment and Cospas-Sarsat search-and-rescue terminals.

On 9 December 2005 the French space agency CNES approved the investment of $89 million in a Ka-band radar altimeter for India's Oceansat-3 satellite, currently scheduled for launch in 2008. The AltiKa instrument for the Indian Space Research Organization's (ISRO's) satellite is being built by prime contractor Alcatel Alenia Space (France), with subcontract support by EADS Astrium (France) and Thales (France). Designed to provide precise sea-surface-level measurements, the AltiKa altimeter will operate in tandem with the U.S. – European Jason-2 ocean-altimetry spacecraft, also

planned for launch in 2008.

The Japan Aerospace Exploration Agency (JAXA) launched the Multifunctional Transport Satellite-2 (MTSat-2) on 18 February aboard an H-2A rocket from the Tanegashima Space Center. At over 4.2 tonnes one of the heaviest satellites ever launched by Japan, MTSat-2 is being used for weather forecasting and air traffic management in the Asia-Pacific region. Built by Mitsubishi Electric on the company's DS-2000 bus, it is owned and operated by the Japan Meteorological Agency and Japan's Civil Aviation Bureau, which are both in the Ministry of Land, Infrastructure, and Transport (MLIT). MTSat-2 will deliver atmospheric data to the Japan Meteorological Agency, as well as provide voice communications, Global Positioning System (GPS) augmentation and route surveillance for the Civil Aviation Bureau. MTSat-2 follows MTSat-1R, launched a year earlier by an H-2A rocket in February 2005.

China announced on 30 March intention to donate data-receiving stations for its Fengyun weather satellites to seven nations, including Bangladesh, Indonesia, Iran, Mongolia, Pakistan, Peru and Thailand. Chinese managers will train staff members from these countries in use of the system, which has been used in China to track climate change, forecast the weather, conduct disaster and environmental monitoring as well as to service agriculture, forestry and for civil aviation functions.

IV. HUMANS IN EARTH ORBIT

A. Space Station Deployment and Operations

During a 5-1/2-hour spacewalk on 7 November 2005, Expedition-12 crewmembers William McArthur and Valery Tokarev attached a television camera to the end of the P-1 truss, for use on the installation of the P-3/P-4 truss elements and another solar array. They removed an obsolete instrument, which was installed at the top of the P-6 truss in the year 2000 to measure the electrical environment around the existing solar arrays. The crewmembers also retrieved a failed rotary-joint motor controller for return to Earth and replaced a malfunctioning circuit-breaker on the Mobile Transporter. It was the first spacewalk by a Russian cosmonaut using a U.S. spacesuit.

The Russian Progress-19 cargo spacecraft, berthed at the Zvezda module of the International Space Station (ISS), successfully fired its engines on 10 November 2005 to boost the ISS into a nearly circular 352-km orbit. The successful manoeuvre followed a previous attempt on 18 October, that failed due to premature shut down of the Progress's engines.

McArthur and Tokarev filled a Russian spacesuit with discarded clothing and launched it into a retrograde orbit during a 3 February spacewalk to repair the platform carrying the station's robot arm. "SuitSat-1," equipped with three batteries, sensors to monitor battery power and suit temperature, and an amateur ("ham") radio transmitter

and antenna, was to have transmitted a message in five languages on FM frequency 145.990 for two weeks before re-entering the atmosphere. The message was to include a digital image and secret words for student ham-radio operators to decipher. However, SuitSat-1 fell silent two orbits after its launch, thought to have been due to battery failure as a result of excessive temperatures, but amateur radio operators claimed to have received weak signals from the spacesuit well into the following week.

On 12 January the ISS Expedition-12 crew completed installation of a Recharge Oxygen Orifice Bypass Assembly, which will conserve ISS oxygen during Space Shuttle visits and reduce wear on the station's oxygen compressor. The device, built by Boeing (USA), was installed between the ISS Quest airlock and the Shuttle docking port to allow use of the Shuttle's oxygen supply by ISS crewmembers preparing for spacewalks instead of tapping the ISS storage facilities.

The Expedition-12 crew conducted another spacewalk on 20 March to move the Soyuz lifeboat from the front docking port on the Zarya module to the aft docking port, in preparation for docking the Soyuz spacecraft carrying the next crew to the ISS. That flight arrived at the ISS on 31 March, carrying Expedition-13 crew members Pavel Vinogradov (commander) and Jeff Williams (flight engineer), as well as Brazilian astronaut and fighter pilot Marcos Pontes, who were launched to the ISS by a Soyuz rocket from the Baikonur Cosmodrome on 29 March. Pontes remained on board the ISS for a week and then on 8 April returned to Earth aboard the docked Soyuz lifeboat with Expedition-12 crew members William McArthur and Valery Tokarev. The Brazil space agency paid the Russian space agency Roskosmos $10 million for Pontes' trip.

On 26 April a Russian Progress-21 vehicle docked with the ISS, bringing 1,050 kg of spare parts and other hardware, 300 kg of water, 47 kg of oxygen and air, and 870 kg of propellant for the ISS's thrusters. It also brought the first of three volleyball-sized microsatellites powered by carbon-dioxide thrusters for use inside the ISS to validate station-keeping software for future spacecraft constellations. Autonomous testing of the first of these Synchronized Position Hold, Engage and Reorient Experimental Satellites (Spheres) was conducted by Jeff Williams inside the U.S. Destiny module on 18 and 20 May, when it was successfully maneuvered using two beacons. The student-designed experiment was built by Payload Systems Inc. (USA).

The Expedition-13 crew conducted a 6-hour spacewalk on 1 June from the Russian side of the ISS to install a new valve nozzle on the Zvezda service module for the Elektron oxygen generator, to replace a broken television camera on the ISS mobile transporter, to retrieve samples from two external experiments, one monitoring thruster-jet contamination and the other studying the effect of the space environment on microorganisms, and to tighten a loose cable that might have interfered with a Zvezda-module antenna needed to guide ESA's Automated Transfer Vehicle during docking.

The Russian Progress M-57 cargo vehicle docked with the ISS on 26 June, bringing 2,600 kg of cargo consisting of food, clothing, batteries, experiments, spare parts, 860 kg of propellant, over 45 kg of air and oxygen, and about 110 kg of water. It

remained attached to the docking port of the Zvezda service module to provide stowage space for the supplies delivered in July by Shuttle Discovery.

Space Shuttle Discovery, launched on 4 July, docked uneventfully with the ISS on 6 July following an exhaustive examination of its thermal protection system by the Expedition-13 crew. In addition to the Shuttle crew, ESA astronaut Thomas Reiter was aboard to be transported to the ISS for his scheduled six-month tour of duty, thus for the first time since the loss of Shuttle Columbia in February 2003 the ISS returned to the crew complement of three. Reiter is Germany's first astronaut to serve on the ISS and ESA's first full-mission ISS crew member. On 4 August he also became Europe's longest-flying astronaut, with his stints aboard the ISS and Russia's Mir in 1995-96 exceeding the previous record of 209 days, 12 hours, and 25 minutes held by Jean-Pierre Haignere.

The Italian Leonardo cargo module was attached to the ISS Unity node on 7 July, unloaded, and returned to Discovery's cargo bay for return to Earth. The Shuttle crew conducted three spacewalks on 8, 10, and 12 July to test the Shuttle's new 30-m Orbital Boom Sensor System, to restore the station's mobile base system, and to test thermal-protection-system repair materials before undocking Discovery on 15 July for its return to Earth.

Shuttle orbiter Atlantis, launched on 9 September, docked with the ISS two days later, following the inspection of its thermal protection system. It brought the $372-million, 16-tonne P3/P4 truss segment that was mounted to the port beam on the ISS by the ISS mobile transporter the day after the docking. The truss carries the electrical and mechanical systems to unfurl the four new solar array panels also carried by Atlantis. The panels had been waiting at the Kennedy Space Center for 67 and 73 months due to the Shuttle fleet stand-down following orbiter Columbia's failure.

In a 6-1/2-hour spacewalk Atlantis astronauts Joe Tanner and Heidemarie Stefanyshyn-Piper then connected data and power cables, installed the gear needed to drive the solar arrays' rotating joint, activated the gimbals to feather the arrays for maximum power generation, unlatched the restraints that had held the solar arrays in place, and prepared them for unfurling. The next day, 13 September, Shuttle crewmembers Dan Burbank and Canadian astronaut Steve MacLean conducted a 7-hr, 11-min spacewalk preparing the truss to receive the new solar panels. They released 16 launch locks (held by 243 bolts) on the 3-m diameter Solar Alpha Rotary Joint that keeps the solar arrays pointing at the Sun, and verified its 180-degree rotation by ground controllers. Following the unfurling and deployment of the solar arrays to their full 73-m span, Tanner and Stefanyshyn-Piper returned outside the ISS on 15 September to complete the installation and make final adjustments to the panels, which added 66 kW to the ISS solar powerplant. Cargo transfer from Atlantis to the ISS was completed on 16 September, and the Shuttle left the ISS the following day to return to a successful landing at the Kennedy Space Center on 20 September.

On the same day, a Soyuz spacecraft delivered the new Expedition-14 crew to the ISS: NASA astronaut Michael Lopez-Alegria (commander) and Roskosmos cosmonaut Mikhail Tyurin (flight engineer and Soyuz commander). They were joined by the first female space tourist, Anousheh Ansari, who remained on the ISS until returning to Earth on 28 September aboard the Soyuz lifeboat with the Expedition-13 crew, cosmonaut Pavel Vinogradov and astronaut Jeff Williams.

A Progress M-58 cargo ship, launched on 24 October, docked with the aft port of the ISS Zvezda service module three days later with 2,182 kg of resupply cargo, including 869 kg of propellant, 49 kg of oxygen, and 1,262 kg of space parts, repair equipment, and life-support hardware, most notably repair parts for the Russian Elektron oxygen-generating system which had been shut down for about a month. On 31 October the Expedition 14 crew used the new parts to restore the Elektron oxygen generator to service.

On 27 March ESA successfully simulated a communications link between the ISS and the future Automated Transfer Vehicle (ATV). Ground stations in Spain played the role of the ATV for a total of 40 minutes during three passes of the ISS, which was oriented so that the ATV communications antenna on the Zvezda module pointed toward the Earth.

ESA's 10.3-tonne Columbus space laboratory for the ISS was handed over to the agency by prime contractor EADS Space Transportation (Germany) on 2 May, and was shipped to the Kennedy Space Center on 30 May. The $1.3-billion module was then pressure-tested for four months and placed in storage, awaiting a systems power-up to take place seven months before its planned launch in September 2007. It was manufactured by a 40-company industrial consortium led by EADS Space Transportation and Alcatel Alenia Space (France) under a $1.3-billion 1996 ESA contract.

U.S. President George W. Bush signed Senate bill S.1713 on 22 November 2005, opening the possibility for NASA to purchase services related to the use of the Soyuz and Progress vehicles from Russia, needed to support the ISS**.** The agreement by which Russia had been supplying services from these vehicles terminated in April. However, on 6 January, Russia and the U.S. agreed on a price of $21.8 million for NASA astronauts to travel to and from the ISS on Soyuz rockets after April. The Russian space agency Roskosmos agreed to fix the $21.8-million price until 2011.

On 28 November 2005 the U.S. National Research Council (NRC) released a report, "Review of NASA Plans for the International Space Station," in which the NRC cited the critical role the ISS will play in laying the groundwork for human exploration beyond low Earth orbit, for long-duration lunar stays, and especially for eventual human missions to Mars. The report's main conclusion was that "Completion of ISS research and testing essential for human missions to Mars and beyond will require a full six-person crew," and that NASA should give "top priority" to enabling six-person crews by 2008. The report also cited the need for an integrated plan for using the ISS to support NASA's human space exploration goals. The NRC also expressed concern about

NASA's ability to complete the station before retiring the Shuttle in 2010, and called for a backup plan to complete the station without the help of the Shuttle.

Space agency leaders on 2 March announced a new schedule for completing the assembly of the ISS. The U.S. agreed to operate 16 Shuttle flights to launch the major elements of the station before retiring the Shuttle fleet. Europe's Columbus module is to be launched in 2007 on the seventh flight following resumption of Shuttle operations this year, and the three flights needed to launch Japan's Kibo Experiment Module will be the eighth (in 2007), the ninth (in 2008) and the twelfth (also in 2008). The Russian solar power platform was dropped from the Shuttle manifest; instead, the Russian sections of the space station will draw power from the U.S. power system from 2007 through 2015. The space agencies also agreed to increase the crew of the ISS to six, beginning in 2009.

Russian flight surgeons cleared Japanese information-technology entrepreneur Daisuke Enomoto on 9 March for his planned tourist flight to the International Space Station (ISS) aboard a Soyuz rocket on 14 September. His trip was brokered by Space Adventures Ltd., which had negotiated previous ISS tourist flights with the Russian space agency Roskosmos. However, on 21 August Enomoto's trip was cancelled by Roskosmos due to medical reasons.

Space Adventures also announced on 3 April that their next client for a tourist flight to the ISS, International Software Corporation founder Charles Simonyi (USA), had signed on and completed preliminary training and medical examinations. He was certified by the Russian Government Medical Commission on 25 August as being medically fit for his flight to the ISS, and his contract with the Russian space agency Roskosmos for the flight was signed on 20 September. He is expected to fly with the ISS Expedition 15 crew in the spring of 2007. Simonyi is reported to have paid more for his flight than previous space tourists, between $20 million and $25 million. On 26 October he created a website to document his experiences, www.charlesinspace.com. Simonyi is no newcomer to space: in 1963, at age 13, he was selected as his native country Hungary's Junior Astronaut and was flown to Moscow, where he met several Russian cosmonauts. He is also a jet aircraft and helicopter pilot with over 2,000 hours of flight time.

On 8 May Roskosmos approved Anousheh Ansari as a future space tourist to the ISS, at an estimated price of about $20 million. Iranian-born Ansari was a primary sponsor of the Ansari X-Prize, won in 2004 by Scaled Composites' SpaceShipOne. Ansari was launched on 18 September, arriving at the ISS two days later for her one-week stay, during which she conducted a series of experiments for the European Space Agency on the human body's response to a microgravity environment. She was the first space traveller born in Iran and the first female space tourist.

On 8 May Constellation Services International (USA) signed an agreement with Space Adventures (USA), the agent for several previous space tourists lofted by Soyuz vehicles to the ISS, to pre-deliver to the ISS any cargo required by future space tourists

such as experiments, media equipment and other supplies.

Space Adventures also announced on 21 July the availability of spacewalking opportunities for future ISS space tourists. The spacewalks with a Russian cosmonaut would be of 90-minute duration and cost the tourist an additional $15 million, and would include an extra eight days aboard the ISS. The tourist would be tethered to the station at all times and would be able to view a sunrise and a sunset during the spacewalk. The experience will require the tourist to undergo an extra month of ground training, about 190 hours, in addition to the standard six-month training period required for previous visitors to the ISS.

A visit to the ISS by the first Malaysian astronaut was approved by Malaysia and Russia on 19 May as part of a contract offset for Malaysia's $1-billion order of Russian Sukhoi Su-30 MKM fighter aircraft. The candidate will be selected from two finalists among four Malaysian astronauts undergoing examinations at the Gagarin Cosmonaut Training Center in Star City, Russia. The Malaysian will not fly as a tourist, but as a full member of the ISS science and research programme, conducting experiments for the Malaysian Ministry of Science. The 19 May contract includes training and launch of the Malaysian astronaut to the ISS, which is planned for September 2007.

B. Other Earth-Orbital Flight Operations

On 14 March NASA announced that the next Shuttle flight would be delayed from its original May 10 – 22 window to no earlier than 1 July. It was decided that wiring defects found in some engine cutoff sensors could falsely report a dry fuel tank and thereby cause an early engine shutdown. The extra time allowed replacement of the four sensors inside orbiter Discovery's liquid hydrogen fuel tank. Errant readings of the sensors had appeared previously, during an April 2005 fueling test and prior to Discovery's 26 July 2005 launch. All these sensors, including the ones in Discovery's tank on 14 March, had been manufactured in 1996. They were replaced with new ones for the forthcoming mission.

Discovery was rolled out to Launch Complex 39B at the Kennedy Space Center on 19 May, and was then loaded with Italy's Leonardo logistic module, a large backup coolant module, and a replacement umbilical reel for the ISS mobile transporter. A Debris Verification Review was held on 30-31 May to review aerodynamic and tank foam-insulation issues, and a Design Certification Review (DCR) was held on 7 June to assess the performed tank modifications. Despite the expected loss of insulating foam from the external tank, NASA concluded at the DCR that such losses would be small enough and pose little risk to the orbiter on re-entry. A concern was raised for improving design of 37 foam-insulated brackets holding pressure and power lines in place on the tank, known as ice-frost ramps, but then decided they were sufficiently safe to allow the launch to take place. The Flight Readiness Review (FRR) was held on 16-17 June in conjunction with the Terminal Countdown Demonstration Test, with the crew on board but with the vehicle unfueled. After the FRR, the opening launch window for the STS-21 mission was set for 1 July, with the countdown beginning 28 June.

The launch finally took place on 4 July. Although several small pieces of foam were observed to break off the external tank, the Shuttle had by then reached an altitude at which the dynamic pressure was too low to cause any significant impact should they have struck the orbiter. Subsequent observation by a camera mounted on the Shuttle manipulator arm revealed no damage to the orbiter's thermal protection system, and 350 digital photos of the orbiter's underside taken by ISS Expedition-13 crew confirmed this initial observation. Discovery subsequently docked uneventfully with the ISS on 6 July and landed normally at the Kennedy Space Center on 17 July, following a last-minute runway change due to rain showers.

NASA subsequently reported that for the first time since the fatal failure of Shuttle Columbia in February 2003, the external tank (ET) performance on this mission has given the agency and its contractors a technically sound foundation on which to continue the Shuttle operations needed to complete the ISS and the transition to the new Orion vehicle. The success of the ET redesign and performance demonstration during the launch allowed NASA on 5 July to approve mating of the ET to its solid-rocket boosters for the next Shuttle flight of orbiter Atlantis. On 16 August NASA completed the Flight Readiness Review for Atlantis's flight and set the opening launch date window for 27 August. The launch was postponed twice due to bad weather conditions (the second postponement due to hurricane Ernesto), but Atlantis was finally launched successfully to the ISS on 9 September.

The day after the launch, the Shuttle robot arm with its 15-m extension was used to conduct a cm-by-cm inspection of Atlantis' thermal protection systems. No damage was observed, so on 11 September Atlantis docked with the ISS. Following undocking from the ISS on 17 September, the crew again carefully examined the thermal protection system of Atlantis to make sure that several pieces of debris spotted in the area on 19 September would not pose any risk to the Shuttle's return. After the crew declared the craft shipshape, Atlantis deorbited and returned to Earth successfully on 20 September. Shuttle Discovery had been cited as being ready for a "launch on demand" to rescue Atlantis' crew from the ISS if Atlantis were to have run into trouble and been unable to land safely.

On 26 July ESA announced its intention to award three $190,000 grants to European companies having an interest in space tourism. The awards, which were motivated by ESA studies indicating a potential European space tourism market, will include consultations with ESA launch-vehicle experts to assist with programme and mission planning. The purpose of the grants is to encourage development of a space tourism industry.

On 24 February China announced that Shenzhou-7, scheduled for launch in 2008, will feature a space walk by one or two taikonauts and that Shenzhou-8, planned for 2009 – 2011, would demonstrate the ability to dock, that could lead to a development and flight of a Chinese space station. The 1500-kg Shenzhou-6 orbital module launched on 12 October 2005 re-entered the atmosphere on 18 April after having released its 2-person

crew on 17 October 2005.

C. Life Sciences

The first NASA crew to occupy the Aquarius Underwater Laboratory off the Florida Keys arrived on 3 April for a 17-day tour to conduct tests of space-medicine concepts and practice Moon-walking techniques, returning to the Earth's surface on 20 April. NASA's Extreme Environment Mission Operations project involved a crew of three astronauts, a medical doctor and two professional divers. In one space-medicine experiment doctors at a remote location performed surgery on a simulated patient aboard the underwater laboratory. In a Moon-walk simulation experiment, the crew built an underwater structure using a remotely operated vehicle. A mission-control centre for the laboratory, set up at the Johnson Space Centre, was designed to simulate the two-second communications delay between Earth and the Moon. On 16 September a second crew of four astronauts embarked on a seven-day exercise in the underwater laboratory, conducting similar operations.

Kayser-Threde (Germany) announced on 23 November 2005 that lichens exposed to space radiation for 14 days last June aboard the company's Biopan exobiology research platform on a Russian Foton spacecraft subsequently resumed normal metabolism after their return to Earth. The tolerance of these cyanobacteria to the harsh space radiation environment, especially the high levels of ultraviolet radiation, suggest that living organisms could withstand the radiation rigors of interplanetary travel.

On 9 September China launched a Long March 2C rocket carrying a spacecraft based on China's FSW recoverable reconnaissance satellite, with a payload consisting of about 215 kg of seeds of 2,000 plant varieties. The payload was recovered two weeks later for analysis by Chinese researchers to assess the effects of gravity and radiation on germination and plant growth. The experiment was aimed at increasing crop yields in China.

V. SPACE STUDIES AND EXPLORATION

A. Astronomy and Astrophysics

On 10 January the Space Telescope Science Institute (USA) announced that the Hubble space telescope had discovered a third small star in the Polaris system, confirming that the previously identified double North Star was actually composed of three stars. The Hubble's high resolution was able to distinguish the new partner less than 0.2 arcsec from the main star, despite the fact that the main star is 2,000 times brighter than the Earth's Sun.

The telescope's Advanced Camera for Surveys (ACS) shut itself down on 19 June due to out-of-limits power-supply voltage, but was restored to service early in July by switching to a redundant power supply. Following the successful flight of Space Shuttle

Discovery to the ISS on 4 – 17 July and Atlantis on 9 – 20 September, NASA began setting up plans to conduct the long-debated final servicing mission to Hubble, and on 31 October NASA Administrator Michael Griffin announced that the mission will be conducted in May 2008, most likely by Shurttle Discovery. Its estimated cost is $900 million, most of which has already been spent on preparatory work. The crew, to be commanded by astronaut Scott Altman, who was also in command of the 2002 repair mission, will conduct five spacewalks on the 11-day servicing mission, bringing 9.98 tonnes of equipment to the telescope platform. The equipment includes two new instruments, the Cosmic Origins Spectrograph and the Wide Field Camera 3, along with a refurbished Fine Guidance Sensor to replace one of the three units onboard. They will also replace batteries and all six of the spacecraft's gyroscopes, and attempt to repair the Space Telescope Imaging Spectrograph, which stopped working in 2004. Griffin cancelled an earlier plan to install a de-orbiting thruster on the Hubble, based on the fact that the telescope's orbit will not decay significantly until 2020, when the new Orion vehicle will be available to implement a de-orbiting scenario if necessary. The mission will be backed up by a second Shuttle, ready to launch as a crew rescue vehicle in case of critical damage to the mission's primary Shuttle orbiter.

On 7 July NASA downgraded its multi-billion-dollar Space Interferometry Mission (SIM), a progenitor for the agency's future Terrestrial Planet Finder mission, to a research and technology programme in order to release funds needed to complete the joint U.S. – German Stratospheric Observatory for Infrared Observatory (SOFIA). The SIM project, which originated in the early 1990s and was planned for launch in 2016, had been intended to measure distances between stars with an extremely high accuracy and to identify stars likely to harbor Earth-type planets.

On 11 May ESA awarded a $403-million prime contract to EADS Astrium (France) for the Gaia star-mapping satellite. Gaia is scheduled for launch in 2011 to the L-2 Sun-Earth Lagrange libration point, 1.5 million km from Earth, aboard a Russian Soyuz-Fregat rocket. It will map stars in the Milky-Way galaxy and search for planets around them. Gaia is designed to "take a census of everything that moves" in the Milky Way, measuring the temperature, age, and composition of over a billion stars and compiling a list of extra-solar planets, asteroids, and comets. Total cost of the five-year mission, including the spacecraft, launch, insurance, ground facilities and five years of operation planned to begin in 2011, is expected to be about $709 million.

The 2-tonne Gaia's twin silicon-carbide telescopes will feed a billion-pixel focal array, the largest ever built. They are capable of measuring the angular position of stars to between 7 and 300 microseconds of arc, 100 times the accuracy of Hipparcus, the previous ESA star-mapper. Specific mission targets are the identification of 10 million galaxies, 500,000 quasars, 50,000 brown dwarf stars, 1 million asteroids and comets, and 30,000 extrasolar planets, monitoring each target object up to 100 times to verify the accuracy of the observations.

ESA's Space Science Advisory Committee, meeting on 18-19 January, decided to postpone two major missions in order to free up budget opportunities for new mission

ideas, due to be proposed later in the year. The planned Solar Orbiter launch was delayed by two years, to 2017, and no work will be committed to the Lisa gravity-wave detector, which depends heavily on NASA budgetary support, until the Lisa Pathfinder technology demonstrator mission has been confirmed.

On 22 February the Japan Aerospace Exploration Agency (JAXA) launched Japan's first infra-red astronomy telescope Astro-F into a 304-km x 733-km Sun-synchronous near-polar orbit, aboard a M-5 rocket from the Uchinoura Space Center. The 925-kg satellite, subsequently renamed Akari ("Light"), began conducting infrared surveys on 13 April, following completion of a two-month checkout period. Its 68.5-cm telescope, cooled to 6 Kelvins, has a range of 1.7 μ (near infrared) to 180 μ (far infrared), and is used in conjunction with a Far-Infrared Sensor (FIS) and a Near-and-Mid-Infrared Camera (IRC). First images by Akari of the spiral galaxy M81 in constellation Ursa Major, about 12 million light-years from Earth, and nebula IC4954, about 600 light-years away, were released by JAXA partner ESA on 22 May. Akari's mission is to study protogalaxies, search for as-yet undiscovered comets and penetrate cosmic dust to study star formation. ESA collaborates with JAXA on the mission by providing ground and data-processing support.

B. Plasma and Atmospheric Physics

NASA's Imager for Magnetopause-to-Aurora Global Exploration (IMAGE) satellite, launched to a highly elliptical Earth orbit in March 2000, stopped responding to ground commands on 20 January due to a power-supply system failure. Its primary mission to study the structure of the Earth's magnetosphere as it responded to solar-wind energy, was completed in two years, but IMAGE continued to collect and transmit data until December 2005.

On 8 May NASA designated the Goddard Space Flight Center to develop the four-satellite Magnetospheric Multistage mission, which will conduct high-resolution observations of plasma phenomena in the Earth's magnetosphere. Instruments for the spacecraft are being developed by the Southwest Research Institute. This fourth mission in the Solar Terrestrial Probes programme is scheduled for launch in 2013. On the same day NASA awarded the two-satellite Radiation Belt Storm Probe mission to the Johns Hopkins University Applied Physics Laboratory. This second mission in the agency's "Living with a Star programme", planned for launch in 2012, will collect data on the interactions of Earth's radiation belts and magnetic fields with solar storms. It is aimed at helping enhance space weather predictions.

NASA on 25 May extended the mission of the Thermosphere, Ionosphere, Mesosphere Energetic and Dynamics (TIMED) spacecraft from October 2006, when it was due to complete its studies, to 2010. The extended mission will focus on observing the response of the Earth's middle and upper atmosphere to solar and geomagnetic phenomena that were not covered during the primary mission, enabling a better understanding of the processes leading to the escape of oxygen and hydrogen from the upper atmosphere. This information is expected to bring insights into atmospheric

evolution and possibly on the fate of the Earth's atmosphere, as well as better understanding of the evolution of other planetary atmospheres such as those of Mars and Venus.

Following several postponements, mainly due to concerns about a potential leak in the Boeing Delta-2 launch-vehicle's second-stage oxidizer tank, built by Alcatel Alenia Space (Italy), NASA finally launched the STEREO mission from Cape Canaveral Air Force Station on 25 October. The concern had arisen after a leak was discovered in the second-stage oxidizer tank of the Delta-2 launcher for NASA's five-spacecraft Time History of Events and Macroscale Interactions during Substorms (THEMIS) mission, necessitating a delay in the THEMIS launch from October to December.

STEREO consists of two nearly identical spacecraft that will capture 3-dimensional views of the Sun. The two-year Solar Terrestrial Relations Observatory mission will explore the origin, evolution, and interplanetary consequences of solar coronal mass ejections, which are a major source of magnetic disruptions on Earth. The spacecrafts, which were injected into the same 1,800 x 417,000-km elliptical orbit that extends from Earth's orbit to an apogee just beyond the Moon, were built by the Johns Hopkins University Applied Physics Laboratory and are operated by NASA's Goddard Space Flight Center. They each carry 16 instruments. Using lunar gravity-assist swingbys, they were subsequently moved to 346-day and 388-day heliocentric orbits, one ahead of Earth and one behind, to provide the three-dimensional perspective. The third mission in NASA's Solar Terrestrial Probes programme, STEREO was the first mission ever to use lunar swingbys to tailor the orbits of more than one spacecraft. Total cost was $520 million, including development and construction of the two 640-kg spacecrafts, their launch and a $60 million contribution from France and other European participants. Some components were built by Germany, Italy, and the UK.

The mission of ESA's Solar and Heliospheric Observatory (Soho) spacecraft was extended on 1 June from April 2007 to December 2009, to allow the eleven-year-old observatory to support the operations of Japan's Solar-B and NASA's two Stereo satellites, launched this year, ESA's Proba-2 spacecraft, scheduled for launch in September 2007, and NASA's Solar Dynamics Orbiter, planned for 2008.

On 17 November 2005, EADS Astrium was awarded a $101-million contract by ESA to build three Swarm satellites intended for studies of the Earth's magnetic field. Planned for launch in 2010, two of the satellites will fly in a 450-km polar orbit, with the third orbiting about 80 km higher.

Japan's Solar-B observatory was launched into a 280 x 686-km Sun-synchronous 98.3-degree orbit by an M-5 rocket from the Uchinoura Space Center on 23 September. The 900-kg follow-on to Solar-A (Yohkoh) will study the Sun's atmosphere, magnetic field and coronal mass ejections for three years using a Solar Optical Telescope, an X-ray telescope and an ultraviolet telescope developed and built by Mitsubishi Electronics for the National Astronomical Observatory of Japan. The project is a joint effort of the Japanese Aerospace Exploration Agency (JAXA), NASA, and ESA.

C. Space Exploration

On 1 November 2005 NASA Administrator Michael Griffin announced an intention to seek participation by other nations in the agency's space exploration programme**,** whose transportation architecture will be based on the Crew Exploration Vehicle Orion, the Crew Launch Vehicle Ares-1, and the Heavy Lift Vehicle, Ares-5.

NASA's Mars Reconnaissance Orbiter (MRO), launched on 12 August 2005 arrived on Mars on 10 March and was successfully inserted into a 400-km x 44,000-km elliptical orbit by a 27-minute burn of its six orbit injection rockets, which accelerated the spacecraft to match Mars' higher speed around the Sun. The $450-million spacecraft, built by Lockheed Martin, carries six instruments on a bus significantly larger than any of the three spacecraft currently orbiting Mars: Mars Global Surveyor, Mars Odyssey, and Mars Express. Goals of the $720-million, 2-year mission, which began in November, are to seek more evidence of current or past water or ice on the red planet and to identify the best locations for future landers or rovers to hunt for such evidence. Subsequently, beginning in December 2008 the 2,170-kg MRO will serve as a communications relay between future Mars exploration spacecraft and Earth. On 29 March MRO began a seven-month series of 550 aerobraking maneuvers to reach an interim 298-km x 250-km Sun-synchronous orbit, which was achieved on 11 September following a final burn of its thrusters on 30 August. Additional aerobraking maneuvers brought the spacecraft into its final operational 298-km orbit in October, from which it transmitted its first few dozen images. Mars then moved behind the Sun, so MRO was unable to transmit images and data until the planet emerged from the Sun's shadow on 1 November.

Preliminary images transmitted on 23 March and 25 March by MRO's High Resolution Imaging Science Experiment (HiRISE), the most powerful camera ever to leave Earth orbit, measured the instrument's sensitivity to "jitter" due to other moving parts of the spacecraft and showed great clarity of Mars' surface. No further images were taken until completion of the aerobraking maneuvers.

On 29 March NASA announced the agency's future Mars exploration plan: a stationary lander called Phoenix, scheduled for launch in August 2007; and the Mars Science Laboratory, carrying a nuclear-isotope-powered rover, to be launched late in 2009. The draft plan, based on a 2007 budget that reduced Mars exploration funding through 2010 by over $2 billion, also calls for a competitively selected Scout mission to be launched in the 2011 window; a Mars science and communications orbiter to be launched in 2013; and a lander mission in 2016 that could be either an Astrobiology Field Laboratory to search for past life or one or two rovers similar to Spirit and Opportunity. Mars prospects beyond 2016 could include a mix of Scout missions, sample-collection missions and a network of small landers working in concert.

A review of NASA's future Mars robotic exploration programme by the ad hoc Mars Architecture Assessment Committee of the U.S. National Academy of Sciences was released on 6 July. The report called for two new major projects: a Mars Long-Lived

Lander Network, a grid of science stations to make coordinated measurements around the globe for at least one Martian year; and a pair of medium-sized rovers based on the highly successful Spirit and Opportunity rovers now exploring the red planet, to evaluate the geological context of specific sites and search for organic compounds at targets identified by prior missions. The Committee urged NASA to begin planning for the all-important robotic sample-return mission "at the earliest possible opportunity."

NASA announced on 6 December 2005 that the Cassini spacecraft transmitted images of the south polar region of Saturn's moon Enceladus, showing jets of fine icy particles that are most likely to have occurred due to warm fractures in the area. Such fractures are a clear indicator of geological activity. Later observations of the same phenomenon during a March flyby of Enceladus indicated that the jets were probably issued from a subsurface reservoir or reservoirs of liquid water, heated by an as-yet unknown internal source within the satellite, which may have occured due to the tidal stresses and strains in the rocky interior. The data suggest that the water may be only a few tens of meters below the surface. The discovery stimulated discussion of the prospects for life on this tiny (300-km) moon.

On 22 July Cassini's cloud-penetrating radar sensor discovered several extremely smooth well-defined dark patches on the Saturn's moon Titan, with features that appear to be liquid-carved channels flowing into them. Cassini scientists believe the patches are lakes of liquid methane, which would explain the data obtained previously by the Huyghens probe, which had suggested that Titan's surface receives about 5 cm of methane rain each Earth year.

NASA's long-planned New Horizons mission to Pluto, its moon Charon, the two newly discovered satellites of Pluto and several objects in the far-distant Kuiper Belt just outside the Solar System, was finally launched by a three-stage Lockheed Martin Atlas-5 rocket from Cape Canaveral on 19 January. The 480-kg spacecraft, which was designed, built and in-flight controlled by the Johns Hopkins University's Applied Physics Laboratory, was the fastest spacecraft ever launched. At over 56,000 km per hour it passed the Moon just nine hours after launch. The first course correction firings were conducted for 5 minutes on 28 January and for 12 minutes on 30 January, imparting a velocity change to the spacecraft of 18 m/sec. on its way to Jupiter, where it will get a gravity assist in February 2007 to sling it to a summer 2015 arrival at Pluto. The trip to Jupiter will take only 1 year, as compared with the typical 3-year flight times of previous missions.

Six out of seven of the spacecraft's science instruments were satisfactorily checked for functionality by 29 March. The seventh instrument, the Radio Science EXperiment (REX), is part of the spacecraft's communications system, which was checked satisfactorily in mid-April. While near Jupiter, controllers will check out New Horizons' seven instruments by observing the giant planet and its moons, after which the spacecraft will be put in a hibernation mode, to be wakened once a year for system health checkups. The seven instruments, all powered by only 28W of the radioisotope thermoelectric generator's 200-W output include three cameras to transmit images in the

visible, infrared and ultraviolet spectral; three spectrometers to study the composition and temperature of Pluto's surface and atmosphere; and a dust counter, designed by students at the University of Colorado as the first planetary-mission instrument designed and operated entirely by students. The spacecraft also carries commemorative material on Clyde Tombaugh, Pluto's discoverer, a piece of SpaceShipOne and a list of 430,000 space enthusiasts' names.

New Horizons is scheduled to spend five months studying Pluto and its satellites, approaching to within 9,900 km of the 2,350-km planet on 14 July 2015 and to within 27,000 km of 1,200-km-diameter Charon, which is 19,000 km from Pluto. It will then be redirected to study one or two Kuiper-belt objects. The spacecraft's 20-cm-aperture Lorri long-range reconnaissance imager provides planetary-surface resolution down to 25 m; the Ralph visible/infrared imager/spectrometer has 0.5-km monochromatic and 1.5-km color image resolution and 7-km resolution of infrared surface composition and temperature; the Alice ultraviolet imaging spectrometer, similar to that aboard ESA's Rosetta comet-chaser spacecraft, will obtain data on Pluto's atmospheric composition and temperature/pressure structure; the Swap solar-wind instrument will detect the intersection of Pluto's atmosphere with the solar wind and measure the rate at which the atmosphere is escaping the planet; the Pepssi energetic-particle spectrometer will help characterize Pluto's atmosphere; and the Rex radio science experiment will use the spacecraft's 2-m antenna to collect atmospheric data and measure surface temperatures. The New Horizons spacecraft transmitted its first images on 27 August, when the Lorri instrument photographed Messier-7, a star cluster in the Milky Way galaxy.

The instruments' data will be collected by two 64-GB solid-state recorders, which will take nine months to transmit the encounter data at 768 bps. Transmission time to Earth, at the speed of light, will be about 4-1/2 hours. Total cost of the mission, which is the first in NASA's New Frontiers programme of medium-sized exploration spacecraft, is $700 million, including launch and ten years of operation.

On 15 February images taken by the Hubble telescope confirmed the presence of two small satellites of Pluto that were discovered by the telescope in May 2005. Their size is 56 - 160 km in diameter, which is about one-tenth of the size of Charon, but the two small satellites are 600 times fainter than Charon and 4,000 times fainter than Pluto, making them indiscernible by ground-based telescopes. On 23 June, the International Astronomical Society formally christened the new moons Nix (the inner satellite) and Hydra (the outer satellite), whose initials were selected to honour the New Horizons mission. In Greek mythology Nix was the goddess of the night and mother of Charon, the Styx river ferry man. Hydra was the nine-headed serpent that guarded Pluto's underworld realm. The spelling of Nix (Egyptian spelling) was changed from the original Nyx (Greek spelling) to avoid confusion with the previously named Nyx asteroids.

In early April Hubble also confirmed the size of "the 10th planet," formally titled 2003 UB313 and nicknamed "Xena" when it was discovered last year. Originally estimated to be about 3,000 km in diameter, the new Hubble estimate placed its size at

2,400 km, with 95 km uncertainty. This makes it somewhat larger than Pluto's 2,300 km diameter. Xena is 16 billion km from Earth. On 24 August the International Astronomical Union General Assembly in Prague adopted a statement declaring that only the eight Solar System planets from Mercury to Neptune are true planets, and that Pluto, Xena, and other small round objects in the Solar System are to be called "dwarf planets." That decision, however, will continue to be debated by astronomers for at least several years.

NASA's $212-million Stardust mission launched in February 1999 returned its collection of cometary and interstellar dust particles to Earth on 15 January, following the highest-speed re-entry ever of any man-made object: 12.8 km/sec. The 45-kg sample container, with its 35-cm aerogel collector intact, landed successfully on the salt flats of the U.S. state of Utah within 100 m of its predicted touchdown point. The examination of the collector's contents in the Stardust Laboratory at NASA's Johnson Space Center, that started on 16 January, revealed over a million particles bigger than a micron, many large enough to be visible to the naked eye, and hundreds of particle tracks left in the aerogel medium. In addition to the dust collected during a close encounter with Comet Wild-2 near Jupiter on 2 January 2004, Stardust's samples included what are believed to be pristine remnants of material that formed the Solar System 4.6 billion years ago. After depositing its payload, the Stardust spacecraft was put into a long-term hibernation mode on 29 January, leaving open options for possible future reuse as it travels in its heliocentric orbit between Earth and Mars. The first analyses of Stardust's samples, announced on 13 March, revealed a somewhat surprising result: the minerals collected from Wild-2 were formed at extremely high temperatures, such as might be found close to a star, and not in the frigid cold of the solar system's outer reaches where most short-term comets are born.

On 2 March NASA announced the cancellation of the agency's Dawn mission to explore the two large asteroids Ceres and Vesta. Originally scheduled for launch in June, the mission was cited as having 29 major issues that needed to be addressed, plus a 14-month launch delay and a cost escalation to $446 million, well above its $373-million cap. The mission was managed by NASA's Jet Propulsion Laboratory (JPL); Orbital Sciences Corporation built the ion-propelled spacecraft.

However, on 9 March NASA agreed to review the cancellation decision based on additional information generated by JPL, and on 27 March the agency reinstated the mission. The spacecraft will carry a camera designed and built by the German space agency DLR, based on the camera now flying on ESA's Mars Express, and a mapping spectrometer provided by the Italian Space Agency (ASI) and built by the Institute for Space Astrophysics in Rome. Dawn team members also include the University of California and the University of Maryland. Launch aboard a Boeing Delta-2 rocket is planned for summer 2007.

NASA announced on 13 April that the Lunar Reconnaissance Orbiter (LRO), planned for launch in October 2008, has experienced cost growth from its initial budget of $310 million (plus launch) to about $370 million. Nevertheless, on 2 August a larger

launch vehicle, Atlas V-401, was substituted for the originally planned Delta-2. Although this added up to $80 million to the mission costs, it allowed the addition of a $73-million, 880-kg Lunar Crater Observation and Sensing Satellite (LCross). This project, which will be by the NASA Ames Research Center with industry support by Northrop Grumman Space Technology, was announced by NASA on 10 April as a prospective mission. The main LCross spacecraft will watch the Atlas-V's 2,000-kg spent Centaur upper stage crash into the 2-km-deep hydrogen-rich Shackleton Crater in the lunar south pole region at 9,000 km/hr, studying a debris cloud that is expected to rise about 55 km above the surface. Fifteen minutes later a separate 534-kg Shepherding Spacecraft (S-S/C) will fly through the resulting plume, using its infrared spectrometer to search for traces of water ice. It will then crash into the crater floor while ground-based telescopes search its plume for ice, along with the LRO, India's Chandrayaan lunar orbiter and other spacecraft. The LRO/LCross mission is the first in NASA's Robotic Lunar Exploration Programme (RLEP), its next planned mission, RLEP-2, will be a lander planned for launch in 2011.

Russia announced on 1 June an ambitious programme for resuming its robotic exploration of the Moon. Planned for launch in 2009 on a Soyuz booster or the Molniya version, with an extra upper stage, the new Luna orbiting spacecraft will carry three separate lunar surface systems: ten High-Speed Penetrators (HSPs), two slower Penetrator/Landers (PLs) and a Polar Station. Each of the HSPs will carry a seismometer and a communications antenna. They will strike the lunar surface in the Sea of Fertility at speeds up to 2.4 km/second and burrow a meter or more into the Moon, leaving their antennas on the surface. The resulting seismic array should be able to characterize Moonquakes caused by Earth's gravitational pull.

The PLs, carrying more advanced sensors to collect broadband seismic data, are equipped with solid-propellant retro-rockets to reduce their impact speeds to a maximum of about 200 m/second, and will also leave their communications antennas on the surface. They are planned to land near the Apollo 11 and Apollo 12 sites explored by U.S. astronauts in 1969, and will compare current seismic data with those taken by the Apollo crews. The Polar Station lander is to be released from the polar-orbiting mother spacecraft, settling down in a crater near the Moon's south pole where water ice is believed to exist. Its retrorockets will land it at a gentle 25 m/second, delivering a mass spectrometer, a neutron spectrometer and another seismometer to the lunar surface. The Vernadsky Institute of Geochemistry and Analytical Chemistry is leading the development of the science payloads. The Institute expects Luna's data can be helpful to the nations planning their first lunar explorations; i.e. Japan, China, and India. Russia has outlined further plans for a new unmanned lunar rover mission in 2015 – 2016.

Russia also announced in July the advanced development of a robotic sample return mission to the Mars moon Phobos. The original design by Lavochkin envisioned a 2-tonne spacecraft, as contrasted to the failed 1988 Phobos spacecraft mass of 5.5 tonnes, by capitalizing on advances in materials, computers and electronics so as to be able to perform far better than the 1988 mission, and also enable launch on a Soyuz rocket instead of the more expensive Proton. A later Lavochkin design indicated a spacecraft mass of over 8 tonnes.

The Russian Space Research Institute IKI is developing the sensors for the Phobos spacecraft, with participation of ESA, the French space agency CNES and U.S. researchers. Planned for launch in 2009 from the Baikonur Cosmodrome, the Phobos spacecraft would land, drill a meter below the Mars moon's surface, retrieve a two-hundred-gram sample of both soil and rock, and return it to Russia in 2012. The lander will be designed to remain on Phobos' surface for a year. Other goals for the mission include mapping the surface of Phobos, measuring its mass and dimensions, and analyzing the plasma and dust around the Martian moon. On 23 August the Chinese Academy of Space Technology announced that China will participate in the mission by providing the survey equipment.

IKI also suggested a manned space station to be placed in orbit around Mars, a lunar penetrator mission for launch in 2012, a Mars rover launch in 2013, a lunar rover in 2015-2016, and a robotic Mars sample return mission in 2020. Funding for Russia's ambitious new lunar and planetary exploration programme, which now combines human and robotic activities, will come from a 30% increase in the space agency Roskosmos' budget that was approved for 2004 – 2005 and an additional 50% increase expected by the end of 2006. The effect of these increases translates to an overall 15% annual growth through 2015.

On 23 May NASA announced that during the next year Voyager 2, which will then be 76 astronomical units (AUs), about 11.4 billion km from the Sun in the southern region of the Solar System, will cross the Solar System's termination shock - the boundary of the Solar System. Voyager 1 had begun detecting charged particles travelling toward the Sun as it approached the shock in the Solar System's northern region about a year earlier, when it was 85 AUs from the Sun. Hence the southern Solar System boundary appears to be about 9 AUs (about 1.4 billion km) closer to the Sun than the northern boundary.

ESA's Venus Express mission was launched successfully from the Baikonur Cosmodrome on 9 November 2005 aboard a Russian Soyuz-Fregat rocket. Built by EADS Astrium (France) and Alcatel Alenia Space (France), the 1,240-kg spacecraft was injected into a 330,000 x 390-km 9-day elliptical orbit around Venus on 11 April by a 50-minute burn of its main engine to begin its 16-month observation programme. The first photos of Venus were transmitted on 13 April, and insertion into the spacecraft's final 250 x 66,000-km 24-hour elliptical orbit was accomplished on 7 May by a delicate series of aerobraking and propulsion manoeuvres that consumed most of the spacecraft's fuel. Following checkout of the craft's seven instruments, its science mission began on 4 June. The pointing mirror of one of the instruments, the Planetary Fourier Spectrometer (PFS), was locked in a position which prevented the PFS from collecting any data on the atmospheric and surface temperatures it had been designed to measure, and on 13 July ESA confirmed that the problem remained a mystery. Total cost of the 16-month mission was budgeted at $264 million.

Following its highly successful mission, ESA's Smart-1 lunar orbiter was guided to a controlled crash-landing on the "Lake of Excellence" in the Moon's mid-southern latitudes on 3 September. Originally planned to crash on the far side of the Moon on 17 August, the mission was extended to provide good viewing of the impact from telescopes in the Americas and to collect more high-resolution images from the spacecraft as it neared the lunar surface. The impact, which created a 80-km plume that lasted for 130 seconds, was viewed by the 3.6-m Canada-France-Hawaii Telescope in Hawaii and other observatories in Africa, Australia, Europe, South America and the U.S.

The German Aerospace Center DLR issued a contract in July to OHB-System AG (Germany) for Mona Lisa, a 10-month and $640,000 worth study of a future lunar-lander exploration project. OHB is designing potential scenarios for German industry to play a major role in the preparation for a sizable German contribution to a European or international lunar exploration programme.

Japan's Hayabusa spacecraft, launched on 9 May 2003, was scheduled for a landing rehearsal on asteroid Itokawa on 4 November 2005. The rehearsal was aborted due to anomalous information detected by the onboard computer and was rescheduled for 9 November, when it was conducted successfully, verifying the spacecraft's guidance and navigation functions. An attempted landing of Hayabusa's Minerva probe on 12 November was unsuccessful, and the probe drifted off into space. Hayabusa's first landing on Itokawa took place on 20 November, but the spacecraft lifted off the asteroid without collecting samples. A second landing on the "Muses Sea" site took place on 26 November, but shortly after the spacecraft had begun collecting samples it was discovered that one of its thrusters was leaking and another was disabled by a frozen fuel line. Contact with the spacecraft was lost shortly afterward, but was re-established again in January. Controllers repositioned Hayabusa, so that its solar panels could warm up the spacecraft, and on 6 March its position and speed were confirmed: 13,000 km from Itokawa and travelling away from the asteroid at 3 m/sec. With 42 – 44 kg of xenon propellant still remaining and two of the spacecraft's four engines in good operating condition, controllers started the ion-propulsion engines in June to begin the long trip back to Earth. Arrival is expected in June 2010. Data from Hayabusa's encounter with the 600-m x 120-m asteroid suggest that is one of the youngest Solar System objects ever seen, made up of pebble-sized rocks packed solidly together.

The U.S. and India agreed on 20 January that two U.S.-built instruments will fly on India's $85-million Chandrayaan-1 Moon mission, planned for launch in September 2007. The Johns Hopkins University Applied Physics Laboratory will provide the MiniSAR, a miniature synthetic-aperture radar to search for ice in the Moon's polar regions, and NASA's Jet Propulsion Laboratory will build the Moon Mineralogy Mapper, an imaging spectrometer to assess lunar mineral resources. The official memoranda of understanding on the two instruments were signed on 9 May.

VI. TECHNOLOGY ADVANCEMENT

A. Propulsion

(1) Earth to Orbit

On 12 July the U.S. Air Force Research Laboratory (AFRL) conducted the first firing of their Integrated Powerhead Demonstration (IPD) ground-test engine at its full thrust of 1.1 MN. The engine, developed as part of the U.S. government-industry High Payoff Rocket Propulsion Technology programme, had previously undergone 300 seconds of lower-thrust operation during 21 firings at NASA's Stennis Space Center. NASA's Exploration Systems Mission Directorate, Pratt & Whitney Rocketdyne, and Aerojet are the AFRL's partners on the programme.

The Ground Demonstration Engine (GDE-2) of Pratt & Whitney Rocketdyne's closed-loop hydrocarbon-fuelled supersonic-combustion ramjet (scramjet) development programme was hot-fired for the first time at hypersonic conditions on 26 July. The engine underwent several successful runs at Mach 5 in the High-Temperature Tunnel at NASA Langley Research Center.

The Zefiro-9 third-stage 305-kN solid-propellant rocket engine for ESA's four-stage Vega launcher was successfully test-fired on 23 December 2005. The test, which was the first of any of the four Vega engines, was conducted at a reduced thrust of 280 kN by Avio (Italy), the engine's builder. Vega's 2.15-MN Zefiro-23 solid-propellant second-stage engine, also built by Avio, was test-fired successfully for 75 seconds on 26 June. It was one of the largest filament-wound, carbon-epoxy casing motors ever fired in Europe. The test included successful operation of the motor's thrust-vector-control system. Vega's P80 first-stage motor, the largest single-piece composite casing motor ever built, is planned for testing in November by prime contractor Eurpropulsion, a joint venture of Avio and Safran's Snecma Solid Propulsion unit. The Avum liquid-propellant fourth stage, being developed by Avio using a Ukrainian Yuzhmash engine, also has yet to be tested.

On 10 January the Indian Space Research Organization (ISRO) announced the successful completion of ground testing on an indigenously designed and built supersonic-combustion ramjet (scramjet), culminating in a 7-second firing at Mach 6 late in November 2005.

The latest test launches under the University of Queensland's Hyshot supersonic-combustion ramjet (scramjet) programme were conducted at the Woomera test range in Australia on 25 March (Hyshot III) and then again on 30 March (Hyshot IV). The data from these tests feed into the UK's Sustained Hypersonic Flight Experiment (SHYFE), funded by the British Defense Ministry. The scramjet test engine flown on 25 March, built by Qinetiq (UK), was boosted by a Terrier-Orion Mark 70 rocket combination to its flight speed of about Mach 8 from an altitude of 314 km. The engine flown on 30 March, designed by the Japanese space agency JAXA, reached an altitude 30 km lower than the

planned 320 km due to failure of the nose cone to jettison, and on 19 April JAXA declared the experiment a failure.

(2) Orbit Transfer

On 18 April NASA awarded ATK GASL (USA) a $10.3-million contract to design, develop, and test a 34-kN thrust pressure-fed rocket engine using liquid oxygen and methane propellants. Originally planned for use with the Crew Exploration Vehicle Orion, the engine could reduce the handling and servicing issues involved with conventional toxic propellant combinations such as hydrazine and nitrogen tetroxide. The contract includes options to design a larger prototype of a flight-capable engine.

Aerojet (USA) delivered a new high-thrust ion thruster to NASA's Glenn Research Center (GRC) on 19 July. The device, developed by Aerojet under NASA's Evolutionary Xenon Thruster (NEXT) project, has a 30,000-hour service life and generates three times the thrust of the Solar Electric Propulsion Technology Applications Readiness ion thruster that was used on NASA's Deep Space 1 mission. After completing acceptance tests at GRC, the unit was shipped to the Jet Propulsion Laboratory (JPL) for environmental testing.

B. Power

On 1 December 2005 NASA's Marshall Space Flight Center's programme on Nuclear Energy Research for Space Exploration and Propulsion announced contract awards of $30,000 each to three universities for nuclear power and propulsion research applicable to lunar and planetary exploration. The Florida Institute of Technology and Oregon State University received awards for nuclear propulsion studies and the University of Illinois is studying electric power generators for use on the Moon and Mars.

On 7 June NASA's Jet Propulsion Laboratory released data on the photovoltaic arrays planned for the Jupiter orbit mission Juno. The spacecraft's solar array of 45 sq. m will carry ultra-triple-junction gallium arsenide photovoltaic cells on germanium substrates, which not only offer the highest efficiency of any cells in production (29%), but can also survive Jupiter's intense radiation fields. The key to enabling the use of solar arrays at Jupiter, where the solar intensity is only 4% of that in Earth orbit, is an orbit that has no eclipses and allows array inclinations that remain almost perpendicular to the incident rays from the Sun. Juno will fly in a polar orbit at altitudes of 1.06 – 39 planetary radii (75,000 – 2.7 million km) to achieve these parameters.

C. Spacecraft Design, Technology, and Development

On 23 November 2005 Orbital Sciences Corporation (USA) received a $27-million contract from NASA to develop Space Technology 8, the next project in the agency's New Millennium programme to validate new spacecraft technologies. The 175-kg satellite, planned for launch in 2008 aboard an Orbital Sciences Pegasus rocket, will carry four experimental spacecraft "housekeeping" technologies: a large, flexible solar

array, a 40-m deployable boom, high-radiation-resistant electronic equipment and a spacecraft thermal control device.

Another project in the agency's New Millennium programme, the $130-million Space Technology-5 (ST-5) mission, was launched into a 300 x 4,500-km elliptical orbit by an Orbital Sciences Pegasus rocket on 22 March. A constellation of three microsatellites weighing 28 kg each and flying 350 km apart, the satellites spent their 90-day mission testing better methods of collecting space weather data by using multiple small satellites to take measurements of phenomena such as the Earth's magnetic field, solar wind, solar flares, coronal mass ejections, charged particles and gamma radiation at the same time from different locations. Their ability to make simultaneous magnetometer measurements across a single auroral current sheet demonstrated the unique value of small, affordable satellites working together as a fleet. ST-5 was shut down on 30 June after completing its mission

Early in February NASA announced a major expansion in its Centennial Challenges prize programme to encompass technologies specifically oriented toward space exploration. Previous Centennial Challenges had focused primarily on robotics technology. The new competitions include a $5-million prize to build, launch and demonstrate the ability to produce and store liquid oxygen and hydrogen in orbit; two incremental prizes of $2.5 million each for sending a solar sail to the L-1 Sun-Earth Lagrange libration point and then sailing it out of the ecliptic for 90 days; $1 million for a lunar all-terrain vehicle; $500,000 for a low-cost commercial spacesuit; $500,000 for a rechargeable power source able to operate through the two-week lunar night; and $2 million for a micro re-entry vehicle able to return at least half a dozen hen's eggs from orbit unbroken.

On 5 May NASA also joined with the X-Prize Foundation (USA) in offering a $2-million prize for development of vehicles designed to go to the Moon. The competition was held on 22-23 October during the X-Prize Cup Expo in Las Cruces, New Mexico. The teams participating in the Lunar Lander Analog Challenge were rated on demonstrations of their vehicles' abilities to launch vertically, hover in mid-air, land on a target about 100 m away, and then repeat the maneuver.

The U.S. Defense Advanced Research Projects Agency (DARPA) issued a broad agency announcement in November 2005, seeking proposals for a robot "tow-truck" that would use mechanical arms and hands to grasp satellites and move them to new orbits without damaging them. Based on flight software developed and tested early in 2005 by the U.S. Naval Research Laboratory, the Spacecraft for the Universal Modification of Orbits (SUMO) would study target spacecraft to determine the best approach to connecting with them (e.g., by grasping the bolt ring that had attached the spacecraft to its launch vehicle), and then transport them to their new orbits. The target spacecraft would need no special attachment or docking hardware. DARPA has allotted $32 million for SUMO over the next two years, with a demonstration launch planned for 2010. SUMO would supplement DARPA's Orbital Express project, which is designed to replenish propellant tanks and replace electronic "boxes" in the target spacecraft.

The two spacecraft that comprise the Orbital Express project were mated at Cape Canaveral during the week of 11 September. Nextsat, the target satellite, was built by Ball Aerospace; the "chase" satellite Astro was built by Boeing, the Advanced Technology Programme's prime integrator. The mission involves separating the spacecraft by up to 7 km following their launch by a Lockheed Martin Atlas-V, after which they will conduct several autonomous rendezvous and capture sequences, some of which include propellant and battery transfers. The Orbital Express mission is expected to demonstrate that two different contractors can build two different satellites in two different places, coming together for the first time when they are in orbit. DARPA has dispensed with a ground-based full-system dry run.

The Microsatellite Technology Experiment (MiTEx) was launched by a Boeing Delta-2 rocket on 22 June. Sponsored by the U.S. Defense Advanced Projects Agency (DARPA), the U.S. Air Force, and the U.S. Navy, the experiment is demonstrating new low-mass technologies for power, propulsion, and avionics. The two spacecraft involved were built by Lockheed Martin (USA) and Orbital Sciences (USA).

The first flight of a secondary payload ring developed as part of the U.S. Air Force Evolved Expendable Launch Vehicle (EELV) programme is scheduled to take place late this year aboard a Lockheed Martin Atlas-V, whose main payload is the U.S. Defense Advanced Research Projects Agency's (DARPA's) Orbital Express. The EELV Secondary Payload Adapter (ESPA) is to orbit five secondary payloads: Falconsat-3, a 50-kg satellite carrying three experiments, built by students at the U.S. Air Force Academy; MidStar-1, a satellite carrying two experiments, built by students at the U.S. Naval Academy; NPSAT-1, an 80-kg satellite with two experiments, built by students at the U.S. Naval Postgraduate School; the Cibola Flight Experiment Satellite (CFESat), built by the Los Alamos National Laboratory; and Space Test Programme Satellite-1 (STPSat-1), a 170-kg satellite built by AeroAstro (USA), carrying several experiments and two 1-kg picosatellites to be deployed at the end of the mission. The ESPA ring was developed and built by CSA Engineering (USA) under a U.S. Air Force Research Laboratory contract. Cost to the research community of an ESPA launch slot is between $1 million and $2 million.

On 2 August Lockheed Martin (USA) announced their receipt of an $8-million contract from the U.S. Air Force to develop an experimental spacecraft able to accompany other satellites in orbit and examine them for signs of trouble. The Autonomous Nanosatellite Guardian Evaluating Local Space (ANGELS) system is to be demonstrated in space in late 2008 or early 2009. Launched into a geostationary orbit along with a host satellite, ANGELS will trail that satellite and demonstrate its autonomous inspection abilities. ANGELS is expected to weigh between 10 and 50 kg and cost less than $20 million.

Surrey Satellite Technologies Ltd (UK) shipped the bus for CFESat to Cape Canaveral in October, following completion of a final round of thermal and vacuum testing. The 160-kg Cibola Flight Experiment (CFE), developed by the Los Alamos

National Laboratory (USA), is due for launch aboard a Lockheed Martin Atlas-V in December. It will validate a host of new spacecraft technologies, including power supply systems, inflatable antennas, deployable booms, a new launch-vehicle-separation concept, high-density lithium-ion batteries, and especially a supercomputer based on nine new-technology field-programmable gate arrays that can be reconfigured in flight and enable computer speeds of 300 Gflops, about 100 times faster than current space-qualified machines. This will allow the spacecraft to process data in orbit and transfer results rather than raw data to the ground.

On 15 June the French space agency CNES approved an investment of $21 million in Sweden's Prisma project to validate technologies for formation flying and on-orbit rendezvous and docking. The two-satellite Prisma system employs a 40-kg target spacecraft and a 140-kg "chaser" satellite in a 600-km orbit. The German Aerospace Center DLR and Denmark's Technical University also support the project, which is planned for launch in 2008.

D. Materials and Structures

On 16 February researchers at Northwestern University (USA) announced successful testing of a new niobium alloy that demonstrated burn resistance in oxidizing atmospheres up to 1,300 Celsius, considerably higher than current nickel-based alloys used in turbine blades. The new alloy, named "noburnium," could be of value in rocket engines employing oxygen-rich cycles.

A new nonflammable composite material for liquid-oxygen propellant tanks was announced by XCOR Aerospace (USA) on 29 March. The thermoplastic fluoropolymer material is laced with a Teflon fiber that prevents it from igniting and burning in a 100% oxygen atmosphere, eliminating the need for the metal liners used on conventional composite liquid-oxygen tanks. These liners are not only heavy, but also cause problems due to differential shrinking of the metal liner and the composite shell when the tank is filled with liquid oxygen.

On 12 July Bigelow Aerospace (USA) launched its Genesis-1 expandable space module demonstration prototype into a 550-km, 64-degree orbit aboard an International Space Company (ISC) Kosmotras Russian/Ukrainian Dnepr rocket from Kosmotras' Yasny Launch Base in the Orenburg region of Russia. Communication with the module's sensors was established successfully after orbit insertion and inflation of the module, initiating the demonstration project. Temperatures, avionics, battery power and solar arrays were all verified, and the module pressure of 0.5 atm established and sustained. A NASA Ames Research Center "Genebox" biology experiment was carried aboard the module and was successfully activated on 25 July. Bigelow had succeeded in obtaining a U.S. export license for the Russian launch.

Genesis-1 had originally been scheduled to be orbited by the first flight of Space Exploration Technology's Falcon-5 rocket in November 2006. The 2.5 x 3-m module is based on an early NASA design for the inflatable Transhab that had originally been

planned for use on the ISS. It is a one-quarter-scale prototype for the full-scale 13.6 x 6.7-m, 18-22 tonne manned BA-330 Nautilus module Bigelow expects to employ as the first private-sector space station. Bigelow is planning a second Genesis launch, followed by two one-third-scale Guardian modules that will carry life-support system demonstration hardware.

E. Information Technology

The first two-way laser communication link between satellites was established on 9 December 2005, when Japan's Kirari satellite, in a 600-km orbit, communicated with ESA's Artemis spacecraft in its geostationary orbit. Artemis's previous laser communications experiments with France's Spot-4 Earth observations satellite was one-way only. Artemis has been operational since 2003; Kirari was launched in August 2005 as the Optical Interorbit Communications Engineering Test Satellite (OICETS). The first laser communication between a fast-moving satellite and the ground took place on 31 March, when Kirari transmitted signals from its 600-km near-polar orbit, while moving at 7 km/sec, to Japan's National Institute of Information and Communications (NICT) ground station in Tokyo. Laser communication between the satellite and a mobile optical ground station, a 40-cm telescope operated by the German Aerospace Center DLR in Wessling, Germany, was established for three minutes on 7 June.

F. Automation and Robotics

On 2 December 2005 NASA announced two new Centennial Challenge prize competitions, each worth $250,000. The Telerobotic Construction Challenge, a team effort with the Spaceward Foundation that began in August, seeks the best remote-controlled robot builder. The Planetary Unmanned Aerial Vehicle Challenge, to begin in October 2007 in cooperation with the California Space Education and Workforce Institute, will seek the best autonomously operated aerial vehicle able to fly a roller-coaster-type flight path using only visual navigation technology. Another series of much larger Centennial Challenge awards, announced early in February, is focused on space exploration.

NASA's Space Technology-5 (ST-5) satellite, launched 14 March, is equipped with a temperature-control device using a microelectromechanical system (MEMS) to open and close tiny shutters that change the satellite skin's emissivity. The 10-cm square ST-5 demonstration package, formally designated Variable Emittance Coatings for Thermal Control, employs shutters whose width is about a third that of a human hair. Developed by the Johns Hopkins University Applied Physics Laboratory, it is the first demonstration of MEMS technology for active thermal control.

On 15 May NASA issued a summary report of the investigation into the failure of the Demonstration of Autonomous Rendezvous Technology (DART) mission in April 2005. A primary cause was found to be the constraints of the U.S. International Traffic in Arms Regulations (ITAR), which imposed restrictions on communications between the spacecraft builder, Orbital Sciences Corporation (USA), and the supplier of the satellite's

Global Positioning System (GPS) receiver, Surrey Satellite Technology Ltd. (UK), resulting in a discrepancy between the receiver and the spacecraft's software of 0.6 m/second in DART's velocity. Other causes of the failure were identified as a lack of adequate experience and training of the spacecraft development team, their failure to draw on relevant available experience, and DART's origin as a high-risk, low-cost mission. The mission of the 362-kg satellite ended up costing $110 million, initial estimation of costs was $47 million.

G. Space Research Facilities

The first flight of a Brazilian-powered sounding rocket was successfully conducted from Sweden's Esrange facility on 1 December 2005. The two-stage Texus-EML rocket, driven by Brazil's VSB-30 rocket motor, attained an altitude of 264 km and provided its payload with 6.5 minutes of microgravity conditions. The vehicle also used a new parachute recovery system developed by the German Aerospace Center DLR, replacing the previously used U.S.- built system that had become embroiled in U.S. technology export restrictions. The payload included ESA's Electromagnetic Levitation (EML) furnace, which was used to explore the melting of titanium and aluminum in microgravity conditions.

Following the launch from Esrange on 5 April of a small Rexus-3 rocket carrying student experiments, on 2 May the seventh successful mission of the Maxus sounding rocket (Germany and Sweden) was launched from the Swedish range, carrying five ESA experiments to an altitude of 702 km. The experiments, subjected to microgravity conditions for 12 minutes, all performed successfully and were recovered by helicopter 85 minutes after the liftoff of Maxus-7. This mission was followed on 11 May by the successful launch from Esrange of the Texus-43 mission (Germany and Sweden) to an altitude of 237 km, providing three ESA experiments with 5 minutes, 47 seconds of microgravity conditions. Two of the experiments were successful.

France and Sweden agreed in December 2005 to join the French Simbol-X orbital observatory to examine formation-flying concepts. The mission will employ hard X-ray observations to demonstrate the feasibility of using small satellites for astronomy. It will study disk and particle accretion, nucleosynthesis, and other cosmic phenomena that are characterized by X-ray and gamma-ray emissions in the 0.5-kev to 70-keV energy range. The Simbol-X constellation will consist of a primary spacecraft carrying grazing-incidence mirrors and a secondary spacecraft with focal-plane detectors, both flying in a highly elliptical orbit. The mission will seek to demonstrate the ability of satellites to stay within 30 m of each other and within 10 cm of the target position along the longitudinal axis, with a lateral tolerance of +/- 1 cm. Launch is planned for 2013. Sweden will provide the Simbol-X propulsion system, with Italy responsible for the spacecraft buses and mirrors and Germany the detectors.

H. Environmental Effects of Space Flight

(1) Orbital Debris

A sudden external impact, ostensibly by a piece of orbital debris or a micrometeorite, disabled the Russian Express-AM11 communication satellite on 29 March. The impact caused instant depressurization of the thermal control system fluid circuit and an outburst of the fluid, resulting in loss of spacecraft orientation and rotation. The satellite was subsequently moved from its geostationary-orbit slot at 96.5 degrees east longitude into a ”graveyard” orbit, to avoid potential damage by the resulting debris to any satellite placed later in that orbital slot. AM11 communication traffic was shifted by the Russian Satellite Communications Company (RSCC) to other RSCC spacecraft.

(2) Near Earth Objects

On 15 May NASA issued a call for papers on alternatives to divert space objects found to be on a collision course with Earth, following the directive contained in legislation enacted by the U.S. Congress in December 2005. That legislation mandated NASA to provide by the end of this year an analysis of the possible alternatives for diverting NEOs that are on a likely collision course with Earth. The NASA call for papers follows up the Near Earth Object Survey programme to detect, track, catalog, and characterize near-Earth objects (NEOs) of 140 m or greater diameter and assess their potential threat to Earth. The 15 May call for papers was the first step in planning and conducting an NEO Detection, Characterization, and Threat Mitigation workshop, which was held on 26 – 29 June. The principal conclusion of the workshop was that detection of potential collision-oriented NEO’s was of the highest priority, and that putting in place the survey skills to detect NEOs with diameters of 140 m or larger was a key goal, aiming at 90% completion of an NEO catalogue within 15 years.

On 10 April ESA awarded competing study contracts worth $544,000 each to three consortia for an asteroid-deflection mission. The teams, led by Alcatel Alenia Space (France), EADS Astrium (France), and Qinetiq (UK), are to produce a preliminary design for the Don Quixote mission, which consists of two spacecraft – one to ram into an asteroid, the other to witness the collision and measure the resulting change in the asteroid’s trajectory. ESA is considering a 2011 launch for the mission.

VII. EDUCATION

A. Teaching Programmes

Students at the U.S. Air Force Academy designed, built, and tested the 20-kg FalconSAT-2 satellite and its payload, a Miniature Electrostatic Analyzer (MESA) experiment to measure space plasma phenomena such as “plasma bubbles” in the ionosphere, which often disrupt communications. The 32-cm cube was launched by the

inaugural flight of Space Exploration Technology's (Space-X's) Falcon-1 rocket from Kwajalein on 20 March, but was unfortunately lost when the launcher failed. The students developed the spacecraft in their Astronautics 436 course, "Small Satellite Engineering-1," which was designed to give students hands-on experience building and flying spacecraft. The Academy's first flight, of FalconSAT-1 in 2000, was unsuccessful due to inadequate preparation and testing procedures, which had been totally revamped for FalconSAT-2.

On 14 February two middle-school teachers, Perry Lopez and Tyrel Cooper, flew on NASA's C-9 microgravity aircraft to test the performance of a student-designed robotic arm in the reduced-gravity environment and compare it with the arm's performance at Earth-normal gravity. Following the flight the teachers reported the results back to students at the Bridger Middle School in Texas via videoconference, and then joined with the students to write a full report to NASA on their findings and conclusions.

Ten student-built experiments were selected on 14 March to fly on NASA's Orion sounding rocket, launched from the Wallops Flight Facility on 7 June. The experiments had been developed by students and teachers from eight schools working with NASA engineers and technicians. Five of the experiments were located in the body of the rocket and five in the nose cone. Research subjects included wireless communications, magnetic fields, fluid dynamics, and thermal dynamics. The experiments reached an altitude of 40 km and were deposited in the ocean by parachute for retrieval and return to the students the same day.

The National Space Frontier Foundation (NSFF, USA) announced its Teachers in Space project on 8 April. Unlike other efforts to support teachers in their efforts to create space-oriented curricula for their students, the NSFF programme hopes to place teachers on suborbital flights to be operated by companies planning to develop and fly people into space on a commercial basis. Although these companies have yet to fly any passengers, several have committed future free flights for qualified teachers under the NSFF programme; namely Armadillo Aerospace, Rocketplane Kistler, and XCOR Aerospace. NSFF is seeking corporate sponsorship to cover the cost of tickets for additional candidates.

On 18 May NASA announced the selection of eleven winners of the Administrator's Fellowship Programme, which offers the student Fellows access to NASA's internal and informal information networks in order to expand knowledge and opportunities at minority institutions. On the same day the NASA Institute for Advanced Concepts, operated for NASA by the Universities Space Research Association, announced the five winners of its annual Student Fellows Prize competition, which gives undergraduate students awards of $9,000 each to investigate innovative ideas in space and aeronautics systems or architectures.

A UP Aerospace Spaceloft XL sounding rocket was launched on 24 September as the inaugural flight from New Mexico's new spaceport, carrying a number of student

payloads, but failed shortly after liftoff and crashed in a remote section of the White Sands missile range. The payloads included New Mexico State University's vehicle altitude sensor slated for use in a nanosatellite; a University of Colorado and the Colorado Space Grant Consortium experiment to measure microwave radiation and cosmic rays; a prototype star-tracker and data-logger developed by Brown University and AeroAstro; a variety of thermocouples to record characteristics of the space environment for Central Connecticut State University; a test by the University of Hartford of a vapor-phase catalytic ammonia removal system for use in next-generation water-recovery devices for human space flight missions; and another 40 experiments from high-school students across the U.S. and several commercial companies.

7,000 students in 678 teams from 47 U.S. states entered the qualifying round of the third Team America Rocketry Challenge. The criteria for this year's competition were sharpened, requiring entries to deliver their payload of a raw egg (which must be returned to Earth intact) to an altitude of exactly 244 meters with a flight time of exactly 45 seconds, the first time the challenge has stipulated both altitude and time criteria. The top 100 teams competed on 20 May for the $60,000 prize plus a trip to the Farnborough International Air Show in the UK. Sponsors of the event were the Aerospace Industries Association (AIA; USA) and the Raytheon Company (USA). The winner, with a score of 179 for achieving a perfect altitude and a time only 2 seconds off the mark, was a team from Statesville Christian School, North Carolina, who named their rocket in honour of two team mates who had been killed in automobile accidents just prior to the final competition. Second place went to Notre Dame Academy, Toledo, Ohio, with a score of 193, and third to West Point/Beemer Junior/Senior High School, Nebraska, with a score of 291.

The first webcast of a joint effort sponsored by NASA and AOL to encourage the interest of young people in space exploration was broadcast on 4 May in honour of National Space Day in the U.S. This first edition of "KOL-Expeditions NASA Earth Crew Missions" ("KOL" is AOL's Kids online service) enabled students to talk to the crewmembers of the International Space Station's Expedition 13. The website, www.kol-expeditions.com, provides children, parents and teachers with interactive missions, videos and other activities, that encourage interest in science and technology.

During the week from 19 to 23 June, the Florida Space Authority conducted a programme for students in grades 7 to 12 (junior and senior high school), providing the students with hands-on experience at Cape Canaveral in real-world engineering and problem-solving in robotics, payload integration, rocket propulsion, space life sciences, and the use of the Global Positioning System.

As part of its Minority University Research and Education programme, NASA issued a request for proposals on 1 May that will lead to a 3-year cooperative education agreement with a minority-serving educational institution, offering $10,000 one-year competitive scholarships to minority students. The $1.75-million programme is expected to help diversify the future science and technology work force.

An engineering model of the first KentuckySatellite (KySat), announced by the Kentucky Science and Technology Corporation (USA) on 23 June, was designed and built by a core team of students from universities in the state of Kentucky during a 10-week summer session at NASA's Ames Research Center, assisted by personnel from Ames, the Stanford Space and Systems Development Laboratory, and the California Polytechnic State University. The 1-kg cube-shaped KySat-1 will carry a communication system; a camera; and temperature-monitoring, voltage, and science sensors. The flight model, built this fall at the University of Kentucky, is planned for launch in 2007, with follow-on projects, each budgeted at about $450,000, contemplated every 12 to 18 months.

240 teachers from all 50 U.S. states and 15 other countries participated this summer in a programme of microgravity flights, conducting experiments and developing curricula to share their experiences with their students. Sponsored by Northrop Grumman (USA) under the Northrop Grumman Weightless Flights of Discovery programme, 20 teachers were carried on each of 12 parabolic flights of the G-Force One aircraft operated by Zero Gravity Corporation (USA) from airstrips in the Kennedy Space Center (KSC), Cleveland, Huntsville, San Diego, and Washington. Zero Gravity Corporation also conducted five workshops to train the teachers prior to their flights and offer suggestions for their curricula. The first two flights were conducted at KSC on 10 June.

Seven teachers from NASA Explorer Schools across the U.S. were brought by NASA to Chile's Atacama Desert on 20 June to participate under NASA personnel guidance in a week's research on communications and robotic rover technologies in an environment comparable to that on the Moon and Mars. The project was part of NASA's Spaceward Bound programme, in which teachers design and conduct field research and use the experiences in their classrooms to inspire students' interest in space exploration.

The Universe Awareness Programme for children between 4 and 10 years of age was announced on 22 August by the International Astronomical Union in Prague. The project uses games, songs, films, and other media to expose children in four developing countries and four disadvantaged regions in the European Union to the wonders of astronomy. It follows pilot projects in Venezuela and Tunisia that were conducted earlier this year.

On 10 June the Unisat-4 microsatellite, designed and built by students at the University of Rome, Italy, was flown to the Baikonur Cosmodrome. On 28 June the 12-kg spacecraft was launched from there into a low Earth orbit by a Russian-Ukrainian Dnepr rocket, along with four other small spacecraft. Unisat-4 was designed to test components that have not yet been proven in space. The University's three previous Unisats were launched in 2000, 2002 and 2004.

Brazil's Universidade de Santo Amaro (Unisa) announced on 7 November 2005 a digital distance-learning initiative using the Estrela do Sul–1 satellite, operated by Loral Skynet's Brazilian affiliate, Loral Skynet do Brasil. The initiative began in February to

provide general and technical courses, originating at Unisa's Sao Paulo campus, to thousands of students in over 100 Brazilian communities.

On 10 May the Industrial Collaboration Department of Japan's space agency JAXA issued a solicitation for candidate university payloads weighing up to 50 kg to fly free on H-2A flight opportunities once each year beginning in 2008. Winners are to be announced no later than 15 months prior to each flight. Japan's universities, which had been flying their experiments on Russian rockets at a cost of about $9,000 per kilogram, welcomed the new programme, but expressed concerns that safety and integration requirements for the H-2A launches might impose difficulties, including higher payload development costs.

VIII. INTERNATIONAL COOPERATION AND SPACE LAW

A. Global developments and organizations

(1) New signatories, accessions to or ratifications of space treaties

Since 1987, the International Institute of Space Law (IISL) has compiled an Annual Report on the status of international agreements relating to activities in outer space. This report includes signature, ratification, as well as declaration of acceptance of rights and obligations that have taken place since January of the current year.

In 2006, the following accessions to, and/or ratifications of space treaties have taken place:

- **Brazil** has acceded to and ratified the 1975 Registration Convention;
- **Indonesia** has acceded to and ratified the 1967 Outer Space Treaty;
- **Italy** has acceded to and ratified the 1975 Registration Convention;
- **Nigeria** has acceded to and ratified the 1972 Liability Convention;
- **Perú** has acceded to and ratified the 1979 Moon Treaty.
- **EUMETSAT**, the European Organization for the Exploitation of Meteorological Satellites, has signed a declaration of acceptance of rights and obligations regarding the 1968 Agreement on the Rescue of Astronauts, the Return of Astronauts and the Return of Objects Launched into Outer Space, as well as in regard to the 1972 Liability Convention.

(2) International Institute of Space Law (IISL) Activities

IISL/ECSL Space Law Symposium 2006

The annual IISL/ECSL (European Centre for Space Law) Space Law Symposium was held in April 2006, in Vienna, Austria, during the 45th Session of the Legal Subcommittee of the United Nations Committee on the Peaceful Uses of Outer Space (COPUOS). This year's topic was on Disaster Communications and the use of remote sensing satellites.

IISL Regional Symposium on Space Law, Bangkok, Thailand

The IISL held the Regional Symposium on Space Law in Bangkok, Thailand, in August 2006. The symposium was attended by participants from Australian, Indian, Malaysia, Thailand, and nationals of other Asian countries; several professions such as lawyers, engineers and academics were represented. The regional symposium in Bangkok, Thailand is the latest in a series of such symposia, established by the IISL a few years ago.

Manfred Lachs Space Moot Court Competition

The IISL held the final rounds of its 15th Manfred Lachs Space Moot Court Competition during the IAC's Congress in Valencia, Spain. More than 50 teams from Europe, North America, and Asia competed in the early rounds. The final rounds, judged by Judges Koroma, Tomka and Sepúlveda of the International Court of Justice, The Hague, were won by the teams from McGill University and the University of Auckland, New Zealand. The McGill University team received the best oral and the best written brief awards. The winning team came from the University of Auckland, NZ, and runner-up was the Catholic University of Leuven, Belgium. The Manfred Lachs Trophy was awarded to the Auckland team, which will keep it until next year's Space Moot Court competition, to be held in Hyderabad, India.

Workshop on Policy and Law Relating to Outer Space Resources, Montreal, Canada

The IISL, in cooperation with the Institute of Air and Space Law of the McGill University from Montreal, Canada, held an interdisciplinary workshop, from 28 to 30 June 2006. The Workshop with the title "Policy and Law Relating to Outer Space Resources: The Example of the Moon, Mars and Other Celestial Bodies," was dedicated to Dr. Eilene Galloway, who proposed it several years ago, and who has been advocating international cooperation and the peaceful uses of outer space since 1957. It was attended by space lawyers, academics and scientists from Australia, Canada, Czech Republic, Germany, Japan, South Korea, the Netherlands and the United States. A Summary Report is available by the Centre for Research of Air and Space Law of the McGill University, Montreal, which will also publish the Workshop's full proceedings in the near future.

B. EUROPE

(1) European Centre for Space Law (ECSL) Activities

The European Center for Space Law of the European Space Agency (ECSL/ESA) organized a conference on the "Legal and Ethical Framework for Astronauts in Space Sojourns". The aim is to develop a broad view and multidisciplinary discussion on astronauts' life in outer space. Other participants included the United Nations Educational, Scientific and Cultural Organization (UNESCO), ESA's Legal Department,

the Institute du Droit de l'Espace et des Télécommunications (IDEST) of the Faculty Jean Monnet (University of Paris XI). The conference took place at the UNESCO Headquarters in Paris, on 29 October 2005. The main idea of this symposium was to provide legal and ethical experts with a common ground for discussion and to focus the latter on the real needs of astronauts, as human beings and as persons carrying rights and obligations.

The ECSL dedicated its 2006 Practitioners Forum on 17 March 2006 to the issue of space tourism, and in particular some of the major legal and policy aspects thereof. These included the licensing of companies, vehicles and crews, the status of crews and passengers, liability and insurance issues, and the financing and securities of such financing. These issues were primarily approached from an international perspective, but the role of national legislation in general and the substance of US developments thereon, were also discussed.

The 15th ECSL Summer Course on Space Law and Policy took place at the ESA ESTEC facilities in Noordwijk, the Netherlands from 4 to 15 September 2006. The main objective of the Summer Course is to stimulate students' interest in this particular field of international law and to provide them with a basic, solid knowledge upon which they can build their professional career or carry out further academic research. ECSL each year publishes the proceedings of the Summer Course.

(2) European Space Policy Institute (ESPI)

European and overseas experts in politics, economy, industry, research and diplomacy met on 20 - 22 September 2005 to discuss the future of European space policy. The meeting was held in ESPI's new headquarters. ESPI was founded in November 2003 by the European Space Agency (ESA) and the Austrian federal government, represented by the Federal Ministry for Transport, Innovation and Technology (BMVIT), which is the leading Ministry in charge of space affairs, and which is in turn represented by the former Austrian Space Agency (ASA), now the Austrian Research Promotion Agency/Aerospace Agency (FFG/ALR).

(3) European Union Satellite Centre (EUSC)

The European Union Satellite Centre (EUSC) is an Agency of the Council of the European Union, dedicated to the exploitation and production of information derived primarily from the analysis of earth observation space imagery in support of Union decision-making in the field of the EU Common Foreign and Security Policy (CFSP). The EU considers the EUSC an essential asset for the strengthening of CFSP (and of the European Security and Defense Policy, which is part of CFSP), especially in the crisis monitoring and conflict prevention function. EUSC, created by the Council Joint Action in 2001, and operational since January 2002, is under the political supervision of the Political and Security Committee (PSC) and the operational direction of the PSC Secretary-General. The Centre has own legal personality in order to carry out its functions, and also conducts research and development projects. The Centre also carries

out training activities for expert personnel in the fields of Digital Geographic Information Systems and imagery analysis. It is located in Torrejón, in the vicinity of Madrid, Spain.

(4) European Space Policy

At the Competitiveness Council on 29 – 30 May 2006, Vice-President of the European Commission's Enterprise and Industry, Gunter Verheugen, presented a progress report on the development of European Space Policy. Its main objective is the adoption of the European Space Policy and related European Space Programme (ESP) by the European Commission in the first quarter of 2007, and its endorsement by the Space Council under the future German Presidency of the EU in the second quarter of 2007.

The third Space Council, a joint meeting of the European Space Agency Council and the European Union Competitiveness Council, was held in Brussels on the 28 November 2005, to take measures to pave the way for GMES. The Ministers present stressed the importance of a European autonomous Earth Observation and of the international dimension of GMES. GMES is the main European contribution to the worldwide Global Earth Observation System of Systems (GEOSS). At a later meeting, the Council reaffirmed its commitment to one of Europe's primary space projects, placing it high on the agenda of European economic competitiveness.

The Eighth European Inter-parliamentary Space Conference (EISC), held in Brussels in June 2006, brought together MPs from 10 European countries, as well as EU and ESA Member States and representatives of the Russian, Chinese and the Ukrainian space organizations, to discuss European Space Policy, emphasizing international co-operation, space applications and education. The European Space Council is scheduled to endorse a new EU Space Policy, currently being prepared by the European Commission and ESA, in the first half of 2007.

The European Council adopted a common position on the Seventh Framework Programme (FP7) at a Competitiveness Council meeting, in 25 September 2006 in Brussels. FP7 will give priority to four specific areas: Cooperation - collaborative research; establishment of the European Research Council (ERC); strengthening of human resources in research and technology in Europe by putting into place a coherent set of Marie Curie actions. Lastly, FP7 will give priority to supporting research infrastructures, research for the benefit of SMEs and the research potential of European regions (Regions of Knowledge). One goal is to stimulate the realization of the full research potential (Convergence Regions) of the enlarged Union and build an effective and democratic European Knowledge society.

Another objective of the FP7 space work programme is to support a European Space Policy focusing on applications such as GMES (Global Monitoring for Environment and Security), thus contributing to the overall objectives of the European Space Policy, and complementing efforts of Member States and of other key players, including the European Space Agency. Beyond GMES and in line with the European

Space Policy, other topics will be addressed in the current FP7 Space work programme, to strengthen the European Space foundations.

(5) EU Radio Spectrum Policy

The Radio Spectrum Decision 676/2002/EC, adopted by the European Parliament and the Council on 7 March 2002 laid the foundation for a general Community radio spectrum policy. The Decision's objective is to ensure co-ordination of radio spectrum policy approaches, harmonized conditions for the availability and efficient use of radio spectrum, in particular to support specific Community policies. The Decision sets provisions on relevant information of spectrum usage and on co-ordination of Community interest in international negotiations in relation to existing EU policies, such as in electronic communications, transport, research and development, and in broadcasting. The Communication " A Forward-looking radio spectrum policy for the European Union – Second annual report", issued in September 2005 set out the Commission's strategy for a coherent EU radio spectrum policy as part of the i2010 initiative.

(6) European Defense Agency

The European Defense Agency was established under a Joint Action of the Council of Ministers on 12 July, 2004. A first attempt to create a European Defense Equipment Market was launched on 1 July 2006, with the participation of 22 out of 24 participating Member States of the European Defense Agency. The new market framework covers defence equipment purchases which governments choose to exempt from EU public procurement rules, and usually do not involve any cross-border competition. The "Code of Best Practice in the Supply Chain", approved by Ministers in May 2006, is intended to extend the benefits of greater competition to smaller companies which may not be able to bid for contracts directly but could act as sub-contractors.

(6) European Space Agency (ESA)

On 22 June 2006 the Council of the European Space Agency announced the renewal of the mandate of Mr. Jean-Jacques Dordain as Director General of ESA for a further period of four years. At the same meeting, held at the Agency's headquarters in Paris, the ESA Council also renewed the mandate of Mr. Antonio Fabrizi of Italy as Director of Launchers for another four years.

Jean-Yves Le Gall, CEO of Arianespace, and Anatoly Perminov, director general of the Russian space agency Roscosmos, signed a supply contract in February for the first four Soyuz vehicles that will be launched from the Guiana Space Center in Kourou, French Guiana. The European-Russian partnership on Soyuz calls for launches from Baikonur under the responsibility of Starsem, a joint subsidiary of EADS/Arianespace and their Russian partners, and for launches from the Guiana Space Center, under the responsibility of Arianespace. A Soyuz launch pad is under construction in French Guiana and is co-financed by ESA and Arianespace with a total of 344 million euros.

The first Soyuz launch from Guiana is slated for November 2008. Arianespace has already signed several launch contracts for Soyuz, which will round out the company's family of launchers, alongside Ariane 5 and Vega. Under the new agreement joint space initiatives will comprise projects of mutual interest, to be implemented through established instruments, including ESA programmes, the space programme of the Russian Federation and the space work programme of the Seventh EU Framework Programme (FP7) for Research and Development.

ESA and the China National Space Administration signed their first framework cooperative agreement on 18 November 2005. The agreement, which covers space science, Earth observations, telecommunications, and navigation, also permits ESA's ERS-2 and Envisat radar satellite data to be used for disaster management and environmental monitoring in China. It builds on prior European-Chinese cooperation in the Double Star science satellite programme.

The EU Competitiveness Council at its April meeting in Graz gave support to the emerging European Space Policy, including strengthening ties between the European Commission (EC) and the European Space Agency (ESA). In the debate on the Global Monitoring for Environment and Security (GMES) initiative, the Council reaffirmed its commitment to one of Europe's primary space projects, placing it high on the agenda of European economic competitiveness policies.

The ESA government ministers approved at their from 5 to 6 December 2005 conference in Berlin a five-year (2006 – 2010) budget package totalling $9.67 billion for the agency. The package includes $708 million for the 2011 ExoMars project to explore Mars with a rover vehicle; an average science-programme budget of $492 million per year; $146 million to develop technologies that might be needed for future international programmes to explore the Moon and Mars; $350 million for payload development for Alphasat, a large communications technology development satellite initiated by a $236-million contract to EADS Astrium and Alcatel Alenia Space in June 2005; $117 million for development of a low-mass, low-power communications satellite demonstrator; about $735 million for two phases of the Global Monitoring for Environment and Security (GMES) programme; and $289 million to support Vega launch-vehicle development. A $58-million proposal to explore a European role in Russia's Klipper manned space vehicle was not approved.

The budget for 2006 until 2008, approved by the European Space Agency (ESA) members, includes a new Earth observation program. ESA announced that the Global Monitoring for Environment and Security (GMES) program will be a key European contribution to the Global Earth Observation System of Systems initiative. The Council, comprised of ESA's 17 member states and Canada, also approved a measure that requires European government satellites to be placed into orbit by European launch vehicles.

The 8th European Inter-Parliamentary Space Conference (EISC) was held in Brussels in June 2006. Parliamentarians from 10 European countries met to discuss European Space Policy, emphasizing international co-operation, space applications and

education. The Conference brought together members of the EISC, the EU and ESA Member States, as well as representatives from the Russian, Chinese and the Ukrainian space organizations. The Conference came at a critical moment in the development of a comprehensive European approach to space activities, as the EU is in the process of finalizing the 2007-2013 Financial Perspective, under which €1.43 billion has been earmarked for space research within the Seventh EU Research Framework Programme. Meanwhile, the European Space Council is scheduled to endorse a new EU Space Policy, currently being prepared by the European Commission and ESA, in the first half of 2007.

On 19 to 22 September 2006, the Western European Union Assembly and the European Interparliamentary Space Conference held a colloquium on Space, Defence and European Security in Kourou, French Guiana, in association with the European Space Agency (ESA), France's Centre National d'Etudes Spatiales (CNES) and Arianespace. The event brought together over a hundred members of the national parliaments of the EU countries, members of the European Parliament and senior executives from ESA, CNES, Arianespace and the space industry in Europe. The main aim of the discussions was to examine the space sector and its application to security and defence, and to assess industrial capabilities in the light of the challenges Europe faces at present.

ESA announced October 5 that the upper composite of Vega, its new small launch vehicle, passed vibration tests at ESA's European Space Research and Technology Centre. Vega's first launch is planned for the end of 2007 from Kourou, French Guiana.

(a) Galileo

A Soyuz rocket carrying the first Galileo test satellite, constructed by Surrey Satellite Technology Ltd. (UK), was successfully launched from the Baikonur Cosmodrome Kazakhstan in December 2005. This marks a major step in the Galileo Program in space. GIOVE-A is the first European navigation satellite and the first European satellite in the medium earth orbit, about 23,200 km from ground level. It will secure the Galileo frequencies allocated by the International Telecommunication Union (ITU) and test certain Galileo satellite components. The reception of the first Galileo signal took place on 12 January 2006. The first of four operational satellites is scheduled to be launched in 2008, and the contract for their development and in-orbit validation was signed in January 2006, by the European Space Agency and Galileo Industries GmbH, the European company steering a consortium of over a hundred firms. The €950 million contract will pave the way for the operational deployment of Galileo.

The European Commission, in June 2006 adopted a Communication taking stock of the Galileo satellite radio-navigation programme. The communication outlines key components of this European project and includes an updated timetable for its implementation. It will be forwarded to the European Parliament, the Council, the Economic and Social Council and the Committee of the Regions. The communication also examines the main elements of the programme.

Since the beginning of 2006, negotiations for the system concession contract have entered a decisive phase. The candidate for the concession is a consortium comprised of eight members: Aena (ES), Alcatel (FR), EADS (FR/D), Finmeccanica (I), Hispasat (ES), Inmarsat (UK), Thales (FR) and TeleOp (D). German companies will receive additional work on Europe's Galileo program, under an agreement reached on December 5 among European companies involved in the project. The latest agreement, signed by the eight European companies that form the concessionaire, calls for a consortium of German companies to be added to the satellite navigation project.

Under the agreement, Inmarsat will have overall management of the newly formed Galileo Operations Co., which will be responsible for the Galileo and EGNOS global network operations. The headquarters for the Galileo Concessionaire will be located in Toulouse, France, while operations will be based in London. The two control centres, along with a pair of performance evaluation centres, will be located in Germany and Italy. Spain will host facilities that will serve as backups for the primary control centres, as well as provide safety applications. The concession partners will now work on finalizing the concession contract with the Galileo Joint Undertaking. The contract is expected to be finalized in the course of 2007. The Supervisory Authority, the European agency tasked with managing the public interests connected with the European GNSS programmes and acting as regulatory authority for them, is temporarily located in Brussels. The activities of the Galileo Joint Undertaking will be transferred to the Supervisory Authority and the Joint Undertaking will wind up its operations by 31 December 2006.

The European Geostationary Navigation Overlay Service (EGNOS), Galileo's precursor, is now in operation and has successfully passed its first Operational Readiness Review. Of the five services to be offered by Galileo, the Public Regulated Service (PRS or governmental service) will most likely be restricted for security reasons to the use by the European Union/Member States' public bodies. The access policy is being drafted.

The European Commission is also committed to promoting the use of satellite radio-navigation, and will present a Green Paper on Galileo applications by end 2006. In addition, international cooperation is an essential component of Galileo, which is designed for worldwide use. Cooperation agreements have been concluded with China, India, Israel, Morocco, South Korea the United States and Ukraine. The EU-South Korea agreement provides for numerous areas of co-operation, including cooperative activities in the areas of scientific research and training, industrial cooperation, trade and market development, standards, certification and regulatory measures.

The European Union approved on October 12 for the European Global Navigation Satellite System (GNSS) Supervisory Authority to complete the development phase of the Galileo program. By a 555-27 vote (with 27 abstentions), the European Parliament adopted a non-binding report by Giles Chicester, chairman of the European Union's Industry, Research and Energy Committee, detailing the management of the European Satellite radio-navigation program. The Galileo Joint Undertaking is planned to be concluded by December 31; its activities will then be transferred to the European GNSS

Supervisory Authority, which will be responsible for Galileo and the European Geostationary Navigation Overlay Service (EGNOS).

(b) Global Monitoring for Environment and Security (GMES)

Global Monitoring for Environment and Security (GMES) is European initiative for the implementation of information services dealing with environment and security. GMES will be based on observation data received from Earth Observation satellites and ground-based information. These data will be coordinated, analyzed and prepared for end-users. Through GMES the state of our environment and its short, medium and long-term evolution will be monitored to support policy decisions and/or investments. GMES will be built up gradually, it will start off with a pilot phase which targets the availability of a first set of operational GMES services by 2008, followed by the development of an extended range of services to meet user requirements.

The 2004 GMES final report for the Initial Phase, by the European Commission and the European Space Agency proposed the way forward towards the full implementation of a GMES structure, including ways to foster the partnership of all relevant players. This led to the setting up of the GMES Advisory Council (GAC) and of the GMES Programme Office (GPO). In a Decision dated 8 March 2006, the European Commission announced its willingness to complement the GMES management structure through the establishment of a specialized core team, the Bureau for GMES. The Bureau, which will operate for a period of 3 years starting on 1 June 2006, will contribute to the long-term sustainability of GMES. Its primary objective is to "fast track" delivery of Earth Observation services by 2008. Three implementation groups are developing draft guidelines for land, maritime and emergency response services. With staff coming from a number of sectors, the GMES Bureau's unique structure reflects its special role and mission. In June 2006, Valère Moutarlier was appointed Director of the GMES Bureau.

(c) INSPIRE

INSPIRE is the European Commission's proposal aimed at creating a system for access to and exchange of spatial information, needed to monitor the quality of air, water, soil and the countryside. It was submitted to the European Parliament for a third reading during the July 2006 Plenary session, which dealt with access to environmental data, specifically the application of the Aarhus convention to the EU institutions.

In June 2006, the European Commission launched a major public consultation related to the Green Paper, "Towards a future Maritime Policy for the Union: A European vision for the oceans and seas". The Green Paper stressed the need for the status of marine resources to be maintained and improved and that ecosystem-based management, built on scientific knowledge, is essential. GMES Ocean fast-track services will contribute to the objectives laid down in the Green Paper.

(7) European Organization for the Exploitation of Meteorological Satellites (EUMETSAT)

EUMETSAT is an intergovernmental organization that operates 4 meteorological satellites in geostationary orbit for 20 European States (Austria, Belgium, Croatia, Denmark, Finland, France, Germany, Greece, Ireland, Italy, Luxembourg, Norway, Portugal, Slovakia, Spain, Sweden, Switzerland, Turkey, the Netherlands and the United Kingdom). It has signed 10 Cooperating State Agreements; agreements with Bulgaria, Hungary, Iceland, Latvia, Lithuania, Poland, Romania, Slovenia and the Czech Republic have entered into force, whereas agreements with Croatia, Serbia, and Montenegro are pending ratification.

Three "MetOp" next-generation satellites are being built by EADS Astrium, and will operate from a polar orbit through 2020. The first MetOp launch from Baikonur, Kazakhstan on a Soyuz/ST launcher, originally planned for 17 July, had to be called off after three consecutive attempts due to technical reasons related to the Soyuz's ground system. On October 2, 2006 the launch was again postponed as the Upper Composite (comprising the MetOp spacecraft, the Fregat upper stage and the Soyuz fairing) experienced a slight mechanical shock while being transported to the launch pad. MetOp was subsequently launched on October 19.

Planned programmes such as the Jason-2 Ocean Surface Topography mission, the Meteosat Third Generation, and the Post-EPS programmes, will further assure EUMETSAT's long-term service.

EUMETSAT is likely to become the operational satellite agency of choice for European Earth Observation programmes for atmosphere and oceans, such as the Global Monitoring for Environment and Security (GMES) initiative led by the European Commission (EC) and the European Space Agency. The EC and EUMETSAT signed letters of intent in January 2006, setting forth the areas of cooperation in the near term between the two parties. The EC will draw on existing EUMETSAT satellite data and services, while EUMETSAT will offer technical support on establishing operational services. The EC will strive to support initiatives to improve the use of satellite data and recognize EUMETSAT as an operational agency for future GMES initiatives.

EUMETSAT's polar-orbiting satellite, Metop-A delivered its first images on 25 October, the first day when the Advanced Very High Resolution Radiometer (AVHRR) of the U.S. National Oceanic and Atmospheric Administration (NOAA) was operational. An agreement between NOAA and EUMETSAT coordinates the activities of respective polar satellites to improve coverage of weather and climate conditions.

EUMETSAT and South America

EUMETSAT signed a contract with Globecast of Spain, which will extend the dissemination of Meteosat Second Generation data to South America, beginning in early 2006. The data will be used by organizations such as national weather services,

environmental monitoring organizations, research institutes and air traffic control authorities.

The service will use EUMETCast, the existing digital broadcast system of EUMETSAT, which is based on DVB technology, and utilizes the services of a satellite operator and telecommunications provider to disseminate High Rate Meteosat Second Generation image data every 15 minutes.

(8) European Commission (EC)

The European Commission (EC) has filed charges against 13 countries for violations of a wide range of EC telecom regulations. The most common charge was failure of countries to complete complex 18-part reviews of their local telecom markets.

(9) European Private Sector / Industry

(a) ALCATEL Alenia Space

ALCATEL Alenia Space announced on November 17 that it has finished the installation of 51 weather data receiving stations in Africa, linking 47 countries to the Meteosat Second Generation (MSG) weather satellite. Alcatel Alenia Space is prime contractor for this deployment, which will bolster environmental monitoring in Africa. The project is financed by the European Commission through the European Development Fund and represents a considerable step forward for meteorological monitoring over Africa and the Indian Ocean.

Alcatel and China

Alcatel Alenia Space announced on December 5 that it had signed a contract with China Satellite Communication Corporation to design and manufacture the Chinasat 6B satellite. Chinasat 6B will be based on the Spacebus 4000 C2 platform and fitted with 38 C-band channels. The spacecraft, weighing about 4,600 kilograms at launch, will be placed into orbit by a Chinese Long March 3B launch vehicle and reside at 115.5 degrees East. Alcatel Alenia Space will assist China Satcom with the launch campaign, orbital positioning and in-orbit testing.

(b) Arianespace

Arianespace and the French defense procurement agency, the Délégation Générale pour l'Armement (DGA) signed a contract in September 2006 for the launch of the Helios IIB military satellite. It will weigh about 4,200 kg at lift-off, and will be launched by an Ariane 5 rocket into Sun-synchronous polar orbit in the first half of 2009. Helios IIB, like the Helios IIA satellite launched by Arianespace in December 2004, is being built by Astrium as prime contractor.

Syracuse 3B, the second satellite in France's third generation Syracuse III system, dedicated to secure military communications was launched in August on board an Ariane 5 rocket, on behalf of the French defence procurement agency DGA (Délégation Générale pour l'Armement), which is a part of the Ministry of Defense. Alcatel Alenia Space, in charge of the space segment and Thales, responsible for the ground segment and network stations, are co-prime contractors for Syracuse III.

On May 27, 2006, Arianespace placed two satellites into geostationary transfer orbit, the Satmex 6 for the Mexican operator Satélites Mexicanos S.A. de C.V., and Thaicom 5 for the Thai operator Shin Satellite Plc. This is the fourth time that Mexico has used Arianespace to launch a communications satellite. Mexico had already chosen Arianespace to launch Solidaridad 1 in November 1993, Solidaridad 2 in October 1994 and Satmex 5 in December 1998.

Thaicom 5 was the fifth satellite launched by Arianespace for private Thai operator, Shin Satellite, following Thaicom 1 in December 1993, Thaicom 2 in October 1994, Thaicom 3 in April 1997 and Thaicom 4 in August 2005.

On March 11, 2006, Arianespace placed two satellites into geostationary transfer orbit: SPAINSAT for Hisdesat, the Spanish military operator, and HOT BIRD™ 7A for Eutelsat.

An Arianespace Ariane-5 rocket completed a daylight launch from French Guiana on October 13, orbiting the DirecTV-9S and Optus-D1 satellites along with the Japan Aerospace Exploration Agency (JAXA)'s LDREX-2 piggyback payload. This was the fourth Ariane-5 multi-payload mission in 2006. DirecTV 9S, built by Space Systems/Loral, will provide high-definition (HD) programming and back-up capacity for DirecTV. This is the fourth satellite the company placed into orbit in the past two years, and DirecTV plans to launch two more in 2007.

Optus D1, the first of two satellites that Orbital Sciences Corporation is building for Optus Networks Pty Limited of Australia, will provide transmission capability for Sky Digital New Zealand, TVNZ and Australia's ABC and SBS while boosting capacity for Internet and voice and data communications services in Australia and New Zealand. Optus D2 is scheduled for completion and launch in 2007.

(c) Eutelsat

Eutelsat initial public offering (IPO) took place in December 2005. The corporation issued more than 71 million new shares of stock through its initial public offering (IPO), raising about 860 million euros ($1 billion). Eutelsat set the price of its shares at 12 euros ($14), about 20 % below the company's initial expectations.

On 12 March 2006 Eutelsat Communications announced that its HOT BIRD™ 7A broadcast satellite has been successfully launched by an Ariane 5 ECA rocket from the European spaceport in Kourou, French Guiana. HOT BIRD™ 7A has 38 Ku-band

transponders and is designed to renew current capacity and to provide redundancy for the HOT BIRD family.

Eutelsat's HOT BIRD™ 8 broadcast satellite was successfully launched by a Proton Breeze M launch vehicle from the Baikonur Cosmodrome on 4 August 2006. Weighing 4.9 tonnes, HOT BIRD™ 8 is the largest and most powerful European Ku-band broadcast satellite to be launched into the geostationary orbit.

Eutelsat signed a contract with Morocco's national public broadcaster, Société Nationale de Radio et de Télévision Marocaine (SNRT), to broadcast six television channels and four radio stations using Eutelsat's Hot Bird 4 satellite. The new multiplex, which marks the transition of Morocco's leading national channels to digital format, is part of the reform of Morocco's broadcasting landscape, initiated by the Moroccan Ministry of Communications.

(d) IMSO/Inmarsat

The IMSO's Assembly of Parties was convened from 25 to 29 September 2006. Member governments were asked to consider and act on proposals to amend the intergovernmental IMSO Convention, to expand IMSO's scope of authority and to elect a new Director of the Organization. One proposal would extend IMSO's oversight to include all mobile satellite service providers, specifically in the provision of capacity for Global Maritime Distress and Safety Services (GMDSS). Another proposal would allow IMSO to perform certain review and auditing functions for a new "Long Range Identification and Tracking" (LRIT) vessel tracking program, originally introduced by the U.S. Department of Homeland Security, on behalf of the United States Coast Guard, as a national security initiative. Formal amendments to the IMSO Convention have been introduced by fifteen European countries so that "the Organization may assume any other functions or duties (related to mobile satellite services), subject to the decision of the Assembly."

IMSO's Advisory Committee is reviewing a draft Public Services Agreement, which satellite service providers will be required to sign before being allowed to provide services for the GMDSS. The Public Services Agreement would require the payment of new fees to the IMSO.

The launch of Inmarsat's second I-4 satellite took place from a Sea Launch Zenit on November 8, 2005. This was the second satellite launched to provide Broadband Global Area Network services (BGAN). Inmarsat's I-4 satellites are being built by EADS Astrium and are part of an eight-year, $1.5 billion development of Inmarsat's next-generation satellite network. They are 60 times more powerful and have 20 times more capacity than their predecessors, the Inmarsat-3 satellites.

Inmarsat and its major service providers, France Telecom Mobile Satellite Telecommunications, Stratos Global Corp., Telenor Satellite Services and Xantic, announced on December 7 the commercial availability of Inmarsat's Broadband Global

Area Network (BGAN) service. The service is available to subscribers in Europe, Africa, Asia and the Middle East, with coverage scheduled to expand into North and South America in the second quarter of 2006. BGAN offers data communications at speeds up to 492 kilobits per second and the ability to conduct voice and data communications simultaneously.

Inmarsat's Broadband Global Area Network (BGAN) was used to file the first news reports of floods in the Phiippines, according to Stratos Global Corporation. A BBC journalist and cameraman began reporting from the Philippines' southern Leyte Province on the mudslides that hit Guinsaugon village in February. The village is located more than six hours from the nearest airport in Leyte's provincial capital of Tacloban, and normal communications methods were not available following the disaster. The BBC's success in using BGAN demonstrated how the service allows lightweight newsgathering with minimum equipment in remote region, that have little or no telecommunications infrastructure.

Inmarsat is part of a consortium of European aerospace companies and satellite operators, including Aena, Alcatel, EADS Space Services, Finmeccanica, Hispasat, Thales and TeleOp, which are involved in the development of Galileo, the European Global Positioning System (GPS). The consortium, which will now be known as the Galileo Operating Company (GOC), has approved Inmarsat to take overall management leadership of the Galileo Operations Company (OpCo) that will look after global network operations, including performance monitoring and operations security. OpCo will be based in the UK.

(10) Finland

Finland’s Nokia, and Japan’s Kyocera Corporation with its Kyocera Wireless Corporation subsidiary resolved in January a nearly two-year-old patent-litigation dispute over wireless mobile telephone products and technologies via new two-way patent-licensing agreements.

(11) France

(a) Alcatel Alenia Space

Alcatel Alenia Space will provide Defence User Ground Segment for the Cosmo-Skymed Earth observation program to the French Ministry of Defence. The 32 million Euro ($38.3 million) contract from the Italian Space Agency, which acts as a procurement agency for the Italian and French Ministries of Defence, is part of the Italian inter-governmental agreement to ensure interoperability and data exchange between Cosmo-Skymed and the French Helios 2 system. The equipment will be installed in the French Ministry of Defence military center of Creil.

(b) Cosmo-SkyMed

Cosmo-SkyMed is part of ORFEO, a dual-use Earth observation satellite network, developed jointly by France and Italy. The system consists of two satellites equipped with advanced electro-optical payloads, known as Pleiades, and four satellites equipped with a synthetic aperture radar, known as Cosmo-Skymed.

(12) Germany

German satellite TerraSAR-X will be launched at end 2006. The project is financed by both public and private sector. The German Space Agency, part of the German Aerospace Agency (DLR), is responsible for the management of the entire project and, together with DLR research institutes, will pay 80 percent of the satellite's cost. The satellite was built by EADS SPACE, which will provide the remaining 20% of financing. The overall cost for the construction and launch of the satellite amounts to about €130 million, of which DLR contributed €102 million and EADS SPACE €28 million. An extra €55 million will be needed to develop the ground segment and fund operation of the satellite over five years; of this, €45 million will come from research institutes at DLR and the remaining €10 million will be invested by Infoterra GmbH. The long-term aim of the TerraSAR-X mission is to provide both scientific and industrial users with remote-sensing data collected using radar. DLR´s German Remote Sensing Data Center (DFD) will coordinate use of the data by the science community, while Infoterra GmbH, a subsidiary of EADS SPACE, will develop geo-information products and will market the data commercially. Both commercial and scientific users will share access to the available observation time.

The German Aerospace Center/German Space Agency (DLR) and EADS Astrium GmbH signed a cooperation agreement in August 2006, to build a new satellite mission, the TanDEM-X. The partners will finance the 85 million euro satellite jointly as a public-private partnership, with DLR contributing €56 million and Astrium investing €26 million. The partners expect to generate €3 million through the resale of excess payload capacity on the satellites. DLR will be responsible for the use of the data for scientific applications, while ccommercial marketing of the data will be managed by Infoterra GmbH, a subsidiary of Astrium. TanDEM-X is scheduled for launch in 2009. Together with the almost identical satellite TerraSAR-X, scheduled for launch in the end of 2006 from Baikonur, TanDEM-X will circle the Earth in close formation flight. This “two-for-one” constellation will enable a complete survey of the Earth's land surface(150 million square kilometres) within only three years. One of the goals is also to produce a global Digital Elevation Model with unprecedented accuracy.

(13) Italy

The Italian Government in 2005 enacted a law in regard to the registration of spacecraft, essentially transposing the principal requirements of the 1976 Registration Convention into the national legislation. Under this legislation, the National Registration

Registry was created, and the Italian Space Agency (ASI) is responsible for setting up and maintaining the Registry. Each space object, launched either by Italian physical or juridical persons, Italian launch base or under Italian control, must be filed in the Registry. No mention is made of objects launched abroad by Italian subjects, or upon request of Italian clients or for the eventual registration of foreign operators or international organisations whose headquarters are in Italy. The list of elements that needs to be registered corresponds to what is established in the 1976 Registration Convention, with the addition of the "general function" of the space object.

On 5 June the Italian Space Agency ASI announced a cooperative programme with Argentina involving two projects. One is a cooperative agreement with the Argentinian space agency Conae and the University of Cordoba (Spain) to make Earth observation data and services available to other Latin-American countries, building on existing collaboration in Siasge, a project which combines environmental-monitoring and disaster-management data from Italy's CosmoSkyMed X-band radar satellite and Argentina's Saocom L-band imaging network. The other project will incorporate Rosa, an Italian GPS occultation experiment, on the Argentine-U.S. environmental satellite Sac-D Aquarius in 2009.

(a) Emercomsat

Emercomsat, a civil protection satellite network built by Telespazio, began operations with the opening of the 2006 Winter Olympics in Turin. The system provides secure broadband communications and is interoperable with the national fire service network already active in the region.

(b) Skylogic Italia

Skylogic Italia, a Eutelsat subsidiary, won a contract to provide satellite broadband access to public administrators in Tuscany, Italy. Under the contract awarded by the region of Tuscany, Skylogic will provide broadband service to officials unable to receive access via terrestrial means.

The deployment of this turnkey satellite-based network will primarily be in the mountainous areas and islands off the coast of Tuscany. Up to 90 locations will be connected to the Rete Telematica Regione Toscana, whose operating centre is in Florence. The first 30 terminals have been installed, and all locations were scheduled to be equipped by end April.

(14) Kazakhstan

Kazakhstan planned to launch its first satellite by end 2005, and a second spacecraft within 2 years. Kazsat was built by the Krunichev Space Centre, and launched from the Baikonur Cosmodrome.

Separately, Interfax reported preparations were underway for the launch of three satellites for the Global Navigation Satellite System (Glonass) on a Proton-K rocket from Baikonur on December 25, 2005.

(15) Luxembourg

SES GLOBAL announced in March 2006 that it had completed the acquisition of 100% of the New Skies Satellites (NSS), for $22.52 per share, leading to an enterprise value of $ 1.15 billion. The transaction was completed following satisfactory closing conditions, including obtaining the remaining US regulatory approvals. With the acquisition of New Skies, the satellite fleet of SES GLOBAL and its affiliates now comprises 43 spacecraft at 32 orbital locations.

SES ASTRA, a SES GLOBAL company, announced in April 2006 that its new ASTRA 1KR satellite had been successfully launched into orbit by an Atlas V rocket from Cape Canaveral, Florida and will be located at 19.2° East. SES ASTRA also announced in June 2006 that the German Federal Cartel Office had approved the full acquisition of the satellite communications supplier ND SatCom. The acquisition allows SES ASTRA to enter the fast growing government sector and take advantage of the growth potential for its core satellite infrastructure business.

(16) Netherlands

New Skies Satellites, the world's fifth largest satellite operator based on in-orbit capacity, was acquired by SES in March 2006. The company operates five spacecraft positioned at orbital locations around the globe and plans to launch a sixth satellite before year-end 2006.

New Skies Satellites announced in May 2006 that it had signed a framework agreement with the Netherlands Ministry of Defence to support the Netherlands Armed Forces with satellite communication services on its NSS-7 and NSS-703 satellites. The new agreement is an example of recent efforts to restructure and harmonize procurement activities of the Netherlands Armed Forces, by signing a single agreement with a vendor for satellite communication services to serve the Dutch Army, Navy and Air Force on their global missions.

(17) Norway

Telenor Satellite Services and Addvalue Technologies announced that the two companies entered into a strategic business agreement to provide satellite communications services for the terrestrial, maritime and aeronautical markets. Under the agreement, the companies will design, develop, market and distribute satellite services. The initial focus will be the distribution of Inmarsat's Broadband Global Area Network (BGAN) communications.

(18) Russian Federation

The Modern University for the Humanities from Moscow will receive Gilat Satellite Networks Ltd.'s Skyedge broadband satellite hub station and VSATs for use by Teleport-Services, a Russian satellite-services operator. In addition to providing 300 sites for the university, Teleport-Services will use the VSAT network to serve businesses and government agencies in remote regions of eastern Russia, where terrestrial connectivity options are either unavailable or unreliable. Teleport-Services' clients will use the VSAT connectivity for Internet access, distance learning, video conferencing and other interactive data applications.

(19) Spain

Valencia, Spain was the venue for the 57th Congress of the International Astronautical Federation and 49th Colloquium of the IISL on Space Law, with more then 2500 participants attending these events. Proceedings of both events will be published in the near future.

SPAINSAT, launched by Arianesapce, is the first Spanish satellite aiming to secure government communications. It will be operated by Hisdesat, a subsidiary of Hispasat. Its main customer is the Spanish Ministry of Defence. SPAINSAT was built by Space Systems/Loral, Palo Alto, California. It will be positioned at 30 degrees West, equipped with 13 X-band transponders and one Ka-band transponder. Spanish industry will supply several major subassemblies and the ground segment.

Telefónica announced in January that it had acquired more than 75 percent of the voting rights attached to U.K. mobile operator O2 plc shares, thus its $31.4 billion offer to acquire O2 plc, made in late 2005, is no longer conditional.

(20) Sweden

The Swedish National Post and Telecom Agency granted Swedish Space Corporation an S-band license for a telemetry, tracking and command antenna for the Galileo satellite navigation system, the company announced on September 14. The license, which runs until 2037, was applied for on behalf of the European Space Agency (ESA).

In July, ESA awarded a contract to Swedish Space to provide a site for the northern telemetry, tracking and command antenna for Galileo at Esrange Space Center near Kiruna, Sweden. The 13-meter antenna will be one of the two, used during Galileo's In Orbit Validation Phase. The second antenna will be located in Kourou, French Guiana, near the equator. SES Astra Techcom and partner Hitec Luxembourg will design, build and install the antennas, which are expected to be operational in late 2007.

(21) Turkey

The Supreme Council for Science and Technology (SCST) determined that Space research and space technologies should be priority areas in Turkey's Science and Technology Policy. The SCST reviews policy matters annually and guides the design of science and technology policies with the participation of ministers, high level bureaucrats and representatives of non-governmental organizations. At a meeting in 2004, the SCST, taking into consideration the proposal designed by TÜBİTAK, the Scientific and Technological Research Council of Turkey, approved the National Science and Technology initiative for the period of 10 years. One part is the Space Research Programme, which was initiated by the Prime Minister. At the end of 2004, the SCST delegated to the TÜBİTAK the preparation of a space research programme for Turkey, which was initiated by TÜBİTAK in March 2005. This programme is designed to contribute to the development of a European Space Policy, complementing efforts of EU Member States and other key players, including the European Space Agency.

Turkey, through TÜBİTAK, is a co-operating member of the Disasters Charter, a voluntary association that provides remote sensing data to territories stricken by natural disasters, in accordance with the terms of the Disasters Charter and the UN's Principles on Remote Sensing.

(22) United Kingdom

The UK's Science and Technology Committee in July 2006 launched a wide-ranging inquiry into various aspects of the UK space policy. The Committee will be monitoring progress towards the strategic objectives of the UK space policy and addressing some key broad issues, including (1) the impact of current levels of investment on space-related activities on the UK's international competitiveness in this sector; (2) the benefits and value for money obtained from participation in the European Space Agency and other international programmes; (3) the maximization of commercial benefits and wealth creation from UK space-based technologies through innovation and knowledge transfer; (4) the delivery of public benefits from the space-related activities of different Government departments (e.g. DEFRA, MoD, DTI, DfT), and the co-ordination of these activities; and (5) support for space-related research and the UK skills base.

Time Warner subsidiary AOL disclosed plans to spend as much as $214 million to build its own digital subscriber loop (DSL) infrastructure in the U.K., taking advantage of the local loop unbundling (LLU) rules that force BT to allow other carriers to use its last-mile copper to users' premises.

European digital video recorder (DVR) deployment is advancing rapidly, according to IMS Research, which estimates that by the end of 2005 more than 2.6 million households in Europe were using a digital video recorder (DVR). By 2010, this market is forecast to reach more than 41 million households. Growth is expected to come primarily from operator deployments of integrated DVRs, although digital terrestrial television (DTT) and free-to-air satellite DVRs will make a significant contribution to the

total market. Prior to 2005, the only successful DVR story in Europe was Sky+ in the United Kingdom, but in 2005 various other pay-TV operators were launched, including Sky Italia, Telewest, NTL, Viasat, Casema, and Premiere, and digital services were adopted in the United Kingdom, France and Germany.

C. Africa and the Middle East

Representatives of the African Union, the ACP Secretariat and the five African Regional Economic Groupings (CEMAC, ECOWAS, IGAD, IOC and SADC) signed a joint declaration calling for the European Commission to consider an extension of its Global Monitoring for Environment and Security (GMES) initiative to include Africa.

'GMES Africa' would be a continuation of the African Monitoring of Environment for Sustainable Development (AMESD) project, recently approved by the European Commission. The implementation of the GMES Africa initiative might be funded as part of the 10th European Development Fund. The present initiative would be the third pan-African project funded by the European Union and implemented with the support of EUMETSAT, the European Organization for the Exploitation of Meteorological Satellites.

(1) Algeria

Following the signing of space agreements with France, Russia, and Argentina, Algeria on 25 July signed the space agreement also with the UK. Algeria also announced plans for a small communications satellite and for an African resource and environmental sensing network, to be built in cooperation with Nigeria and South Africa, with whom Algeria also plans to sign bilateral agreements.

(2) Morocco

SNRT Morocco chose ND Satcom Mobile Broadcasting Equipment for a classic SNG vehicle and two flyaway systems, ND Satcom announced on September 14. The classic SNG-Sprinter offers full redundancy for core transmission components and disposes of two transmitting channels for reliability. The two flyaway systems are lightweight and designed for fast, reliable and efficient news reporting.

(3) Saudi Arabia

Saudi Arabia's Communications and Information Technology Commission (CITC) decided in August to postpone plans to issue new licenses for a third mobile service, due to a shortage of available spectrum. CITC is also delaying opening up the fixed line market, while it studies new regulations that would allow for Voice over the Internet (VoIP). These postponements could cause delays in the availability of the broadband services. In a population of 24 million, there are more than 15 million mobile telecom users, but only 4 million fixed-line users.

(4) Arabsat

Arabsat teamed up with Cetel Germany, a provider of teleport and satellite services, to launch a satellite broadband initiative in the Middle East and Africa. The new service, which will be offered from Cetel's 7.3-meter antenna in Germany via a C-band transponder on Arabsat 2B, will offer one- and two-way service, as well as the possibility for dedicated connections for big communication carriers between the Middle East and Africa into the European fiber network. Cetel's new service is a natural complement to Arabsat's existing satellite business and will allow Cetel to provide various broadband Internet via satellite solutions

An upper-stage failure aboard a Russian Proton rocket left the Arabsat 4A satellite short of its intended orbit, when launched in March, according to launch provider International Launch Services (ILS).

(5) Thuraya Satellite Telecommunications Co.

Thuraya Satellite Telecommunications has enhanced its high-speed data product Thuraya DSL to increase the speed of the offering. The terminal's preliminary design was approved in May, and Thuraya plans to unveil the new product in the first quarter of 2008. Thuraya plans more consultations with manufacturer Hughes Network Systems before the launch. Thuraya's current plug-and-play terminal, launched in 2005, is widely used in the oil and gas, and media and non-governmental sectors.

D. Asia and the Pacific

(1) Cambodia

The Cambodian government set up the government-owned wireline phone network in the country's capital, Phnom Penh, as a separate company named Telecom Cambodia, with plans to privatize the company by 2008.

(2) China

China has started to build its own satellite navigation system. The planned network, Compass (or Beidou, in Chinese) will reportedly include five geostationary and 30 medium-Earth-orbit satellites. The country is said to be interested in cooperating with other nations to develop its satellite navigation industry and allow the Compass system to operate with other GPS systems. China is also cooperating with the European Union and the European Space Agency on the Galileo satellite navigation system.

Vice Administrator Luo Ge of the China National Space Administration announced on 5 April that China is open to international cooperation in all types of space activities, including human space flight. Luo also outlined China's multi-step lunar

exploration programme: a lunar orbiter mission in 2007, a rover on the Moon's surface by 2012, and a sample-return mission in 2017.

The China Telecommunications Group (CTG) planned to spin off its engineering-and-telecom services arm later in 2006, according to local press reports, hoping to get between $200 million and $400 million for the unit, however it is still unclear which assets are included in the deal.

Sinosat-2, Chinas' first direct broadcasting satellite (DBS), was launched aboard a Long March-3B rocket in October. The bird will be positioned at 92.2 deg. East, and will be able to provide TV and radio signals across China. It has an expected life in orbit expectancy of 15 years.

China-Singapore

Singapore's Pacific Internet (Hong Kong) Limited, in its first foray into the mainland China market, signed a joint venture deal with Zhong Ren Telecom to market integrated IP communication applications in southern China.

(3) India

Indian Government approved funding for the Insat-4E spacecraft, which will be built by the Indian Space Research Organisation, and is intended to provide digital multimedia broadcasting services to mobile phones and vehicles, as well as provide a test platform for technologies such as a large unfurlable antenna. Launch is expected to take place in 2008, aboard India's Geosynchronous Satellite Launch Vehicle.

India and Pakistan in January agreed to establish what will be the first direct land fiber link between the two neighbours.

India's state-controlled telco Mahanagar Telephone Nigam Ltd (MTNL) was negotiating with an unidentified Chinese carrier in what would be the first-ever investment by an Indian company in the Chinese telecom market.

In 2005, Worldspace Inc. rolled out its satellite radio services in nine cities in India, enabling the company to access a population of about 29 million people. Worldspace Inc. announced that it surpassed 100,000 subscribers globally in 2005.

India and Russia will share use of Glonass, a 24-satellite navigational and global positioning system, the Russian Federal Space Agency announced on October 4. Glonass is designed for military and civilian users to receive global signals from satellites to identify their positions in real time. It can also be used in geological prospecting. The system is expected to be fully deployed by 2010 when the number of satellites in the constellation increases from 17 to 24. Currently, the system consists of Glonass and Glonass-M spacecraft. Tests of the new Glonass-K model are expected to begin in 2007.

(4) Japan

The Japan Aerospace Exploration Agency (JAXA) launched the Advanced Land Observing Satellite (ALOS) aboard a H-2A launch vehicle in January. The rocket was launched from the Yoshinobu Launch Complex at the Tanegashima Space Center in Japan. ALOS will be used for cartography, regional observation, disaster monitoring, and resource surveying.

Rocket System Corporation and JAXA launched the Multi-functional Transport Satellite 2 (MTSat-2) on February 18 aboard an H-2A launch vehicle. MTSat-2, owned by the Ministry of Land, Infrastructure and Transport, is designed to collect data that will improve weather forecasts, mitigate natural disasters and help improve transportation security.

JAXA postponed the launch of the Astro-F satellite aboard a M-5 rocket that was scheduled for February 21 due to weather conditions. The launch of this infrared astronomy satellite was rescheduled for a later date.

JAXA completed the initial functional verification and calibration tests of the Advanced Land Observing Satellite, and began operations on 24 October. Daichi was launched in January, and data from the spacecraft will be available to the public from either the Remote Sensing Technology Center of Japan or the Earth Remote Sensing Data Analysis Center. JAXA also set a date for the launch of its Engineering Test Sattellite 8 aboard a H-2A rocket, which is to be on December 16.

JCSAT-10, belonging to the Japanese operator JSAT Corporation, was launched in August on board an Ariane 5 rocket, at the same time as the French Syracuse 3B. JCSAT-10, built by Lockheed Martin Commercial Space Systems, consists of 30 Ku-band transponders and 12 C-band transponders. JCSAT-10 will supply SKY PerfecTV, direct-to-home (DTH) services in Japan and communications services for Japan, the Asia-Pacific region and Hawaii. The satellite's design life is approximately 15 years.

Japanese wireless carrier NTT DoCoMo in January acquired a 7-percent stake in Philippine Long Distance Telephone Company (PLDT) for $443.7 million as part of a deal that will bring NTT DoCoMo’s i-mode service to the islands.

Japan submitted a draft law on space activities to the Diet, the Japanese Parliament, during its session in October 2006.

(5) Malaysia

Vodafone signed a partner network agreement with Telekom Malaysia (TM) that will enable TM customers to access Vodafone’s international voice and data roaming services; in return, TM will market various Vodafone offerings.

(6) Mongolia

Wireless digital TV has become available to some viewers in Ulan Bator, Mongolia by Yangtze Telecom Corporation, following a month-long trial of signal quality.

(7) Thailand

Thaicom 5, the fifth satellite launched by Arianespace for private Thai operator, Shin Satellite, was launched in May 2006. The Ariane launch follows Thaicom 1 in December 1993, Thaicom 2 in October 1994, Thaicom 3 in April 1997 and Thaicom 4 in August 2005.

The International Institute of Space Law (IISL), in collaboration with the Thai Ministry of Information and Communication Technology, held a regional symposium in Bangkok, from 1 to 4 August. Among the participants were more than 50 lawyers, engineers, scientists and academicians from Australia, India, Malaysia, Thailand and other Asian countries. This regional symposium is the latest in a series of such symposia, established by the IISL a few years ago.

In late August Thailand announced the founding of the Space Forum at Chulalongkorn University. The Space Forum comprises space lawyers, engineers and scientists who are interested in Thailand's space activities. The objective of the Forum is to focus on current problems, such as disaster management, land erosion, remote sensing, tele-medicine and tele-education. The Forum will organize a monthly seminar on one of these issues.

E. The Americas

(1) Argentina

Argentina is the recipient of the first multilateral loan from the Inter-American Development Bank (IADB) to develop a satellite system, PROSAT, for Earth observation applications. The $50 million loan will also receive local counterpart participation of $100 million. Argentina's Comisión Nacional de Actividades Espaciales (CONAE) will be in charge of PROSAT, an initiative of the country's Science and Technology Policy and National Development Strategy, to help increase long-term productivity and economic sustainability. The spacecraft will be used for mapping soil humidity and to improve timing of sowing specific crops, thus increasing agricultural productivity and reducing crop loss.

The program is expected to strengthen Argentina's existing science and technology capacity, positioning the country in a technological niche. Private sector participation will be fostered for the development of value-added services. PROSAT is the first satellite development programme funded by a multilateral development agency,

although some of these agencies have financed satellite-related activities, such as the development of earth stations and use of Landsat data and satellite imagery.

CONAE, established over 20 years ago, is the agency responsible for Argentina's space-based activities, including the launch of three small earth observation satellites. CONAE works closely with other space agencies, notably NASA, ESA, and the Brazilian Space Agency.

(2) Brazil

ANATEL, the Brazilian National Telecommunications Agency, authorized Iridium Satellite to provide a variety of Iridium products and services throughout the country. There seems to be great growth potential in the transportation sector, including vehicle tracking for cars, trucks buses and other means of professional transportation. More than 20,000 vehicle-tracking units have already been installed, but there are more than 1.5 million vehicles circulating in the country.

ANATEL also granted Intelsat rights to operate the Intelsat Americas-8 (IA-8) satellite in the Brazilian market, the company announced in February. IA-8, launched in June 2005, employs six C-band and 12 Ku-band transponders for broadcast content distribution, corporate VSATs and broadband applications, including high-speed Internet access, multicasting and streaming.

Shareholders of the five major Brazilian Vivo-brand mobile carriers comprising a Portugal Telecom/Telefónica Móviles joint venture, approved a merger that may be the prelude to a wider transaction between the Portuguese and Spanish parent companies.

The Brazilian delegation to the United Nations Committee on the Peaceful Uses of Outer Space (COPUOS) Legal Sub-Committee presented a proposal during its June session, to study some of the issues related to the 1986 Remote Sensing Principles. The COPUOS accepted the proposal, which will become part of a 3-year work/study programme to be undertaken by the COPUOS.

Brazil will join several other countries in signing up for the worldwide Global Earth Observation System of Systems (GEOSS), stressing the importance to have centralized data on disasters, and potential relief operations. The GEOSS will acquire data not only from satellites but also from terrestrial monitoring systems, such as buoys, seismic meters, etc. GEOSS proponents hope that by centralizing data, they can share them more effectively, and therefore mitigate natural disasters.

Brazil and Galileo

Galileo program officials announced on December 9 the opening of the Galileo Information Centre for Latin America in Sao Jose dos Campos, Brazil. The centre will provide a focal point for the promotion of the Galileo satellite navigation system services and applications throughout the region and is also intended to implement information and

training activities, and to facilitate interaction between Latin America and Europe.Officials also announced that a Galileo cooperation project for Latin America, which will support satellite navigation plans and development, will be launched shortly by the Galileo Joint Undertaking.

(3) Canada

The Institute of Air and Space Law (IASL) at McGill University, in conjunction with the International Institute of Space Law (IISL), hosted a 3-day workshop from 28 to 30 June, 2006. This interdisciplinary event was entitled "Policy and Law Relating to Outer Space Resources: The Example of the Moon, Mars and Other Celestial Bodies." It was dedicated to Dr. Eilene Galloway, who proposed the topic several years ago, and who has been advocating international cooperation and the peaceful uses of outer space since 1957.

The Workshop brought together space lawyers, academicians, scientists and academicians from countries worldwide, including Australia, Canada, Germany, Japan, South Korea, the Czech Republic, the Netherlands and the United States. Summary Report is available from the Centre for Research of Air and Space Law, McGill University, Montreal, which will also publish the Workshop's full proceedings in the near future.

The IASL at McGill University successfully concluded its ICAO/McGill Worldwide Symposium on Air Navigation in Montreal from 27 to 29 September, with approximately 200 delegates from around the world**.** The IASL hopes to co-sponsor another conference with ICAO in Montreal in the fall of 2007, preceding the ICAO General Assembly meeting.

McGill University will cosponsor a workshop and conference in Macau, China, in April 2007, thanks to a IASL graduate, Aurora Santos, who is active on behalf of the IASL Asia-Pacific Alumni(ae) Association.

The McGill University Moot Court team was the winner of the best brief and best oralist awards, during the final rounds of the Manfred Lachs' Space Moot Court competition, held in Valencia Spain in October.

(4) Colombia

ViaSat is supplying its Surfbeam broadband satellite network to Telesat, enabling Telesat customers in Colombia to provide Internet access to schools and other projects. ViaSat will supply more than 3,700 satellite terminals to Telesat customers, while Telesat will provide the Ku-band capacity for the network via its Anik F1 satellite. Telesat customers Comsat de Colombia and Internet por Colombia will be the service providers for the network, which is part of the Compartel Social Telephony Program, a national program to facilitate universal access to telecommunications in rural areas of the country.

Colombia, which functioned as the Secretariat Pro-Tempore of the 4th Pan-American Space Conference from 2002 to 2006, ceded this role to Ecuador during the Fifth Space Conference of the Americas, held in Quito, Ecuador in July 2006. During this event, Colombia announced its plans to set up an entity to continue studying space-related issues as they may affect Colombia.

(5) Ecuador

Ecuador's government was the host of the Fifth Space Conference of the Americas, held in July 2006 in Quito. Participants included representatives from Argentina, Brazil, Colombia, Peru, Venezuela, as well as the European Space Agency, the Internet Society (ISOC), and other organizations.

Plans were developed to make better use of the existing satellite capacity in Latin America, particularly of remote-sensing/Earth Observation spacecraft, to monitor the environment, with the view of preventing natural disasters, and mitigating damage caused by them. The Brazilian delegation urged the participating countries to cooperate in the use of remote sensing data with a view of preventing natural disasters.

(6) Mexico

The Chamber of Deputies (House of Representatives) of the Mexican Congress enacted a law by which the Mexican Space Agency has been created. The next step is for the Senate to approve the law; which has been delayed due to elections.

In 2005, Mexico assigned the orbital position at 78 deg. West; in 2006, the 109 W orbital position was put into auction, but has not been assigned yet to any bidder.

Satmex 6, belonging to the Mexican operator Satélites Mexicanos S.A. de C.V., was launched on board an Arianespace 5 rocket in May 2006. This is the fourth time that Mexico has used Arianespace to launch a communications satellite. Mexico had already chosen Arianespace to launch Solidaridad 1 in November 1993, Solidaridad 2 in October 1994 and Satmex 5 in December 1998.

(7) Nicaragua

The Empresa Nicaraguense de Telecomunicaciones (Enitel) selected Gilat Satellite Networks to provide a Skyedge broadband satellite hub station and VSAT terminals. Enitel, Nicaragua's largest telecommunications operator, will use the system to provide Nicaraguan and Latin American customers with services such as Internet access, rural telephony, GSM trunking, fax and prepaid telephony. Skyabis enables the telecom operator to deploy a hybrid network, extending the reach of its terrestrial and cellular infrastructure to remote communities and to provide voice and data services, where voice coverage was previously unavailable.

(8) United States

On 2 March the U.S. announced completion of agreements that will allow the launch of U.S. satellites and satellites containing U.S. components by Indian launch vehicles. A technical safeguards agreement was included, but there were no price or quantity constraints imposed on the Indian launches as had been the case in prior similar U.S. agreements with China and Russia in the 1980s and 1990s.

Based on the successful cooperation between the U.S. and Russia on the International Space Station, especially since the loss of Shuttle Columbia, NASA Administrator Michael Griffin on 5 June invited Russia's participation in cooperative lunar and planetary exploration programmes.

During the visit of NASA Administrator Michael Griffin to China in September, in conjunction with visits to ISS partners Russia and Japan, Griffin and China National Space Administration Director Sun Laiyan agreed to meet at least once a year to explore the establishment of working groups in a number of areas, including Earth science, climate research, robotic missions, and various science missions. On 18 April China and the U.S. signed a protocol for a five-year extension of bilateral science and technology cooperative agreements in fisheries, infectious diseases (including Asian flu and AIDS), Earth and atmospheric sciences, basic research in physics, chemistry, and agriculture, energy, geology, health, civil and industrial technology, and disaster research.

Mobile Satellite Ventures (MSV) received a patent from the European Patent Office for ancillary terrestrial component (ATC) technology that will be used in the formation of a hybrid satellite/wireless communications network. The European patent relates to ATCs using GSM or CDMA wireless technologies and covers Belgium, Finland, France, Germany, Italy, Portugal, Spain, Sweden, the Netherlands and the United Kingdom. MSV received a similar patent in the United States earlier this year and announced in October the completion of its first hybrid network proof-of-concept trial.

(a) The FCC and Spectrum Issues

The Technology CEO Council, representing executives of U.S. high-tech companies, called on the Administration and Congress to revamp spectrum policy by leveraging unused radio frequencies for new wireless applications.

Rural U.S. residents are still lagging behind their urban and suburban counterparts in terms of broadband Internet usage, but they have been closing the gap, according to a survey released in February 2006 by the Pew Internet & American Life Project (PIP).

According to a new research from In-Stat, business customers continue to represent one of the most attractive market segments for wireless carriers, because of their ability to generate higher average revenues per user (ARPU).

The FCC is seeking, through a Notice of Proposed Rule making (NPRM), to change the spacing requirements for DBS satellites, at least nationally. Currently, under the Region 2 Plan devised by the ITU in 1983, the BSS or DBS satellites are required to be 9 degrees apart, but the FCC is seeking to reduce the spacing requirement, which would essentially allow for more DBS/BSS satellites to provide coverage in the USA.

The FCC took several first-step actions, including the partial grant of a Qualcomm petition, to start considering new broadband, video and other potential uses of the 700 MHz analog RF bands being freed by the U.S. broadcasters' digital-television (DTV).

(b) Private Sector

Bellsouth

Bellsouth extended its marketing alliance with DirecTV Inc. for another five years and created a new sales channel in February. Under the marketing agreement, Bellsouth is able to bundle local, long distance, wireless, Internet and digital video services in a single offering.

Under the new agreement, BellSouth is responsible for the sales and ordering functions, and DirecTV is responsible for the installation and ongoing service for BellSouth customers who subscribe to DirecTV service through BellSouth. As part of the extension, DirecTV residential customer across Bellsouth's nine-state service area will be able to BellSouth DSL services directly from DirecTV.

BellSouth and AT&T, the former parent company of Bellsouth, are seeking approval to merge operations. The U.S. Department of Justice has granted approval, but the FCC is seeking to avoid rubber-stamping the U.S. Department of Justice imprimatur on the AT&T $67.1 billion proposal to purchase BellSouth. Hearings are being held in Washington, DC, and comments are expected against the merger, which would create one of the largest, if not the largest telco.

Globalstar

Globalstar Inc. priced its initial public offering at $17 per share, the company announced on November 2, 2005. The company also added 1 million shares to the offering, bringing the total to 7.5 million shares. The stock has begun trading on the Nasdaq under the symbol GSAT.

Globalstar intends to use the proceeds from the offering to fund, in part, the procurement and launch of its second-generation satellite constellation and related upgrades to its gateways and other ground facilities. In late 2005, Globalstar opened a new gateway or ground station in Sebring, Florida.

Alcatel Alenia Space signed an agreement to start work on Globalstar's second-generation satellite constellation in October. The contract, expected to be finalized by

November 15, calls for 48 low-Earth-orbit satellites, weighing about 500 kilograms apiece, at an overall price tag of 7.7 million euros ($9.7 million).

Intelsat and Panamsat

The FCC approved Intelsat and Panamsat's merger in June. Upon completion of the transaction, PanAmSat will become an indirect wholly-owned subsidiary of Intelsat. Post-merger, PanAmSat and its subsidiaries will continue to operate as separate corporate entities. The transaction involves the transfer of control to Intelsat, of licenses and authorizations issued by the FCC and now held by PanAmSat Licensee Corp. and PanAmSat H-2 Licensee Corp., two subsidiaries of PanAmSat. The two licensees are authorized to operate non-common carrier Fixed-Satellite Service (FSS) satellites using the C- and Ku-bands, as well as numerous non-common carrier Earth stations that transmit and/or receive signals in those frequency bands.

Intelsat is an FSS operator that owns and operates a global satellite system providing end-to-end network services to telecommunications operators, corporate network integrators, governments, Internet service providers, and broadcasters around the world. Intelsat primarily serves the voice, data, and interconnectivity requirements of telecommunications and government customers. PanAmSat is an FSS provider that serves the video market in North America and Latin America and provides satellite services elsewhere in the world.

The transaction was unopposed, although the FCC conditioned its approval on Intelsat's compliance with certain national security and law enforcement commitments and undertakings that Intelsat made to the U.S. Department of Justice, the Federal Bureau of Investigation, and the U.S. Department of Homeland Security. It should be recalled that in 1986, President Reeagan issued an Executive Order, allowing Panamasat to provide satellite services separate from Intelsat, thus beginning the competition between them. Twenty years later, the competitors have merged into the single largest satellite service operator and provider.

ITSO, the inter-governmental remains of Intelsat, has filed a petition with the FCC, to look into what some observers believe to be Intelsat's shaky finances, especially its indebtedness after purchasing Panamsat. ITSO is concerned that Intelsat won't live up to its commitments to provide public services, as required in the ITSO Amended Agreement. However, the FCC deemed such a plea to be premature, and suggested that ITSO should wait until some of the finer economic details of the merger, and Intelsat's indebtedness, are clearer.

Iridium

Iridium Satellite LLC unveiled a new range of solutions for satellite-based rural communications for Africa and other remote regions, the company announced on February 20. Iridium, which provides voice and data communications through a constellation of 66 satellites, will provide services such as fixed or mobile public calling

office systems, unattended satellite pay phone stations, vehicular systems and asset tracking solutions. Iridium's rural communications services will be packaged and sold by authorized service providers, who will offer a wide range of attractive rural communications solutions and pricing programs, including convenient scratch-card billing.

Iridium announced in February that Global Marine Networks LLC launched an automatic vessel tracking service using the Iridium satellite system to transmit location reports from ship to shore. The XGate vessel tracking system provides data such as GPS time, latitude and longitude, course and speed, and selected weather parameters. The information can be embedded in ship-to-shore email messages and/or reported to a central database with each email session. Automatic tracking reports also can be delivered according to a predetermined schedule. According to the Iridium executives four expedition cruise ships and multiple passenger vessels operating in the Arctic and Antarctic waters have installed the system.

The first Iridium-based satellite pay phone able to use a credit card swiper for direct billing to the caller, was launched by World Communication Center (WCC), a provider of global satellite voice and data communications. The pay phone allows owners to vary the per-minute charges. In addition to credit cards, callers can use pre-paid scratch cards to contact crews or to those without credit cards. The addition of a self-sustaining solar panel booth supplies an ideal solution for those with a limited or non-existent power source, according to Iridium. The satellite credit card pay phone starts at $3,000.

Societé Européenne des Satellites (SES)

The U.S. Department of Justice has completed its review of SES Global's acquisition of New Skies Satellites, permitting the deal to be completed. The acquisition was announced on 14 December, 2005. New Skies announced on 10 February that shareholders of the New Skies Satellites Holdings Ltd. approved the acquisition of the company by SES Holdings Ltd.

Antitrust reviews in the United States and Germany have been completed but other U.S. regulatory approvals remain pending, including approvals from the U.S. Federal Communications Commission, New Skies said.

The deal, which would cement SES as the second largest Fixed Satellite Services company in the world behind the combined Intelsat-Panamsat, was expected to close in the second quarter 2006.

SES Global reported revenues of 1.3 billion euros ($1.5 billion) in 2005, a 17 percent increase over 2004, while profits improved 12 percent to 382 million euros ($456.4 million) in the same period. SES attributed the improvement in revenues to continued organic growth, as well as the contribution from the acquired businesses of APS and Verestar and the impact of consolidating Satlynx in April. Fleet utilization remained stable at 74 percent, with 549 of SES' 745 commercially available transponders

in use, the company said. SES continues to invest in developing satellite-centric service offerings within SES and these have contributed to the financial growth recorded in the period. Their contribution will grow over the coming years.

New Skies Satellites B.V., now part of SES, donated satellite transmission services for a TV broadcast by the International Federation of Red Cross and Red Crescent Societies for an anti-malaria campaign on 19 December, 2005. The International Federation used the donated capacity on New Skies' NSS-7 satellite to provide live shots from Niger to various television outlets across Europe and the United States. The effort was part of an International Federation campaign to fight malaria in Niger through the use of mosquito nets. Under the program, more than 2 million mosquito nets have been distributed to about 3.5 million children in total.

Stratos Global Corporation

Stratos Global Corp. closed its $191.3 million acquisition of rival satellite communications company Xantic B.V. in February, creating a half billion-dollar company with a 44 percent market share of Inmarsat mobile satellite telecommunications revenue.

The acquisition combines Stratos' satellite Internet protocol (IP), data and voice strength in the Americas with Xantic's position in Europe and the Asia-Pacific region, making it the market leader in each of the key vertical markets for mobile satellite services, including the government and military, maritime, leasing and telecom carrier sectors. The acquisition of Xantic significantly enhances Stratos' geographic and vertical market presence to better serve the critical remote communications needs of its customers, and its expanded scale will drive significant operational synergies and an improved cost structure. The deal combines Stratos' 25 percent market share of Inmarsat revenue with Xantic's 19 percent.

Dutch telco KPN sold its 65 percent stake of Xantic because the business was no longer part of KPN's core activities. KPN expects to clear about 65 million euros ($77.4 million) in the deal. The remaining 35 percent of Xantic is held by Telstra, the Australian telco.

Stratos financed the acquisition of Xantic and refinanced its existing debt through the completion of $270 million of new senior secured credit facilities and the issuance of $150 million of senior notes. Stratos expects to record a $24 million non-cash write-off in the 2006 first quarter related to "the rationalization of its post-acquisition land earth station network" and for costs previously deferred in connection with its December 2004 refinancing. Stratos also reported it expects to realize savings of $20 million to $25 million in annual operating expense and capital expenditure synergies within 24 months.

(9) Venezuela

EMS Satcom, a division of EMS Technologies Inc., said on 5 December that Venezuela's Instituto Nacional de Aviación Civil awarded EMS Satcom a $2.9 million contract for the company's search and rescue system. EMS Satcom will provide Venezuela with a SARMaster rescue coordination centre automation system for deployment throughout the country; it will also provide 600 low earth orbit satellite ground stations and the OCC 200 mission control centre.

Telecom Italia (TI) is selling its 100-percent stake in Venezuelan mobile operator Corporación Digitel (Digitel) to Telvenco, a company owned by investor Oswaldo Cisneros, for $425 million.

Venezuela's Science Ministry signed a contract with the China National Space Administration on 1 November 2005 to build and launch the Simon Bolivar telecommunications satellite. Services are to include secure government communications, links to rural Venezuelan villages, and possibly Earth observations. Included in the contract, which calls for launching the satellite aboard a Long March rocket in 2008, is the training in China of 90 Venezuelans in satellite operations and control. Among the trainees will be 15 doctoral candidates and 15 Master's candidates.

In late 2005, Venezuela announced that it was creating a Commission on the Peaceful Use of Outer Space, and was going to acquire a satellite for governmental communications. Delegates visited China and India, further details on the status of the plans for a national satellite are yet unknown.

(10) Satellites and the Nobel Prize

Two scientists who helped create the Cosmic Background Explorer (COBE) satellite have been awarded the Nobel Prize in Physics for 2006, the Royal Swedish Academy of Sciences announced on 3 October.

The academy stated that John Mather of NASA's Goddard Space Flight Center in Greenbelt, Md., and George Smoot of the University of California at Berkeley, California, were recognized "for work that looks back into the infancy of the universe and attempts to gain some understanding of the origin of galaxies and stars. It is based on measurements made with the help of the COBE satellite launched by NASA in 1989." They will split the prize of 10 million Swedish krona (US $1.36 million).

(11) Future Events

The International Astronautical Federation will hold its annual congress in Hyderabad, India, from 24 to 28 September 2007. More information, including call for papers, deadlines for submission of abstracts and other, may be found on the website http://www.iafastro.com.

IX. GLOBAL SPACE MARKET ISSUES AND OPPORTUNITIES

A. Government Programmes

On 10 November 2005 NASA released data on its contract awards during fiscal year 2004, disclosing a total of $9,025,668 in contracts with industry that amounted to about 85% of the agency's total contract funding. About 19.7% of the industry total went to United Space Alliance, 11.4% to Boeing companies, and 11.3% to Lockheed Martin divisions.

On 7 November 2005 NASA created a Commercial Crew/Project Office at the agency's Johnson Space Center to manage demonstration projects that may lead to commercial space transportation services to the space station and elsewhere. The following month, on 20 December, NASA issued the agency's requirements for commercial cargo delivery services to the International Space Station (ISS). During an Exploration Systems Mission Directorate briefing on 1 November 2005, interest in the opportunity had been expressed by U.S. companies Boeing, Constellation Services International, Lockheed Martin, Northrop Grumman, SpaceDev, Space Exploration Technologies (Space-X), Spacehab, and t/Space, all of whom submitted proposals.

The competition was subsequently won by Rocketplane/Kistler and Space-X. On 18 August NASA issued a $207-million contract to Rocketplane Kistler and a $278-million contract to Space-X. Both companies plan to invest substantial additional funding to develop new kerosene-fueled rockets and conduct test flights. Rocketplane Kistler's initial launch to rendezvous with, and conduct close proximity operations with a spacecraft simulating the ISS, is planned for 2008, with two flights of their K-1 vehicle to the ISS itself to be completed by the spring of 2009. Their original partners included Alcatel Alenia Space (Italy) and Orbital Sciences Corporation (OSC, USA). The latter was to have invested $10 million, and also was to have overseen the final development and production of the K-1 vehicle and manage its flight operations. However, following a disagreement on design changes to the K-1, OSC subsequently withdrew and was replaced by Andrews Space. Other partners are Northrop Grumman (USA), lead contractor for the K-1 structure; Lockheed Martin (USA), who are building the K-1's fuel tanks and integrating the vehicle; and Aerojet (USA), who are providing the four AJ-26 engines needed for each K-1 launch (the AJ-26 engines are derived from Russian NK-33s, 50 of which had been bought by Aerojet several years ago). The K-1 will be launched from Kistler's facility in Woomera, Australia.

Space-X plans a first test flight in late 2008 or early 2009 to "prove out the fundamentals," followed by a Falcon-9 launch of the company's 3.8-m diameter Dragon capsule to the Falcon-9's spent upper stage (as a stand-in for the ISS), with which it will rendezvous and conduct proximity operations. The third Space-X flight, to the ISS, will be an actual cargo-delivery mission that will also demonstrate the transport of discarded ISS cargo back to Earth. Although Space-X plans to do most of the COTS work in-house, they will involve partners MacDonald Detwiler (Canada) for an automated guidance system, Spacehab (USA) for logistics support, ARES Corporation (USA), Odyssey Space

Research (USA), and Paragon Space Development Corporation (USA).

AirLaunch LLC (USA) received a one-year, $17.8-million contract from the U.S. Defense Advanced Research Projects Agency (DARPA) on 2 November 2005 for demonstration of a rocket able to launch small payloads on short notice for less than $5 million. The company's QuickReach satellite launch rocket uses an unmodified C-17 transport aircraft. Successful drop tests had been conducted in 2005 and 2006.

On 20 September NASA established a privately managed strategic venture-capital investment fund, to be managed by the nonprofit organization Red Planet Capital (RPC). RPC plans to seek private venture capital, seeded by a NASA investment of $75 million over the next five years, to promote broader private-sector participation in NASA activities in the expectation of obtaining earlier exposure to emerging technologies. Some target technologies are information technology, communications, biomedical support, environmental systems, person-machine systems, "smart" manufacturing, energy, and advanced materials.

On 9 June Russian president Vladimir Putin announced the merger of a number of Russian space enterprises into a new umbrella company owned by the government, The Information Satellite Systems Company (ISS), which is expected to be formed at the end of this year or early in 2007. The Russian cabinet endorsed the "2015 Strategy on Development of the Rocket and Space Industry" on 6 July.

The core organization in the new company is the Academician Mikhail Reshetnev Scientific Production Association of Applied Mechanics (NPO PM), which built the Glonass navigation satellites, the Express and Gonets communications satellites, and the Gorizont television broadcast spacecraft. Other companies to be integrated into ISS, which is expected to have about 12,000 employees, are the Scientific Production Association Polyus, the Scientific Production Enterprise Kvant, Siberian Instruments and Systems, the Scientific Production Enterprise Geofizica-Kosmos, the Scientific Production Association of Space-Instrument Engineering Kvant, and Siberian Institute of Design of Machine-Building Enterprises. The ISS goal of increasing sales by 50% is expected to be accomplished by developing and building next-generation multi-media communication satellites using the lightweight Express-1000 bus and the heavier Express-2000 bus, and upgrades of the Glonass and Gonets spacecraft. The new strategy also includes setting up a second holding whose core asset is the Scientific Research Institute of Space Device Engineering, and a third conglomerate to be built around the Scientific Production Association of Machine-Building.

ESA released its 2006 budget on 17 January. The major share of the $3.5-billion total, $660 million (18.29%), goes for launchers. New emphasis has been placed on technology development, which grew from 3.1% to 4.5% of the total, and communication satellites, whose budget commitment increased from 5.5% to 7.35%. The balance of the new budget was roughly comparable to the 2005 levels.

The French space agency CNES released its 2006 budget of $1.67 billion on 3 April. CNES's annual contribution to ESA from 2006 through 2010 will remain at $830 million, but the balance, to be committed to national programmes, will increase from its 2006 level of $839 million by 1.5% per year through 2010. One of the new French initiatives will be a Ka-band communications satellite named Athena, which will be developed in cooperation with the Italian space agency ASI to deliver dual-use two-way broadband services to French and Italian military forces and to civil customers as well. Launch is expected in 2008.

A second new prospect for CNES and partners Alcatel, Orange (a ground-based cellular network operator), Eutelsat, and SES Global is an S-band satellite system that will use ground-based signal boosters to provide video communications to mobile telephones. An $8.5-million demonstration of this system in Toulouse was announced on 18 July to prove out its business case. The demonstration, using a helicopter to carry the satellite payload, was conducted for the balance of the year. The French Agency for Industrial Innovation committed $48 million in grants and loans to assist developer Alcatel in rolling out the required terrestrial repeaters for a nationwide system.

On 1 September Eutelsat ordered its W2A satellite from Alcatel Alenia Space and will decide later this year whether or not to include a 12-m unfurlable S-band antenna for the mobile-telephone video communication system, depending on their success in marketing up-front commitments from ground-based cellular networks, television broadcasters, and handset manufacturers. The 5.7-tonne W2A spacecraft, being built on the Alcatel Alenia Space 4000C4 bus, will carry 37 Ku-band transponders for video and data broadcasting to Europe, Africa, and the Middle East, plus 12 Ku-band transponders to service South Africa and 10 C-band transponders for Africa.

On 2 May Germany's new Chancellor Angela Merkel endorsed a multi-year increase in the nation's space budgets, citing the long-term nature of returns from basic research and the high value that has often resulted from unpredictable advances fostered by such research. In commemorating the transfer of the Columbus space station laboratory from builder EADS Space Transportation to ESA, Chancellor Merkel also noted that space research contributed to job creation and scientific research, adding dividends in terms of both material and symbolic value. The annual budget for the German space agency DLR is expected to grow steadily by about 2.5% from 2006 until 2009.

B. Commercial Enterprises

Space News (USA) reported on 30 January that civil, military, and commercial organizations worldwide had conducted a total of 56 orbital launches of payloads in 2005, as compared to 54 in 2004. Russian government launches topped the list with 18 launches, of which 3 failed to deliver their payloads to the planned orbits. Commercial companies operated a total of 28 launches, including one failure.

The Satellite Industry Association (USA) released its annual "State of the Satellite Industry Report" on 14 June. The industry as a whole generated revenues of $89 billion worldwide in 2005, a growth of 7.4% over 2004. Services accounted for 60% of the total 2005 sales, a third greater than the sales in 2000 (45%). The only declining sector was satellite manufacturing, which dropped by 24% to $7.8 million, mostly due to a lower level of government contract sales, which fell to 71% of all satellite manufacturing revenues, as compared to 82% in 2004.

SkyTerra Communications (USA) completed its purchase of Hughes Network Systems (USA) from HNS owner DirecTV (USA) on 10 November 2005. SkyTerra had bought 50% of HNS previously, in April 2005. Total investment by the purchaser was $160 million plus 300,000 shares of SkyTerra. Broadband services provided by HNS, which have been handled by leases from PanAmSat and other satellite fleet operators, include DirecWay and other high-speed broadband Internet links to business customers. As part of the transaction, the new owner received HNS's Spaceway-3 Ka-band satellite, launched late in 2006, which took over services formerly provided by the leases from other fleet operators. The purchase was approved by U.S. regulatory agencies this year.

On 26 June *Space News* published its 2005 data for fixed satellite service operators. Revenues for the top ten were as follows:

COMPANY	2005 REVENUES ($Million)	GROWTH OVER 2004 (%)
SES Global, Luxembourg	1,480	- 5.1
Intelsat, Bermuda	1,170	12.5
Eutelsat, France	885	-14.7
PanAmSat, USA	861	4.1
Telesat Canada	407.3	35.5
JSAT, Japan	373	-13.4
New Skies, Netherlands	240.5	14.1
SingTel Optus,Australia/Singapore	165	-1.6
Star One, Brazil	164.5	7.9
Space Communications, Japan	153.7	-29.4

At its annual World Summit for Satellite Financing in September, Euroconsult (France) projected satellite transponder capacity to grow by 6% this year, the biggest increase in five years, and to grow at rates in excess of 4% annually through 2010. By 2015 the demand will reach 6,350 transponders, as compared to 4,535 in 2005. Astrium (France) predicted a market for 98 geostationary-orbit satellites, worth $10.7 billion, during the years 2007 – 2011, which is an increase of 12% over last year's five-year projection. Eutelsat (France) also projected that its earnings before interest, taxes, depreciation, and amortization (Ebitda) would reach 78% this year, on a projected revenue of $1.02 billion, and remain above 76% for the next two years, based on a

projected annual revenue growth rate of 4.5%. This has motivated Eutelsat to increase capital expenditure plans by 15%.

At the same conference, satellite insurers announced on 7 September that the insurance premium on a $200-million satellite to cover launch and its first year of operations had dropped to less than $30 million, more than $10 million less than it was 2 years ago, and that annual in-orbit satellite insurance rates had dropped from 2.5% of the insured value to about 2.1%. Available coverage has also increased to a projected $475 million or more by the end of the year. The satellite insurance industry's profit for 2006 was projected at $500 million. Over the past five years it had reached $2 billion, *vs* the average profit during the past 15 years of only $90 million per year.

On 19 October Aon Space won a hotly contested three-year exclusive contract to provide satellite insurance brokerage services to Intelsat, with 50 satellites now the world's largest commercial satellite fleet operator (see above). Other bidders were Marsh, PanAmSat's former insurance broker; International Space Brokers, who had handled Intelsat prior to its merger with PanAmSat; and Willis Aerospace. The specific policy structure has yet to be decided by Intelsat, who had up to this point had self-insured its satellites following their launch and initial year in orbit.

Loral Space and Communications (USA) emerged from bankruptcy on 21 November 2005, 28 months after its filing in June 2003. On 23 November Chairman Bernard Schwartz announced that the company will keep both its major elements, satellite fleet operator Loral Skynet and satellite manufacturer Space Systems/Loral, and, indeed, expects to expand the workforce at Space Systems/Loral and purchase any additional spacecraft that the U.S. government may require Intelsat and PanAmSat to divest as a condition on their planned merger.

That merger took a major step toward fulfillment with the 26 May approval by the U.S. Department of Justice, which put no conditions on the $6.4-billion acquisition of PanAmSat by Intelsat and hence did not require any divestiture of any of the 51 satellites in the merged companies' fleet or their five satellites on order. The final approval, by the U.S. Federal Communications Commission (FCC), was granted on 19 June, and the purchase was consummated on 3 July. The combined 2005 revenues of the merged companies, $2.031 billion, makes the new entity the largest fixed satellite service operator in the world, exceeding the former leader SES Global, whose 2005 revenues (including those of recently purchased New Skies Satellites; see below) were $1.725 billion. The combined Intelsat-PanAmSat backlog as of 31 March was $8.3 billion. The merger is claimed to offer the companies over $400 million in savings over the next five years, mainly as a result of foregoing the purchase of three satellites, reducing total workforce from the current 1,400 employees to 1,000, and closing down PanAmSat's former headquarters facility in Connecticut, USA.

SES Global purchased New Skies on 15 December 2005 for $1.15 billion. The deal became effective on 30 March, following U.S. government approval and the suspension of New Skies share trading on the New York stock exchange. The merged

company has 45 satellites and is now the world's second largest fixed satellite service operator. The New Skies network will retain its identity under SES Global, joining SES's Americom and Astra units, and operating mainly in the Middle East and Asia.

On 7 September Lockheed Martin (USA) sold its majority share of International Launch Services (ILS; USA/Russia) to Mario Lemme, a member of the ILS Board of Directors and founder of Space Transport, Inc. (British Virgin Islands), which will manage the ILS investment. As President of Weissker Inc. (Russia), Lemme assisted ILS to obtain the necessary U.S. regulatory approvals for export of U.S. satellites to Kazakhstan for ILS Proton launches from the Baikonur Cosmodrome. Lockheed Martin Commercial Launch Services will now take over commercial launch marketing and operations of the Atlas-V, which had formerly been carried out by ILS. The prospect for offering Atlas-V and Proton launch customers a backup in case one of the two launchers became unavailable, which ILS had been providing, is now subject to negotiation between ILS and Lockheed Martin. As part of the transaction, which was completed on 11 October, Lockheed Martin also sold its interest in Lockheed Khrunichev Energia International, the partnership under which Lockheed Martin had accessed Proton launch services for ILS.

Inmarsat (UK) announced on 4 September its purchase of Asia Cellular Satellite International Ltd. (ACeS, Indonesia) for $15 million, plus an investment of $45 million in ACeS over the next two years in a new voice coder and other ground infrastructure. The deal will provide Inmarsat with $3 million to $5 million in annual revenue, plus access to L-band radio spectrum over Asia and the ACeS R190 telephone handset design that Inmarsat plans to upgrade. ACeS's Garuda-1 satellite had lost about half its capacity due to failures two years ago, but Inmarsat will transfer some ACeS customers next year to its Inmarsat-4 satellite over Asia. ACeS will distribute Inmarsat services in Asia, including Inmarsat's new BGAN mobile broadband service (see above).

EUTELSAT successfully completed its initial public offering (IPO) of shares on 2 December, 2005, at an offering price of $14 per share. The company owns 18 satellites, has partial ownership of five others, and subsequent to the IPO launched two direct-to-home television broadcast satellites. Solicitations for bids on two more spacecraft are expected to reach contracts later this year.

On 11 October SES Global completed a two-part bond issue totaling $1 billon, about 2.6 times the amount sought, from 126 European and U.S. investors. The company reported gross 2005 revenues of $1.58 billion, with a 10 October estimate of a greater than 20% increase in 2006 when the acquisitions of New Skies (see above) and ND Satcom are included.

Early this year the use of satellite-transmitted high-definition television advertising in retail stores began to grow at a high rate. By March digital signage via satellite was being used at over 27,000 sites in the USA alone. Although currently limited to large corporations, which can afford the relatively high cost and have a sufficiently

broad customer base, the technology is developing so rapidly that its use is expected to double by 2010, with smaller companies accounting for much of the growth.

Another new development in satellite communications marketing, pioneered early this year by a small U.S. company called On-Band, is the practice of charging customers by the megabyte of usage rather than by the conventional flat monthly fee. This practice is similar to the extremely successful method used by ground-based cellular telephone networks, which charge customers for minutes used plus additional charges for "roaming."

XM Satellite Radio (USA) announced on 2 November 2005 that its agreement with Nissan (Japan) will be extended to provide over 500,000 future Nissan and Infiniti automobiles in North America with factory-installed satellite radios that will include navigation and messaging services.

An analysis by S.G. Owen and Co, (USA) released on 5 January, estimated satellite radio subscribers as of 31 December 2005 at 6 million for XM Radio and 3.3 million for Sirius Satellite Radio. Both companies had substantial subscriber growth during the last quarter of 2005: 1.13 million for Sirius and 980,000 for XM Radio. On 20 March Sirius announced its subscriber roster at 4 million, and on 3 April XM Radio said it had signed up 6.5 million subscribers. Despite their sizable growth, however, both companies' reports for the first quarter of 2006 indicated net losses: Sirius $458 million; XM $149 million. Second quarter growth for Sirius of 600,000 subscribers brought its 30 June total to 4.7 million, an increase of 370% over 30 June 2005. XM added 400,000 subscribers in the second quarter, bringing its 30 June total to 6.9 million. At the end of the third quarter, Sirius had a total of 5.1 million subscribers; XM had logged 7.2 million. On 30 October XM's fourth satellite, named Blues, was launched by a Sea Launch Zenit3SL rocket into a geosynchronous orbit, from which it was placed into a geostationary-orbit slot at 115 degrees east longitude. The 5.2-tonne spacecraft, built on a Boeing Satellite Systems 702 platform redesigned to eliminate the solar power system flaws that had marred some previous 702 spacecraft, joined the three XM spacecraft Rock, Roll, and Rhythm launched in March 2001, May 2001, and February 2005, respectively.

Canadian Satellite Radio Holdings (CSR) announced on 14 July that it had booked 80,000 subscribers during its first three quarters of operations, which ended 31 May. Total revenues for CSR, which operates under the XM Canada brand name, were $3.53 million, with a net loss of $79 million. On 31 May the company raised its monthly subscription price from $12.99 to $14.99, and will not change it again until at least September 2007.

Iridium Satellite (USA) announced on 9 November 2005 that their volume of aeronautical communications had doubled during the past year, with over 5,000 aircraft now carrying the company's equipment. Iridium's aeronautical communications are now increasing twice as fast as voice communications, the company's primary business service. On 24 January the company announced that Israel's El Al Airlines would use the

Iridium network for passenger service aboard its long-haul Boeing 767 aircraft beginning early this year. Gilat SatCom subsidiary GayaCom (Israel) is installing the satellite terminals on the aircraft. Passengers pay $1.60 per minute for calling cards that are valid for up to a year. On 4 October Iridium also began equipping 132 ships of Zodiac Maritime Agencies (UK) with communications services through reseller AND Group (UK), using a transceiver built by Thrane & Thrane (Denmark).

Iridium subsequently announced the securing of $210 million in new debt financing on 7 August, via investment brokers Lehman Brothers Inc. (USA) and Morgan Stanley Senior Funding Inc. (USA). The new funds are being used to repay existing debts, to develop new services, for collateral, and for dividends to investors.

SpaceDev (USA) completed its acquisition of Starsys (USA) on 2 February, paying $9 million in cash and assuming or forgiving Starsys debt totaling $5.8 million. Starsys builds robotic spacecraft systems and structures.

In a 15 March filing with the U.S. Securities Exchange Commission (SEC), EchoStar (USA) stated that the company had six satellites on order with Space Systems/Loral and expected to spend $1.5 billion building and launching them by 2009. The five new satellites (one had been disclosed previously) are to carry a mix of Ku-band and Ka-band transponders, some of which are planned to provide two-way broadband data service. EchoStar also has two all-Ka-band spot-beam A-2100 spacecraft on order from Lockheed Martin Commercial Space Systems, and has agreed to lease all the capacity of several satellites operated by SES Americom and Ciel Satellite Communications (Canada; see above).

On the same day EchoStar chairman Charles Ergen also indicated interest in a possible joint venture with competitor DirecTV Group, and in entering the fixed-satellite services market in competition with PanAmSat (now Intelsat) and SES. The 50-50 joint venture subsequently crystallized on 17 July as Wireless DBS LLC, depositing $973 million with the U.S. Federal Communications Commission (FCC) for the FCC's August spectrum auction. The auction began on 9 August, and by 11 August, after seven rounds of bidding, Wireless DBS had committed $470 million toward 10 licenses for various U.S. regions. SpectrumCo LLC, a joint venture of major U.S. cable companies including Comcast and Time Warner Cable, had committed $308 million toward 4 licenses, and T-Mobile (Germany) had committed $266 million toward 24 licenses. Total commitments by 11 August had reached $2 billion for about 520 of the 1,122 total licenses up for auction among 168 eligible bidders.

Orbimage (USA) completed its $58.5-million purchase of Space Imaging (USA) on 12 January, creating a new company called GeoEye. The combined 2005 revenue of the two companies was $160 million, making GeoEye the world's largest satellite imagery company. Capital for the purchase was provided via debt financing by Deephaven Capital Management, Citadel Capital Management Group, Farallon Capital Management LLC, and Concordia Capital Corporation (all USA). GeoEye began its life with three high-resolution satellites, Orbview 2 and 3 and Ikonos (the latter two have 1-m

black-and-white and 4-m color resolution). The new company will add 0.4-m resolution Orbview-5 following its launch, currently scheduled early in 2007.

On 6 January Orbcomm (USA) completed a $110-million financing package to replenish its 30-spacecraft fleet of communications satellites for two-way messaging in 75 nations around the world. Funding was supplied by Pacific Corporate Group ($60 million), MH Equity Investors, Torch Hill Capital, Ridgewood Capital, Northwood Ventures (all USA). An additional $108 million is expected to be raised by an initial public offering (IPO) of Orbcomm stock beginning on 30 October. Six satellites had been ordered from Orbcomm's parent company Orbital Sciences Corporation (USA) in March 2005; OHB Technology (Germany) is building the satellite bus and providing integration and launch services. The six new spacecraft, which cost $6 million each including launch on Polyot Kosmos rockets (Russia), are to be flown in 2007; another 18 of the new constellation are planned for launch in 2008. Orbcomm reported that as of 30 September it had 200,000 subscribers, *vs* 113,000 at the end of 2005. The company's new ground terminals sell for $100, *vs* the $280 units marketed in 2003. In October Orbcomm signed a contract worth up to $57 million with the GE Asset Intelligence unit of General Electric for delivery of up to 412,000 subscriber terminals through 2009, with 270,000 under firm contract.

On 21 February Space Adventures (USA) announced plans to develop a suborbital space tourism enterprise by building a new 5-passenger suborbital spacecraft and constructing spaceports in the United Arab Emirates (estimated cost: $265 million) and Singapore (estimated cost: $115 million). The company had brokered the flights of space tourists Dennis Tito, Mark Shuttleworth, Gregory Olsen, and Anoushe Ansari to the International Space Station aboard Russian Soyuz rockets. The new suborbital spacecraft, named Explorer, is being developed by Space Adventures in partnership with Prodea (USA), a venture capital firm owned by the Ansari family, who sponsored the X-prize won by Burt Rutan's and Paul Allen's SpaceShipOne in 2004. It is based on Cosmopolis 21 (C-21), a multipassenger space plane designed by Russia's Myasishschev Design Bureau that would be launched by an M-55X aircraft. Space Adventures claims to have received over 200 reservations for future suborbital flights from people in 18 different countries.

The directors of Thales Group (France) approved the purchase of Alcatel's space business (France) on 4 April. The deal included Alcatel's transport-security business and its 33% share of satellite service company Telespazio, for which Alcatel received 12.1% of Thales stock, increasing its total holdings to 21.5%. Following approval of the purchase by French and European regulators, Thales will pay Alcatel an additional $816 million. 2005 sales revenues of the transferred businesses totaled $2.42 billion

Thales subsequently announced the sale of its satellite-navigation division, Thales Navigation, to Shah Capital Partners (USA) on 20 July for $170 million. The deal was finalized on 31 August. The division, renamed Magellan Navigation, Inc., manufactures and markets to consumers navigation devices for use with the Global Positioning System (GPS), including automobile navigation systems used by car-rental company Hertz.

Thales had purchased the company from Orbital Sciences Corporation (USA) for $70 million in 2001.

On 7 August the private-equity investment company Cinven Ltd (UK) announced that it had purchased Avio SpA (Italy) from the Carlyle Group (USA) and Finmeccanica (Italy) for $3.3 billion. Carlyle and Finmeccanica had purchased Avio in September 2003 for $1.93 billion. Avio owns 70% of ELV SpA (Italy), which is building the Vega launcher and is a major subcontractor for the Ariane 5. The company's 2005 sales revenue was $1.64 billion. As part of the purchase agreement, Finmeccanica is purchasing 15% of Avio back from Cinven, and retains the right to buy another 15% back if it acts before the sale closes late this year, after the requisite regulatory approval.

On 26 October Apax Partners (UK) purchased Telenor Satellite Services (Norway) for $400 million, following its previous purchase of France Telecom's mobile satellite division in July. The combined purchase means that Apax, an Inmarsat distributor, will generate 37% of Inmarsat's (UK) annual revenues, second only to Stratos (USA), which resells 47% of Inmarsat's revenues. The Telenor sale is expected to close early in 2007, following regulatory reviews. Telenor reported revenues of $377 million in 2005.

Astrium Satellites (formerly EADS Astrium) bought a 42% share in the Brazilian satellite equipment supplier Equatorial Sistemas on 23 May in order to establish a foothold in Brazil's space business. Equatorial Sistemas is a vendor to the Brazilian Space Agency (AEB) and the National Space Research Institute (INPE). The company is prime contractor for the Wide Field Instrument on the China-Brazil Earth observation satellite (CBERS), and was also prime contractor on the humidity sounder aboard NASA's Aqua satellite.

On 24 August DirecTV Brasil completed its purchase of Sky Brasil as part of an overall plan to merge Sky Latin America and DirecTV Latin America into a single television platform. The deal included the merger of DirecTV's Galaxy Mexico into Sky Mexico. DirecTV paid $579 million for the transactions. Globo Comunicaceo e Participacoes SA, the former majority shareholder of Sky Brasil, retains 26% of the merged company and will continue to be the lead supplier of Brazilian programming. DirecTV Brasil and Sky Brasil had a combined roster of 1.3 million paid subscribers, about one third of the entire Brazilian market.

Intelsat (Bermuda) received approval from Brazil's National Telecommunications Agency on 31 August to offer services to Brazilian business and government customers. Intelsat's GlobalConnex Managed Solutions unit will provide Internet trunking, Voice-Over-Internet Protocol, and very small aperture terminal (VSAT) services to multi-national corporations, financial services firms, retailers, offshore communications providers, and government agencies. Marketing support, installation of ground-sector equipment, and maintenance will be provided by Intelsat's Brazilian partners.

On 1 December 2005 Dutch Space announced that it had accepted an offer to be purchased by EADS Space Transportation (Germany). Formerly part of the Fokker Group (Netherlands), the supplier of solar arrays and space robotic systems had reported revenues of $85 million in 2004. EADS Space Services also purchased a 49% share of London Satellite Exchange (LSE) on 30 March, with an option to buy the entire company. LSE, which sells spot-market satellite capacity to both government and commercial customers, had revenues of $1.8 million in 2005 and expects that to double in 2006.

Virgin Galactic (a US company with a UK investor) reported in August that nearly 200 people have made reservations with deposits to fly two-hour suborbital missions on the company's SpaceShipTwo vehicles and that Virgin Galactic had received about $20 million in deposits, some of which represented full payment for the flight and some of which comprised deposits averaging $33,000. Design of SpaceShipTwo has been completed, and Virgin Galactic announced plans to conduct its operations from the new New Mexico spaceport, whose facilities will accommodate all aspects of Virgin Galactic's 3-day spaceflight experience. Virgin Galactic is investing between $200 million and $240 million in developing the new venture. First commercial flight is planned for 2009, preceded by flight testing.

Design details of SpaceShipTwo, unveiled on 28 September, showed a craft about three times as big as SpaceShipOne, fitted to carry two crewmembers and six passengers on cushioned reclining seats, with multiple viewing windows. It will be carried aloft by White Knight Two (see above).

On 6 April BAE Systems (USA) and Surrey Satellite Technology Ltd. (SSTL; UK) signed an agreement to cooperate on the development and marketing of small satellites. SSTL will develop the satellite buses and BAE Systems will provide the payloads. BAE Systems will be the prime contractor on work for the U.S. government, which will be the initial focus of the team, but subsequent marketing thrusts will include the UK. Surrey subsequently purchased electro-optical instrument manufacturer Sira Technology's space group (UK) on 11 April to strengthen SSTL's position as a mission prime contractor for space imaging systems. Sira built the imaging camera on the SSTL-built Beijing-1 microsatellite.

On 16 June Saab Group (Sweden) announced the purchase of Ericsson Microwave Systems, the 40% of Saab Erickson Space not previously owned by Saab, for $520 million. Saab Ericsson Space (Sweden) reported annual revenues of $95 million in 2005, with a then-current backlog of $101 million. 85% of the company's business is in satellite systems; it also builds payload-separation devices for European, Russian, and U.S. launch vehicles.

Hispasat (Spain) announced on 2 May that growth in the Latin American market generated by the Amazonas satellite launched in 2004 had sparked a 2005 revenue increase for the company of 18% and quadrupled its net profit for the year. The satellite delivers broadband service, primarily for rural education, in 10 Latin American nations,

including four new countries added in 2005: Colombia, Costa Rica, Guatemala, and Nicaragua.

In the first private-sector investment of its kind, Deimos Space SI (Spain) on 2 October purchased an Earth observation satellite from Surrey Satellite Technology Ltd. (SSTL, UK) as the first step in building a commercial Earth observation business, at an estimated investment of $38 million over the next five years. With no anchor tenant or commitments from either government or commercial entities to purchase data, Deimos expects to recoup its investment by joining the existing five-satellite Disaster Monitoring Constellation (DMC) managed by SSTL, giving Deimos access to the DMC data as well as those from its own satellite, planned for launch in 2008. Deimos-1 will have a ground resolution of 22 m and a swath width of 600 km.

Mitsubishi Electric Corporation (Melco) announced on 1 November 2005 that it is the first Japanese company to receive a domestic commercial satellite manufacturing contract, for Space Communications Corporation's Superbird-7. To be built on Melco's DS2000 bus, the 5-tonne spacecraft will carry 28 Ku-band transponders, and is to be launched to a geostationary-orbit slot at 144 degrees east longitude in the first quarter of 2008. Its service life is expected to exceed 15 years. All eighteen of Japan's current and past commercial communications satellites were built by U.S. suppliers.

On 30 June Space Systems/Loral (USA) announced that EchoStar (USA) had ordered the CMBStar satellite for mobile video service to hand-held devices that Chinese customers expect to use during the 2008 summer Olympics in Beijing. Because the deal does not involve the export of U.S.-built satellites or components to China (EchoStar will launch and operate CMBStar), the U.S. International Traffic in Arms Regulations (ITAR) constraints are not applicable. EchoStar has committed an initial $150 million in financing for the project, which China's State Administration of Radio, Film, and Television (SARFT), China's broadcast regulatory agency, wants to be operational in time for the 2008 Olympics. EchoStar hopes to attract a large portion of China's 300 million mobile-device users, who comprise the world's largest mobile communications market.

PART TWO

PROGRESS IN SPACE RESEARCH 2005-2006

I. SPACE STUDIES OF THE EARTH'S SURFACE, METEOROLOGY AND CLIMATE

This chapter provides an overview of the contributions and main scientific achievements related to the studies of the Earth's surface, meteorology and climate from space for the period covering 2005-2006. The current state of governmental policies towards global Earth observations is first summarized.

In 2005-2006, several satellites were launched for the study of terrestrial surfaces and/or clouds and atmospheric aerosols; some of these were mainly devoted to meteorological applications and to climate studies. The list of satellites launched into space is given in the third section of this chapter together with their characteristics and their primary application domains. A list of selected refereed scientific papers is then given to provide examples of the latest scientific findings for which remote sensing data from space proved to be crucial. Concluding remarks are given in the last section.

The Global Challenge Using Space Observations

Scientific studies on global change based on model simulations and on in situ and satellite measurements suggest that human activities are able to induce climatic and biological changes comparable to those caused by natural processes. These model simulation results are, however, still associated with large uncertainties due to several factors, including inadequate knowledge of small-scale phenomena like clouds and the virtual absence of relevant systematic observations at the global scale. Information on these and other processes are needed to improve the model simulations.

At the international level, the current space-borne Earth observing systems, including a series of space-borne platforms associated with a research and development component, support long-term global observations of the land surface, the atmosphere and oceans. Geophysical products derived from space remote sensing data are required to improve the understanding of the Earth as an integrated system. Advanced space-based observations help to make progress, because satellites best capture a global spatially and temporally consistent perspective.

The issue of global climate change was raised at the G-8 meeting in Scotland in July 2005, while the planning for the Global Earth Observation System of Systems (GEOSS) is encouraging. In this context, both the Integrated Global Observing Strategy (IGOS) theme reports and the published strategies for the Global Climate Observing System (GCOS) address the identified and quantified needs for global climate change parameters and related emerging issues. The re-focusing of the priorities of the United States National Polar-orbiting Operational Environmental Satellite System (NPOESS) programme resulted in the elimination of important climate sensors, creating a challenge

for GEOSS to sustain long-term observations for global climate studies and to minimize data gaps, which are two important principles of the GEOSS.

The exchange of satellite data and information products at minimal cost is a principle of the GEOSS. The number and diversity of existing products promotes the need to evaluate their reliability and accuracy as well as to provide ranges of uncertainty so that their further interpretation can be conducted with appropriate caution. The availability of given geophysical products from different sources and origins highlights the need for international research cooperation to generate jointly high level scientific information.

Earth Observation Policy

The Group on Earth Observations (GEO) was formally established at the Third Earth Observation Summit in February 2005 to carry out the GEOSS 10-Year Implementation Plan. The GEO Secretariat was established in Geneva in May 2005 and serves as the center of international coordination for the world-wide GEOSS effort. The GEO includes 65 member countries, the European Commission and 43 participating international organizations. It has been established on a voluntary and legally non-binding basis, with voluntary contributions to support its activities. GEO consists of a Plenary, an Executive Committee, a Secretariat, together with committees and working groups. GEO congregates in plenary session at least annually at the senior-officer level and, periodically, at the Ministerial level. GEO takes decisions by consensus of its Members. The GEO vision for GEOSS is to realize a future in which decisions and actions for the benefit of humankind are informed via coordinated, comprehensive and sustained Earth observations and information. GEOSS will build on and add value to existing Earth-observation systems by coordinating their efforts, addressing critical gaps, supporting their interoperability, sharing information, reaching a common understanding of user requirements, and improving the delivery of information to users. In 2006, GEO began the implementation of the GEOSS 10-Year Implementation Plan as endorsed by the Third Earth Observation Summit. GEO programme activities will cover nine societal benefit areas and five transverse areas that were identified in the 10-Year Plan.

The COSPAR Council, at its meeting in July 2006, called for COSPAR to become a participating organization in the GEO in order to contribute to the work of GEOSS as it strives to understand the integrated global Earth system.

Space Missions in 2005-2006

MTSAT

The Multi-Function Transport Satellite 1 (*MTSAT-1*), launched on 25 February 2005, is operational at 140° east and *MTSAT-2*, launched on *18* February 2006, is on station at 145° east. The *MTSAT-2* meteorological payload will be placed in stand-by mode until the end of the 5-year *MTSAT-1R* mission, around 2010. *MTSAT* is a dual mission satellite for the Japan Ministry of Land, Infrastructure and Transport and the

Japan Meteorological Agency performing an air traffic control and navigation function as well as a meteorological function. Mounted on its Earth-facing side are the Image Sensor, the S-band Receive and Transmit antennas and the Ultra High Frequencies (UHF) antenna for the meteorological mission and the Ku and Ka spot antennas for the aeronautical mission. Also mounted on this side is the Earth Sensor, which is used by the attitude control system that maintains the spacecraft's position in space using 12 small thrusters. Mounted on the West side L-band global antenna is the Telemetry, Tracking and Command omni-directional antenna.

Cartosat-1

Cartosat-1, launched on 5 May 2005, is a remote sensing satellite built by the Indian Space Research Organisation (ISRO), which is mainly intended for cartographic applications. *Cartosat-1* carries two state-of-the-art Panchromatic (PAN) cameras that take black and white stereoscopic pictures of the Earth in the visible region of the electromagnetic spectrum. The swath covered by these high resolution PAN cameras is 30 km and their spatial resolution is 2.5 m. The cameras are mounted on the satellite in such a way that near simultaneous imaging of the same area from two different angles is possible. This facilitates the generation of accurate three-dimensional maps.

NOAA-N

The US National Oceanic and Atmospheric Administration satellite, *NOAA-N*, was launched on 20 May 2005 to provide global data for NOAA's operational user requirements including short- and long-range weather forecasts. Observations include Earth radiation, sea and land surface temperatures, atmospheric vertical temperature, water vapour, and ozone profiles in the troposphere and stratosphere. The *NOAA-N* scientific instruments include: the Advanced Very High Resolution Radiometer (AVHRR), the High Resolution Infrared Radiation Sounder/4 (HIRS/4), the Advanced Microwave Sounding Units (AMSU-A1 and -A2), the Microwave Humidity Sounder (MHS), the Solar Backscatter Ultraviolet Radiometer (SBUV/2), and the Space Environment Monitor (SEM). *NOAA-N* is the first in a series of polar-orbiting satellites to be part of a joint cooperation with the European Organisation for the Exploitation of Meteorological Satellites (EUMETSAT).

Monitor-E

Monitor Experimental (*Monitor-E*) is a Russian Earth Observation (EO) mission of Roskosmos, the Russian Space Agency, and part of a small-class generic satellite series. Launched on 26 August 2005, this mission represents the first operational use of the newly-developed Yakhta platform intended for use in various remote sensing and space research applications. The *Monitor* programme includes the following future EO mission scenarios: (1) Monitor-I where the imager is provided with an observation capability in the infrared region; (2) Monitor-S: a mission with a panchromatic stereo imager; (3) Monitor-O: a mission with a high-resolution (1 m) imager for the operational

support of a commercial customer base; (4) Monitor-R: a mission featuring a Synthetic Aperture Radar (SAR) payload in X-band and/or L-band as well as featuring panchromatic imaging of the Earth's surface with an 8-m spatial resolution within a swath width of no less than 90 km, and multi-band imaging of the Earth's surface with a 20-to 40-m spatial resolution within a swath width of no less than 160 km.

CryoSat

Lost during its 8 October 2005 launch, *CryoSat* would have been Europe's first spacecraft dedicated to the study of ice. Its mission was to measure precisely variations in the thickness of polar ice sheets and floating sea ice. *CryoSat* would have flown in an unusually highly inclined polar orbit, just two degrees short of true north, to maximize its coverage of the poles. Its main payload was an instrument called the Synthetic Aperture Interferometric Radar Altimeter (SIRAL) which was the first sensor of its kind designed for ice. A *CryoSat* recovery plan has been presented to the European Space Agency Programme Board by ESA's Executive, which explained the status of ongoing activities and outlined the preparatory work leading to a *CryoSat-2* mission in March 2009. It will monitor the thickness of land ice and sea ice and help explain the connection between the melting of the polar ice and the rise in sea levels and how this is contributing to climate change.

TopSat

TopSat was launched on 25 October 2005 onboard a Kosmos launch vehicle from the Pletsesk Cosmodrome. *TopSat*'s primary mission is to demonstrate that a microsatellite can deliver responsive high-resolution Earth images delivered directly from the satellite to ground terminals within the same footprint. *TopSat* is a British microsatellite that provides low-cost 2.5-m resolution black and white images, and 5-m resolution colour images.

Beijing-1

Beijing-1 is part of the Disaster Monitoring Constellation and is operated by Tsinghua University for a Chinese company (Beijing Landview Mapping Information Technology Ltd). The microsatellite provides accommodation for two imagers: a 32-m multi-spectral imager and a new 4-m panchromatic imager. The satellite bus provides highly agile attitude control to provide accurate pointing and the knowledge necessary for the mapping requirements of the mission. The satellite was launched on 27 October 2005.

MSG-2

Meteosat Second Generation (*MSG*)-*2*, a cooperative programme between EUMETSAT and ESA, that was launched on 21 December 2005, serves the needs of 'nowcasting' applications and numerical weather prediction in addition to providing important data for climate monitoring and research. The meteorological sensor is the Spinning Enhanced Visible and Infrared Imager (SEVIRI), which provides full resolution

data in 12 bands of the visible and infrared spectrum every 15 minutes to facilitate a continuous display of the weather's evolution. For climate research, the satellite carries the Geostationary Earth Radiation Budget (GERB) experiment which measures the short wave and total radiation from the Earth about every 6 minutes. The satellite also carries the Meteorological Communications Payload (MCP) which consists of particularly sophisticated antennas and transponders to receive and transmit data.

ALOS

The *Advanced Land Observing Satellite* (*ALOS*), a component of the Japanese Earth observing satellite programme, follows the *Japanese Earth Resources Satellite* (*JERS-1*) and the *Advanced Earth Observing Satellite* (*ADEOS*) and enhances terrestrial observing technology. *ALOS* was launched on 24 January 2006 from the Tanegashima Space Center. The platform has three instruments: (1) the Panchromatic Remote-sensing Instrument for Stereo Mapping (PRISM) for digital elevation mapping is a panchromatic radiometer with 2.5-m spatial resolution having three optical systems for forward, nadir and backward view; (2) the Advanced Visible and Near Infrared Radiometer type 2 (AVNIR-2) is a visible and near-infrared radiometer for observing land and coastal zones that provides a spatial resolution of 10 m (nadir) with four spectral bands; (3) the Phased Array type L-band Synthetic Aperture Radar (PALSAR) which is an active microwave sensor that has a beam steerable in elevation and a Scanning Synthetic Aperture Radar (ScanSAR) mode.

Formosat-3/Cosmic

The Constellation Observing System for Meteorology, Ionosphere and Climate (COSMIC) programme is a collaborative enterprise between the Taiwan Province of China and the USA, that will use a constellation of six remote sensing micro-satellites, of which *Formosat-3* is one, to collect atmospheric data for weather prediction and for ionosphere, climate and gravity research. Data from the satellites are made available to the international scientific community in near real-time. *Formosat-3/Cosmic* was launched on 14 April 2006.

Calipso

The *Calipso* (*Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observation*) satellite was launched on 28 April 2006. *Calipso* is a joint US National Aeronautics and Space Administration (NASA) and French Centre National d'Etudes Spatiales (CNES) satellite mission designed to provide new informationon on the role that clouds and atmospheric aerosols play in the Earth's weather, climate, and air quality. *Calipso* consists of three co-aligned nadir-viewing instruments: (1) the Cloud-Aerosol Lidar with Orthogonal Polarization (CALIOP) is a 2-wavelength polarization-sensitive lidar that provides high-resolution vertical profiles of aerosols and clouds; (2) the Imaging Infrared Radiometer (IIR) is a nadir-viewing, non-scanning imager with a 64 km by 64 km swath and a pixel size of 1 km; (3) the Wide Field Camera (WFC) which is a fixed, nadir-viewing imager with a single spectral channel covering the 620-720 nm region, selected

to match band 1 of the MODerate resolution Imaging Spectro-radiometer (MODIS) instrument on *Aqua* (launched in May 2002).

CloudSat

The NASA/Canadian Space Agency (CSA) *CloudSat* was launched on 28 April 2006 at the same time as *Calipso* becoming part of the A-Train constellation. *CloudSat*'s primary goal is to furnish data needed to evaluate and improve the way clouds are parameterized in global models thereby contributing to better predictions of cloud development and thereby improving understanding of their role in influencing climate change through what is referred to as cloud-climate feedback. The Cloud Profiling Radar (CPR) is a 94 GHz nadir-looking radar which measures the power backscattered by clouds as a function of distance from the radar. The requirements on CPR are sensitivity defined by a minimum detectable reflectivity factor of -26 dBZ, along-track sampling of 2 km, a dynamic range of 70 dB, 500 m vertical resolution and calibration accuracy of 1.5 dB.

GOES-N

The Geostationary Operational Environmental Satellite (GOES) programme is a joint effort of NASA and NOAA. *GOES-N* was launched on 23 May 2006, with the launches of GOES-O and GOES-P scheduled for 2007 and 2008, respectively. This series has several new capabilities including the shift of the weather facsimile service from analogue to digital. The energetic particle sensors comprise the Energetic Proton, Electron and Alpha Detector (EPEAD) and the Magnetic Electron Detector (MagED) which measure the radiation environment at geosynchronous altitude. The magnetometer, mounted on the end of an 8.5-m boom, measures the magnitude and direction of the Earth's geomagnetic field. The three instruments mounted on the solar array yoke to gather data from the Sun are the Solar X-ray Imager (SXI), the X-ray Sensor (XRS), and the Extreme Ultraviolet Sensor (EUV). The UHF and S-/L-band antennas provide communications with ground networks for command, telemetry, data, as well as search and rescue.

Resurs-DK1

Resurs-DK-1 (High Resolution-1), Russia's first civil Earth observation imaging satellite capable of transmitting high-resolution imagery (1 m), was launched on 15 June 2006 from the Baikonur Cosmodrome, Kazakhstan. The satellite is designed for multi-spectral mapping of the Earth's surface in the visible and near-infrared bands. The Earth Surface Imager (ESI), which is an optoelectronic push-broom imaging instrument, takes high-resolution imagery of the Earth's surface for commercial and research applications. The instrument provides panchromatic and multi-spectral imagery in a total of four bands in the visible to near-infrared spectral range. A survey observation mode provides image scenes of up to 2100 km (along-track). Anticipated applications of ESI data include: sea surface status, ice situation, meteorological conditions in the Earth's polar regions,

information for the study of the Earth's natural resources, data on ecology and emergencies, as well as to support digital data exchange between ground users.

BelKA

Belarusian Cosmic Apparatus (*BelKA*) was planned to be the first satellite of Belarus. It was a remote sensing satellite which measured data at a maximum resolution of 2-2.5 metres. The spacecraft was launched on 26 July 2006, but crashed 86 seconds after launch.

Kompsat-2

The Korea Multi-Purpose Satellite (*Kompsat-2*), a Korea Earth Observation satellite, was launched on 28 July 2006. It is a very-high-resolution optical imaging satellite (1 m resolution in black and white, 4 m in colour) capable of acquiring up to 7500 images with a ground footprint of 15 km x 15 km every day – equivalent to 1.7 million km² a day. These features and imaging capacity make *Kompsat-2* a key asset for land mapping at scales of 1:5000 to 1:2000.

Orfeo-COSMO-SkyMed

The Optical and Radar Federated Earth Observation (Orfeo) enterprise comprises a network of Earth observation satellites: the Constellation of small Satellites for Mediterranean basin Observation (COSMO) to provide dedicated services to the communities around the Mediterranean Sea, although it will be fully capable of offering innovative services world-wide. The constellation comprises four satellites (SkyMed), funded by ASI (Agenzia Spaziale Italiana) and the Ministry of Defence of Italy, equipped with X-band multipolarimetric SARs providing high resolution imagery with a swath width of 520 km in real time through cloud and at night for monitoring environmental events such as wild fires, floods, oil spills and landslides, together with two French satellites, to replace the *Spot-5* Earth observation satellite, each being equipped with advanced electro-optical payloads to provide high resolution (70 cm) panchromatic imagery with a swath width of 20 km. The launch of the first spacecraft in the SkyMed constellation is planned for late 2006, with completion being expected in 2007.

MetOp

The Meteorological Operational satellite programme (MetOp), established by ESA and EUMETSAT and forming EUMETSAT's Polar System (EPS) programme, includes three satellites the first of which was launched on 19 October 2006 from Baikonur, Kazakhstan, on a Russian Soyuz 2/Fregat rocket. The instruments on *MetOp-A* include: an Infrared Atmospheric Sounding Interferometer (IASI) to derive humidity and atmospheric temperature profiles in the troposphere and lower stratosphere; a Global Navigation Satellite System Receiver for Atmospheric Sounding (GRAS) providing a minimum of 500 atmospheric profiles per day through a process of Global Positioning Satellite (GPS) radio occultation; an Advanced Scatterometer (ASCAT) that measures

wind speed and direction over the ocean; the Global Ozone Monitoring Experiment-2 (GOME-2), a spectrometer that collects light from the Sun to derive the atmospheric profiles of ozone, nitrogen dioxide, water vapour, oxygen, bromine oxide and other gases. The meteorological instruments also include AMSU-A1 and AMSU-A2, HIRS/4, AVHRR/3, MHS and SEM-2.

Selected Scientific Achievements

This section highlights a few scientific papers published in the peer-refereed scientific journals *Nature* and *Science* for 2005 and 2006. This list of abstracts of the highlighted papers overviews some scientific domains in which space-borne remote sensing data over the Earth has been utilized, but does not represent all domains of scientific applications.

J. I. Goes *et al*. 2005 'Warming of the Eurasian Landmass Is Making the Arabian Sea More Productive'. *Science,* 308, 5721, pp. 545-547: "The recent trend of declining winter and spring snow cover over Eurasia is causing a land-ocean thermal gradient that is particularly favorable to stronger southwest (summer) monsoon winds. Since 1997, sea surface winds have been strengthening over the western Arabian Sea. This escalation in the intensity of summer monsoon winds, accompanied by enhanced upwelling and an increase of more than 350% in average summertime phytoplankton biomass along the coast and over 300% offshore, raises the possibility that the current warming trend of the Eurasian landmass is making the Arabian Sea more productive."

B. A. Wielicki *et al*. 2005 'Changes in Earth's Albedo Measured by Satellite'. *Science,* 308, 5723, p. 825: "NASA global satellite data provide observations of Earth's albedo, i.e., the fraction of incident solar radiation that is reflected back to space. The satellite data show that the last four years are within natural variability and fail to confirm the 6% relative increase in albedo inferred from observations of earthshine from the moon. Longer global satellite records will be required to discern climate trends in Earth's albedo."

C. Frankenberg *et al*. 2005 'Assessing Methane Emissions from Global Space-Borne Observations'. *Science,* 308, 5724, pp. 1010-1014: "In the past two centuries, atmospheric methane has more than doubled and now constitutes 20% of the anthropogenic climate forcing by greenhouse gases. Yet its sources are not well quantified, introducing uncertainties in its global budget. We retrieved the global methane distribution by using space-borne near-infrared absorption spectroscopy. In addition to the expected latitudinal gradient, we detected large-scale patterns of anthropogenic and natural methane emissions. Furthermore, we observed unexpectedly high methane concentrations over tropical rainforests, revealing that emission inventories considerably underestimated methane sources in these regions during the time period of investigation (August through November 2003)."

A. Richter A. *et al.* 2005 'Increase in tropospheric nitrogen dioxide over China observed from space'. *Nature,* 437, pp. 129-132: "Observations of nitrogen dioxide, inverted from

the GOME-1 instrument, which flies aboard the ESA ERS-2 since 1995 and the SCIAMACHY instrument, which flies aboard the ESA ENVISAT since 2002, have shown unambiguously very significant increases over China, in disagreement with emissions inventories, and decreases over large parts of central Europe, in agreement with emission inventories. This manuscript demonstrates unambiguously the importance of the observation of atmospheric composition space for the assessment of the changing atmospheric pollution, which is driving and responding to global climate change."

C. A. Mears & F. J. Wentz 2005 'The Effect of Diurnal Correction on Satellite-Derived Lower Tropospheric Temperature'. *Science,* 309, 5740, pp. 1548-1551: "Satellite-based measurements of decadal-scale temperature change in the lower troposphere have indicated cooling relative to Earth's surface in the tropics. Such measurements need a diurnal correction to prevent drifts in the satellites' measurement time from causing spurious trends. We have derived a diurnal correction that, in the tropics, is of the opposite sign from that previously applied. When we use this correction in the calculation of lower tropospheric temperature from satellite microwave measurements, we find tropical warming consistent with that found at the surface and in our satellite-derived version of middle/upper tropospheric temperature."

B.J. Soden *et al*. 2005 'The Radiative Signature of Upper Tropospheric Moistening'. *Science,* 310**,** 5749, pp. 841-844: "Climate models predict that the concentration of water vapor in the upper troposphere could double by the end of the century as a result of increases in greenhouse gases. Such moistening plays a key role in amplifying the rate at which the climate warms in response to anthropogenic activities, but has been difficult to detect because of deficiencies in conventional observing systems. We use satellite measurements to highlight a distinct radiative signature of upper tropospheric moistening over the period 1982 to 2004. The observed moistening is accurately captured by climate model simulations and lends further credence to model projections of future global warming."

O. M. Johannessen *et al.* 2005 'Recent Ice-Sheet Growth in the Interior of Greenland'. *Science*, 310, 5750, pp. 1013-1016: "A continuous dataset of Greenland Ice Sheet altimeter height from European Remote Sensing satellites (ERS-1 and ERS-2), 1992 to 2003, has been analyzed. An increase of 6.4 ± 0.2 centimeters per year (cm/year) is found in the vast interior areas above 1500 meters, in contrast to previous reports of high-elevation balance. Below 1500 meters, the elevation-change rate is –2.0 ± 0.9 cm/year, in qualitative agreement with reported thinning in the ice-sheet margins. Averaged over the study area, the increase is 5.4 ± 0.2 cm/year, or ~60 cm over 11 years, or ~54 cm when corrected for isostatic uplift. Winter elevation changes are shown to be linked to the North Atlantic Oscillation."

J. L. Chen *et al*. 2006 'Satellite Gravity Measurements Confirm Accelerated Melting of Greenland Ice Sheet'. *Science* (in *Science* Express Reports, August 2006): "Using time-variable gravity measurements from the Gravity Recovery and Climate Experiment (GRACE) satellite mission, we estimate ice mass changes over Greenland during the period April 2002 to November 2005. After correcting for effects of spatial filtering and

limited resolution of GRACE data, estimated total ice melting rate over Greenland is -239 ± 23 cubic kilometers per year, mostly from East Greenland. This estimate agrees remarkably well with a recent assessment of -224 ± 41 cubic kilometers per year, based on satellite radar interferometry data. GRACE estimates in southeast Greenland suggest accelerated melting since the summer of 2004, consistent with the latest remote sensing measurements."

Concluding Remarks

Several instruments and satellites launched during 2005 and 2006 have joined a large constellation of low-Earth orbiting and geostationary satellites for studies of the integrated global Earth system. Space studies of the Earth's surface, meteorology and climate are progressing through the availability of data and geophysical products and by the collaboration between various scientific communities. The past and current satellite missions have increased understanding of the integrated global Earth system, but have also increased the recognition of the severe limitations of our knowledge to project future evolution of many important phenomena that influence society. Nevertheless, these limitations promote the design of new space sensors, such that science applications can benefit from improved data and products as well as enhanced scientific expertise. At the present time, various space missions for Earth observation are being considered; the process to confirm new space missions is becoming longer, which could produce data gaps and increase the challenges inherent in sustaining long-term Earth system data records. Complementary techniques in space observations are required for improving the understanding of the Earth as a global integrated system, where science questions related to the atmosphere, ocean and terrestrial surface components are jointly considered. In general, the aim is for improving instrumentation to be launched quickly enough, enabling the continuity of key datasets for this emerging science, which is of key significance for sustainable development. The GEO represents an exciting new forum to sustain key data records with minimal data gaps and effective calibration and validation of satellite data products.

II. SPACE STUDIES OF THE EARTH-MOON SYSTEM, PLANETS AND SMALL BODIES OF THE SOLAR SYSTEM

Lunar Exploration

SMART-1, the first ESA Small Mission for Advanced Research in Technology, was launched on 27 September 2003. As its name implies, it is principally a technology mission, in this case aimed at demonstrating electric propulsion in deep space. After a 14-month cruise, *SMART-1*'s lunar capture took place on 15 November 2004, followed by a spiralling down to a lunar orbit with a 450 km perilune and 3000 km apolune, reached on 15 March 2005. This was followed by a nominal 5-month science operations phase, with a re-boost using electric propulsion (2 August to 17 September), allowing an extension until August 2006. The spacecraft carried a small scientific payload (AMIE – Advanced

Moon micro-Imaging Experiment, D-CIXS – Demonstration of Compact X-ray Spectrometer, SIR – SMART-1 Infrared spectrometer, SPEDE/EPDP – Spacecraft Potential Electron and Dust Experiment/Electric Propulsion Diagnostic Package, KATE/RSIS - Ka-band Telemetry and telecommand Experiment/Radio Science for SMART-1 experiment) in order to study surface composition, the formation and evolution of the Moon, and to survey resources for future exploration. *SMART-1* lunar science investigations included studies of the chemical composition of the Moon, of geophysical processes (volcanism, tectonics, cratering, erosion, deposition of ices and volatiles) for comparative planetology, and high resolution studies in preparation for future steps of lunar exploration. The mission addressed several topics such as the accretional processes that led to the formation of rocky planets, and the origin and evolution of the Earth-Moon system. The *SMART-1* mission ended with a controlled impact in the lunar Lake of Excellence on 3 September 2006. A world-wide observing campaign was organized to study the impact and debris in real time.

The integration of the data from the *SMART-1*, *Lunar Prospector* and *Clementine* missions into a global database is continuing. The joint interpretation of these data together with the analyses of lunar samples has provided new views on the composition and evolution of the Moon. The comparison of element abundance from *SMART-1* and previous orbiters and surface sample missions, has given new information on lunar mare, highlands and impact basins, such as the giant South Pole-Aitken basin.

The Chinese mission Chang'E1 is due for launch in spring 2007 carrying a payload including: a CCD stereo camera, an imaging interferometer, laser altimeter, gamma/X-ray spectrometer, microwave radiometer, solar high-energy particle detector and low-energy ion detector. Subsequent developments in the Chang'E programme include lunar rovers (Chang' E2) and sample return missions (Chang' E3).

The Japanese (JAXA) orbiter mission SELENE (Selenological and Engineering Explorer) is to be launched in mid 2007 by an H-IIA rocket. It carries a comprehensive set of instruments for multi-spectral remote sensing of the lunar surface (X-ray and gamma-ray spectrometers, multi-band imager and spectral profiler, terrain camera, radar sounder), for gravity studies (VLBI and data relay), and for lunar environment studies (magnetometer/plasma imager, charged-particle spectrometer and plasma analyser, radio science). In the framework of the Japanese lunar exploration programme, the SELENE-B mission (with a lander element and a demonstration of technologies for future lunar exploration) is under discussion.

The Indian ISRO mission Chandrayaan-1 is due for launch using a Polar Satellite Launch Vehicle in early 2008 with the objectives of studying lunar origin and evolution, producing a 3-D atlas and carrying out chemical mapping. Its core payload includes: a terrain mapping stereo camera, the hyperspectral wedge filter, laser ranging, a low energy X-ray/C1XS X-ray spectrometer, a solar X-ray monitor, a high energy X-ray sensor, a descent system 'ranger module'. The payload includes international instruments, from ESA (SIR2, CIXS, SARA) and from the US (Moon mineralogy mapper, radar).

Lunar-A, an ISAS Japanese lunar penetrator mission, is being considered for launch using an M-V vehicle after 2009. It would deploy two scientifically-equipped penetrators at widely separated sites (one on the near side, the other one on the far side of the Moon) to provide insights into the deep internal structure of the Moon (using seismometers and heat flow probes). It will also carry a monochromatic camera for topographic mapping.

A proposal for a sample return mission from the South Pole Aitken Basin, recommended as part of the US Decadal plan, has been studied within NASA's New Frontiers programme.

A new mission, the Lunar Reconnaissance Orbiter (LRO), is being developed by NASA for launch at the end 2008 for survey measurements of the lunar surface as preparation for future exploration. From a 50 km orbit, it would study the Moon's surface environment, produce high resolution maps and a geodetic grid, and survey lunar resources. Its instruments include a camera, a laser altimeter, a Lyman-alpha mapper, a neutron detector, a surface temperature mapper, and a lunar radiation environment sensor. A current proposal is for the LRO to be launched together with the Lunar Crater Observation and Sensing Satellite (LCROSS) that will target the southern polar Shackleton Crater. Utilizing an impact, this mission is aimed at studying the lunar regolith and characterizing potential polar ice deposits.

Several agencies have performed studies of lunar lander missions in the context of preparations for future human exploration. The International Lunar Exploration Working Group (ILWEG) has coordinated a forum for the exchange of information between the agencies. After the COSPAR Scientific Assembly and the 8th ILEWG conference in Beijing in July 2006, a 'Beijing Lunar Declaration' with 13 recommendations was unanimously endorsed.

Mercury and Venus Exploration

On 3 August 2004, NASA launched the *Messenger* mission, a Mercury orbiter, as a part of its Discovery programme. A significant part of its instrumentation is dedicated to geological studies of this, the innermost terrestrial, planet. *Messenger* is to be inserted into orbit in 2009, after multiple gravity assists, to undertake global mapping of Mercury, to characterize the planet's exosphere and to study its magnetosphere.

ESA and JAXA have completed the scientific payload selection for the BepiColombo mission to Mercury. BepiColombo will contribute to our understanding of the evolution and dynamics of Mercury and its magnetospheric processes. The mission consists of a Mercury Planetary Orbiter (for high resolution multi-wavelength geophysical and geochemical observations, and gravimetry/fundamental physics studies), and a Mercury Magnetospheric Orbiter (dedicated to a study of particles and fields). The latter will be provided by JAXA to ESA for integration and launch on a Soyuz-Fregat launcher in August 2013. With the innovative combination of electric propulsion and gravity assists, the planned cruise duration is about six years.

ESA's *Venus Express,* launched on 9 November 2005, is a mission to investigate the Venusian atmosphere and surface. The probe has re-utilized hardware developed for the *Mars Express* spacecraft. Instruments developed for other ESA planetary missions have been adapted in order to have a faster and cheaper payload development. The *Venus Express* payload comprises a combination of spectrometers, spectro-imagers and imagers covering a wavelength range from the UV to the thermal infrared, a plasma analyser and a magnetometer. This set of instruments provides a wealth of detail on the atmosphere, plasma environment and surface of Venus. The investigation aims to enhance our knowledge of the composition, circulation and evolution of the atmosphere of Venus. The surface properties of Venus and the interaction between the atmosphere and the surface is being examined and evidence of volcanic activity is being sought. The spacecraft entered Venusian orbit on 11 April 2006.

Japan has also recently approved a mission to Venus, concentrating on plasma and atmospheric studies.

Mars Exploration

NASA's *Mars Global Surveyor*, which has been in orbit since September 1997, continued to operate well and to provide impressive images of the surface of Mars. Clear evidence has been found for a 'sapping' origin of many channels, probably from melting of subsurface ice, suggesting the possible existence of liquid water in the recent past of Mars. *Mars Global Surveyor* has fulfilled all of its science objectives and continues to evolve with the Mars Exploration Programme. Principal goals for the orbiter's latest mission extension include continued weather monitoring to form a continuous set of observations with NASA's *Mars Reconnaissance Orbiter*; imaging of possible landing sites for the Phoenix 2007 Mars Scout lander and the 2009 Mars Science Laboratory rover; continued mapping and analysis of key sedimentary-rock-outcrop sites as well as continued monitoring of changes on the surface due to wind and ice. The orbiter's current mission extension was planned to end in September 2006.

NASA's *Mars Odyssey*, mainly devoted to the mapping of chemical elements and minerals on the Martian surface, was launched on 7 April 2001, and arrived in the vicinity of the planet on 24 October 2001. After a manoeuvre into a 25-hour capture orbit, aerobraking was used to achieve a low Mars orbit. The orbiter carries three science instruments (THEMIS – Thermal Emission Imaging System, GRS – Gamma-Ray Spectrometer, and MARIE – Mars Radiation Environment Experiment). THEMIS maps the mineralogy and morphology of the Martian surface using a high-resolution camera and a thermal infrared imaging spectrometer. The GRS, a rebuild of the instrument lost with the *Mars Observer* mission, achieves global mapping of the elemental composition of the surface and determines the abundance of hydrogen in the shallow subsurface. Evidence has been found for the widespread distribution of water ice, buried to a depth of at least 1 m and mixed with rocky material. MARIE characterizes aspects of the near-space radiation environment as related to the radiation-related risk to human explorers. Five years after leaving Florida for Mars, the *Mars Odyssey* spacecraft is still orbiting the

red planet, in its extended mission phase, collecting scientific data and relaying communications from NASA's two Mars rovers to Earth. During its primary science mission which continued through to August 2004, *Mars Odyssey* has made global observations of the Martian climate, geology and mineralogy. The spacecraft's Gamma Ray Spectrometer has led to the preparation of maps of the elemental distribution of hydrogen, silicon, iron, potassium, thorium, and chlorine on the Martian surface. A global map of minerals associated with water, essential to life – as we know it, guided NASA in its selection of Meridiani Planum as the landing site for NASA's Opportunity rover, an area rich in haematite. Odyssey is currently supporting landing site selection for the Phoenix Scout Mission, to be launched in 2007, using data showing that the surface areas near the poles of Mars consist of more than 50% water ice by volume. Other Odyssey accomplishments include the measurement of radiation, a prerequisite for future human exploration because of its potential health effects, and a ground-breaking programme in education outreach that has allowed students to take pictures of Mars and conduct scientific investigations with cameras on Odyssey.

The ESA *Mars Express* mission, launched on 2 June 2003, arrived at Mars on 25 December 2003. *Mars Express* consists of an orbiter with eight experiments. These are a High Resolution Stereo Camera (HRSC), an IR mineralogical mapping spectrometer - Observatoire pour la Mineralogie, l'Eau, la Glace et l'Activité (OMEGA), an atmospheric occultation spectrometer (SPICAM UV and IR), the Planetary Fourier spectrometer (PFS), Analyser of Space Plasma and Energetic Atoms (ASPERA), the Mars Radio Science experiment (MaRS), the Mars Advanced Radar for Subsurface and Ionosphere Sounding (MARSIS), and a lander. The lander, *Beagle 2*, was planned to be a valuable complement to the main mission with in situ analysis of the Martian subsurface chemistry relevant to exobiology, using a suite of cameras, spectrometers, and gas and environment analysis sensors. The *Beagle-2* lander, after a nominal separation from the *Mars Express* orbiter and nominal injection, entered the Martian atmosphere on 25 December. However, no contact could be established with the lander after that point.

Following commissioning of the *Mars Express* spacecraft at Mars in January 2004, most experiments on board began their calibration and testing phase while already acquiring scientific data. This phase lasted until June 2004 when all the commissioned instruments started their routine operations. The MARSIS radar antenna deployment was postponed for technical reasons until May 2005, and it became operational in July 2005. ESA's *Mars Express* mission was extended by one Martian year, or about 23 months, from the beginning of December 2005.

Since the start of science operations in early 2004, the *Mars Express* orbiter delivered new science results related to the water ice in polar caps, the presence of sulphates, the evidence for recent volcanic and glacial activity, methane detection in the atmosphere and signatures of atmospheric escape. *Mars Express* has started mapping water in its various states. In building up a global dataset on the composition and characteristics of the surface and atmosphere, *Mars Express* has revealed that volcanic and glacial processes are much more recent than expected. It has confirmed the presence of glacial processes in the equatorial regions, and mapped water and carbon dioxide ice,

either mixed or distinct, in the polar regions. Through mineralogical analysis, it found out that large bodies of water, such as lakes or seas, might not have existed for a long period of time on the Martian surface.

Mars Express may possibly have detected methane in the Martian atmosphere. This, together with the possible detection of formaldehyde, suggests either current volcanic activity on Mars or, more excitingly, that there are current active 'biological' processes. This hypothesis may be reinforced by the fact that *Mars Express* saw that the distribution of water vapour and methane, both ingredients for life, substantially overlap in some regions of the planet. Furthermore, the mission detected aurorae for the first time on the Red Planet. The probe has made global mapping of the density and pressure of the atmosphere between 10 and 100 km altitude, and provided data for studies of atmospheric escape processes in the upper layers of the atmosphere. This is contributing to our understanding of the weather and climate evolution of the planet.

There is still much to be discovered by the set of instruments on board *Mars Express*. First, the 23-month extension will enable the *Mars Express* radar, MARSIS, to restart Martian night-time measurements. MARSIS will continue its subsurface sensing mainly in the search for liquid and frozen water. By combining subsurface, surface and atmospheric data, *Mars Express* should provide an unprecedented detailed global picture of Mars and, in particular, its water. So far, the High Resolution Stereo Camera has imaged only 19% of the Martian surface at high resolution. In the extended phase, it will be able to continue the 3-D high-resolution colour imaging. Thanks to the extension, *Mars Express* will also be able to obtain data for a study over a second year of the way the atmosphere varies during different seasons, and to observe again variable phenomena such as frost, fog or ice. Finally, *Mars Express* will be able to revisit those areas where major discoveries, such as new volcanic structures, sedimentary layering, methane sources, nightglow and auroras, have been made, thus contributing to the confirmation and understanding of all aspects related to these discoveries.

Further to providing an impressive wealth of scientific results on its own, *Mars Express* has also successfully co-operated with NASA's Mars Exploration Rovers, in terms of coordinated scientific observations and to test *Mars Express* in relaying the rover data to Earth. Further scientific collaboration between *Mars Express, Mars Odyssey* and both rovers is expected, as well as with NASA's *Mars Reconnaissance Orbiter* mission during the extended mission.

Two identical lander missions (Mars Exploration Rovers) were launched by NASA on 10 June and 7 July 2003, respectively arriving on 4 and 25 January 2004. Pathfinder-derived airbag technology was used for landing the rover vehicles Spirit and Opportunity on to the Martian surface. The rovers are considerably larger and more sophisticated than the Sojourner/Pathfinder rover, and include multiple camera systems as well as a variety of experiments for compositional investigations in an integrated science payload. The primary science instruments carried by the rovers include:

- Panoramic Camera (Pancam) for determining the mineralogy, texture and structure of the local terrain;
- Miniature Thermal Emission Spectrometer (Mini-TES) for identifying promising rocks and soils for closer examination and for determining the processes that formed Martian rocks. The instrument will also look skyward to provide temperature profiles of the Martian atmosphere;
- Mössbauer Spectrometer (MB) for close-up investigations of the mineralogy of iron-bearing rocks and soils;
- Alpha Particle X-Ray Spectrometer (APXS) for close-up analysis of the abundances of elements that make up the rocks and soils;
- Magnets to collect magnetic dust particles. The Mössbauer Spectrometer and the Alpha Particle X-ray Spectrometer will analyse the particles collected and help determine the ratio of magnetic particles to non-magnetic particles. These instruments will also analyse the composition of magnetic minerals in airborne dust and rocks that have been ground by the Rock Abrasion Tool;
- Microscopic Imager (MI) to obtain close-up, high-resolution images of rocks and soils;
- Rock Abrasion Tool (RAT) for removing dusty and weathered rock surfaces and exposing fresh material for examination by instruments onboard.

The findings from the Mars Exploration rovers have been largely reported in the refereed literature (*Science* special issues) and in the media. Major results to date include evidence for evaporate minerals in exposed rock layers, and other signs strongly suggesting the presence of standing bodies of water on Mars when the rocks formed. The project has been extended due to the rovers' survival through the depth of the Martian winter and may, ultimately, last for a year or more. Two and a half years after landing, both rovers are still working and have far exceeded their initial 90-day warranties on Mars.

Since leaving their landing sites, the twin rovers, Spirit and Opportunity, have sent to Earth more than 100,000 spectacular, high-resolution, full-colour images of Martian terrain as well as detailed microscopic images of rocks and soil surfaces. Four different spectrometers have amassed unparalleled information about the chemical and mineralogical makeup of Martian rocks and soil. Special rock abrasion tools, never before sent to another planet, have made it possible to examine the interiors of the dusty and weathered surfaces of Martian rocks.

Opportunity rover observations have revealed evidence for past inter-dune playa lakes that evaporated to form sulphate-rich sands. The sands have been reworked by water and wind, solidified into rock and soaked by groundwater. During the current extended mission, the Opportunity rover is now examining more sedimentary bedrock exposures where an even broader, deeper section of layered rock appears to be exposed, possibly revealing new aspects of Martian geological history.

While Spirit's initial journeys revealed a more basaltic setting, the rover found a variety of rocks indicating that early Mars was characterized by impacts, explosive volcanism and subsurface water. Unusual looking bright patches of soil turned out to be extremely salty and affected by past water. Spirit also discovered finely-layered rocks that are as geologically compelling as those found by Opportunity and which may hold clues to a history of past water.

NASA's *Mars Reconnaissance Orbiter*, launched in August 2005, arrived at Mars on 10 March 2006. It will characterize the surface, subsurface and atmosphere of Mars, and will identify potential landing sites for future missions. The *Mars Reconnaissance Orbiter* carries six science instruments, three engineering instruments that will assist spacecraft navigation and communications, and two more science-facility experiments. The science package includes:

- High Resolution Imaging Science Experiment (HiRISE) able to reveal small-scale objects in the debris blankets of mysterious gullies and details of geological structure of canyons, craters and layered deposits.
- Context Camera (CTX) to provide wide-area views to help present a context for high-resolution analysis of key spots on Mars provided by HiRISE and CRISM.
- Mars Colour Imager (MARCI) for monitoring clouds and dust storms.
- Compact Reconnaissance Imaging Spectrometer for Mars (CRISM) for identifying minerals, especially those likely to be formed in the presence of water.
- Mars Climate Sounder (MCS) to detect vertical variations of temperature, dust, and water vapour concentrations in the Martian atmosphere.
- Shallow Radar (SHARAD) for probing beneath the Martian surface to see if water ice is present at depths greater than one metre.

The *Mars Reconnaissance Orbiter* carries the most powerful camera ever flown on a planetary exploration mission for homing in on details of Martian terrain with extraordinary clarity. This capability will not only provide an astoundingly detailed view of the geology and structure of Mars, but will help identify obstacles that could jeopardize the safety of future landers and rovers. The *Mars Reconnaissance Orbiter* also carries a sounder to find subsurface water, an important consideration in selecting scientifically worth-while landing sites for future exploration.

Other science instruments on this multi-tasking, multipurpose spacecraft will identify surface minerals and study how dust and water are transported in the Martian atmosphere. A second camera will generate medium-resolution images to provide a broader geological and meteorological context for more detailed observations from higher-resolution instruments.

The *Mars Reconnaissance Orbiter* will also serve as the first installment of an 'interplanetary Internet', a crucial service for future spacecraft. As the first link in a communications bridge back to Earth, several international spacecraft are expected to use the *Mars Reconnaissance Orbiter* in coming years.

The *Phoenix* mission is the first to be chosen for NASA's Scout programme, an initiative for smaller, innovative, lower-cost spacecraft complementing earlier missions in the Mars exploration programme. *Phoenix* will be launched in August 2007. It will use a lander that was intended for use by 2001's Mars Surveyor lander prior to its cancellation. It also will carry a complex suite of instruments that are improved variations of those that flew on the lost *Mars Polar Lander*. Phoenix will land on the icy northern pole of Mars between 65º and 75º north latitude. During the course of the 150 Martian day mission, *Phoenix* will deploy its robotic arm and dig trenches up to half a metre (1.6 ft) into the layers of water ice. These layers, thought to be affected by seasonal climate changes, could contain organic compounds that are necessary for life. To analyse the soil samples collected by the robotic arm, Phoenix will carry an 'oven' and a 'portable laboratory'. Selected samples will be heated to release volatiles that can then be examined for their chemical composition and other characteristics.

The *Mars Science Laboratory* is NASA's next rover mission being planned for travel to Mars before the end of the decade (planned for launch in the fall of 2009). Twice as long and three times as heavy as the Mars Exploration Rovers Spirit and Opportunity, the *Mars Science Laboratory* would collect Martian soil samples and rock cores and analyse them for organic compounds and environmental conditions that could have supported microbial life now or in the past. The mission is expected to have a truly international flavour, with a neutron-based hydrogen detector for locating water, provided by the Russian Federal Space Agency, a meteorological package provided by the Spanish Ministry of Education and Science, and a spectrometer provided by the Canadian Space Agency.

ExoMars (for possible launch in 2011) is the first of ESA's *Aurora* flagship missions to be assessed. Its aim is to characterize further the biological environment on Mars in preparation for robotic missions and then human exploration. Data from the mission will also provide invaluable input for broader studies of exobiology – the search for life on other planets. This mission calls for the development of a Mars orbiter, a descent module and a Mars rover.

Dwarf Planets and Small Solar System Bodies Exploration

Kuiper Belt objects and dwarf planets Pluto and Eris

In August 2006, the International Astronomical Union (IAU) officially defined the concept of a planet, changing the designation of Pluto to a new class of objects called dwarf planets and including Ceres in this category. Joining this group is Eris, discovered in 2003 and thought to be larger than Pluto at about twice its distance from the Sun. It is expected that many more dwarf planets will be discovered in the trans-Neptunian region of our Solar System within the next decade. Currently, we know of more than 1100 smaller trans-Neptunian objects and this number is rapidly growing. During this reporting period, two small moons of Pluto were discovered (named Nix and Hydra), making a total of known satellites to three, and a moon has been discovered orbiting Eris (named Dysnomia). Other large bodies recently found in this region and ranging in size between

Pluto and Ceres are 2005 FY_9 (nicknamed 'Easterbunny'), 2003 EL_{61} (nicknamed 'Santa'), Orcus (a plutino), and Sedna (a distinctly red planetoid). Whether these objects qualify as dwarf planets is not yet clear. The total mass of the Kuiper Belt is now estimated to be less than one-tenth the Earth's mass, but that is still quite uncertain.

New Horizons, NASA's New Frontiers mission to the Pluto system (and then to one or more Kuiper Belt objects), was successfully launched in January 2006. Speeding past the Moon only nine hours after launch, the spacecraft is one of the fastest ever and is on track to fly by Jupiter in early 2007 for a gravity assist and for scientific studies. It is expected to arrive at Pluto in 2015. Seven scientific instruments onboard the spacecraft include imaging spectrometers (ultraviolet to infrared spectral ranges), energetic particle spectrometers (to study solar wind interactions), a radiometer for radio science investigations, and a dust counter operated by students. *New Horizons*' primary goals are to characterize the geology, morphology and chemical compositions of the surfaces of Pluto and Charon, and to characterize Pluto's neutral atmosphere with, in addition, many lower priority objectives including a search for additional satellites and rings.

Asteroids and dwarf planet Ceres

The JAXA *Hayabusa* ('peregrine falcon', formerly MUSES-C) mission was launched in May 2003 to investigate a near-Earth asteroid and to return a sample of its surface to Earth. Using solar electric propulsion, *Hayabusa* arrived at the asteroid 25143 Itokawa in September 2005 and observed it at an altitude of between 20 km and 3 km throughout November 2005. Many new results using its four science instruments (imagers, X-ray and near infrared spectrometers) were obtained pertaining to the asteroid's shape, its geographical features, surface altitude variation, albedo, spectrum, mineral composition, gravity, and its main chemical composition. A miniature rover (Minerva) failed to reach the asteroid, but the spacecraft successfully landed on the surface and collected samples. After some technical difficulties with the spacecraft, these samples are planned to be returned to Earth in June 2010.

The *Dawn* mission continues to be developed in the NASA's Discovery series. It is designed to orbit and study two of the most interesting large bodies in the main asteroid belt, Vesta which seems to be highly evolved, and Ceres, the newly designated dwarf planet, which may be water-rich in the form of ices and/or hydrated minerals. The payload, comprising two cameras, a visual and infrared mapping spectrometer, and a gamma-ray and neutron spectrometer, has been fully integrated on the spacecraft and *Dawn* is now ready to be launched in June 2007. It will use solar electric propulsion to rendezvous with Vesta and Ceres. By observing both with the same set of instruments, *Dawn* will be able to specify the properties of each asteroid and probe conditions that existed in the early solar system.

Comets

After travelling nearly 3 billion miles during its seven-year round-trip odyssey to comet 81P/Wild 2, NASA's *Stardust* sample return mission returned safely to Earth. The

capsule, carrying cometary and interstellar particles, became an artificial meteor on 15 January 2006 and successfully touched down in the desert salt flats of Utah. Two days later, the sample return capsule's science canister and its cargo of comet and interstellar dust particles were transferred to the Johnson Space Center (Clear Lake, Texas, USA) where it was opened for scientific investigation and curation. The *Stardust* project has delivered to the international science community material that has been unaltered since the formation of our solar system, and it should help provide answers to fundamental questions about comets and the origins of the solar system. Samples from comet 81P/Wild 2 have produced surprises in showing a remarkable range of minerals, with some of these particles containing minerals that form only at extremely high temperatures that could not have existed where the comets formed, indicating that the formation of at least some comets may have included materials ejected by the early Sun to the far reaches of the solar system. Many of the comet particles are built like loose dirt-clods composed both of 'large strong rocks' as well as very fine powdery materials. The public has been invited to join in the search for tiny particles of interstellar dust at the interactive, internet-based website, http://stardustathome.ssl.berkeley.edu/, where the aerogel collector can be examined. During its flyby, *Stardust* returned high-resolution images of the nucleus of comet 81P/Wild 2, expanding our knowledge of these small solid bodies that are the source of cometary activity. In the mean time, the *Stardust* spacecraft was placed into hibernation mode for possible use in an extended mission to another target.

The current renaissance in cometary science continues with NASA's Discovery-class *Deep Impact* mission. Its goal is to study the pristine material of a cometary nucleus by excavating an artificial crater to release subsurface materials. The probe was launched on 12 January 2005, and delivered a 370 kg copper projectile travelling at a velocity of 10.2 km s^{-1} into the nucleus of comet 9P/Tempel 1 on 4 July 2005. This spectacular event resulted in the formation of a crater and of ejecta that were observed by an extensive network of ground-based and Earth-orbiting telescopes as well as from the *Deep Impac*t spacecraft and ESA's *Rosetta* spacecraft (see below). The results seem to indicate that the cratering process was gravity-dominated, supporting the notion that the comet nucleus consists of porous, pristine, unprocessed material of very low tensile strength. Spectra taken shortly after impact revealed emission lines of water, HCN, carbon monoxide and dioxide, and several organics in the hot volatile-rich vapour plume. The amount of dust released that was greater than expected, consisted of very fine particles and contained crystalline and amorphous (glassy) silicates, amorphous carbon, carbonates, and clay minerals (phyllosilicates). Images of the nucleus of comet 9P/Tempel 1 revealed a rugged surface with relatively flat areas, scarps and circular features thought to be impact craters. Small patches of water ice were detected for the first time on the surface of a comet. Analysis and interpretation of the results of this mission are ongoing.

The *Rosetta* mission, an ESA Cornerstone project to rendezvous with comet 67P/Churyumov-Gerasimenko in 2014, was launched on 2 March 2004 using an Ariane-5 from Kourou (French Guiana). The *Rosetta* project consists of an orbiter with eleven experiments and a lander with nine further experiments. The spacecraft and instruments have undergone initial testing and evaluation successfully. One of the major objectives of the orbiter is to study the development of cometary activity and the processes in the

surface layer of the nucleus as the solar distance of the nucleus decreases. The near-nucleus phase will start at a heliocentric distance of about 3.25 AU and continue until perihelion passage at about 1 AU. To gain enough orbital energy to reach the cometary target, gravity assists (accompanied by science studies) with Mars and Earth were executed successfully in late 2005, with one additional Earth assist scheduled for November 2007. The orbiter will deploy the lander after the first year of operation. It will focus on making elemental and molecular determinations. In addition, the properties of the near surface will be studied and the coarse internal structure will be revealed. During its cruise to the comet, *Rosetta* will fly past two asteroids, 2867 Steins and 21 Lutetia. Various onboard instruments have already acquired scientific data on the Earth and many comets. In particular, *Rosetta* participated in the observation campaign that accompanied the *Deep Impact* event on 4 July 2005, obtaining many useful data.

Space-based Observatories and Small Bodies Research

The JAXA *Akari* ('Light', formerly ASTRO-F) mission to produce a second-generation survey of the entire infrared sky was launched on 22 February 2006. Compared to its predecessor - *IRAS*, *Akari* excels at better sensitivity and spatial resolution as well as wider spectral coverage ranging from 1.7 to 180 μm. *Akari* has a 68.5 cm IR telescope cooled to 6 K. After achieving a Sun-synchronous polar orbit of about 700 km, it returned the first images in April 2006. A portion of its observing time will be devoted to Solar System studies, including small bodies.

The *Hubble Space Telescope* is continuing to participate actively in research on small bodies. In the last two years, HST was used to image Ceres – possibly finding impact features on its surface, the Kuiper Belt object Sedna, and the dwarf planet Eris with its moon Dysnomia. Extraordinary views were also provided of the fragments of the comet 73P/Schwassmann-Wachmann 3 and of the effect of the collision between the projectile released by the *Deep Impact* spacecraft and comet 9P/Tempel 1.

The *Spitzer* Space Telescope joined observers around the world in the *Deep Impact* campaign, observing the cloud of material that was ejected when the impactor struck the surface of 9P/Tempel 1 on 4 July 2005 with its infrared spectrograph.

Through various automated, ground-based observational programmes, asteroids are being discovered at a rate of about 5,000 per month. A total exceeding 342,000 are registered as minor planets at the time of this report, more than 136,000 of these having well-determined orbits and having been given permanent official numbers: some 13,350 even bear official names. Roughly 1,000 Near-Earth Asteroids with orbits close to Earth's orbit are currently known.

Outer Solar System Space Probes

Jupiter

NASA has selected a Jupiter mission, named *Juno*, as the second of its New Frontiers missions (the first being the *New Horizons* mission now on its way to Pluto and the Kuiper Belt). *Juno* is an orbital mission, scheduled for launch in about 2010. The mission will utilize a highly elliptical, near-polar orbit to permit very low altitude observations while minimizing exposure to Jupter's radiation belts. The primary objectives of *Juno* are to determine the internal structure of the giant planet through detailed study of the magnetic and gravity fields with unprecedented precision, and determine the abundance of water, and therefore of oxygen, deep in the Jovian atmosphere, a key measurement not accomplished by the *Galileo* atmospheric probe, which descended in a dry portion of the atmosphere where water was highly depleted.

Saturn

The *Cassini-Huygens* mission, a joint programme between NASA and ESA, was launched in October 1997. It was designed to provide an intensive investigation of the Saturn system including Titan, the chemical environment of which may resemble that of the primordial Earth and thus provide valuable clues as to the chemistry of the early Earth. The *Cassini* spacecraft with the *Huygens* probe attached went into orbit around Saturn on 1 July 2004. A major goal of the mission was achieved when ESA's Huygens probe successfully completed its mission, becoming the first spacecraft to land on Titan. The only anomaly in the technical performance of the probe was the loss of one of the two redundant radio channels to the orbiter due to a commanding error. One of the main science experiments on the lost channel was the Doppler-Wind radio experiment, but fortunately the objectives of this experiment were achieved using an experimental direct-to-Earth tracking channel and an extensive international effort by radio astronomers to detect and measure the probe's radio signal from Earth-based radio telescopes.

During its approximately three-hour descent through Titan's cold, thick nitrogen atmosphere, the *Huygens* probe sent back data on the composition and structure of the moon's atmosphere and took panoramic images of its dimly lit surface. Images taken below about 12 km altitude show the surface of Titan in unprecedented detail, including hills over a hundred metres in height, with channel and valley networks apparently carved by flowing liquid, probably liquid methane. *Huygens* landed on a solid, icy pebble-strewn plain, possibly the outflow deposits from the channels seen in the nearby hills. Although no liquid was detected on the surface in the vicinity of the landing site, data from the Mass Spectrometer experiment on board showed a sharp increase in methane gas following the landing and heating of the surface by the probe, indicating that the soils may contain liquid methane below the surface. Another major discovery from the chemical analysis of the atmosphere was the lack of primordial noble gases (^{36}Ar, Kr and Xe), a finding that strongly suggests that the origin of Titan's nitrogen atmosphere is the break down of ammonia rather than delivery of nitrogen trapped in very cold icy planetesimals during Titan's formation.

The *Cassini* orbiter also made extensive studies of Titan, performing close flybys, typically within a few thousand kilometres. As of October 2006, 19 targeted flybys had been successfully achieved. The orbiter carries out remote visual, infrared and radar observations of the atmosphere and surface, and can also perform *in situ* analyses of Titan's atmosphere during close encounters. Synthethic aperture radar (SAR) images of Titan's surface have revealed a geologically young surface, with only a few large impact craters detected. In addition to channel systems similar to those seen in the *Huygens* descent images, the radar has also mapped extensive dune fields in the equatorial regions, likely to be composed of solid hydrocarbon particles. Observations near Titan's north pole show extensive dark lake-like features, interpreted as liquid methane/ethane lakes which may be part of a seasonal exchange of methane from the south to the north poles, as well as supplying methane to the atmosphere to create the rainstorms recorded in the erosion channels seen by *Huygens*.

In addition to observing Titan, the *Cassini* orbiter is making extensive measurements of Saturn's ring system, of the smaller icy satellites, and of Saturn's magnetic and plasma environment. One of the major discoveries of the mission to date has been the detection of huge geyser-like eruptions from cracks in the south polar region of tiny Enceladus, an icy moon close to Saturn and only ~500 km in diameter. These plumes are composed primarily of water vapour and tiny ice particles and appear to be responsible for creating the huge, extended E-ring around Saturn. The source of the heat to produce these eruptions is still unknown, probably a combination of radioactive heating from the rocky portion of the satellite and tidal heating. The preliminary interpretation of the data on the plumes suggests strongly that there may be liquid water at shallow depths beneath at least the south polar region on Enceladus, and simple hydrocarbons have been detected on the surface and in the plume gas. Enceladus is thus of major interest to the astrobiologist, as yet another planetary environment (along with Mars, Jupiter's moon Europa, and Titan) where the basic requirements for terrestrial life (water, organic material and energy) may have been or are currently present.

Cassini's nominal mission ends in 2008, but NASA is studying plans to extend the mission until at least 2010 or 2011 as long as the spacecraft systems remain healthy.

Other Studies, including Remote Space Studies of Exo-Planets

The solar system observations with the NASA-ESA *Hubble Space Telescope* (*HST*) have continued to be very productive with, for example, the observation that several Kuiper Belt objects are actually binary systems, most likely borne as a result of mutual encounters and collisions. The ESA-NASA *Solar and Heliospheric Observatory* (*SOHO*) has almost completed an 11-year solar cycle of observations during which it has discovered more than 1000 comets. The *Odin* sub-millimetre satellite, led by Sweden and involving Canada, Finland and France, was launched in February 2001, and is contributing to the study of water vapour in weakly active comets. The current generation of X-ray space telescopes like *Chandra* have continued to provide important information for the study of solar wind-comet interaction and the X-ray spectroscopy of cometary

comas. Key measurements of the auroral X-ray emissions of Jupiter and of Saturn have also been made by *Chandra* and *XMM-Newton*. The *XMM* observations showed that the Jovian aurora is likely to be produced by the precipitation of captured solar wind ions.

Ground-based activities (observations, laboratory measurements, modelling studies) of major interest for the preparation of future space missions are being performed in various parts of the world. A new trend has appeared with the development of 'laboratory' experiments under microgravity conditions on-board rockets, spacecraft and the *International Space Station* (e.g. the International Microgravity Plasma Facility and the facility for Interactions in Cosmic and Atmospheric Particle Systems), to study dusty plasmas, dust aggregation, planetesimal formation and the light scattering properties of dust particles.

Several Earth-orbiting satellites are expected to provide results on exo-planets and exo-planetary systems. The NASA SIRTF (Space Infra-Red Telescope Facility) now called the *Spitzer* space telescope, was launched in August 2003, and will facilitate the study of Kuiper-belt dust out to 50-100 AU around nearby stars. The French-European *Corot* mission, scheduled for launch in 2006, will search for signatures of the transits of telluric-type and giant planets in front of 30 000 stars, observed continuously over 150 days. The NASA *Kepler* Discovery class mission, to be launched in 2007, consists of a space telescope that will use photometric transit measurements, also to search for Earth-like planets. The NASA *SIM* (Space Interferometer Mission) is planned for launch in 2008. With a 5-year operational lifetime, it should complete the census of nearby stellar systems, using ultra-high precision, micro-arcsec interferometry to detect several Earth-mass planets around nearby stars, and larger planets around more distant stars. Finally, the ESA Cornerstone *Gaia* astrometric observatory mission, to be launched before 2012, is expected to detect the astrometric signatures of tens of thousands of Jupiter-type planets around stars in our galactic neighbourhood. In addition, it should provide a large, uniform census of minor planet kinematics, Near-Earth objects, trojans, trans-Neptunians, and give information on galactic perturbations to the Oort cloud.

III. SPACE STUDIES OF THE UPPER ATMOSPHERES OF THE EARTH AND PLANETS, INCLUDING REFERENCE ATMOSPHERES

1. The Earth's Middle Atmosphere and Lower Ionosphere

The Earth's middle atmosphere and lower ionosphere is an active and diverse region that couples the lower terrestrial atmosphere with the near Earth space environment. This region of the atmosphere is driven by waves and tides propagating upward from the lower atmosphere, and can be significantly perturbed by solar particle and radiative inputs from above. These external forcing mechanisms are of similar magnitude and importance in driving the global structure of the middle atmosphere and lower ionosphere.

The mesopause is the coldest place in the terrestrial environment and the turbopause, where the atmosphere makes the transition from well mixed to diffusive equilibrium, is located in this region. While dynamics play a major role in forcing the summer mesopause out of radiative equilibrium, chemistry also plays a significant role in this region. The constant ablation of meteors creates metallic layers.

The scientific community is working to understand the processes present in the middle atmosphere and lower ionosphere, along with their impact on the region and their coupling to other regions above and below. Topics relevant to understanding the region have grown out of recent symposia, including meetings sponsored by COSPAR. These areas include: understanding the processes that couple the lower atmosphere to the middle atmosphere and then into the lower ionosphere; the global distribution of waves from small-scale gravity waves to large-scale planetary waves and their influence on the system; coordinated ground- and space-based observations; meteoric input and its influence on the region; understanding the impact of geomagnetic storms on the region; understanding the processes that control the polar regions; layered phenomena such as noctilucent clouds; climatic impact of changes in trace constituents and solar input; impact of cosmic forcing; and the global electric circuit.

Recent Progress on Selected Scientific Topics

Selected results from topically relevant areas are presented below, though there are many other themes that researchers exercise in this field.

Small-Scale Waves. Small-scale gravity waves play a critical role in the transport of heat and momentum throughout the middle atmosphere. Accurately parameterizing gravity waves in global circulation models continues to be a key problem. Recent results in gravity wave studies include the construction of a climatology of gravity wave activity above Davis in Antarctica, using 10 years of medium frequency (MF) radar data. This climatology was compared to those from Syowa (Antarctica) and from northern hemisphere sites at similar latitudes. Seasonal variations in the Arctic differ from those in the Antarctic and a hemispheric asymmetry in wave drag is thought to be the cause.

In a French and Australian collaborative project, gravity-wave parameters are being extracted from the long-duration balloon-borne measurements (VORCORE - Vortex-Core - experiment campaign) of winds in the Antarctic stratosphere. During September and October 2005, 25 super-pressure balloons were launched from McMurdo base in Antarctica. Planning for future campaigns and the development of the next generation of experimental payloads is currently under way.

Planetary-Scale Waves. The dynamics of the middle atmosphere near the time of the major southern hemispheric stratospheric warming of 2002 have been described using Antarctic radar. It was found that the zonal winds were weaker and reversed prior to the stratospheric warming in the mesosphere when compared to the stratosphere. The temperature field at the height of the hydroxyl layer during the time of the warming was also shown to be anomalously warm. Observations from the SABER (Sounding of the

Atmosphere Using Broadband Emission Radiometry) instrument on the *Thermosphere-Ionosphere-Mesosphere Energetics and Dynamics* (*TIMED*) satellite have shown the evolution of eastward and westward propagating planetary waves, with periods longer than 10-days prior to this major stratospheric warming.

Tidal studies continue in the Arctic and Antarctic with a keen interest in the recently discovered non-migrating semi-diurnal tide with zonal wavenumber 1 in the Antarctic. Studies using observations from the network of Antarctic radars have identified a combination of zonal wavenumber 1 and 2 components and climatalogical studies have also identified a possible zonal wavenumber 0 component. The low- and mid-latitude structure of the non-migrating diurnal and semi-diurnal tides throughout the mesosphere has recently been determined from *TIMED* Doppler Interferometer (TIDI) measurements. These new data from TIDI complement previous results from the High Resolution Doppler Interferometer (HRDI) instrument on the *Upper Atmosphere Research Satellite* (*UARS*) spacecraft which only provided results at 95 km.

Non-linear interaction between planetary waves and atmospheric tides continue to attract significant attention as such mechanisms play a role in the redistribution of energy throughout the Mesosphere and Lower Thermosphere Region (MLT). Recent modelling results have shown a causal effect between the amplitude of the diurnal tide and the quasi-two-day wave. Analysis has also indicated a correlation between the amplitude of the semi-diurnal tide in the Arctic mesosphere and the amplitude of the stationary planetary wave 1 in the opposite hemisphere stratosphere.

Propagation of planetary waves into the ionosphere and their effect on the quiet-time ionospheric structure is an area of growing interest. Studies from ground-based and satellite observations continue to show a causal relationship between large-scale planetary wave structure in the mesosphere and the ionosphere. The physical mechanisms responsible for producing these interactions are still unknown.

Polar Mesosphere Echoes and Polar Mesospheric Clouds. Polar mesospheric echoes, both summer and winter, in addition to polar mesospheric clouds continue to be an area of vigorous research. These phenomena, typically observed by radar and lidar at polar latitudes during summer may be connected to global change; the focus of NASA's forthcoming Aeronomy of Ice in the Mesosphere (*AIM*) mission revolves around these phenomena.

Observations of polar summer mesospheric echoes (PMSE) were made using the Davis Antarctica 55 MHz MST radar and were compared to the thermal and dynamical environment, while links to cosmic noise absorption have also been explored. Properties of the Polar Mesospheric Clouds (PMCs) have been derived from observations made with the upgraded Davis lidar. The mean centroid altitude of the clouds is about 1 km higher than for similar latitudes in the Arctic and is consistent with previous results. During the 2005/06 austral summer, the first southern hemisphere common-volume observations of PMCs and PMSE were obtained.

Simultaneous measurements of PMC and iron (Fe) density by the Fe Boltzmann lidar at the South Pole shows a depletion of iron atoms by the PMC ice particles. Combined with laboratory measurements of the iron uptake rate on the ice surface and a middle atmosphere chemistry model, the iron depletion is well explained by the uptake of iron on the surface of PMC ice particles. Further lidar observations have shown that the potassium (K) and sodium (Na) atoms can also be trapped on the ice particle surface.

Lidar-temperature measurements at Kühlungsborn in Germany have recently yielded the first common volume and simultaneous temperature measurements in the presence of noctilucent clouds (NLCs) and mesospheric summer echoes (MSE), proving that temperatures are in all cases low enough for mesospheric ice particles to exist. This strengthens the hypothesis that mesospheric summer echoes are closely linked to ice particles in the mesopause region.

NLC observations at the Atmospheric Lidar Observatory for Middle Atmsophere Research (ALOMAR) have been extended, so that a continuous dataset covering nine years of observations is now available. Among many other things, this time series is now being studied for the potential signatures of solar activity effects on the properties of NLC.

The Fe Boltzmann lidar observations at Rothera in Antarctica have show that the engine exhaust (98% containing water) from the *Columbia* Space Shuttle launched in January 2003 could be transported to Antarctica and form polar mesospheric clouds and high altitude sporadic-Fe layers. This calls into the question the role of human space activities in the PMC enhancement observed in the last four decades.

Very high frequency (VHF) radar measurements of polar mesosphere winter echoes have been performed over a 4-year period between 2001 and 2005 and the statistics of their appearance and dependence on ionospheric parameters has now been established.

Polar Stratospheric Clouds and Aerosols. Lidar and ozonesonde data have been used to investigate the role of planetary and gravity waves in the climatology and microphysics of the Polar Stratospheric Clouds (PSCs). Lidar measurements are being used to develop an improved PSC detection method using infrared satellite imagery. The dust cloud from the disintegration of a large meteor was observed by the Davis Antarctica Lidar in September 2004; this provided a tracer for examining circulation of the polar vortex in the stratosphere.

Meteors. Very High Frequency (VHF) radar observations of meteor trails between 30 and 55 MHz are being used to measure winds, temperatures and meteor characteristics in the MLT region. Temperature estimates, using a pressure model have been calculated, and are found to agree with independent measurements better than when a temperature gradient model is used. Work continues to extend the capabilities of VHF meteor radar measurements that are currently deployed around the world. Many of the

new radars that have come on line recently in the Arctic, Antarctic and South America are such flexible meteor radar systems.

Meteor radar measurements have been analysed at high, mid and low latitudes to establish the diurnal and seasonal variation of meteor rates as a function of latitude. These results indicate that the high-latitude meteor radars in both the northern and southern hemispheres see a similar structure in the annual flux rates.

The high power large aperture radars at Arecibo, ALTAIR (Advanced Research Project Agency (ARPA) Long Range Tracking and Identification Radar), Jicamarca, the Japanese MU radar, and Sondrestrom have been used to study the mass flux, orbital distribution and entry velocity of meteoric particles into the Earth's atmosphere. These particles are the source of metal layers in the lower thermosphere, are important to the chemistry of the region and have been accepted as the condensation nuclei required for the formation of NLCs. Recent studies have helped to start mapping the geographical, diurnal and seasonal variability of meteoric mass input into the upper atmosphere. In addition, these very high resolution measurements are providing insight into the study of field-aligned plasma instabilities surrounding the non-specular meteor trail echoes.

Long-term trends. The 9+ year duration of the Davis Antarctica hydroxyl temperature dataset has facilitated investigations of the influence of solar variability on the structure of the Antarctic middle atmosphere. Analysis is also being conducted using the long duration temperature measurements from the South Pole and Eureka (Canada) to extract solar cycle and secular trends. The long duration MF measurements at Scott Base Antarctica and Birdling Flats New Zealand have also been analysed and show the presence of a secular and solar trend in the wind fields. Mesosphere and lower thermosphere datasets are now reaching a sufficient temporal length to conduct statistically significant solar cycle influence studies.

Solar and Geomagnetic Effects. Large variability in the wind pattern at lower thermospheric altitudes has been investigated with a focus on wind variations caused by geomagnetic forcing. Data have been collected and analysed during a number of storm events from 1998 to 2006, which was led by the Incoherent Scatter Radar (ISR) community with an emphasis on storm studies in the alert-based Lower Thermosphere Coordinated Study (LTCS) campaigns. The results show that during major geomagnetic storms, the tidal pattern of neutral winds in the lower thermosphere at middle latitude is significantly disrupted and dominated by the ion-driven convection. At middle latitudes, the influences of storm effects are seen at altitudes as low as 100 km.

Recent 30-day ISR World Month campaigns (September 2005, March-April 2006) have provided a large dataset, which is being used to characterize quantitatively variability in the dynamics of the lower thermosphere. A large difference was found between the average September 2005 winds and the average fall equinox winds measured during earlier campaigns. Both the zonal and meridional components have higher tidal amplitudes in the September campaign, while the mean winds show a significant altitude gradient in both zonal and meridional components. Large variations in the dominant tidal

modes are observed from day to day, with the semi-diurnal tide disappearing on several occasions.

Global Electric Circuit. Upgraded atmospheric circuit instrumentation has been developed and used to replace existing instrumentation at Vostok base in Antarctica. Previous Vostok data have shown the inter-annual variation of the seasonal-diurnal vertical electric field and is consistent with variations in global thunderstorm activity. Links to cosmic rays, geomagnetic activity and heliocentric current sheet crossings have also been explored.

Advances in Ground-based Observing Systems

The list of new ground-based radar and optical instrumentation continues to grow with a particular focus on the polar regions. There has also been an increase in the deployment of optical and radar instruments in the southern hemisphere, primarily within South America. This effort is largely driven by the dearth of prior observations in this region and a need to conduct broader regional and global studies of the middle atmosphere and of the lower ionosphere to discern the processes relevant to the region. However, a dearth of measurements from Southern Africa in particular continues to make global studies of the southern hemisphere difficult.

The Advanced Modular Incoherent Scatter Radar (AMISR), a major radar infrastructure project sponsored by the US National Science Foundation, is currently being installed and tested in Poker Flat, Alaska. AMISR is a modular, mobile radar facility that will be used around the world to conduct studies of the upper atmosphere and to observe space weather events. Observations from this new instrument are expected to have a significant impact on the mesosphere and lower-thermosphere community.

The global network of meteor and MF radar systems, making measurements in the mesosphere and lower thermosphere (MLT), continue to operate and share data with the community for scientific collaboration. Intercomparisons between measurement techniques are continuing in an effort to understand more clearly the strengths and limitations of each technique. Major efforts have also been put into the calibration of different VHF radars for the study of PMSE in order to allow proper comparison of properties of these echoes at different locations, including PMSE in the southern hemisphere. A new MF-radar was installed in Juliusruhr (Liebniz Institute of Atmospheric Physics), which will be used mainly for turbulence studies in the upper mesosphere-lower thermosphere region.

The recent availability of high speed, greater than 50 MHz data acquisition systems has spurred the development of direct digital receivers throughout the atmospheric radar community. Many of the large radar installations, in addition to some of the smaller research groups in the community, are currently developing software to take advantage of this new technology. It is expected that these new digital receivers will enable new experimental modes for all of the radar systems in the near future.

Advances in lidar technology are progressing at a rapid pace and some recent achievements include:

The Colorado State University sodium (Na) wind and temperature lidar has been developed into a narrow-band resonance Doppler lidar with full diurnal coverage for both temperature and wind measurements in the MLT. Recently, the lidar was upgraded to enable three-beam (north, east and west) operation for both wind and momentum flux studies. Continuous observations by the CSU Na lidar during periods of up to 10 days (max.) have led to an advancement in understanding of atmospheric tides and planetary waves at middle latitudes.

The University of Illinois Na wind and temperature lidar has been integrated with large aperture (over 3.5 m in diameter) telescopes through a Coude optical path at the Starfire Optical Range in Albuquerque, New Mexico and at the Maui Space Surveillance Complex in Maui, Hawaii. High-resolution (90 s) measurements of temperature and winds have been achieved. These data have enabled a sophisticated study to be made of MLT thermal structure and dynamics including instabilities, momentum, heat and Na constituent fluxes.

The University of Illinois iron (Fe) Boltzmann temperature lidar has been developed into a mobile solid-state resonance lidar for full diurnal measurements of temperature, polar mesospheric clouds, Fe density and polar stratospheric clouds. Pole-to-pole measurements, extending from the North Pole to the South Pole have been achieved by this mobile lidar. Significant new scientific findings relate to studies of polar mesospheric clouds, polar middle atmosphere thermal structure, polar mesospheric Fe layers, heterogeneous chemistry in the mesopause region, and gravity wave activity.

The Arecibo Observatory potassium (K) Doppler lidar is now making high quality measurements of the night-time mesopause temperature, and has generated the first climatology of the MLT thermal structure in the tropics. It is now being upgraded to a day-time measurement capability for full diurnal coverage at this important tropical location.

The IAP (Kühlungsborn Germany) potassium (K) Doppler lidar has been developed into a mobile solid-state resonance Doppler lidar. This system has made full diurnal-cycle measurements of temperature and PMC at Svalbard in the Arctic and at Kühlungsborn.

There have been major advances in Rayleigh lidar capabilities from the IAP Rayleigh-Mie-Raman lidar at ALOMAR in Andoya, Norway, the SRI Rayleigh lidar at Sondrestrom, Greenland, and the Australian Antarctic Division Rayleigh lidar at Davis Station in Antarctica. The Sondrestrom Rayleigh lidar makes measurements within a 16 hour period centred around local midnight. It is now being upgraded to have a Raman channel for lower atmosphere temperature measurements. The ALOMAR Rayleigh lidar is capable of full diurnal measurements of PMC and temperature, and also has made

sophisticated measurements of PMC particle sizes. The Davis Rayleigh lidar is making temperature and PMC measurements in Antarctica.

Another significant achievement in new techniques for the middle and upper atmosphere is the development of the solid-state Na wind and temperature lidar. One was the Weber Na wind and temperature lidar at ALOMAR. This utilizes the sum frequency generation to obtain a CW 589 nm light by mixing frequencies of two solid-state CW Nd:YAG lasers, and then amplifies the laser output by means of a pulsed dye amplifier. Another was the Japanese Shishu University full-solid-state Na temperature-measuring Lidar, generated by mixing the frequencies of two pulsed Nd:YAG lasers. The Japanese Na lidar made measurements of MLT temperatures in three austral winters at the Syowa Station in Antarctica.

The lidar systems (that is, a combination of a Rayleigh-Mie-Raman lidar and a resonance-lidar) at Kühlungsborn have been upgraded and now provide continuous temperature measurements from the ground to maximum altitudes of ~100 km. This enables studies of the evolution of gravity waves, from their excitation level in the troposphere up to altitudes of the lower thermosphere. The work with these lidar systems includes the development of a new fully daylight-capable Fe-resonance lidar.

Rocket Systems, Results and Campaigns

In October 2004, IAP launched the prototype of a new detector for the measurement of very small (typical radii ~1-5 nm) meteoric smoke particles. The instrument detected such particles at altitudes above ~80 km, thereby confirming the suitability of the design of the instrument for launch in three upcoming rocket campaigns in the framework of the Norwegian-German ECOMA (Existence and Charge state Of Meteoric Dust Particles in the Middle Atmosphere) project. In January 2005, a sounding rocket campaign was dedicated to the study of the so-called polar mesosphere winter echoes (PMWE). These are strong radar echoes in the mesosphere which occur predominantly during times of enhanced lower D-region ionization, e.g. during times of solar proton events. Both meteorological rockets, equipped with falling spheres and instrumented mini-rockets with positive ion probes, were launched and provided strong evidence that the simultaneously observed PMWE were caused by strong mesospheric turbulence.

The MaCWAVE (Mountain and Convective Waves Ascending Vertically) coordinated rocket, ground-based and satellite measurement programme was designed to study gravity wave dynamics and forcing of the mesosphere and lower thermosphere (MLT) during typical summer and winter conditions. The summer MaCWAVE programme was performed at the Andøya rocket range (ARR, 69.3^{o} N) in northern Norway in July 2002. The winter programme was performed at ESRANGE (67.9^{o} N) in northern Sweden in January 2003. Neither programme, however, occurred under typical solstice conditions. Instead, each programme revealed considerably greater variability in gravity wave, and in larger-scale dynamics and their influences, than had been seen previously at these latitudes. Indeed, the MaCWAVE programme appears to have

obtained the only suite of comprehensive measurements throughout the lower and middle atmosphere at polar latitudes during stratospheric warmings, or during their large-scale precursors.

Summer measurements were performed together with the Middle Atmosphere Dynamics And Structure (MIDAS) programme, designed by German and Norwegian colleagues. Together, the unique MaCWAVE/MIDAS dataset includes measurements employing the ALOMAR MF, MST and meteor radars, ALOMAR RMR and Na lidars, and radiosonde, MET rocket falling spheres, and Terrier-Orion soundings of winds, temperatures, neutral and electron densities, as well as plasma measurements extending from the surface into the thermosphere. Winter measurements employed the ground-based instrumentation at ALOMAR noted above, as well as a Rayleigh lidar, meteor radar, and the all-sky camera at ESRANGE, additional radiosondes, falling spheres, and Terrier-Orion payloads launched from ESRANGE. Several of the fallings spheres, during both summer and winter campaigns, were launched to coordinate as much as possible with SABER temperature measurements during overpasses of the *TIMED* satellite.

From 29 June to 7 July 2003, the ROMA/SVALRAK campaign (Rocket-borne Observations in the Middle Atmosphere) took place at the Svalrak rocket range at Ny-Ålesund, Spitzbergen (79°N, 11°E) as a combined effort of the Leibniz Institute of Atmospheric Physics, Germany, and the Norwegian Defense Research Establishment, Norway. The main scientific aim of this campaign was to study polar mesosphere summer echoes (PMSE) and mesospheric turbulence. During the campaign, three instrumented sounding rockets were launched successfully. In addition, ground-based observations with a VHF radar and a potassium lidar at Longyearbyen complemented the *in situ* measurements. All three sounding rockets were equipped with the Combined sensor for Neutrals and Electrons (CONE) instrument to measure the small-scale structure of neutral air and electron density, and neutral temperature. The Positive Ion Probe (PIP) instrument was used to measure small-scale structure of the positive ion density. Furthermore, two cold plasma probes (CPP) were used to measure electron temperature, and a particle detector was employed to detect signatures of charged aerosols. During the first launch, an electric field experiment was also incorporated; during the other two launches, Faraday rotation experiments yielded absolute electron number densities. During all three rocket flights, a PMSE was observed by the VHF radar, whereas the potassium lidar detected a noctilucent cloud (NLC) during the second launch. Signatures of the charged particles forming the PMSE and NLC layers were recorded by the onboard particle detectors. In addition, the measurement of electron temperature and positive ion density fluctuations gave clear evidence of plasma instabilities in the altitude range between 90 and 105 km altitude during the third rocket flight. A detailed analysis of this comprehensive dataset is currently being made, expected to yield unprecedented insight into a variety of mesospheric, thermospheric and ionospheric processes.

Satellite Systems

TIMED

The Thermosphere-Ionosphere-Mesosphere Energetics and Dynamics (*TIMED*) satellite is a current NASA mission that was launched in December 2001 and which has been approved for an extended mission through 2008. The primary *TIMED* mission was to study the energy balance (solar heating, IR cooling, transport) and basic state (density, composition, temperature, wind) of the Earth's atmosphere between 60 and 180 km. With five years of data now available starting near solar maximum, the extended mission goals of *TIMED* have been expanded to include the atmospheric and ionospheric changes from solar maximum to solar minimum.

The four *TIMED* instruments are the Global Ultraviolet Imager (GUVI), the Sounding of the Atmosphere using Broad-band Emission Radiometry (SABER), the TIMED Doppler Interferometer (TIDI), and the Solar EUV Experiment (SEE). While the SEE instrument measures the solar EUV irradiance in the spectral range from 0.1 to 195 nm (with 7 nm resolution at wavelengths less than 27 nm and 0.4 nm resolution for wavelengths longer than 27 nm), the other three *TIMED* instruments measure the atmospheric response to solar input. SABER provides vertical profiles of kinetic temperature and density from the lower stratosphere to the lower thermosphere in addition to ozone, water vapour and volume emission data (NO, OH and O_2). TIDI provides pole-to-pole continuous measurements of the horizontal wind field in the mesosphere and lower thermosphere while the GUVI measures ionospheric parameters including total electron content and the O/N_2 ratio. The first few years of the mission were intensely focused on developing and validating the measurements. Currently the SABER temperatures, now at version 6, include non-LTE (non-local thermodynamics effect) corrections and show better agreement in the mesopause regions with high latitude ground-based optical measurements around summer solstice when the temperatures are at a minimum. The TIDI team has made significant strides in modifying their inversion algorithms to account for crosstalk from the four telescopes and a complex background. With refined data products available, the middle atmosphere and lower ionosphere community is using the *TIMED* data for detailed scientific analysis. This is evidenced by the recent special issue of the *Journal of Geophysical Research* with its focus on the *TIMED* mission.

ODIN

Odin is a joint Swedish-Canadian-French-Finnish satellite which was launched in February 2001 into a Sun-synchronous (97.8^o inclination) orbit with an ascending node at 1800 hours. The Optical Spectrograph and InfraRed Imaging System (OSIRIS) instrument onboard *ODIN* comprises an optical spectrograph designed to measure the spectrum of sunlight scattered by the limb in the spectral range from 280 nm to 800 nm at an approximate resolution of 1 nm and can measure from 10 to 100 km. This is combined with a three-channel infrared (IR) imager that is designed to measure both scattered sunlight and airglow emissions at 1.27 μm and 1.58 μm. There are numerous goals of

OSIRIS: to elucidate the geographical extent of ozone depletion in the 'ozone hole' region and the mechanisms responsible for it; to study dilution effects and possible heterogeneous chemistry due to sulphate aerosols, even outside the polar regions; to investigate the relative role of odd hydrogen chemistry, and the effects of ordered and turbulent transport and corpuscular radiation. It will also establish the variability of mesospheric water vapour, including an assessment of the required fluxes for aerosol formation in the polar mesosphere, i.e. polar mesospheric clouds. Moreover, it will study some of the mechanisms that provide coupling between the upper and lower atmosphere, e.g. downward transport of aurorally-enhanced NO with its effects on ozone photochemistry and the vertical exchange of minor species such as odd oxygen, CO and H_2O.

AIM

*The Aeronomy of Ice in the Mesosphere (*AIM) mission is currently being developed by NASA. The overall goal of *AIM* is to discover why Polar Mesospheric Clouds (PMCs) form and why they vary. By measuring PMCs and the thermal, chemical and dynamical environment in which they form, *AIM* will quantify the connection between these clouds and the meteorology of the polar mesosphere. This will be accomplished by a complement of three instruments mounted on a spacecraft that will be a follow-on to the NASA Solar Radiation and Cloud Experiment (SORCE), placed into a 600 km, Sun-synchronous orbit. The Cloud Imaging and Particle Sizes (CIPS) instrument will use backscattered solar radiation at 265 nm to provide panoramic ultraviolet images showing the effects of gravity wave activity and PMC particle properties with a horizontal resolution of ~ 2 km x 2 km. The Solar Occultation for Ice Experiment (SOFIE) will use infrared solar occultation measurements to provide 2 km vertical resolution profiles of temperature, H_2O, CH_4, O_3, CO_2, NO, aerosols and particle size distribution from the stratosphere to ~120 km altitude in the case of temperature. The Cosmic Dust Experiment (CDE), mounted on the zenith side of the spacecraft will provide a measurement of the daily cosmic dust flux input to the atmosphere by measuring depolarization signals created by dust impact on polyvinyldifluoride (PVDF) films. An important objective of *AIM* is to establish the basis for the study of long-term changes in mesospheric climate and their relationship to global change by providing a comprehensive observation baseline and a thorough validation of predictive models that can be used to assess future changes. *AIM* was confirmed for flight in April 2004. The mission is currently in Phase C/D development and on track for a March 2007 launch, with a Pegasus XL rocket from Vandenberg Air Force Base, California.

Modelling and Modelling Activities

The suite of models, used by the middle atmosphere and lower ionosphere community, include complex global circulation models that span the column from the Earth's surface up into the thermosphere, in addition to linear and non-linear mechanistic models and specialized phenomenological models. Some of the models and their recent results are given below.

TIME-GCM

The NCAR thermosphere-ionosphere-mesosphere-electrodynamics general circulation model (TIME-GCM) has been used recently to study the dynamical processes of the mesosphere and lower thermosphere (MLT), including the MLT coupling with the stratosphere during sudden stratospheric warmings (SSW), changes of circulation and transport in the MLT during equinox transition, and planetary wave propagation, amplification, and seasonal variability in the MLT region. Using TIME-GCM, with its lower boundary either flux-coupled to the NCAR Community Climate Model (CCM3) or specified by the National Centers for Environmental Prediction (NCEP) re-analysis data, the MLT impacts of SSW, detailed processes of planetary wave amplification, and the possible role of the mesosphere in SSW have been studied. The model simulations showed that waves may experience resonant amplification prior to the peak warming. The mean wind in the high latitude winter stratopause and mesosphere decelerates and reverses to a westward flow due to planetary wave forcing and forms a critical layer near the zero wind lines. The wind deceleration and reversal also changes the filtering of gravity waves by allowing more eastward-flowing gravity waves to propagate into the MLT, which in turn causes eastward forcing and reverses the westward jet in the MLT. This also changes the meridional circulation in the upper mesosphere from poleward/downward to equatorward/upward, causing adiabatic cooling in the mesosphere and warming in the lower thermosphere. It also leads to a depletion of the peak atomic oxygen layer and significant reduction of green line airglow emission at high and mid-latitudes. Analysis of the TIME-GCM simulation of the 2002 southern hemisphere SSW event showed that changes in the wind and temperature fields first occur in the mesosphere, due to a strong wave event, about a month before the major warming. This was followed by a series of wave events that eroded the polar jet and altered the transmission conditions for planetary waves at progressively lower altitudes.

Both ground-based and satellite observations have shown a ‘springtime transition’ in the night-time O I 557.7 nm airglow emission and O_2 atmospheric band emission characterized by a relatively persistent period of very low emission rates around the spring equinox at mid- and high-latitudes, indicating depletion of the peak atomic oxygen between 95 and 100 km. The salient feature of this depletion is reproduced by the TIME-GCM simulation. The simulation results were analysed and showed that the mean circulation in the upper mesosphere/mesopause and lower thermosphere is altered significantly by changes in gravity wave filtering and gravity wave forcing around the equinox. Additional variability of the atomic oxygen and corresponding airglow emissions may result from the variability of the gravity wave sources, planetary waves and transience of their amplitudes and phases, and circulation changes due to a late and final stratospheric sudden warming.

WACCM

The Whole Atmosphere Community Climate Model Version 3 (WACCM3) is a comprehensive model that spans the range of altitude from the Earth’s surface to the thermosphere. This model is based on the software framework of the Community

Atmospheric Model Version 3 (CAM3), and thus takes advantage of parallel scalar hardware architecture. WACCM3 incorporates a detailed neutral chemistry model for the middle atmosphere, including heating due to chemical reactions, a model of ion chemistry in the mesosphere/lower thermosphere (MLT), ion drag and auroral processes, parameterizations of short-wave heating at extreme ultraviolet (EUV) wavelengths, and infrared transfer under non-local thermodynamic equilibrium (NLTE) conditions. The dynamical and transport equations are solved using an explicit flux-form semi-Lagrangian scheme. This numerical method calculates explicitly the fluxes in and out of a given model volume, thus ensuring mass conservation. The numerical solution is obtained on a standard latitude/longitude grid of either 4° x 5° or 1.9° x 2.5°. Vertical resolution is approximately one-half of the local scale height above 65 km, 1.75 km near the stratopause, and 1 km in the lower stratosphere and upper troposphere.

Orographically-generated gravity waves are parameterized while a spectrum of non-stationary gravity waves is launched at 100 hPa, with phase velocities between -80 ms^{-1} and +80 ms^{-1} every 2.5 ms^{-1}. The spectrum at the source is aligned in the same direction as the local wind, with a Gaussian spectral distribution. Ion drag and Joule heating are included and follow previous parameterizations. The model also needs to take into account the rapid increase with altitude of molecular diffusion which leads to diffusive separation and becomes the principal dissipation mechanism for upward-propagating waves. Enhanced molecular diffusivity suppresses the breaking of parameterized gravity waves above about 100 km, where wave dissipation occurs via molecular diffusion. The diurnal tide and upward-propagating waves explicitly resolved by the model are also damped by molecular diffusion at these altitudes.

In the upper mesosphere and above, additional processes such as auroral heating have to be included. An auroral parameterization, based on existing code from the NCAR TIME-GCM model, has been developed for rapid calculation of the total auroral ionization rate. In addition, particle precipitation in the polar cusp and general polar cap precipitation (‘polar drizzle’) are also accounted for. The parameterization takes as input hemispheric power, and as outputs total ionization rates and neutral heating. Once these are determined, the production rates for the E-region ions N_2^+, O_2^+, N^+ and O^+ are calculated, along with O^+ densities. Auroral production of NO can then be determined from the reaction of molecular oxygen and $N(^2D)$, the latter being produced through dissociative recombination and charge exchange.

CMAM

The extended Canadian Middle Atmosphere Model (CMAM) and the regular CMAM (with upper boundaries at ~210 and ~100 km, respectively) are both proving valuable in examining the role of various physical processes in the dynamics and transport in the mesosphere and lower thermosphere (MLT). Earlier research established the relevance of this model by showing that the mean fields and migrating tidal structures, simulated by the model, were in reasonable agreement with observations. Over the past few years, further comparisons with observations have been undertaken and the dynamical features in the model have been examined in more detail.

More detailed comparisons between the CMAM climatology of planetary waves and tides and radar observations have been undertaken at the University of Saskatchewan. These confirm earlier conclusions regarding the overall favourable comparison between the model and observations. The comparisons also show detailed differences in tidal phases at mid-latitudes and in the seasonal cycle of tidal phases, and amplitudes between the radar observations and CMAM results. These differences will be examined further as more observations become available.

At the University of New Brunswick, the non-migrating tidal signatures in extended CMAM runs have been studied. There is a rich spectrum of tidal features in this model, which dominate the day-to-day variability in the mesosphere and lower thermosphere. Migrating and non-migrating features (wave numbers 0-5, periods 3-24 hours) have been identified, and their seasonal variation and form is currently being investigated. Comparisons of non-migrating features with analyses of data from the TIDI instrument show the extended CMAM results to be in reasonable agreement with observations, a result that might not have been expected given that the tidal source in the model is a convective parameterization. Expansion of the CMAM tidal fields into Hough modes shows interesting structures and suggests that the form of many tidal components is the result of superposition of several modes. Verification of these model results is under way and further comparisons with radar, lidar, and satellite observations are being made.

At the University of Toronto, a comprehensive study of the large-scale dynamics of the mesosphere and lower thermosphere is being conducted using the extended CMAM. This study examines the role of wave forcing of various scales in the generation of instability regions in the model, and the form of the resulting instabilities. They showed that the mesospheric four-day wave results from instabilities, associated with strong vertical shears induced by the parameterized non-orographic gravity wave drag. A similar mechanism appears plausible for the two-day wave and is currently being investigated. The modelled wave forcing was determined, and the migrating diurnal tide was found to provide most of the resolved westward forcing in the equatorial region whereas the eastward forcing was dominated by smaller-scale waves. The resolved waves in the model play a significant role in the zonal mean momentum budget in the mesosphere and lower thermosphere. As a result, gradient wind balance does not hold at these heights with calculations based on this balance, underestimating the actual eastward wind by as much as 40%. Although an appropriate set of observations, to allow validation of these analyses, is not likely to be available for a number of years, these CMAM analyses provide insights into the processes which are likely to be important for the dynamics in this region of the atmosphere.

Work with this model is continuing. Comparisons with the tidal signatures in the Whole Atmosphere Community Climate Model at NCAR have started and data from the CAWSES tidal campaigns will provide a valuable means to validate the model climatology. Interactive chemistry and some ionospheric effects will be introduced into the extended CMAM shortly. Over the next few years, more detailed comparisons

between the model climatology and observations are expected. In addition, general circulation models such as the CMAM, which allow coupling from the troposphere into the thermosphere and ionosphere, will continue being one of the main tools for investigating physical processes important to the maintenance of the large-scale structures at these heights.

Kyushu-GCM

Two new versions of the Kyushu-GCM have been developed. A new GCM covers from ground level to the exobase (~500 km), which makes it possible to study couplings between the neutral lower atmosphere and the ionized atmosphere throughout the thermosphere. The new model is used to investigate the excitation mechanism of intra-seasonal oscillation of the zonally-averaged zonal wind in the MLT region. It has been found that intra-seasonal variations of amplitudes of the ultra-fast Kelvin wave and the diurnal tides are seen in the MLT region, and that these variations of wave activity induce intra-seasonal oscillation of the zonal mean zonal wind by the wave-mean flow interaction. Intra-seasonal variations of the ultra-fast Kelvin wave and the diurnal tides were found at the height range from 20 to 160 km height. These results indicate that the general circulation in the MLT region is closely related with day-to-day variations of the general circulation in the troposphere. The second model is the new Kyushu-GCM (T21L250), which has 250 layers between ground level and 150 km. The increase in the number of vertical layers aims to describe finer vertical-scale motions in the MLT region. It has also been found that the westward propagating diurnal tide with zonal wave number s=2 was mainly excited by non-linear interactions between the migrating diurnal tide and the stationary planetary wave, with zonal wave number s=1 observations.

The vertical propagation of atmospheric tides represents an important mechanism for coupling the troposphere and thermosphere of both Mars and the Earth. Research presented at the 2002 and 2004 COSPAR Assemblies emphasized that interaction between solar radiation and zonal asymmetries near the surface excites different zonal wave number spectra of diurnal tides on the two planets. The spectra depend on the dominant wave numbers characterizing the longitude dependences of near-surface processes responsible for thermal forcing of the tides. Large signatures of these tides have been observed in the lower thermospheres of the Earth and Mars by instruments on the *TIMED* spacecraft, and by the accelerometer on *Mars Global Surveyor*, respectively, and the results have been presented at recent COSPAR Assemblies. The zonal wave number spectra observed in the lower thermospheres of both planets are consistent with those anticipated by the zonally asymmetric topographies of both planets. This work demonstrates firstly, that topographic effects extend into the thermospheres of the Earth and Mars and, secondly, that tides in the thermospheres of both planets depend significantly on longitude.

A three-dimensional middle atmosphere general circulation model (GCM), and a chemical global transport model have been used to calculate the responses of ozone (and other species), and of the wind and temperature regime after the two strongest solar proton events (SPEs) of solar cycle 23. These events occurred in July 2000 and October

2003. The calculated ionization rates showed that the maximum of ionization occurs in the mesosphere and occurs about 1-2 days after the beginning of SPEs. 3-D photochemical calculations showed that ozone density was strongly depressed in the mesospheric region (by about 60-70 %), and that the disturbances could still be traced more than 10 days after SPEs, due to the enhancement of long-lived NO_x. The results of numerical photochemical simulations of ozone depletion after SPEs have been introduced into a three-dimensional middle atmosphere GCM, and showed that such ozone depletion leads to the disturbances in atmospheric temperature and wind regimes. Some differences in dynamical and temperature response between the north and south polar regions have been revealed in the model simulations. Thus, it is possible to conclude that solar energetic particles, which reach the Earth's atmosphere and produce additional oxygen, nitrogen and hydrogen chemical compounds after solar proton events, change the regime of temperature and general circulation of the middle atmosphere. These effects have to be taken into account when investigating mechanisms of global change and climate variability.

KMCM

The Kühlungsborn Mechanistic general Circulation Model (KMCM) has been extended to very high vertical and horizontal resolution (190 hybrid levels between 0.1 km and 125 km, and using a horizontal resolution of T85 corresponding to a horizontal grid spacing of ~1.4º or ~162 km). Gravity waves were self-generated by the tropospheric dynamics and their dissipation in the MLT was induced by non-linear horizontal and vertical diffusion schemes with prescribed vertical profiles of the mixing lengths. Most importantly, this model generates a realistic climatology of the MLT region without a gravity wave parameterization, but resolved gravity waves in the model.

Another focus of the modelling activities is the study of the gravity wave generation by breaking Rossby waves and other tropospheric sources, studied with MM5 simulations. In addition, gravity wave instabilities were studied both theoretically, in the frame of modal and non-modal instability theory, and numerically, with fully non-linear computations. Studies were done on the transition of waves into turbulence, and realistic distributions of turbulent parameters could be simulated, in general agreement with *in situ* measurements, also performed at IAP.

ROSE

Research in the Atmospheric Chemistry Division at the National Center for Atmospheric Research (ACD/NCAR) includes developing and using models to look at interactive dynamics and chemistry in the middle atmosphere. The ROSE model has been used recently to look at chemical processes in the middle atmosphere. Model simulations have tested the long-standing belief that the ozone maximum in the upper mesosphere owes its existence and location to the position of the maximum atomic oxygen density. The simulations show that, while atomic oxygen accounts in part for the high ozone, the ozone is also very sensitive to the temperature. The two factors, atomic oxygen maximum and very strong minimum in global temperature, account in approximately equal measure

for the observed maximum in ozone. The ROSE model has also been used to show that temporal variations in hydroxyl emission measured by SABER on seasonal as well as diurnal time scales are a result of perturbations in temperature and transport by the diurnal tide.

GSWM

The global-scale wave model (GSWM) is a mechanistic model based upon the linearized perturbation equations. The background atmosphere, including mean winds, temperature and dissipation is specified beforehand. Realistic atmospheric tidal forcing is included in the lower atmosphere, and the tidal perturbations are allowed to propagate up into the mesosphere and lower thermosphere when they reach their largest amplitudes before dissipating. Tidal results from the GSWM, which have been used to validate current global circulation models, are available for use by all researchers on the following website: http://www.hao.ucar.edu/modeling/gswm/gswm.html.

LIMA

Layers in the summer mesosphere are studied, using an ice model which applies background conditions from a new model called the LIMA (Leibniz Institute Middle Atmosphere) model. LIMA covers the height range 0–150 km with high resolution. At low altitudes, LIMA assimilates ECMWF ERA 40 data, which introduce variability into the upper atmosphere. LIMA adequately represents the conditions in the mesosphere/lower thermosphere. Ice formation is interactively coupled to background water vapour which leads to 'freeze drying'. Model ice layers vary in time and space and, occasionally, appear at mid latitudes. The geographical distribution of ice clouds generally agrees with observations. For example, the mean noctilucent cloud height at 69°N is 83.8 km (observations: 83.3 km). The occurrence rates of (polar) mesosphere summer echoes from the model also agree with measurements. This model combination is now being used to study the effect of 'weather in mesospheric ice layers'.

Virtual Observatories

The observations required to solve the complex problems in the middle atmosphere and lower ionosphere are fielded by individuals and groups of investigators from around the world. Data collected from the individual instruments are often held at the home institution of the principal investigator, and are available either via the web or by request. In the case of more complex space missions, such as those sponsored by NASA and ESA, the data are disseminated via a national data centre. While the data centre model is viable for large projects, such as a satellite mission, it has difficulty handling many small datasets. A new concept called the Virtual Observatory (VO) has recently taken hold where data can be shared around the world via the web through a virtual observatory. Under the VO concept, all data are served to the web locally and the VO provides search capabilities through this distributed network of data. The Virtual Ionosphere Thermosphere Mesosphere Observatory (VITMO) is currently under

development and will provide a mechanism for researchers in the ionosphere-thermosphere-mesosphere (ITM) community to share their data.

Workshops and Scientific Meetings

The Middle Atmosphere and Ionosphere community participates actively in many international workshops and scientific meetings, such as those described later under the International Reference Ionosphere (IRI) activities.

2. The Earth's Ionosphere, Thermosphere and Mesosphere

The Ionosphere, Thermosphere and Mesosphere (ITM) region extends between approximately 90 and 800 km in altitude. It continues to be an arena of active international space-based and ground-based research. The density, composition and dynamics of this region are very responsive to direct energy inputs, and to their variations, from the Sun, the magnetosphere (high latitudes), and the middle atmosphere. The ionosphere is created by the interaction of solar extreme ultraviolet (EUV) radiation with the upper atmosphere and it extends from about 60 km above the Earth's surface to several thousand km. At high latitudes, energetic electrons precipitate into the lower ionosphere and create additional highly variable ionized regions. The ionized and neutral gases are closely linked through collisions and dynamics, responding to energy and momentum forcing from both the magnetosphere above and the atmosphere below.

Methods by which the ITM is studied include a variety of techniques from ground-based optical and radio instruments to sounding rockets and satellite platforms. Individual and national investigations continue to be enhanced by being organized into large, international, focused study projects. In the 1990s, research was coordinated by the Solar Terrestrial Energy Programme (STEP) and the Coupling, Energetics and Dynamics of Atmospheric Regions (CEDAR) programmes. From 1998 through 2002, the Scientific Committee for Solar Terrestrial Physics (SCOSTEP) actively promoted the SRAMP (STEP Results, Applications and Modelling Phase) and PSMOS (Planetary-scale Mesopause Observing System) programmes while the EPIC (Equatorial Processes Including Coupling) programme studied the ITM coupling processes at low latitudes. These programmes worked in conjunction with the International Solar Cycle Study (ISCS) programme that was also under the direction of SRAMP. Since 2002, SCOSTEP has built upon the successes of previous programmes and, in emphasizing the importance of space weather (the highly variable impact of the Sun's photons, particles, and fields upon the Earth and our technological systems), has implemented a major new programme for the period 2004-2008 called Climate and Weather of the Sun-Earth System (CAWSES). These programmes provide a global network of observing systems and study projects to understand the Sun's effects upon the Earth's ITM and determine, on a global scale, the solar, chemical and dynamical influences on the ITM region.

The multitude of individual programmes and projects studying and characterizing the processes and variability of the ITM have become too numerous for listing in a single article. Some important examples can be highlighted.

Ground-Based Radar and Optical Programmes

These programmes include (1) Fabry-Perot measurements of thermospheric winds and temperatures; (2) ionosonde programmes providing raw ionograms and summary reports; (3) ground-based nightglow observations to monitor variability of the mesopause region; (4) coherent radars for studying auroral zone electrodynamics including plasma convection; (5) GPS-based technology to monitor and understand the ionosphere.

Rocket Campaigns

Rockets programmes have been providing data on thermospheric and ionospheric parameters, high-resolution EUV irradiances, atmospheric density, temperature and winds, electric and magnetic fields, as well as chemical composition, including minor constituents. Many rocket campaigns are coordinated with co-located facilities such as lidars and radars, so that information on the background atmospheric and ionospheric conditions can be determined during the period surrounding the time of specific rocket flights.

Satellite Systems

Many of the major spacecraft that continue to be in operation are important for ITM measurements or related studies. Among these are *ACE* that measures the composition of the solar wind at the L1 position; *CHAMP* which provides accelerometer and GPS data for neutral density specification and 3-D ionospheric tomography; *GOES* that monitors solar X-rays and solar particles (*GOES-13* spacecraft was launched in 2006 with the SXI X-ray imaging and EUV broadband capability) at geosynchronous orbit; *POLAR* obtaining data from both high- and low-altitude perspectives of the polar region of geospace; SDO to be launched in 2008 to understand and, ideally, predict the solar variations that influence life on Earth and humanity's technological systems; *SOHO* which is providing information on the structure of the solar interior, surface magnetic fields, inner corona, coronal mass ejections, and the solar wind; *SORCE* providing measurements of the 0.1-34 nm and 115-2000 nm solar irradiances with four instruments; *STEREO* launched in October 2006 to provide 3-D views of solar phenomena and disturbances travelling in the inner heliosphere; *TIMED* which is gathering data to facilitate studies of the energy balance (solar heating, IR cooling, transport) and basic state (density, composition, temperature, wind) of the Earth's atmosphere between 60 and 180 km. In addition to these specific spacecraft and space probes, related investigations continue to be planned for operation on the *International Space Station*.

Models and Modelling Activities

Modelling activities include substantial advances in empirical and first principles models describing the Earth's upper atmosphere, ionosphere, magnetosphere, and solar radiative and particle inputs. Models are now being included in systems-level characterizations of the Sun-Earth environment. These coupled models are providing the basis for climatological research as well as space weather operations:

Physics-based Thermospheric Models

The Center for Integrated Space Weather Modelling (CISM) is a consortium of ten US institutions centred at Boston University which has, as its overarching vision, to understand our changing Sun and its effect on the solar system, life, and society by developing the first comprehensive community model for space weather analogous to the community models that exist in other fields such as climate research. NCAR's thermosphere-ionosphere-electrodynamic general circulation model (TIEGCM) continues to be updated and used for comparative studies with measurements and other models. The CTIP, CTIM and SUPIM models, variously coupling the thermosphere, ionosphere and plasmasphere, are global, three-dimensional, time-dependent, non-linear models for the neutral thermosphere and for the mid- as well as the high-latitude ionosphere. The Global Numerical Model (GNM) describes the mesosphere, thermosphere, ionosphere and inner part of the magnetosphere of the Earth as a single system by means of numerical integration of the time-dependent three-dimensional continuity, momentum and heat balance equations for neutral, ion and electron gases as well as the equation for the electric field potential. The Global Ionosphere Thermosphere Model (GITM) removes the assumptions of hydrostatic equilibrium, which is present in the other models, and solves on an altitude grid, as opposed to pressure levels. It also includes significant grid flexibility and is completely parallel. GITM was developed at the University of Michigan, and is part of the Space Weather Modelling Framework, which can seamlessly simulate from the 'surface' of the Sun to the Earth's thermosphere.

Empirical Thermospheric Models

The US Naval Research Laboratory's empirical model of the atmosphere, NRLMSISE-00, incorporates new AFRL accelerometer datasets and the CEDAR Database (Millstone Hill incoherent scatter radar and Arecibo) datasets. NRLMSISE will be part of the new COSPAR International Reference Atmosphere (CIRA). The JB2006 model is a modified Jacchia-type model incorporating improved semi-annual variation and solar indices that reduce the uncertainty of previous MSIS and Jacchia-type models by almost 50%. JB2006 will also be part of the new COSPAR International Reference Atmosphere (CIRA).

Physics-based Ionospheric Models

The Global Assimilation of Ionospheric Models (GAIM), of which groups at Utah State University and at the University of Southern California together with JPL have each

developed one version, continues to extend the capabilities of first principles/data assimilation for the ionosphere by assimilating a variety of data types including total electron content (TEC) from ground and space-based GPS receivers, and data from orbiting ultraviolet imagers.

Empirical Ionospheric Models

The International Reference Ionosphere (IRI) steering committee continues to develop and release the updated IRI model which is the basis for ISO TS 16457.

Plasmasphere Models

These are becoming increasingly important in order to specify the electron densities in the higher altitudes of the ionosphere and include: the FLIP (Field Line Inter-hemispheric Plasmasphere) model which describes the seasonal and solar cycle behaviour of the mid-latitude ionosphere during most quiet periods, the La Trobe plasmasphere global electron density model for analysing TEC measurement variability based on GPS data; the Sheffield model which provides an understanding, through physics-based modelling, of the complex physical processes of the plasma flows along the magnetic field lines, the GCPM (Global Core Plasmasphere) model that includes the IRI electron density below 500-600 km and demonstrates sophisticated dependencies of the plasmasphere on the solar and magnetic indices, the GPID (Global Plasmasphere Ionosphere Density) model which includes IRI below 500-600 km extended with theoretical plasmasphere electron density description along the field lines, the IZMIRAN empirical plasmasphere model based on whistler and satellite observations that are smoothly fitted to the IRI electron density profile at 1000 km altitude and extends towards the plasmapause (up to 36 000 km), and the IMAGE plasmaspheric model which is based on Radio Plasma Imager (RPI) measurements of the electron density distribution along magnetic field lines.

Solar Irradiance Models

SOLAR2000 has evolved into a hybrid (empirical, physics-based, and data assimilative) solar irradiance model producing research and operational full solar spectrum irradiances between X-ray and radio wavelengths (1–1 x 10^6 nm) with up to 1 minute time resolution and 0.1 nm spectral resolution. The SunRISE solar synthesis model is a physics-based solar irradiance model using a spectral synthesis approach to making quantitative estimates of IR, VIS, UV, and EUV spectral variability. The HEUVAC high-resolution solar EUV flux proxy model is used for aeronomic calculations of upper atmosphere densities and temperatures. The NRLEUV model utilizes differential emission measure distributions derived from spatially- and spectrally-resolved solar observations, full-disk solar images, and a database of atomic physics parameters to calculate solar EUV irradiance.

3D-MHD Models

Thermosphere/ionosphere disturbances can be generated by solar wind shock waves and coronal mass ejections as a result of dynamic pressure pulses and interplanetary magnetic field polarity and magnitude changes. An ensemble of four physics-based Sun-to-magnetosphere models is being extended to include a three-dimensional MHD model. Complementary to these are the statistical solar wind models developed for precipitating electrons and based on 10 years' worth of *NOAA-12* Space Environment Monitor (SEM) data.

International Programmes

CAWSES

SCOSTEP's mission is to implement research programmes in solar-terrestrial physics that benefit from international participation and that involve at least two ICSU bodies. In the 2004-2008 period, SCOSTEP is implementing a programme called Climate and Weather of the Sun-Earth System (CAWSES). Some of the previous SCOSTEP programmes have been so comprehensive that virtually all of the Committee's energy was dedicated to the implementation of one large programme, thus the IMS in 1976-79, MAP in 1982-85 and STEP in 1990-95. An end-to-end modelling capability is the ultimate goal of solar-terrestrial physics so that the physical processes can be represented throughout the entire Sun-Earth system. With CAWSES, SCOSTEP again recognizes the crucial need for a systems approach in solar-terrestrial physics. CAWSES is being implemented during the 2004-2008 period to foster a scientific approach to understanding the short-term (Space Weather) and long-term (Space Climate) variability of the integrated solar-terrestrial environment, and for its societal repercussions. These include human activities in space, the need for increased reliability of technological systems the performances of which depend on variations in the solar-terrestrial environment, and global changes in climate and ozone. Education also plays an important part in CAWSES.

CAWSES has been organized to accomplish the following specific objectives:

1. Articulate timely and outstanding scientific questions in the connected Sun-Earth system, particularly in cooperation with other ICSU programmes.
2. Coordinate international aspects of specific national programmes when the participating nations find this desirable.
3. Provide a forum to bring together the international solar-terrestrial science community to help define future programmes.
4. Continue to help developing nations to participate meaningfully in international solar-terrestrial programmes.
5. Provide scientific inputs in order to specify the environment for technological systems the performance of which depends critically on solar-terrestrial variations.
6. Provide a coordinated environment in which computer modellers work with observational and analytical programmes to achieve validated, reality-based end-to-end models of the entire Sun-Earth system, and then assist in their transition into applications.

7. Provide scientific inputs that help ensure human safety in space, since humans will be spending increasing amounts of time there.
8. Contribute solar-terrestrial information to the global change community.
9. Help promote international science education actively by providing solar-terrestrial information to the international educational community and promote interactions between scientists and students.
10. Review systematically the quality of solar-terrestrial databases and derived information, and improve metadata for solar-terrestrial products so that they meet needs of the scientific community.
11. Guide ICSU's World Data Centre system in providing needed STP data and in information collecting, processing and archiving services in the modern internet era.

TIGER

In 1998, the long-term TIGER Programme was established within the framework of the SCOSTEP International Solar Cycle Study Working (ISCS) Group 1, Panel 2. The primary objective of this initiative was to determine the variable solar EUV/UV and X-ray fluxes, to improve the existing and future thermospheric-ionospheric (T/I) models and to derive EUV/UV indices or proxies for various applications in space research and space-related fields such as navigation communication. In 2006, the 6th TIGER Symposium was held as a session of the COSPAR Assembly in Beijing, as part of the activity of COSPAR Sub-Commission C1. It emphasized the unique but interrelated contributions of solar irradiance effects on the terrestrial thermosphere and ionosphere (T/I). The general topic of the presentations and discussions was on T/I related solar irradiance research that complements the CIRA and IRI activities currently supported by COSPAR; specific presentations included reports on solar irradiance measurements, models, and proxy developments for T/I uses. COSPAR's publication, *Advances in Space Research*, carries papers on solar measurements, reference spectra, and models that are compliant with the draft ISO Solar Irradiance Standard 21348 'Space environment (natural and artificial) process for determining solar irradiances'. Airglow emissions correlate well with T/I parameters such as densities or temperatures, and reports of airglow modelling results, especially from the *TIMED* mission, were included in the Beijing programme. The programme also included papers on: the measurement of solar EUV/UV radiation, EUV/UV space instrumentation, modelling of solar EUV/UV radiation, modelling of the thermosphere/ionosphere, and airglow measurements and T/I modelling.

To make continuous progress in understanding and modelling the T/I processes, it is necessary to envisage time-scales ranging from minutes (flares) to years (solar cycles). This can be done in the space weather-to-global change context by making use of a broad range of world-wide existing resources with respect to manpower, experience, hardware, methods, flight opportunities, and funding resources. The TIGER Programme aims to facilitate the coordination of these existing and planned activities, and to help define missing links, so that the scientific goals can be achieved. These are dealt with at regularly organized TIGER symposia: the first in Freiburg/Germany (1998), the second in St Petersburg/Russia (1999), the third in Boulder/USA (2001), the fourth on the

Internet (2002), the fifth in Paris/France during the 35th COSPAR Assembly (2004) and the sixth in Bejing/China during the 36th COSPAR Assembly (2006). The 7th TIGER symposium will be held in Montreal/Canada during the 37th COSPAR Assembly in 2008.

Space Weather

The National Space Weather Program (NSWP) in the USA is devoted to improving predictive services for the near-Earth environment. Current work is related to identifying, assessing and predicting the risks to ground-based and space-based technological systems. These are diverse and include the risk of damage due to spacecraft charging, the possibility of disruption to electricity distribution systems and the extent of damage to extended oil distribution pipelines. The efforts are now moving from the phase of initial hazard assessment into prediction and prompt circulation of near-term hazard information. An update of the Implementation Plan was published in July 2000 and an Assessment Committee published in 2006 its recommendations on the direction of improvements to be made to the programme. The NSWP derives particular benefit from the GEM (Geospace Environment Modelling) programme, of the US National Science Foundation, which continues to develop methodologies for the accurate modelling of space weather events in the magnetosphere and the ever more accurate measurement/modelling of important inputs to the ionosphere-thermosphere-mesosphere (ITM) region (e.g. aspects as critical as high latitude ion convection patterns, integrated hemispheric heating rates, solar wind and interplanetary magnetic field configurations, etc.).

Space environment standards continue to be produced by the ISO TC20/SC14 Working Group 4 (ISO TC20/SC14/WG 4 (Space Environment – Natural and Artificial)). There are several draft standards or technical specifications currently in process of being formulated or recently published. These are: ISO 15390 (Galactic Cosmic Rays – published in 2004), CD 15856 (Ionizing Radiation Tests of Materials), TS 16457 (Earth's Ionosphere/Plasmasphere), ISO 21348 (Determining Solar Irradiances – in publication 2006), and CD 22009 (Earth's magnetosphere). In addition, new work items are being considered for the orbital debris environment, guidelines and standards for Earth atmosphere densities, geomagnetic and solar activity prediction, radiation belt characteristics, charging of GEO solar array panels, and lunar dust simulants, creation, and transport. Draft standards at the Working Draft (WD) or Technical Specification (TS) levels are initiated and led by project leaders. At the Committee Draft (CD) level, the standards are already technically mature and are submitted for review by the permanent member countries. The DIS level indicates that a mature document is in preparation for publication. Working Group 4 held special sessions at the 2002, 2004 and 2006 COSPAR Assemblies, and will have a further scientific session at the 2008 COSPAR Assembly. This is part of an on-going effort to bring the international scientific community, involved in the space environment, into the International Standard review and development process.

3. Planetary Atmospheres and Aeronomy

Mercury

The study of Mercury is considered to be very important for comparative planetology since this planet is the closest to the Sun and in many respects is the 'end member' among the terrestrial planets. Our knowledge of Mercury is far from being complete. Even the surface is not fully mapped. The *Messenger* spacecraft, designed and built for the NASA Discovery Programme, was successfully launched on 3 August 2004. After one Earth, two Venus and three Mercury flybys, the spacecraft will reach Mercury in 2011. It will then carry out observations of Mercury from orbit. *Messenger* carries a powerful suite of remote sensing instruments that will perform mapping of the planet's surface, study its geology and composition, and investigate its plasma environment. Mercury has a tenuous atmosphere (exosphere) created by intense interaction of the solar wind with the surface. A spectrometer onboard *Messenger* will study the atmosphere of Mercury in great detail.

BepiColombo, an ESA cornerstone mission, is the second mission to Mercury and is now scheduled for launch in 2013. The mission is a joint effort of the European and Japanese space agencies. It will consist of two orbiters: the first one, the Mercury Planetary Orbiter (MPO), will study the surface and exosphere of the planet and the second one, the Mercury Magnetospheric Orbiter (MMO), will investigate the magnetic field and plasma environment of the planet. The payload proposals submitted to ESA and JAXA in response to the respective Announcements of Opportunity have been evaluated and the final payloads have now been selected. The instrumentation development programmes, involving full international participation, are under way.

Venus

The past several years have been marked by a significant increase of interest in the planet Venus. A great number of fundamental problems in the physics of the planet remain unsolved, despite extensive Venus exploration in the period 1960-90. In less than 3 years, ESA built the *Venus Express* spacecraft, based on the *Mars Express* bus design. *Venus Express* was launched on 9 November 2005 by the Russian Souyuz-Fregat launcher from Baykonur Cosmodrome in Kazakhstan. After a five months cruise, the spacecraft was inserted into a 24-hour period polar orbit around Venus and began observations. Imaging instruments monitor cloud morphology and atmospheric dynamics with high spatial and temporal resolution. Observations of the southern hemisphere discovered a global circulation system spiralling in towards the pole and forming a giant vortex at high latitudes. A powerful suite of spectrometers onboard *Venus Express* is proving to be very efficient in the study of atmospheric composition and structure. Using solar and stellar occultation techniques for the first time at Venus, the spacecraft is monitoring the distribution of such molecules as CO, H_2O, HDO and HCl in Venus's upper atmosphere. Spectroscopic observations have also discovered strong auroral emissions in the CO_2 and O_2 bands used to investigate the conditions in the upper atmosphere. High sensitivity observations on the night side have allowed the payload to

penetrate the dense clouds and to measure the composition of the lower atmosphere. The plasma environment and escape processes are also being investigated by measurements of the energetic neutrals, ions and electrons as well as the magnetic field, at times when *Venus Express* is in close proximity to the planet. The planned nominal mission duration is 500 days. This seems likely to be extended by a further 500 days (extended mission), thus covering four full Venus days.

A Venus (Planet-C) mission has been approved by the Japanese space agency (JAXA). The spacecraft is scheduled for launch in 2009. It will be inserted into equatorial orbit around Venus with a suite of multi-filter cameras and will investigate atmospheric dynamics.

Mars

Investigations of Mars are progressing at a fast pace. Three orbiters: NASA's *Mars Global Surveyor* and *Odyssey* and ESA's *Mars Express*, together with two NASA rovers (Spirit and Opportunity) were recently joined by the NASA's *Mars Reconnaissance Orbiter* (*MRO*). *MRO* was inserted into orbit around Mars in March 2006. After successful completion of the aerobraking phase, the spacecraft reached its final orbit and began observations. *MRO* continues to make observations of the planet, focusing especially on high-resolution multi-spectral imaging of the surface, climate investigations and sub-surface sounding.

Studies of Mars in the last decade have been focused on understanding the geological and climate history of the Red Planet. This research is, to a great extent, related to observations of water in different forms in the atmosphere, in mineral deposits and under the Martian surface. Observations of atmospheric water have revealed details of the Martian water cycle and the role of exchanges with the polar caps and the regolith. Sub-surface investigations have discovered water-rich zones at high latitudes as well as in some equatorial regions. Imaging spectroscopy found clay minerals and sulphates on the surface of Mars that might indicate the presence of open water reservoirs during early Martian epochs. The spacecraft observations are building a new picture of Mars, its history and evolution. The planet might have had a warm and wet climate during the first several hundred million years of its life. These conditions, however, drastically changed and Mars has remained cold and dry for the last 4 billion years. Nevertheless, Mars is still considered a planet on which life might possibly have emerged in the past. Future missions to the planet that will address this intriguing issue directly are currently being developed.

Jupiter and its moons

Launched on 18 October 1989, NASA's *Galileo* spacecraft ended its mission with a high-speed impact into Jupiter's atmosphere on 21 September 2003. This planned manoeuvre ensured that no terrestrial material could possibly contaminate Europa, an icy moon of Jupiter. The main results of the *Galileo* mission, which are still being analysed, are (1) details of the composition and of other parameters of Jupiter's atmosphere

acquired by in situ measurements by the descent probe; (2) the discovery of active volcanism on Jupiter's satellite Io; (3) observations of the icy surface of Europa that strongly imply the existence of a sub-surface ocean; (4) the discovery of an internal magnetic field on the moon Ganymede. To continue the study of Jupiter and its moon system, NASA has selected the New Frontiers Jupiter mission – *Juno* - to be launched around 2010.

Saturn and its system

In July 2004, the NASA/ESA *Cassini* spacecraft reached Saturn and was successfully inserted into orbit around it. The mission also carried the *Huygens* probe, which descended into the atmosphere of Titan and, on 14 January 2005 landed softly on the surface of Titan after a 2.5 hour descent through the atmosphere. The observations and experiments on board the probe provided exciting information about Titan's atmosphere and the surface of the moon. Atmospheric parameters such as temperature and wind speed, intensity of scattered light, gas and aerosol composition were all measured during the descent. The atmosphere was found to be in a state of prograde super-rotation, with wind speeds reaching 100 ms^{-1}. Hydrocarbon compounds were found, with methane being the most abundant, dominating the chemistry of the atmosphere. Photochemical reactions produce a thick layer of organic smog that slowly settles down on to the surface of Titan. Images taken during the descent showed systems of river channels and lakes, possibly created by liquid methane. It is presumed that Titan gives us a picture of the Earth's atmosphere at a very early stage in the Earth's evolution. The primordial conditions on Titan were 'frozen' due to its very cold temperature (-180^{o} C).

The *Cassini* spacecraft remains in orbit around Saturn and continues to collect information about the giant planet. Multispectral imaging is revealing details of the cloud morphology, atmospheric circulation patterns, and wave phenomena that have never been observed before. The *Cassini* instruments have detected strong thunderstorms and lightning, and have also seen powerful aurorae in the polar regions. During recent flyby of Enceladus, a small icy moon of Saturn, the instruments on *Cassini* discovered a water vapour cloud around the planet, indicating geyser-type water volcanism.

Pluto

On 19 January 2006, NASA's Pluto-Kuiper Belt mission was launched. After passing Jupiter in early 2007, the spacecraft will reach the Pluto-Charon system in 2015. Both objects belong to the category of 'dwarf planets' according to the new IAU classification adopted in 2006. Pluto's surface is mainly composed of ices that tend to sublime when the planet comes closer to the Sun in its orbital motion, thus creating a tenuous atmosphere. During the flyby, the probe will study the surfaces and atmospheres of the icy planets.

Theoretical Studies and Numerical Modelling

A vigorous programme of theoretical studies of planetary atmospheres and plasma environments is continuing. Some of these activities are associated with the interpretation of past datasets. However, a wide range of predictive studies and simulations are associated with the provision of essential support for future planetary missions.

4. Task Groups for Reference Models of the Atmosphere and Ionosphere

COSPAR Commission C is charged with the responsibility of developing Reference Models of the Atmospheres and Ionospheres of the Earth, planets and satellites. In order to undertake these activities, Task Groups have been set up that report directly to Commission C. Currently, there are three Task Groups: the International Reference Ionosphere (IRI), COSPAR International Reference Atmosphere (CIRA) and the Reference Atmospheres for the Planetary System (RAPS). The COSPAR International Reference Atmosphere (CIRA) and the International Reference Ionosphere (IRI) are joint projects of COSPAR and URSI.

International Reference Ionosphere (*Joint COSPAR/URSI Task Group*)

The main focus of IRI activities during the period 2004 to 2006 was an improved specification of the topside ionosphere and an extension into the plasmasphere. The correct representation of the variations of electron density and temperature with solar activity are of high priority for the IRI team. These were the subject of a session organized by the IRI steering committee during the COSPAR Assembly in Beijing, China in July 2006. These annual IRI meetings are the main fora for reviewing the progress of the many international collaborative projects that are being undertaken in the framework of the IRI project.

Each workshop focuses on a modelling aspect of special IRI importance. The presentations are peer reviewed and published in dedicated issues of COSPAR's *Advances in Space Research* (*ASR*). The special focus of the 2003 Workshop was ionospheric variability; a selection of the 35 presentations at this workshop was published in *ASR*, 34, no. 9 in 2004. The papers from the 2004 IRI session on the modelling of plasma temperatures and ion composition (COSPAR, Paris) were published in 2006 in *ASR,* 37, no. 5. A wide array of data sources was used in these studies including satellite data from *SROSS C2, CHAMP, GPS, SNOE, SORCE, TIMED, Cosmos 1809*, *Interkosmos 19*, *Rocsat*, *Kompsat* 1, *Akebono*, *ACTIVE*, *ISS-b*, *DE*, *AE-C, D, E*, *OGO-6*, *AEROS*, *ISIS*, *Alouette*, Incoherent Scatter Radar (ISR) data from Saint Santin, Millstone Hill, Irkutsk, and EISCAT, MST radar data, ionosonde data, and rocket-borne measurements. The global reach of the IRI effort was documented by the many countries of contributing authors which included Argentina, Austria, Brazil, Bulgaria, China, the Czech Republic, France, Germany, Greece, India, Italy, Ivory Coast, Japan, Korea, Poland, Russian Federation, South Africa, Taiwan Province of China, UK, and USA.

The 2005 IRI Workshop was held, from 27 June to 1 July at the Ebro Observatory in Roquetes, Spain, as part of the centennial celebrations of Ebro and neighbouring Tortosa. The workshop, titled 'New Satellite and Ground Data for IRI and Comparison with Regional Models', attracted strong attendance by European scientists with close to 70 presentations, grouped in sessions on the lower ionosphere, topside, TEC, irregularities, plasmas temperatures, ion composition, and on IRI applications. As a result of this and earlier workshops, the 2006 version of the IRI model was developed, including many improvements and new features such as: (1) two new options for the topside electron density profile, (2) a model for spread-F probability, (3) a Neural Net model for the electron density in the auroral lower ionosphere, (4) a new model for the topside ion composition, (5) inclusion of a model for the equatorial disturbance ion drift, and (6) an extension of the electron temperature model to plasmaspheric altitudes.

A special IRI workshop took place from 16 to 20 October 2006 in Buenos Aires, Argentina on 'New measurements for improved IRI TEC representation", more information is available on the website http://www. casleo.gov.ar/IRI2006. About 60-80 participants were expected at the workshop, with strong representation of the South-American scientists. Links to reports by the participants can be found on the IRI homepage, at http://modelweb.gsfc.nasa.gov/models/iri.html.

COSPAR International Reference Atmospheres (CIRA) Task Group

During the COSPAR Assembly in Warsaw in July 2000, Commission C re-organized the Task Groups concerned with development of future Reference Atmosphere models. Subsequent scientific meetings held during the COSPAR Assemblies in Houston (October 2002), Paris (July 2004) and Beijing (July 2006) have been used to present and review the very wide range of new data on minor constituent densities in the middle and upper atmosphere, and new empirical models describing atmospheric density, temperature and constituent densities. A further meeting is planned for the 2008 COSPAR Assembly.

The scientific data from NASA's *Upper Atmosphere Research Satellite* (from which the middle atmosphere trace constituent climatology model has been created), and the highly capable new instruments on board ESA's *Envisat*, NASA's *TIMED* and the Swedish *Odin* spacecraft have made particularly important contributions to recent progress in this field.

New models describing the distribution of metal species in the upper atmosphere, and the thermal behaviour of the mesopause region as a function of altitude, latitude and season have recently been completed. These new models represent critical stages in developing our understanding of the complex behaviour of the mesopause and lower thermosphere regions.

During the recent COSPAR Assembly in Beijing, the draft contents of the new CIRA Models were presented and discussed during a very successful special scientific meeting. The considerable progress with semi-empirical models for atmospheric density

was noted. For the first time in some 30 years, a real improvement has been made in the prediction of thermospheric density, which is essential for the understanding of satellite orbit lifetime and decay, and the prediction of satellite re-entry. The new J-B-2004 model also aids the preparations for safe manned flight re-entry manoeuvres. Another major progress has been noted in the prediction of solar and geomagnetic parameters, leading to new indices that are far more representative of the heating and energisation of the upper atmosphere and ionosphere. In particular, it is now possible to consider the prediction of thermospheric density, with moderate accuracy, for epochs in the future.

Reference Atmospheres for the Planetary System (RAPS)

The RAPS task group has held successful meetings during each of the recent COSPAR Assemblies. An International Reference Model for the Martian atmosphere has been prepared to be published shortly. This activity has benefited greatly from the new measurements made by the well-instrumented spacecraft that have visited Mars recently. The next priority of the Task Group is to update and complete an International Reference Model for the Venus atmosphere, exploiting data from the successful *Venus Express* mission. Within the next few years, the vast range of high quality data, now being assimilated from the recent space missions to Jupiter and Saturn, will be used to create the first detailed and comprehensive models, describing the structure, composition and behaviour of the atmospheres of Jupiter, Saturn and Titan.

Development of Models for the International Standards Organization

The IRI model has been proposed to the International Standards Organization (ISO) as the Standard Model for the Ionosphere. This was supported by a resolution of URSI Commission G during the URSI General Assembly in Toronto, Canada in 2004. The new COSPAR International Reference Atmosphere Models under development are also being proposed as new ISO Standard Models.

IV. SPACE PLASMAS IN THE SOLAR SYSTEM, INCLUDING PLANETARY MAGNETOSPHERES

COSPAR Commission D is dedicated to the study of plasmas in the solar system, from the Sun's corona to the outermost regions of the heliosphere where the solar wind meets the local interstellar medium. This includes the magnetosphere and ionized atmosphere of each of the planets as well as the extended plasma environments of comets. Our knowledge of the physics of plasmas in space comes mainly from in situ and remote-sensing measurements made on space probes, but important information also comes from sample return missions, sounding rockets, balloons, and ground-based facilities.

The Sun's Corona and Heliosphere

Since the start of its operations, after a launch in December 1995, the *Solar and Heliospheric Observatory (SOHO)* has been stationed near the first Lagrange point 1.5 million km from the Earth, where it constantly watches the Sun, returning spectacular images and data. The *SOHO* mission is a joint project of ESA and NASA that has involved more than 3200 scientists from around the world. The tenth anniversary of *SOHO*'s launch was a time for celebration for the scientists and engineers in Europe and the USA who conceived, created and still operate this unprecedented solar spacecraft, and who have also rescued it from oblivion three times.

Apart from unmasking the Sun, and teaching us how it works, *SOHO*'s pictures give early warning of storms in space that can affect astronauts, satellites as well as power and communications systems on Earth. Its telescopes probe the Sun from deep in its interior and all the way out to Earth's orbit and beyond, where the magnetized solar wind of atomic particles sweeps through interplanetary space. Originally planned for a nominal life of just two years, *SOHO's* operations are now to set to continue at least until December 2009 due to its good performance and delivery of important data. That corresponds to more than a full 11-year cycle of magnetic storms on the Sun. *SOHO* pictures also reach the general public, as they are featured several times every year on the highly visible 'Astronomy Picture of the Day' website (http://antwrp.gsfc.nasa.gov/apod/).

New research using *SOHO* has enhanced a method of seeing through the Sun to image its far side, so that the entire far side is made visible. This new method uses *SOHO'*s Michelson Doppler Imager (MDI) instrument to trace sound waves reverberating through the Sun to build a picture of the far side. It allows more reliable advance warning of magnetic storms brewing on the far side that could threaten the Earth after rotating to the Sun's near side. Advance warning can help planners prepare for operational disruptions of satellites, radio communications, power grids and other technological systems on the Earth. The Sun rotates once every 27 days, as seen from the Earth, and this means the evolution of active regions on the far side of the Sun has not been detectable previously. Many of these storms originate in groups of sunspots, or active regions, that is in areas with a high concentration of magnetic fields. Active regions situated on the near side of the Sun, the one facing the Earth, can be observed directly. However, traditional methods provided no information about active regions developing on the other side of the Sun.

Polish amateur comet hunter Arkadiusz Kubczak recently discovered his third comet in *SOHO*'s LASCO coronagraph images: a very special 1000th *SOHO* comet discovery in the Kreutz group of Sun-grazing comets. While there is no formal definition of a 'Sun-grazing comet', the term typically refers to the Kreutz-group comets, which have a perihelion distance of less than 0.01 of an astronomical unit (the mean distance between the Earth and the Sun), or some 1,460,000 km. The 1185th comet discovered in data from the *SOHO* LASCO or SWAN instruments (the other 185 are not members of the Kreutz group) is the faint object officially designated C/2006 P7 (SOHO) by the

IAU's Minor Planet Centre. Before the launch of *SOHO* in 1995 December, only some thirty members of the Kreutz group were known. All 1000 Kreutz comets are believed to be fragments of a single comet observed in *ca*. 371 BC by Aristotle and Ephorus, and the fragments themselves continue to fragment, making more Sun-grazing comets.

Complementary solar observations have been provided by the Russian-Ukrainian *Coronas-F* space mission, launched on 31 July 2001. *Coronas-F* was designed to study solar activity and solar-terrestrial relations in the current post-solar-maximum era. Its scientific payload comprises instruments for measuring global oscillations of the Sun in a broad spectral range, for X-ray and UV imaging of the Sun and for detailed diagnostics of coronal plasmas in the temperature range from 100,000 up to millions of degrees Kelvin, including solar flares, as well as for detecting solar energetic particles in the Earth's environment. After a successful mission and more than 20,000 Earth orbits, *Coronas-F's* orbit decayed on 6 December 2005.

The *Reuven Ramaty High Energy Solar Spectroscopic Imager* (*RHESSI*) is a NASA Small Explorer that was launched on 5 February 2002. Its primary mission is to explore the basic physics of particle acceleration and explosive energy release in solar flares. For decades, we have known that soft X-rays from solar flares lag behind the non-thermal signatures in flares, such as hard X-rays or microwave emission. This is often called the 'Neupert Effect' after Werner Neupert, the NASA solar physicist who first noted this relationship in 1968. There is little controversy about the interpretation: it simply takes some time to heat the coronal plasma or to fill up coronal flare loops with newly heated chromospheric plasma, according to the 'chromospheric evaporation' model. Nevertheless, because the data are not complete and theory is far behind, one still finds controversy about the meaning of the Neupert effect. *RHESSI*, with its marvellous and unprecedented energy resolution, can provide the many light curves in the thermal regime, from 3 keV up to about 20 keV, with a spectral resolution of about 1 keV and good sensitivity. Such data are ideal for characterizing timing between non-thermal and thermal emission. In essence, we expect that peak times of soft X-ray light curves (say, at energies below 20 keV) will be delayed relative to the non-thermal peaks (say, above 30 keV - in detail, this distinction depends on circumstances). This assumes the standard model in which hard X-ray emission is produced by high-energy electrons 'precipitating' from the corona. These heat the chromosphere, which then flows upwards as a result of the overpressure developed by this heating. The heated plasma flows into the coronal parts of magnetic loops, and is observable as the rise in the soft X-ray emission. However, what physics can be investigated by measuring these thermal delays? Is the thermal delay controlled by the upflow speed, by the filling time of coronal flare loops, or by cooling times? We do not yet have a good theoretical understanding of the plasma physics of these processes.

Launched in October 1990, the joint ESA/NASA *Ulysses* mission continues to provide a wealth of new information concerning the heliosphere from the unique perspective of this solar polar orbit, into which it was injected with a Jupiter fly-by in February 1992. With the completion of the second polar orbit in mid-2004, *Ulysses* has provided the first and, for the foreseeable future, the only survey of the high-latitude

heliosphere within 5 astronomical units (AU) of the Sun over the full range of solar activity conditions.

In 2005 *Ulysses* has celebrated its 15th anniversary in space and is well on its way into its third polar orbit. For the past few months, the spacecraft has once again been immersed fully in the fast solar wind from the coronal hole that covers the Sun's southern polar cap around solar minimum. This time around, the spacecraft had to climb higher in latitude, to almost 50º south, before leaving the slower, more variable wind behind. In mid-1993, the transition occurred nearer 35º south. The explanation is related to the fact that the Sun's magnetic equator is still more highly inclined with respect to the rotational equator, even though the solar activity cycle is closer to its minimum, compared with the previous occasion. At solar minimum, the Sun's rotational and magnetic axes are most closely aligned. Since the slower, more variable solar wind is mainly confined to the magnetic equator, this in turn means that, until recently, *Ulysses* continued to encounter slow wind once per solar rotation. Observations from the solar wind instrument on *Ulysses* over the past year have shown regular excursions from slow (~400 km s^{-1}) to fast (~700 km s^{-1}) wind every rotation. At the start of the year, however, the speed profile began to show a systematic increase in the minimum speed encountered with each subsequent solar rotation and, since early March, the speed has remained high. Given the fickle behaviour of the Sun, with large outbursts of activity occurring relatively late in the declining phase of the present cycle, it will be interesting to see whether *Ulysses* remains in the fast wind until its trajectory brings it to lower latitudes again after traversing the southern pole in February 2007.

In early September 2005 the Sun, although far into the declining phase of the current sunspot cycle, produced a display of major activity. This included one of the largest solar flares of cycle 23, an X17+ on 7 September, that occurred as the active region responsible rotated into view of the Earth on the Sun's east limb. A very large and very fast coronal mass ejection (CME) was also associated with this flare. At the time, *Ulysses* was positioned almost directly behind the Sun as seen from Earth, at 30º south and 4.8 AU from the Sun. This geometry provided *Ulysses* with a unique view of the source of the activity for several days prior to its appearance on the visible (from Earth) solar disk. Based on observations from the *Ulysses* radio experiment, it is likely that active region 10808 produced at least four intense flares while on the far side as viewed from the Earth. The X17+ flare produced an unusually intense radio burst that was observed by *Ulysses*, and the shock driven by the CME was observed in situ at *Ulysses* on 14 September, implying a transit velocity of ~ 1210 km s^{-1} over a distance of almost 5 AU! The radio bursts associated with some of the X-class flares occurring after the X17+ flare had surprisingly low intensities. This is consistent with what was seen for the series of large flares and solar mass ejection events of 2003, known as the 'Halloween' events. A possible explanation is that the entire inner heliosphere was filled with energetic electrons to a flux level sufficient to block the plasma instability that would otherwise initiate the radio emission process.

One of the greatest highlights in the past two years was provided by one of the oldest spacecraft still in operation: *Voyager 1*. In December 2004, this spacecraft crossed

the solar wind termination shock and entered the solar system's final frontier – a vast, turbulent expanse where the Sun's influence ends and the solar wind crashes into the thin gas between stars.

A trio of surprise discoveries was associated with this transition, but these are just the most recent of many surprises *Voyager* has revealed during its 28 year journey of discovery. They tell us that the interaction of our Sun with the surrounding interstellar matter from other stars is more dynamic and complex than we had imagined, and that there is more yet to be learned as *Voyager* begins the final leg of its race to the edge of interstellar space. When *Voyager 1* passed the termination shock, it was expected that the wind beyond the shock would slow to a few hundred thousand miles per hour. However, the *Voyager* scientists were surprised to find that the speed was much less and that, at times, the wind appeared to be flowing back inward toward the Sun. This could mean that the outward pressure of the solar wind was decreasing as the Sun entered the less active phase of its 11-year cycle of sunspot activity. Another surprise was to find that the direction of the interplanetary magnetic field in the outer solar system varied more slowly beyond the termination shock. As the Sun rotates every 26 days, the direction of the field alternates every 13 days. That field is carried out by the solar wind, with the alternating directions forming a pattern of zebra stripes moving outward past the spacecraft. One could imagine a zebra with giant 'magnetic stripes' running past the spacecraft and *Voyager 1* 'observing' an alternating stripe every 13 days. After the termination shock, the 'zebra' with its stripe pattern was moving at nearly the same speed as *Voyager*, so that it took more than 100 days for the stripe to pass the spacecraft and for the magnetic field to switch directions. And perhaps the most puzzling surprise is what *Voyager 1* did not find at the shock. It had been predicted that interstellar ions would bounce back and forth across the shock, slowly gaining energy with each bounce to become high speed cosmic rays. Because of this, it was expected that those cosmic ray ions would become most intense at the shock. However, the intensity did not reach a maximum at the shock, but has been steadily increasing as *Voyager 1* has been moving further beyond the shock. This means that the source of those cosmic rays is in a region of the outer solar system which has yet to be discovered.

Voyager 1 remains set for new records. It has successfully competed 10,000 days of uninterrupted operations in space. It was already the most distant human-made object in the cosmos when it reached 100 AU from the Sun on 15 August 2006. That means the spacecraft, which was launched nearly three decades ago, will be 100 times more distant from the Sun than is the Earth. *Voyager 1* and its sister spacecraft *Voyager 2* are travelling at a distance where the Sun is but a bright point of light and solar energy is not an option for electrical power. The *Voyager* spacecraft owe their longevity to their nuclear power sources, called radioisotope thermoelectric generators, provided by the US Department of Energy. *Voyager 1* is now in the heliosheath, the zone where the Sun's influence wanes. This region is the outer layer of the 'bubble' surrounding the Sun, and no one knows how big this bubble actually is. *Voyager 1* is literally venturing into the great unknown and is approaching interstellar space. Travelling at a speed of about one million miles per day, *Voyager 1* could cross into interstellar space within the next 10

years. Interstellar space is filled with material ejected by explosions of nearby stars; *Voyager 1* will be the first human-made object to cross into it.

Meanwhile, several missions in Earth orbit or located at the first Lagrange point near the Earth continue to provide valuable data needed as a baseline for the *Voyager* and *Ulysses* deep-space missions, namely the Interplanetary Monitoring Platform – *IMP-8, Wind,* and the *Advanced Composition Explorer – ACE. IMP-8* was launched by NASA in 1973 to measure the magnetic fields, plasmas and energetic charged particles (e.g., cosmic rays) of the Earth's magnetotail and magnetosheath and of the near-Earth solar wind. It continues to operate to this day as an important adjunct to the International Solar Terrestrial Physics programme, and continues to accumulate a long-time series database useful in understanding long-term solar processes. *Wind* was launched on 1 November 1994 and is the first of two NASA spacecraft in the Global Geospace Science initiative and part of the ISTP Project. The science objectives of the *Wind* mission are to provide complete plasma, energetic particle and magnetic field input for magnetospheric and ionospheric studies, to determine the magnetospheric output to interplanetary space in the up-stream region, and to investigate basic plasma processes occurring in the near-Earth solar wind. The *ACE* spacecraft, located at L1 and carrying six high-resolution sensors and three monitoring instruments, samples low-energy particles of solar origin and high-energy galactic particles with a collecting power 10 to 1000 times greater than past or planned experiments. The primary purpose of *ACE* is to determine and compare the isotopic and elemental composition of several distinct samples of matter, including the solar corona, the interplanetary medium, the local interstellar medium, and galactic matter.

The *Genesis* spacecraft, launched on 8 August 2001, was a solar-wind sample return mission that collected ions on large-area ultra-pure substrates between 30 November 2001 and 1 April 2004 at the L1 point. The solar-wind ions embedded themselves in the top 100 nm of ultra-pure substrates that were returned to Earth by capsule on 8 September 8, 2004. However, the sample return capsule drogue parachute did not deploy, and the capsule hit the ground. One of the *Genesis* investigators commented: "When we saw the capsule buried, I knew that people won't understand this, but the science is still there. The solar wind is in these fragments". *Genesis* samples are the first extraterrestrial samples returned to Earth since the *Apollo* programme, which ended in the early 1970s. The collectors returned by the *Genesis* mission contain solar wind atoms which can be analysed by sophisticated laboratory instruments to measure very precisely the composition of the Sun. Since the Sun contains >99% of the mass in the solar system, knowing its elemental and isotopic composition is a good average measure of the composition of the solar nebula at the time when the planets were forming. While rocks and soil from the Moon, Mars and the asteroids and dust specks from comets have already been returned to Earth, the data on the particles in the solar wind from *Genesis*'s collectors should provide new insights in tracing the chemical evolution of diverse planetary samples, most of which came from a common starting material, the solar nebula. In the meantime, preparations are being made for detailed analysis of the most precious and delicate samples, the Concentrator Target, using MegaSIMS. The MegaSIMS is officially a part of the *Genesis* payload and is an

'advanced analytical instrument' specifically designed and funded for *Genesis*. The Science Team will use this special mass spectrometer to extract and count solar oxygen isotopes that have been collected in the target segment. The instrument will eventually be available to the rest of the scientific and engineering (semiconductor) community after its *Genesis* work is completed.

Solar-Terrestrial Connection and Earth Magnetosphere

In the 1990s, collaboration between NASA, ESA, and the Institute of Space and Astronuatical Science (ISAS) of Japan resulted in the International Solar-Terrestrial Physics (ISTP) science initiative. The *Polar*, *Wind* and *Geotail* missions are a part of this initiative, combining resources and scientific communities to obtain coordinated, simultaneous investigations of the Sun-Earth space environment over an extended period of time. More recently, ISTP has been supplemented by the International Living With a Star (ILWS) programme which it is hoped will stimulate, strengthen and coordinate space research designed to understand the governing processes of the connected Sun-Earth system as an integrated entity. Both ISTP and ILWS are overarching programmes of many missions that either are–currently operating (some of which have already been discussed in the previous section) or under development or in the planning stage.

The *Polar* satellite, launched on 24 February 1996, is in a highly elliptical, 86º inclination orbit with a period of about 17.5 hours. As part of the Sun-Earth Connections fleet, *Polar* has the responsibility for multi-wavelength imaging of the aurora, and for measuring the entry of plasma into the polar magnetosphere and the geomagnetic tail, the flow of plasma to and from the ionosphere, and the deposition of particle energy in the ionosphere and upper atmosphere. *Polar* was launched to observe the polar magnetosphere and, as its orbit has precessed with time, has observed the equatorial inner magnetosphere and is now progressing towards an extended southern hemisphere campaign. In NASA's 2005 Senior Review of Mission Operations and Data Analysis Programmes in the Sun-Solar System Connections Theme, *Polar* was granted an extension of mission life to March 2007.

The *Geotail* mission is a collaborative project undertaken by the Institute of Space and Astronautical Science (ISAS) and NASA. Its primary objective is to study the dynamics of the Earth's magnetotail over a wide range of distances, extending from the near-Earth region (8 Earth radii – R_e – from the Earth) to the distant tail (about 200 R_e). The *Geotail* spacecraft was designed and built by ISAS and launched on 24 July 1992. The *Geotail* mission measures global energy flow and transformation in the magnetotail to increase understanding of fundamental magnetospheric processes. This includes the physics of the magnetopause, the plasma sheet as well as reconnection and neutral line formation (i.e. the mechanisms of input, transport, storage, release and conversion of energy in the magnetotail). *Geotail* together with the *Wind*, *Polar*, *SOHO* and *Cluster* projects constitute a cooperative scientific satellite project designated as the ISTP programme which aims at gaining an improved understanding of the physics of solar terrestrial relations.

The *Cluster* mission is currently investigating the small-scale structure (in three dimensions) of the Earth's plasma environment, such as those involved in the interaction between the solar wind and the magnetospheric plasma, in global magnetotail dynamics, in cross-tail currents, and in the formation and dynamics of the neutral line and of plasmoids. Recently, *Cluster* has revealed the magnetic heart of a three-dimensional reconnection event. Magnetic reconnection is a phenomenon of fundamental importance in space and laboratory plasmas. So far, the three-dimensional magnetic structure of a magnetic null – the core region of this physical process – has never been observed in situ, as it requires at least four simultaneous points of measurement to characterize it. For the first time, four spacecraft flying in formation, the *Cluster* mission including the Chinese *Double Star* satellites, have directly observed it in the Earth's magnetotail. Published in the July 2006 edition of *Nature Physics*, an international team led by Chinese scientists not only report this observational first, they also reveal fundamental topological and physical properties of such a null, including its spatial extent. This scientific breakthrough is a truly investigative 'tour de force'.

Cluster has also helped to link magnetic substorms and Earthward-directed high-speed flows. High-speed flows of plasma, known as 'bursty bulk flows' (BBF), are propagating in the inner central plasma sheet of the Earth's magnetotail at velocities higher than 300 km s^{-1}. They are the carriers of substantial amounts of mass, energy and magnetic flux towards the Earth, but their link to magnetic substorms has never been absolutely established. Based on data recorded during July-October 2001 and 2002 by three spacecraft of the *Cluster* mission, a statistical study reveals, for the first time, that more than 95% of magnetic substorms observed in this time period were accompanied by BBF. It also shows that BBF last longer than previously estimated and may account for up to 20% of the energy transport of a substorm. Published in the *Journal of Geophysical Research* in 2006, these results enhance previous studies based on single spacecraft measurements.

Cluster's unique examination of the magnetic bubble that surrounds our planet is about to be enhanced still further as the result of *Double Star*, a ground-breaking collaboration involving ESA and the Chinese National Space Administration (CNSA). Based on recent observations by the *Cluster* and the *Double Star TC-1* satellites, a team of American, European and Chinese scientists have discovered the presence of ion density holes in the solar wind, upstream of the Earth's bow shock, of thousands of kilometres in size. More than 140 of such density holes were found, always observed with upstream particles (propagating against the solar wind flow), suggesting that back-streaming energetic particles interacting with the solar wind are important. This new discovery illustrates the unique capability of *Cluster* and *Double Star* to provide the microscope into shock physics that is necessary to understand fundamental physical phenomena at the Earth's bow shock and extrapolate to the more distant planetary and astrophysical shocks.

Related to both the ISTP and the new Living With a Star (LWS) programme is the *Solar Anomalous and Magnetospheric Particle Explorer* (*SAMPEX*) satellite, launched in 1992 and the first mission of NASA's Small Explorer programme. *SAMPEX* is in a high-

inclination, low Earth orbit, able to measure energetic particles over both the polar cap and in trapped radiation regions. Long-term measurements by *SAMPEX* have revealed fascinating features of the Earth's radiation belts. The Earth's magnetosphere efficiently accelerates and subsequently traps energetic particles. The outer radiation belt consists of electrons with energies of hundreds of keV to several MeV. *SAMPEX* has provided a picture of the radiation belts as a function of L (where L is the radial distance in R_e at the equator if the Earth's magnetic field is approximated as a dipole), near the foot of the field line. The inner proton belt is relatively stable and varies over the time scale of the solar cycle or longer and is anti-correlated with sunspot numbers. The slow variation of the inner proton belt is in contrast to the outer electron belt, which varies on a range of time scales. Several distinctive features are notable in the long-term electron measurements. The outer belt exhibits a strong seasonal and solar cycle variation. It was most intense, on average, during the descending phase of the sunspot cycle, weakest during sunspot minimum and then became more intense again during the ascending phase of the solar cycle. Interestingly, the electrons are not at their most intense approaching or at sunspot maximum conditions.

The *Image* spacecraft, launched on 25 March 2000, is the first satellite mission dedicated to imaging the Earth's magnetosphere, the region of space controlled by the Earth's magnetic field and containing extremely tenuous plasmas of both solar and terrestrial origin. Invisible to standard astronomical observing techniques, these populations of ions and electrons have traditionally been studied by means of localized measurements with charged particle detectors, magnetometers, and electric field instruments. Instead of such in situ measurements, *Image* employs a variety of imaging techniques to 'see the invisible' and to produce the first comprehensive global images of the plasma populations in the inner magnetosphere. With these images, it has been possible to observe, in a way never before possible, the large-scale dynamics of the magnetosphere and the interactions among its constituent plasma populations. *Image,* which has so successfully provided new insights into the workings of our space environment, stopped communicating images to the Earth on 18 December 2005, seemingly due to a fault in a the supply of power onboard.

Other Planetary Magnetospheres

The *Cassini-Huygens* mission is an international collaborative enterprise between three space agencies and 17 nations that contributed to the building of the spacecraft and its payload. The *Cassini* orbiter was built and managed by NASA's Jet Propulsion Laboratory, while ESA built the *Huygens* probe. The Italian Space agency provided *Cassini*'s high-gain communication antenna. More than 250 scientists world-wide are studying the data that are now streaming back from Saturn on a daily basis. On 1 July 2004 UTC, the *Cassini-Huygens* spacecraft fired its main engine to reduce its speed, allowing the spacecraft to be captured by Saturn's gravity and enter orbit. The spacecraft is now on a four-year mission to explore the ringed planet, its mysterious moons, the stunning rings and its complex magnetic environment. During its Saturn tour, *Cassini* will complete 74 orbits of the planet, 44 close flybys of the hazy moon Titan, and numerous flybys of Saturn's other icy moons. Now just halfway through its planned four-

year grand tour of the Saturn system, the mission has already made some astonishing discoveries. There has been a string of remarkable discoveries about Saturn's magnificent rings, its amazing moons, its dynamic magnetosphere and about Titan's surface and atmosphere. Some of the mission highlights so far include the discovery that Titan has Earth-like processes and that the small moon Enceladus has a hot-spot at its southern pole, geysers that spew out ice crystals and evidence of liquid water beneath its surface. The first two years of the *Cassini-Huygens* mission have brought a new understanding of the complex and diverse Saturn system. The next two years are expected to be just as exciting. During the second half of its mission, *Cassini* will be changing its orbit to provide never-seen-before views of the fabulous rings, searching in the gaps for new moons and mapping the ring structure. It will also fly 30 more times past Titan, a world much like an early Earth frozen in time.

A particular highlight of the mission was the descent of the *Huygen*s probe. On 14 January 2005, the probe successfully entered Titan's upper atmosphere and descended under parachute to the surface. The descent phase lasted around 2 hours 27 minutes with a further 1 hour 10 minutes on the surface. Throughout the mission data were collected from all the instruments, providing a detailed picture of Titan's atmosphere and surface. The unique dataset obtained by the six *Huygens* experiments are now being archived in the ESA Planetary Science Archive (PSA). A copy of the archived dataset is also available in the NASA Planetary Data System (PDS). Access to the *Huygens* archive is open to the wide scientific community.

Space Plasma Missions under Development

A number of new space missions and programmes that will enable studies of various space plasma regions are ready for launch, under development, or have been approved recently.

The *Solar Terrestrial Relations Observatory* (*STEREO*) mission will provide a totally new perspective on solar eruptions by capturing images of coronal mass ejections (CMEs) and background events from two observatories at the same time. *STEREO*'s twin observatories will be offset from one another in orbit. One observatory will be placed 'ahead' of the Earth in its orbit and, by using a series of lunar swingbys, the other will travel 'behind'. This placement will allow the observatories to obtain 3-D images of the Sun and, using this unique 3-D imagery, it will be possible to examine the structure of solar eruptions and learn more about their fundamental nature and origin. The launch of *STEREO* was scheduled initially for 2005, but slipped for various reasons mainly connected with the launcher, not the mission. The spacecraft was successfully launched on 25 October 2006 from Cape Caneveral and is being commissioned at the time of writing.

The *Solar Dynamics Observatory* (*SDO*) will be the first mission to be launched for NASA's Living With a Star (LWS) Program, a programme designed to understand the causes of solar variability and its impacts on the Earth. *SDO* is designed to help us understand the Sun's influence on the Earth and near-Earth space by studying the solar

atmosphere on small scales of space and time, and in many wavelengths simultaneously. *SDO*'s goal is to understand, with a view of gaining some predictive capability, the solar variations that influence life on Earth and humanity's technological systems by determining how the Sun's magnetic field is generated and structured, and how this stored magnetic energy is converted and released into the heliosphere and geospace in the form of the solar wind, energetic particles, and variations in the solar irradiance. *SDO* is currently in the 'design and build' phase of mission development, i.e. the instruments and spacecraft are being built, the ground system is being developed, and the flight software is being written. Tests of critical systems have already begun, in preparation for the full spacecraft assembly, system tests and verification, culminating in an August 2008 launch. The prime observing phase of *SDO* is planned to last for five years or half a solar cycle, with the possibility of a 5-year extension.

A mission candidate in the assessment phase is ESA's *Solar Orbiter*, to be launched in 2015 into an elliptical orbit around the Sun with increasing inclination up to a maximum of 35° with respect to the solar equator. By approaching as close as 45 solar radii, the mission will view the solar atmosphere with unprecedented spatial resolution *ca.* 100 km pixel size. Over extended periods, *Solar Orbiter* will deliver images and data of the polar regions and the side of the Sun not visible from the Earth.

The magnetosphere of the planet Mercury will be explored by a magnetospheric orbiter (MMO), that is an element of ESA's *BepiColombo* mission to be implemented in partnership with Japan. Scheduled for launch in September 2013, it will set off on a journey lasting approximately six years. When it arrives at Mercury, it will endure temperatures as high as 250°C to provide new images and data about the least explored planet in the inner solar system during a period of nominally one year in Mercury orbit, with a possible one-year extension.

With the possible return of astronauts to the Moon, reliable forecasts of space weather are now more important than ever. A new mission called *Solar Sentinels* is proposed, that would surround the Sun with spacecraft to keep an eye on solar activity. When a flare occurred between the *Apollo 16* and *17* missions in August 1972, a crew on the surface of the Moon would have become really sick, if not worse. Energetic particles from a super flare, like that recorded by Sir Richard Carrington in September 1859, could even cause death. However, it is not only humans who are at risk. Miniaturized modern electronics are more susceptible to radiation damage than their predecessors were 40 years ago. A recent example is Japan's *Nozomi* Mars probe which was crippled by an intense solar energetic particle event in April 2002. Future probes are also going to be vulnerable. The *Solar Sentinels* mission would consist of six spacecraft, four in the inner heliosphere, one near Earth, and another on the Sun's far side, designed to address the two key questions: How are solar energetic particles accelerated from the Sun, and how are CMEs born?

V. RESEARCH IN ASTROPHYSICS FROM SPACE

1. Astronomy

The use of space techniques continues to play a key role in the advance of astrophysics by providing access to the entire electromagnetic spectrum from the radio to gamma rays. The increasing size and complexity of large space-based observatory missions place a growing emphasis on international cooperation. This is particularly marked by the increasing range of joint missions involving American (NASA), European (ESA), Japanese (JAXA) and Russian space science agencies. A major future contribution is also foreseen for the Chinese space agency.

It is important that the world's space agencies coordinate their mission plans for both large and smaller scale enterprises. The coordination of existing and future datasets from space-based and ground-based observatories is an emerging mode of powerful and relatively inexpensive collaboration, to address problems that can only be tackled by the application of large multi-wavelength datasets.

World-wide Astrophysical Space Programmes

As in previous reports, an updated overview of world-wide space programmes in astronomy and astrophysics is summarized in Tables 1 and 2. The tables list the missions which are operating in space or have continuing data analysis efforts, and those which are approved and either awaiting a start or already under construction. Tables 1 and 2 include:

- The main responsible agency or nation;
- Launch dates (actual or scheduled)
- A brief description of the main characteristics of the mission

Table 1. Missions in Operation/Data Analysis Phase

Year	radio	sub-mm	*IR*	visible/UV	EUV/X-ray	hard X-ray/ gamma ray
1990				*HST*		*Ulysses*
1996						*Rossi-XTE*
1997	*Halca*					
1999				*FUSE*	*Chandra* *XMM-Newton*	
2000						*HETE-2*
2001		*Odin* *WMAP*				
2002						*Integral*
2003			*Spitzer*	*GALEX*		
2004					*Swift*	
2005					*Suzaku*	
2006			*Akari*			

HST (NASA/ESA) Observatory mission with 2.4 m telescope for imaging and spectroscopy of galactic and extragalactic sources.

FUSE (NASA) Deuterium abundance studies. PI mission with GI (guest observer) programme.

XMM/Newton (ESA) Observatory mission. High throughput spectroscopy and imaging in the soft X-ray range.

Ulysses (ESA/NASA) French gamma-ray burst experiment, also with radio and in situ instrumentation.

Rossi XTE (NASA) Temporal studies and broadband spectroscopy of compact X-ray sources (1-200 keV). PI mission with GI programme.

Halca (Japan) Observatory mission. 10 m antenna for orbiting VLBI imaging 1.3, 6, 18 cm.

Odin (Sweden/Finland/Canada/France) 1.1 m telescope for mm (119 GHz) and sub-mm (420-580 GHz). Interstellar chemistry and atmospheric ozone.

WMAP (NASA) Explorer to study anisotropy in the cosmic microwave background radiation.

Integral (ESA) Imaging and spectroscopy from 20 keV to 10 MeV.

GALEX (NASA) Galactic Evolution Explorer. UV all-sky survey mission.

Spitzer (NASA) Observatory mission. Space Infrared Telescope Facility. IR telescope of 0.85 m aperture.

Swift (NASA/UK/Italy) Medium Explorer. Gamma-ray burst detection with X-ray and optical telescopes for rapid follow-up.

Suzaku (Japan/NASA) X-ray and hard X-ray telescopes.

Akari (ISAS) 0.7 m cooled telescope for second generation IR all-sky survey. Previously called Astro-F.

Table 2. Approved Projects

Year	gravity waves	sub-mm	IR	visible/UV	EUV/ X-ray	hard X-ray/ gamma ray
2007		*Planck*	*Herschel*			*AGILE, GLAST*
2008	*LISA Pathfinder*					

AGILE (Italy) Hard X-ray and high-energy gamma-ray telescope.

GLAST (NASA) Gamma-ray Large Area Space Telescope. High energy gamma-ray telescope with low energy gamma-ray burst monitor.

Planck	(ESA) Medium-size mission to study the spectrum and anisotropy of the diffuse cosmic microwave background radiation relic of the 'Big Bang'. To be launched together with *Herschel* to L2.
Herschel	(ESA) Observatory mission 3 m warm Cassegrain telescope for high throughput heterodyne and far IR spectroscopy and imaging.
LISA Pathfinder	(ESA) Technology test mission for future *Laser Interferometer Space Antenna* mission.

Comments on the content of the tables and on the situation in each of the principal spectral regions are given below.

X-rays and Gamma-rays

The NASA *Rossi-XTE* mission (high resolution timing studies of X-ray sources over the 1-200 keV range) continues to operate successfully. The world-wide gamma-ray burst monitoring capability has been enhanced enormously with the launch of the *Swift* mission in November 2004. The mission is managed by NASA, and has significant instrument contributions from Italy and the UK.

Following the successful launch and operation of NASA's *Chandra* observatory in June 1999, the ESA *X-ray Multi-mirror Mission* (*XMM/Newton*) was launched in December 1999 and is operating successfully. With their complementary emphasis on high angular resolution and high throughput spectroscopy, these observatory missions continue to generate major advances in astrophysics. The two missions have been particularly effective in studying distant galaxies, including galactic mergers, the massive black holes at their centres, and the billion-degree gas that permeates the medium in clusters of galaxies. Japan's *Suzaku* X-ray mission was launched in 2005.

At the relatively low gamma-ray energies associated with nuclear spectral lines, ESA's *Integral* (*International Gamma Ray Astrophysics Laboratory*) observatory, launched in 2002, is now supplying the world gamma-ray astronomy community with an important imaging and spectroscopic capability. At the higher energies that will facilitate investigation of the highest energy processes in the universe, Italy's *AGILE* (*Astro-rivelatore Gamma a Immagini Leggero*) and NASA's *Gamma-ray Large Area Space Telescope (GLAST)* are both scheduled for launch in 2007.

For the next generation of X-ray observatories, two projects involving large X-ray telescope systems are being studied intensively. The US Constellation-X is envisaged as a set of four telescopes, in orbits around the L2 point, working together as a single observatory. The European Xeus, a 10 m diameter X-ray telescope that will involve separate spacecraft for the telescope and focal plane packages, is now also being studied for a single launch to the L2 point. Possible joint approaches to these two missions, including Japanese involvement, are being jointly investigated.

UV/Extreme UV and Visible

The *Hubble Space Telescope* (*HST*) continues to operate successfully, with various key sub-systems having been replaced in orbit during 1999 and 2002, including the restoration of the Near IR Camera and Multi-Object Spectrometer (NICMOS) to full operation. Unfortunately, the Space Telescope Imaging Spectrometer (STIS) suffered a catastrophic failure in 2004. NASA is currently planning a manned *HST* servicing mission.

NASA's *FUSE* (*Far Ultraviolet and Spectroscopic Explorer*) remains operational with on-going studies of primordial deuterium and the hot phase of the interstellar medium. NASA's *GALEX* (*Galaxy Evolution Explorer*), which is designed to conduct the first deep all-sky survey in the ultraviolet, has already detected more than one million hot stars and galactic cores in its first years of operation.

Infrared

NASA's *Spitzer* Observatory is detecting tens of millions of infrared point sources and probing the dust and gas in star-forming regions in the Milky Way and in other galaxies. Its extensive legacy programmes are devoted to specific large-scale surveys. NASA is intensifying work on *HST*'s successor mission with extended near-IR capability, this being the *James Webb Space Telescope (JWST)*, in which ESA will play a significant role.

Sub-Millimetre

NASA's *Wilkinson Microwave Anisotropy Probe* (*WMAP*) Explorer mission has reported the spectacular results of its sky survey. While pinning down the age of the universe to approximately 1%, these results also offer powerful confirmation of all the measurable predictions of the 'hot big bang with inflation' history of the early universe. An added surprise of these first *WMAP* results is the apparent evidence for the earlier appearance of the first stars than was expected from the standard model of galaxy formation.

The ESA *Herschel/Planck* mission involves a large general-purpose observatory and a specialist spacecraft to attack the microwave background angular distribution problem. Development is proceeding towards a launch in 2007.

Sweden's *Odin* mission was launched in February 2001 into a Sun-synchronous 600 km orbit. Designed to study the interstellar medium and the Earth's atmosphere at mm and sub-mm wavelengths, the mission continues to operate successfully.

Radio

Halca (formerly *VSOP*), launched by Japan's ISAS in 1997, has produced maps with a resolution of 0.3 milli-arc seconds at an operating frequency of 5 GHz. The mission ended in 2005.

Complementary Research

Gravitational wave astronomy continues to grow in importance. The *LISA* mission is being studied by both ESA and NASA. Both agencies are investigating the requirements for technology demonstration pathfinder activities, with an ESA *LISA Pathfinder* currently planned for a likely launch in 2008.

Conclusions

Astronomy from space is a model for international scientific cooperation. Most missions have some international hardware collaboration, and virtually all feature extensive data sharing. International astronomical databases now include ground-based as well as space-based archival data in standard formats, so that astronomers anywhere in the world can access all results after brief proprietorial periods, and can perform extensive multi-wavelength investigations of large data samples from their desktops.

2. Solar and Heliospheric Physics

The Sun is a relatively ordinary star by cosmic standards, but its proximity offers us a unique astronomical laboratory. Because of the high temperatures reached in the upper chromosphere and corona, the solar atmosphere is best observed at shorter wavelengths: ultraviolet (UV), extreme ultraviolet (EUV), X-ray and gamma ray. Work at these wavelengths must be undertaken from space since the radiation cannot penetrate the atmosphere of the Earth. Even at visible and infrared wavelengths, observations from space eliminate the distorting effects of the Earth's atmosphere. This allows imaging of fine structures on the Sun's surface (photosphere) at size scales of approximately 100 km, and possibly below this eventually. Also visible-light observations of the outer corona, say several solar radii above the Sun's surface, are only made possible with spacecraft-borne coronagraphs thanks to the absence of scattered light from the Earth's atmosphere.

At present times we are enjoying a 'golden age' in solar physics from space; a fleet of advanced solar observatories, namely the *Solar and Heliospheric Observatory* (*SOHO*), the *Transition Region and Coronal Explorer* (*TRACE*), the *Reuven Ramaty High Energy Solar Spectroscopic Imager* (*RHESSI*) and others are all in space, observing the behaviour of the Sun in unprecedented detail. The observations made with *SOHO* allow us for the first time to probe the operation of convective energy transfer from the interior to the surface. Emerging magnetic flux is also being studied in detail from these spacecraft. In the future, emphasis will shift to coordinated studies of how the Sun's interior is magnetically coupled to its high atmosphere and, in particular, how the convective dynamo transfers its energy and initiates the violent events, such as coronal mass ejections (CMEs) and solar flares, which can lead to consequences of major economic importance for spacecraft operating in near-Earth orbits and for power distribution systems on the surface of the Earth itself.

The Japanese Aerospace Exploration Agency (JAXA), in collaboration with NASA and the UK's Particle Physics and Astronomy Research Council (PPARC), launched the *Hinode* ('Sunrise'; formerly Solar-B) spacecraft on 22 September 2006. *Hinode* is currently manoeuvring into its final orbit. First light for the instruments, the Solar Optical Telescope, the EUV Imagine Telescope, and the X-Ray Telescope, was scheduled for the end of October 2006.

'Living With a Star (LWS)' was initiated by NASA in 2001 and has evolved into the 'International Living With a Star (ILWS)'programme. This includes the *Solar Dynamics Observatory* (*SDO*), planned for launch in 2008, which will continue the successful helioseismology observations of the convection zone begun by *SOHO*, along with imaging studies of the photosphere and corona. A set of four *Solar Sentinel* spacecraft are being studied to be placed on the far side of the Sun and in the inner heliosphere, to work with *SDO* on studies of CMEs and other disturbances passing through the interplanetary medium, with special reference to those that impact the Earth. NASA has also developed a pair of spacecraft named *STEREO,* which were launched on 26 October 2006, and will view the Sun from two different lines of sight to study solar atmospheric structures and CMEs.

Understanding the outer layers of the solar atmosphere and the transfer of energy to these regions from the interior represents a major intellectual challenge, that is of substantial cultural signifycance. It also has a huge potential impact both on our economies and, through the Sun's influence on climate, our quality of life on Earth. Thus, work in solar physics needs to be undertaken on a world-wide basis. Fulfilling the requirements for simultaneous ground-based observations at optical, infrared and radio wavelengths is also important and can gradually be achieved by the construction and commissioning of several facilities in countries that do not possess directly the appropriate infrastructure for implementation of space-based observations. However, many nations do work with space data and make valuable contributions to the subject, given the increasingly open access to these datasets that is currently possible. The emphasis on coordination is one of the key elements in most of the major programmes for solar physics. Furthermore, from lengthy experience in solar observing and the need for collaboration with colleagues in many countries, the solar physics community has a long and successful history of international cooperation, which is fully exploited in planning space missions.

Currently Operating Solar Programmes

Current solar programmes are directed at three broad areas of solar-terrestrial science:

(1) the solar interior;

(2) the solar atmosphere;

(3) the influence of the solar wind and large solar events such as CMEs and solar flares on the Earth and the interplanetary medium.

Work continues using the imaging telescopes, spectrometers, and coronagraphs on *SOHO*, *TRACE*, and other spacecraft. These instruments address a broad range of scientific questions concerning the Sun's magnetic activity cycle, solar flares, the nature of the inner and extended corona, CMEs, and the acceleration of the solar wind.

SOHO, a joint ESA-NASA mission, is one of the most ambitious solar physics missions so far deployed. The *SOHO* spacecraft was launched in December 1995 and has been observing the Sun and the heliosphere for more than ten years from the Lagrangian point, L1, between the Earth and the Sun. From this unique vantage point, 1.5 million km in front of the Earth, *SOHO* observes the Sun continuously without day/night cycles and without serious effects from the orbital motion inevitably present in low Earth orbiting missions. L1 also lies outside range of the geocorona ultraviolet emission. Consequently, *SOHO* has an unprecedented view of solar phenomena and is able to detect solar oscillations and solar UV emission with minimum noise. *SOHO*'s scientific payload consists of 12 instruments, including six built by ESA member countries, in collaboration with groups in the USA. These instruments study the Sun, from the solar interior by helioseismology, to the outer atmosphere by remote sensing in the visible and the ultraviolet. The solar wind is simultaneously probed by in situ measurements. The twelfth instrument observes hydrogen Lyman-alpha emission from the interplanetary medium to monitor the mass flow of the solar wind. The ESA-NASA cooperation on *SOHO* includes the staffing of a common operations centre at the NASA/Goddard Space Flight Center for day-to-day operational decisions and collaborative research.

SOHO is successfully probing the interior of the Sun. It does so with several instruments observing the solar surface oscillations that can be detected almost completely free of noise. The measurements are of small periodic variations in emission intensity or in surface velocity. The detection of short-range oscillations due to sound waves has already gas motions occurring just below the solar surface as well as solar rotation in, and below the convection zone to be traced. Rotation has been found to be less dependent on latitude than on the solar surface.

The surface of the Sun turns out to be highly dynamic even in periods of low solar activity, with the continuous emergence and cancellation of magnetic fields, as shown by the high-resolution telescopes observing the solar disk and the inner corona. A new class of phenomena ('blinkers') has been identified, which along with other new variable phenomena, may provide an important input to the problem of heating the solar atmosphere. These telescopes can locate the onset of CMEs near the solar surface, and identify the large global disturbances caused by flare. The disturbances are in the form of waves propagating from the site where the flare occurs throughout the entire solar atmosphere.

The white light and UV coronagraphs on *SOHO* are continuing to provide dramatic images of CMEs, during the course of which the Sun releases large amounts of hot material into the heliosphere. It has been found that the mass input in the solar wind during mass ejections is much greater than expected as is the frequency of these

phenomena. CMEs disturb the entire solar system, can affect the Earth's own space environment, and can have devastating effects on telecommunication satellites.

The fast and slow solar wind flows in the outer solar atmosphere have been mapped by *SOHO* for the first time thereby making it possible to relate the flows to the topology of the solar magnetic fields. The solar wind acceleration has now been traced back to a few solar radii from the solar surface, and has been shown to be much more effective at the solar poles and in other regions, where magnetic fields are open. Here the solar wind speed reaches 800 km s^{-1} at about three solar radii out from the solar surface. Acceleration is less effective near the solar equator, where closed magnetic field lines underlie the streamers, which are probably the source of the slow solar wind.

The *Transition Region and Coronal Explorer* (*TRACE*), a NASA Small Explorer mission, was launched in April 1998 into a Sun-synchronous polar orbit to allow eight months of continuous solar observation without satellite nights. It is being operated in coordination with *SOHO* and *RHESSI* (see below). The objective of the *TRACE* mission is to observe directly the connections between the small-scale features that characterize the photospheric magnetic field and the larger-scale structures that are seen in the solar corona, thereby following up on the discovery by *Yohkoh* that the corona is a continuously dynamic atmosphere which responds to impulses from the photosphere. *TRACE* has been surveying this connection from the photosphere into the corona with unsurpassed temporal and spatial resolution. Discoveries have included active region outflows, the oscillation of entire coronal magnetic loop structures, and the predominance of non-uniform magnetic footpoint-heating in coronal loops in the temperature range 0.8-1.6 million K. With these revelations, *TRACE* is making major contributions to current understanding of the coronal heating mechanism. The *TRACE* instrument is designed to isolate narrow UV and EUV spectral bands containing emission lines formed in the chromosphere, transition region, and corona. As *TRACE* is an open mission, all its data and related analysis software are freely available to the entire solar physics community.

On 23 July 2001, the US National Oceanic and Atmospheric Administration (NOAA) launched the *GOES-12* satellite. It is one of the last in the current series of five advanced NASA weather satellites, operated by NOAA, designed to improve forecasting of Earth and space weather. One of the solar instruments onboard is the SXI, which consists of a grazing incidence mirror feeding a 512 x 512 CCD camera. The X-ray images are used to improve our ability to predict the magnitude of energetic particle events on Earth. The image data are now available online at the NOAA Space Environment Center.

The *Reuven Ramaty High Energy Solar Spectroscopic Imager* (*RHESSI*) mission, one of NASA's Programme for Small Explorers, is an advanced hard X-ray imager of the rotating modulation collimator type for flare observations. Equipped with cooled germanium detectors, *RHESSI* provides hard X- and gamma-ray images of solar flares with unprecedented high spatial and non-dispersive energy resolution over the energy range from 3 keV to 10 MeV. From just after its successful launch on 5 February 2002, the *RHESSI* satellite has provided and continues to provide numerous new results on

electron and ion acceleration in solar flares. *RHESSI*, like TRACE, is an open mission; all data and related analysis software are freely available to the entire solar physics community.

As a successor to the highly successful *Yohkoh* mission, JAXA launched the *Hinode* spacecraft on 22 September 2006. The mission involves collaboration with solar groups in the USA and UK, supported, respectively, by NASA and PPARC. The payload includes an optical telescope capable of producing photospheric images with a spatial resolution of 150 km on the solar surface and of measuring vector magnetic and velocity fields in the photosphere. An X-ray imager for the diagnosis of plasmas having temperatures of 0.5 to 10 million K is also included in *Hinode*'s payload. Line broadening in the transition region and coronal emission lines, which may be manifestations of energy input into the corona, will be observed with an EUV imaging spectrometer. With the coordinated set of these instruments, *Hinode* aims to unveil the coupling of coronal activity with the underlying photospheric magnetic and velocity fields and, furthermore, reveal more about the mechanism of coronal heating – one of the largest puzzles in solar physics. A Sun-synchronous, polar orbit was chosen to avoid the orbital temperature variation due to day/night cycles and to minimize the effects of observing time gaps and of line shifts due to the orbital motion. *Hinode* is currently maneuvering into its final orbit. First light was scheduled for the end of October 2006.

Koronas is a series of Russian satellites designed to observe the solar atmosphere from near-Earth orbit, and to observe solar activity and magnetospheric solar effects. They carry instruments developed by groups from Russia, in collaboration with researchers from the Ukraine, Georgia, Poland, Germany, France, the UK and USA. The instruments include X-ray spectrometers, multi-layer imaging telescopes and coronagraphs, as well as detectors for helioseismology. The first of the series, *Koronas-I*, was launched in March 1994 with a scientific payload of eleven instruments designed to cover a wide region of the electromagnetic spectrum and to measure particles. The second *Koronas-F*, was launched on 31 July 2001 and was operated successfully for more than five years. The twelve instruments on board have observed solar radiation from radio waves to gamma rays, facilitating studies of solar oscillations, the properties of the in situ particle flux, and energy deposition and transport processes in quiet and active conditions. The mission has broad scientific objectives associated with observational solar physics, much like *SOHO*.

All the missions mentioned above have been operated in close collaboration. In addition, simultaneous observations of the Sun with other experiments such as those borne on other satellites, sounding rockets and balloons, as well as ground-based telescopes, are organized regularly and prove particularly fruitful for investigating solar activity.

Other solar physics oriented experiments include operational satellite-, sounding rocket- and balloon-borne experiments. For example, a hard X-ray spectrometer, provided by the Czech Republic, now monitors the Sun from the *Multispectral Thermal Imager* satellite, which is a US Department of Defense Earth observing satellite.

Similarly, the *Solar X-ray Spectrometer (SOXS)* on board an Indian application satellite has been monitoring solar flares continuously since June 2003. In addition, many spacecraft, designed for the study of the heliosphere and the geomagnetosphere, such as *Ulysses*, *Wind*, *ACE*, *Cluster*, *Double Star*, carry instruments that provide relevant data to be analysed together with those from the solar physics missions described above.

Missions Currently in Development

STEREO is a mission in the NASA Solar-Terrestrial Probes programme, which will place two spacecraft in orbit around the Sun and view it from two directions other than the Earth-Sun line. The two spacecraft were in fact launched on 26 October 2006, and are being commissioned at this time. Combining their observations, the two *STEREO* spacecraft will provide a tomographic view of solar atmospheric structures and of the solar surface, thereby enabling major advances in the understanding and forecasting of coronal mass ejections.

NASA is also developing the *Solar Dynamics Observatory (SDO)*, a successor to *SOHO*, for launch in 2008. *SDO* is the first Space Weather Research Network mission in the 'Living With a Star' (LWS) programme of NASA, and will carry a suite of instruments to provide the observations that should lead to a more complete understanding of the solar dynamics, that drive variability in the Earth's environment. The instruments include the Helioseismic and Magnetic Imager, the Atmospheric Imaging Assembly, and the Extreme Ultraviolet Variability Experiment.

The next of the *Koronas* series, *Koronas-Photon*, which is mainly aimed at detecting gamma rays as well as neutrons, is under preparation for launch in 2007

Near-Future Solar Programmes under Investigation

Near-future solar space missions continue to focus on understanding the problems of chromospheric and coronal heating, and the coupling of coronal activity with structures and changes of magnetic and velocity fields in the photosphere. Significant advances in these fields require major improvement in the resolution of the instruments and the use of stereoscopic techniques to define the geometry of the magnetic confinement of the plasma in the solar atmosphere. In addition, the study of coronal mass ejections (CMEs) is assuming increasing importance because of the impact of these events on the near-Earth environment.

The Chinese Space Solar Telescope programme was first proposed in 1992. The telescope system will consist of a diffraction limited optical telescope with a 1 m aperture, spectrographs, and attached telescopes for UV, soft and hard X-rays. The major scientific targets are to seek a breakthrough in solar physics by coordinated high-resolution observations of the magnetohydrodynamic processes in the solar atmosphere. The telescope will obtain two-dimensional imaging spectra, magnetic vector fields, velocity fields and images in the visible, UV and X-ray spectral ranges.

A *Solar Probe* mission to approach within three radii of the Sun is being studied by NASA. The spacecraft would carry a variety of small in situ instruments and imagers for direct testing of current theories concerning the Sun's outer atmosphere. It is also hoped to include a magnetograph and Doppler imaging of the solar poles, along with EUV/X-ray and white-light imaging of the corona. Such a mission would be highly complementary to the ESA *Solar Orbiter* and would fit well with NASA's 'Living with a Star' programme.

ESA is studying the possibility of flying several solar instruments, some of which have been developed for the Eureca platform, on the *International Space Station*. They include systems devoted to the study of solar variability at UV wavelengths, which is of particular importance for the Earth's atmosphere and the evolution of climate.

Conclusions

As this chapter has shown, solar physics activities in space include extensive international cooperation and a rich variety of research goals over the next decade. These involve both the continued operation of existing spacecraft as well as preparation and planning for future missions. Studies of the Sun have a dual importance in that the Sun is not only a prototypical object for much of astrophysics, but also has the driving role in defining the heliosphere, in influencing the Earth, and in controlling the near-Earth environment. It is to be hoped that the long-standing tradition of international cooperation in solar research will be strengthened still further.

VI. LIFE SCIENCES AS RELATED TO SPACE

Gravitational Biology

The COSPAR Sub-Commission F1 on Gravitational and Space Biology focuses on gravity perception, genetic and physiological modifications in response to microgravity or simulated gravity. Genetic studies are typically paired with physiological manipulations and space flight experiments. Unfortunately, the research has to rely on quite limited opportunities for flight experiments, either in sounding rockets or on board of the Space Shuttle. The objective, in all cases, is to understand the effect of gravity on development, generative and vegetative changes, and adaptations that organisms experience with changing gravitational loads. The study of gravity perception mechanism and of related responses shows an ever increasing arsenal of responses and intricate patterns of gravity-dependent processes. Because of the tight linkage between flight experiments and gravitational research, NASA's recent cancellation of life science support dramatically affects many researchers. The life sciences research community hopes that substitutions, international collaboration and opportunities will become available, ranging from the ambitious research programmes in China and Russia and, possibly, other countries. The breadth of the topics discussed at COSPAR Assemblies perhaps best illustrates the span of that community's interests ranging from microgravity

effects on the reproduction of unicells to the effect of cyclotron radiation on the gravisensing mechanisms. The experimental manipulations range from genetic studies to the latest hardware development for space flights and various alternative scenarios (substitutions) available for ground studies.

Concerns related to research and technology development were exchanged and shared at the meetings of the American Society of Gravitational and Space Biology (ASGSB) in November 2006 in Arlington. In addition to space flight results, these meetings also discuss the underpinnings of fundamental problems in biology such as stress responses and cell mechanics in the context of space exploration. The European Low Gravity Research Association (ELGRA), which is associated with ESA, will hold its next meeting in Firenze, Italy in September 2007. ELGRA hosts meetings in European countries that focus on specific missions and scientific problems, but are always interdisciplinary. As the access to space becomes available to other nations, we hope that more exchanges and research fora will develop that foster collaboration and technology development, thus promoting space and microgravity research.

Radiation Environment, Biology and Health

The principal objective of the COSPAR Sub-Commission F2 on Radiation Environment, Biology and Health is to study the biological effects of space radiation on living organisms. The natural radiation environment outside the magnetic shielding of the Earth is rather complex and consists of a mixed field of high energy protons, electrons, alpha particles and heavy ions. As the era of manned space exploration of our solar system is becoming a reality rather than a myth, the potential exposure of astronauts to the high linear energy transfer (LET) radiations, resulting in short and long term health effects on the crew, are one of the major concerns of the space agencies. The focus of this Sub-Commission thus includes studying the influences of external factors, such as radiation quality, weightlessness and environmental stress on radio-biological processes; radiation risk and protection in solar particle events; dosimetry in manned spaceflight; and radiation standards and protection in manned spaceflight.

In the past couple of years, radiation effects of heavy particles were almost exclusively investigated using heavy ions from accelerators. In the framework of the ALTEA project, the effects on the central nervous system of the space environment and of cosmic rays were studied on the *ISS*. Specifically, the project investigates the risks of functional brain damage induced by particle radiation in space. A modular facility (ALTEA) is in place in the *ISS* to record electrophysiological and behavioural parameters of brain function. Most radiobiological experiments in space are lagging behind as a result of the limited crew time available on the ISS, especially after the Shuttle accident which delayed the launch of essential payloads like the ESA Columbus module. Radiation measurements inside the ISS are continuing, focusing more on the inside and outside of the Russian Service Module. One major investigation is the Matroshka project, in which organ-absorbed radiation doses will be determined in a human phantom, as an improved measure for the exposure of astronauts and cosmonauts outside and inside the *ISS*. Twenty international research organizations, space agencies and universities from

Europe, Japan and USA participate in this experiment with active and passive dosimetry systems.

NASA is continuing its ground-based radiobiology programme, which aims to reduce the risk of space radiation for crews in future missions to the Moon and Mars. Twelve new research proposals have been recently funded to help better understand the radiation effects and to develop new counter-measures. NASA and the U.S. Department of Energy (DOE) have joint programmes to fund projects within the DOE Low Dose Radiation Research Programme, to support research that will help determine health risks from exposures to low levels of ionizing radiation.

ESA has released the results of a preparatory study of possible investigations into the biological effects of radiation (IBER). The aim was to make recommendations for a ground-based radiation biology programme, and for suitable irradiation facilities where such a programme could be performed with optimal output. This ground-based programme is expected to be funded by ESA in a manner similar to that of NASA, and includes support for facilities and grants for research proposals.

JAXA and CSA are also supporting activities in the field of radiation biology as part of their space medicine programmes.

The 4th International Workshop on Space Radiation Research was held together with the 17th Annual NASA Space Radiation Health Investigators Workshop in Moscow and St. Petersburg, Russia from 5 to 9 June 2006. The workshop was organized by several Russian scientific and governmental organizations, with the participation of NASA and ESA. Although scientifically and logistically challenging, the Workshop allowed a broad exchange of biological and physical data, obtained by researchers from different counties with the main objectives of providing a deeper understanding of radiation effects and to assure future safe trips to the Moon and Mars.

The annual Workshop on Radiation Monitoring for the *International Space Station* (WRMISS), considered to be one of the best opportunities to discuss the results in space radiation dosimetry, was held in Chiba, Japan, from 7 to 9 September 2005 and in Oxford, UK, 6-8 September 2006. One of the major topics in 2006 was the discussion of the first Matroshka results. The presentations of both workshops as well as the previous ones are available on the website http://www.oma.be/WRMISS/.

The ICCHIBAN project is a research programme for the characterization, calibration and intercalibration of passive and active detector systems for space application. The programme, unique in the world, originated from the WRMISS and started in Chiba, Japan. The ICCHIBAN programme was then extended to the use of proton beams at Loma Linda, USA and heavy ions at Brookhaven, USA and, recently, to the use of the neutron reference field at CERN-CERF. The campaigns are open to all scientists working in the space radiation field.

Astrobiology

The principal objective of the COSPAR Sub-Commission F3 on Astrobiology is the study of the chemical pathway by which life may have arisen. This involves studies of extraterrestrial organic chemistry, chemical evolution, the early geological record (pre-Cambrian, as it pertains to the origin and early evolution of life), the interaction of life with the planet in physical-chemical and evolutionary terms, terrestrial life forms in unusual and extreme environments and, finally, the search for life (including intelligence) in the universe. Its ambit also includes the development of planetary protection plans in solar system exploration and sample return missions. The main activities of this Sub-Commission are described below.

During the 36th COSPAR Scientific Assembly in Beijing, China, from 16 to 23 July 2006, there were four symposia in the field of astrobiology: on Organic Chemistry in the Solar System and other Planetary Systems: Exo-, Astro- and Cosmo-biology Aspects; on Interstellar/ Protostellar Organic Chemistry, on Boundaries of Life and on Biosignatures. The 14th International Conference on the Origin of Life and 11th ISSOL Meeting (ISSOL ’05) were held in Tsinghua University, Beijing, China, from 19 to 24 June 2006. More than 200 papers were presented, either in oral sessions or in poster sessions and treated a wide variety of aspects of the origins of life, one of the main subjects of astrobiology. The International Symposium on Origins of Life and Astrobiology (ISOLAB ’05), held at Toki Messe, Niigata, Japan from 27 June to 2 July 2005, was organized by the Society for the Study of Origin and Evolution of Life, Japan and the Japan Society of Biological Sciences in Space. About 150 papers were presented in either oral or poster sessions distributed among the following nine topics: 1. Chiral Homogeneity and D-Amino Acids; 2. Mars and Titan; 3. ETI and Civilization of other Planets; 4. From Molecules to Life-Like Systems & RNA World; 5. Submarine Hydrothermal Systems; 6. Life under Extreme Environments; 7. Chemical Evolution; 8. Co-evolution of Earth and Life; 9. Extrasolar Planetary Systems. At the International Chemical Congress of Pacific Basin Societies (PACIFICHEM) 2005, a symposium entitled ‘Chemical Approaches to Astrobiology’ was held.

Astrobiology Activities around the World

Europe. Astrobiology is an area of increasing interest in Europe, now explicitly included in the scientific programmes of ESA and of several European national space agencies, like CNES. Several space missions with a particular astrobiological content, directly linked to ESA activities, are already in operation, e.g., *Cassini-Huygens*, *Mars Express* and *Rosetta*, or are in preparation, like *ExoMars* and *Darwin*. Since 2004, *Cassini-Huygens* has been contributing crucial data to our knowledge of the astrobiology of Titan (and, unexpectedly, of Enceladus) while *Mars Express* is doing the same for Mars. ESA is strongly supporting the European Astrobiology Network (EANA) which, having been created in 2001, is coordinating the activities in the field of astrobiology of 17 European nations: Austria, Belgium, Denmark, Finland, France, Germany, Hungary, Italy, Poland, Portugal, Romania, Russian Federation, Spain, Sweden, Switzerland, the Netherlands and the UK. EANA’s objectives are to bring together European researchers,

who are interested in astrobiology programmes and to foster their cooperation, to attract young scientists to this quickly evolving interdisciplinary field of research, to interface the Network with European bodies and institutions that are active in the field, and to popularize astrobiology to the public and to students. EANA is affiliated to the NASA Astrobiology Institute and is also an active member of the Federation of Astrobiology Organizations (FAO), of which Australia, France, Israel, Mexico, Spain, Sweden, UK, USA are members. The federation embraces astrobiology networks, associations, institutes, research groups, and societies. It was created to broaden the opportunities available to talented students from all countries and to support activities that develop their academic and research potentials; it also endeavours to harmonize the numerous astrobiology meetings. EANA itself has organized two European Astrobiology Workshops, in 2004 and 2005:

(i) The Fourth European Workshop on Exo/Astrobiology at the Open University in Milton Keynes, UK, 23-25 November 2004, which was attended by 160 participants and was oriented towards Life in Extreme Environments;

(ii) The Fifth European Astrobiology Workshop in Budapest, Hungary, 10-12 October 2005. The meeting was mostly dedicated to the role of radiation in astrobiology, and was attended by 123 participants.

A European Astrobiology Lecture Course Network has been organized at the ESA/ESTEC Erasmus Centre within the already established Exo/Astrobiology Virtual Institute, fully equipped with electronic communication facilities. Eleven lecturers gave presentations via the internet, followed by a one hour question-and-answer period with students from five European universities (Salzburg, Turku, Paris, Dresden and Milton Keynes). The European Astrobiology Network (EANA) web page is available at http://www.spaceflight.esa.int/exobio, as part of the ESA pilot Virtual Institute at ESA/ESTEC in Noordwijk, The Netherlands.

EANA has also published a European trail guide in astrobiology (Brack, A. *et al.* 2005 *Int. J. Astrobiolology*, 4, 195-202); at least seven other books have been issued by European astrobiologists.

Japan. There are two Japanese societies related to the study of astrobiology: the Society for the Study of the Origin and Evolution of Life, Japan (SSOEL-Japan), and the Japan Society for Biological Studies in Space (JSBSS). Both have annual meetings. An annual symposium on 'Astrobiology: Origins, Evolution, Distribution and Destiny of Life in Space' is also held as part of the Japan Geoscience Union (JGU) Meeting. There is no official Astrobiology Network or Association in Japan, but the possibility of establishing such a network or association is being discussed.

Mexico. There is an increasing interest in astrobiology activities in Mexico, in areas such as the role of clays in chemical evolution and the origin of life, hydrothermal systems, planetary atmospheres, characterizing the last common ancestor, searching for life beyond the Earth, and terraformation. A scientific society, i.e. Sociedad Mexicana de

Astrobiología exists in this field, organizing annual meetings as well as seminars throughout the year, and a research network i.e. Red Mexicana de Astrobiología, which is affiliated to the NASA Astrobiology Institute. The National Autonomous University of Mexico will start offering a BSc programmes in Earth Science with a specialization in Astrobiology next year.

Natural and Artificial Ecosystems

Artificial ecosystems with different degrees of complexity and closure have become the new type of scientific model objects, to study both the particular laws of development of individual elements and components of the ecosystem, as well as the general regularities in the development of the entire biotic turnover. Currently, there are some experimental ecosystems that can be used to conduct investigations with material cycling closed to a greater or lesser extent. These are: the Experimental Complex at the Institute of Biomedical Problems in Moscow, Russia; Bios-3 at the Institute of Biophysics in Krasnoyarsk, Siberia; the Advanced Life support System Test Bed at the NASA Johnson Space Research Center in Houston, Texas; the NASA Kennedy Space Center 'Breadboard' Plant Growth Facility in Florida; Biosphere 2 in Oracle, Arizona; the 'Laboratory Biosphere' in Santa Fe, New Mexico; the CEBAS aquatic ecosystem at the Ruhr University of Bochum in Germany; the CEEF complex at the Institute of Environmental Sciences in Japan; and the Pilot Plant that is being constructed in the framework of the European MELISSA programme at Universidad Autonoma de Barcelona, Spain. New experimental and theoretical findings, and discussions on the development of technologies needed for these systems, are regularly debated at the COSPAR's Scientific Assemblies and mainly published in the issues of the *Advances in Space Research* that are devoted to Life Sciences.

During the 36th COSPAR Scientific Assembly held in Beijing in July 2006, there were six sessions in the area of 'Natural and Artificial Ecosystems Studies for Earth and Space Applications', promoted by COSPAR Sub-Commission F4, at which more than 20 countries were represented. These sessions dealt with new experimental, technological and theoretical findings presented by participants from NASA, ESA, various national space agencies, research institutes and universities from China, India, Japan, Russian Federation and others. In particular, the MELISSA project, an ESA's multi-component project on a closed life support system, was discussed after a series of research presentations. The combination of advanced biotechnology processes with the development of algorithms for control and process modelling have resulted in a number of applications, suitable for recycling and bioremediation processes on Earth.

Researchers from NASA presented data on crop production in a bio-regenerative life support system, which had been tested in NASA's space centres. The results on test closure of BLSS were described and the levels of closure on different components of mass exchange were analysed. US researchers discussed data on atmospheric dynamics, the yield and light efficiency of candidate space crops in the Laboratory Biosphere closed ecological system. They also integrated lessons from recent research for a proposed 'Earth to Mars' Mars prototype life support system and considered the 'Modular

Biospheres' (small, materially-closed ecological system facilities) as a new platform for both public and student environmental education, offering innovative research opportunities.

A team of researchers of the Japanese Closed Ecological Experimental Facility (CEEF) presented data in Beijing on the first week-long habitation of two people in this airtight facility with two goats and 23 crops. The experiment was conducted with 89% self-sufficiency in food and without addition of oxygen or the release of CO_2 from the facility. The efficiency of the exchange of O_2 and CO_2 among organisms, and of the water circulation in CEEF had reportedly been measured.

The prospects of hyper-thermophilic aerobic bacterial composting techniques and entomophagy for space agriculture were also discussed by Japanese researchers at the Assembly. Different possible types of modifications of Life Support Systems (LSS), including variations of physical/chemical and biological components, which can have good prospects for applications in manned space flights as well as for Lunar and Mars stations, were described by representatives of different Chinese research teams. Ground-based facilities with soil-like substrates and white root fungus are of interest for long-term missions. These findings are to be investigated in cooperation with researchers from the Russian Institute of Biophysics, Krasnoyarsk.

Special applications of artificial ecosystem studies, connected with eco-toxicological problems, were discussed by researchers from Germany who used a new eco-toxicological research unit, the AquaHab (aquatic habitat) for biomonitoring and risk assessment on Earth and during exploratory spaceflight missions.

Russian researchers presented new data on the optimization of the water balance during human space flight missions, with good prospects for applications for Lunar and Mars exploration missions. Some tasks of the 'Russian Martian Space Flight Scenario' were presented. This project considered biological and technical aspects of designing a 'salad' machine for its further use in flight regimes, not only as a source of vegetarian food but also for recycling part of the LSS atmosphere of a spacecraft.

Some quantitative criteria for estimating the natural and artificial ecosystems functioning, and the formal features of coefficients of ecosystem closure were discussed by researchers from Siberia. According to generalized criteria, every multi-organism system develops in such a way as to increase the energy flows used by the system and to accelerate the rate of cycling of limiting substances. This is a quantitative interpretation of the biogeochemical principles by the Russian biosphere researcher, Vladimir Vernadsky.

A special session in Beijing was devoted to ground- and flight-borne experimental and theoretical investigations of living biological links as elements of life support systems. The session included presentations on the influence of the complexity of physical factors, associated with spaceflight on biological systems. In particular, the complex effects of long duration space flights on subsequent generations of plants were

discussed by Russian and Chinese researchers. The consequences of stress, experienced by plants during space flight, was observed as morphological changes of plants in later generations. Based on the experimental results, it was noted that the space flight plants could be used for Earth applications. For example, space flight tissue contained high concentrations of anti-histamine components, which can be used in medicine. Australian researchers introduced a proposal for an inflatable greenhouse project of 15,000 m^3 volume for Earth orbit and far space missions. The project was supported by the development of new materials and by experimental tests in a simulated free space environment. Specialists in biological systems were asked to develop CELSS of large volume for the proposed greenhouse.

At the short session devoted to pace environment, effects on systems biology and monitoring, using bio-informatics were discussed at one half-day session. The utility of the bioinformatics systems for monitoring of multiple space stressors such as radiation, chemicals, vacuum of gases, microgravity, and potential synergisms was also addressed. In addition, consideration was given to selective pressures of the space environment on replicating populations of cells and organisms, and to the identification of valuable mutants. The discussions covered space effects on biological aspects on genomic, proteomic, transcriptomic, chromosomal, cellular levels and global analyses.

Research groups from China presented results of space-induced mutations of the genome by using rice, and rice and soybean materials. Some data revealed that space mutants expressed fewer proteins and lower intensity proteins than the controls**.** Studies at the cellular level showed that the space environment can affect cellular morphology and functions, and can induce physiological and biochemical disorders. It was proposed that surface plasmon resonance (SPR) can be a promising tool for monitoring and studying the spatio-temporal and dynamic characteristic of the intricate biochemical reactions inside living cells.

Poster papers, presented during these life science sessions in Beijing, dealt with new findings in physical/chemical, biotechnological and experimental studies of the main features of artificial ecosystems and their links, for both Earth and Space applications.

An international conference on ‘Closed Life Support Systems Development for Human Survival Under Extreme Conditions’ was held in Krasnoyarsk, Russia from 6 to 11 September 2006. The meeting was hosted by the Institute of Biophysics (IBP) of the Russian Academy of Science (Siberian Branch) and included participants from Belarus, China, Canada, Europe, India, Russian Federation and the United States. Talks on current research activities, including posters by students from the IBP were presented during the meeting. As part of the conference, the International Advanced Life Support Working Group (IALSWG) met in Krasnoyarsk on 9 September. The Working Group includes members from ESA, JAXA (including the Institute for Environmental Sciences-IES), NASA, CSA, the Russian Institute of Biophysics (IBP), and the Russian Institute for Biomedical Problems (IMBP). The IALSWG meets annually at different venues around the world with the goal of promoting information exchange on life support technologies, including closed bioregenerative life support systems.

Human Physiology

COSPAR Sub-Commission F5 on Human Physiology in Space focuses on the effects of microgravity on the human body, particularly in studying the way in which reduced gravity affects many physiological systems, including the musculoskeletal, the 'sensorimotor', cardiovascular, pulmonary, immunological and haematological systems, and how these systems adapt to a different gravity environment. For instance, even after only very short periods in space, the cardiovascular system changes, largely due to a decrease in plasma volume, and in the autonomic cardiovascular regulation manifest as aerobic deconditioning and symptoms of orthostatic intolerance upon return to the Earth's 1-g environment (and, possibly, also on landing on Mars). Muscle and bone atrophy and undergo other structural changes, especially in the parts of the body that are normally mechanically loaded in the 1-g environment of the Earth. The sensorimotor system also adapts to microgravity, so that it can respond accurately to the lack of gravitational cues for orientation and balance. Deconditioning of these physiological systems during missions with long transits through space could jeopardize the performance of crew members of a space mission and/or the health of the crew, especially when the crew re-enters a higher gravity environment, as found on the Earth, the Moon or Mars.

Developing counter-measures for astronauts faced with long-duration flights, so that they can maintain their fitness for duty and health when arriving on, say the Martian surface, has to be extremely important. These counter-measures must be time efficient and effective, to allow the astronauts to normally perform their mission tasks. However, astronauts in space, on their way to other planets are not the only ones experiencing this type of deconditioning. On Earth, bed-ridden patients and extremely inactive people experience similar changes in their physiological systems. Counter-measure development, especially against cardiovascular and musculoskeletal deconditioning is the focus of research in a variety of space agencies including NASA, ESA as well as the IBMP in Moscow.

Concerns related to this research area are shared and exchanged at meetings of the International Society of Gravitational Physiology (http://www.isgp.org/), the 'Humans in Space' meetings (http://iaa-his2007.buaa.edu.cn/homepage.php) and the International Astronautics Conference (http://iaaweb.org/ content/ view/228/355/).

VII. MATERIALS SCIENCES IN SPACE

Microgravity Research

In recent decades, we have found that humans can survive without gravity for brief periods. We have shown that plant and animal reproduction is possible in orbit. We have observed changes in virtually every system of the body and tested approaches for keeping these changes within safe limits. In the physical sciences, we have tested fundamental physical theories to degrees of precision not possible in Earth-bound

laboratories. These findings and accomplishments have been based on brief visits to space using the Space Shuttle, the *International Space Station* and supplemented by substantial Earth-based research. Microgravity research involves the study of low gravity on physico-chemical phenomena as applied to materials science, fluid physics, combustion and biotechnology.

Microgravity materials' scientists seek to use microgravity to study the processes by which materials are produced and the relationships between the formation of a material and its properties. Various research programmes are attempting to advance our fundamental understanding of the physics and chemistry associated with phase changes (when a material changes from one phase – liquid, solid, or gas – to another). The materials science programmes in most countries support both fundamental research and applications-oriented investigations of electronic and photonic materials, glasses and ceramics, metals and alloys, and polymers. Consequently, both ground-based and flight research is necessary. A fundamental objective of microgravity materials science research is to gain a better understanding of how buoyancy-driven convection (fluid flow resulting from density differences) and sedimentation (settling of heavier constituents in a liquid) affect the processing of materials. In microgravity, these gravity-driven phenomena are significantly suppressed, allowing researchers to study underlying events and phenomena that are obscured by the effects of gravity and difficult or impossible to study quantitatively on Earth. For example, in microgravity, the significant reduction of buoyancy-driven convection makes it possible to study segregation, a phenomenon that influences the distribution of a material's components as it forms from a liquid or gas.

Fluid physics is the study of the motion of fluids and the effects of such motion. Since three of the four states of matter (gas, liquid and plasma) are fluid and even the fourth (solid) behaves like a fluid under many conditions, fluid physics is vital to understanding, controlling and improving all of our industrial as well as natural processes. The engines used to propel a car or an airplane, the shape of the wings of an airplane that allow it to fly, the operation of boilers that generate steam used to produce over 90% of the world's electric power, the understanding of how cholesterol is transported in our blood stream and how it affects heart disease, and how pollutants are transported and dispersed in air and water are just a few examples of how fluid physics affects our everyday lives and forms the very basis for an industrial society. A low-gravity environment nearly eliminates buoyancy and sedimentation and thereby provides near ideal conditions for probing flow phenomena that are otherwise too complex to study on Earth. It also allows the study of flows (such as surface tension-driven flows) that are nearly masked in Earth's normal gravity. This has the potential to transform tomorrow's information technology. Understanding of liquid-vapour flows and heat transfer in microgravity is also vital to the design of spacecraft and life support systems needed to enable humans to explore and exploit the unlimited potential of space.

The application of biotechnology research results range from the design of new drugs, to protein engineering, synthetic vaccines, and biochip technology for the electronics industry. Biotechnology, under microgravity conditions, has focused on the

study of isolated biomacromolecules, such as proteins and the study of cells in controlled fluid and chemical environments.

The *International Space Station* represents a quantum leap in our capability to conduct research in orbit. It serves as a laboratory for exploring basic research questions in commercial, science, and engineering research disciplines, and as a test bed and springboard for exploration.

The research programmes, such as in Europe and Japan are examples of space utilization for microgravity research. Much work by way of microgravity experiments was accomplished in the last two years, both in space (recoverable satellites) and on the ground, in the fields of fluid and materials sciences. Problems of pattern formation at the surfaces of fluids in the presence of phase change and temperature changes have been studied along with problems of fluid management. Many of the fluid science problems tested fundamental ideas of fluid motion, but also had applications to Earth-based technologies and space-enabling technologies.

The Chinese microgravity programme, which has been very active in the past several years, saw four space experiments and nine experiments performed onboard Chinese recoverable satellites in 2005 and 2006, respectively. The four experiments in 2005 were related to bubble dynamics, boiling heat transfer, wetting behaviour and bioreactors. The nine experiments on board an *SJ-8* satellite in September 2006 were related to some of the above topics as well as research into granular dynamics, free surface convection, diffusion in liquid phases, acceleration measurement, cell culture, and plant cultivation.

The White paper on *China's Space Activities 2006* has been issued by the Chinese government, to announce the policy on space activities in China, where *inter alia* the space environment utilization, including microgravity science and space life science, is a field that will enjoy continued support in space sciences. In its Phase II activities, the development of a laboratory with human presence is expected after a space walk and docking mission. Microgravity experiments will be involved in the utilization system. It is expected that there will be more opportunities for space experiments in China in the next several years on board both manned and unmanned space platforms.

In 2005-2006, major changes occurred in the US microgravity science programme. The Office of Biological and Physical Research of NASA was dissoluted, which led to reductions in the extent and content of the ground and space programmes pertaining to microgravity fluids and combustion studies. The expertise resident in these has led to the successful transition of certain themes of these microgravity research programmes to NASA's new Exploration Systems programmes (for example, cryogenic fluid management, fire safety, in situ resource utilization (ISRU) and human health and performance (HHP)), although the expertise available in the bulk of the microgravity fluids and combustion research communities has yet to be fully utilized. Fundamental microgravity research does continue, however, on the *ISS*, albeit in a reduced form compared to that which was originally planned. In 2006, fluid physics experiments

conducted on *ISS* included the Binary Colloidal Alloy Test (BCAT) which has been on orbit since April 2004. In this experiment, binary colloidal solutions are used in three lines of investigation: the study of binary alloy crystallization, surface crystallization and critical and super critical fluid properties. The Capillary Flow Experiment (CFE) is also on orbit and operational. Results from CFE will be relevant to space fluids management systems. Other experiments are waiting in the wings and include the Flame Extinguishment Experiment (FLEX), the Smoke Aerosol Measurement Experiment (SAME), the Smoke Point in Coflow Experiment (SPICE), the Zero Boil-Off Tank experiment (ZBOT), the Boiling Experiment Facility (BXF) and successors to BCAT in the colloids experiment programme.

VIII. FUNDAMENTAL PHYSICS IN SPACE

COSPAR's Commission H on Fundamental Physics covers the use of space to investigate the fundamental laws of nature. The advantages of space are several. Experiments can be carried out in a 'zero' gravity environment, extremely long path lengths and extremely low vacuum can be utilized and the space environment can be chosen to make extremely small effects more easily measurable than they are on Earth. The scientific areas which flourish in these circumstances include the study of gravity and gravitational waves, tests of general relativity including precision tests of the equivalence principle, the search for antimatter and for long range but very weak forces, quantum phenomena such as Bose Einstein condensates, critical phenomena in superfluids and the use of laser cooling for precision clocks and quantum interference experiments.

A major technical step forward was achieved with the launch and successful operation of *Gravity Probe B* on 20 April 2004. The instrument was housed in a cryogenic enclosure and used some of the highest precision spheres ever made as the sensor components. This experiment, to measure general relativistic precession caused by the Earth's spin, operated for about 50 weeks in space and gathered a Terabyte of data. The results are still being analysed and are to be announced in April 2007. Even before the science results are made public, the technical success has paved the way for future fundamental physics missions using cryogenic techniques.

The ESA-French *Microscope* is still under development with a non-cryogenic test of the equivalence principle being the main scientific goal. A NASA proposal for a cryogenic version which achieves about one thousand times higher accuracy is under study in the US and may be proposed as a joint NASA-ESA mission in the future.

The search for low frequency gravitational waves is being pursued by technical teams in Europe and the US within the framework of the *LISA* mission. In Europe, a technology demonstrator named *LISA Pathfinder* is being prepared for launch in late 2009 with a European technology package to demonstrate inertial sensing and laser technology together with some US spacecraft subsystems. It aims to achieve a residual acceleration only a factor of ten worse than that required for the *LISA* mission itself. *LISA* will comprise three spacecraft in heliospheric orbits with a separation of 5 million km.

LISA has undergone a successful technology readiness review in the US and current planning has a launch in 2017. In orbit, *LISA* will be the largest scientific instrument ever built.

The Alpha Magnetic Spectrometer (AMS) was flown on the shuttle in 1998 and it is now planned to fly it on the *ISS* for a period of years. It is being used to search for antiparticles as well as dark or missing matter.

ESA is anticipating new proposals for space missions in the time frame 2015 to 2025 in the Cosmic Horizons programme. Fundamental physics missions are being prepared for submission and will probably include a mission to study general relativity, quantum coherence and gravitational waves.

The scientific problems, addressed by fundamental physics, are becoming central to our understanding of the universe as time proceed, and the excitement surrounding possible resolution of the conflict between general relativity and quantum mechanics is now regarded as a future turning point in physics. Fundamental physics in space has demonstrated its technical readiness to contribute to these important studies.

IX. SATELLITE DYNAMICS

The central theme of the COSPAR Panel on Satellite Dynamics (PSD) is the precise determination of the motion of artificial satellites, including satellites orbiting the Earth, Sun, Moon, the planets, planetary moons and inter-planetary satellites. Moreover, the Panel addresses activities in support of Precise Orbit Determination (POD), such as definition and establishment of reference frames and systems, improved modelling of gravitational and non-gravitational forces (e.g. atmospheric drag, and solar radiation pressure, albedo, and thermal infrared perturbing forces), and development and application of tracking systems (such as SLR, GNSS, DORIS) as well as new technologies (e.g. low-low radio-wave and laser satellite-to-satellite tracking, space-borne accelerometry and gradiometry).

In recent years, significant advances have been made in many areas associated with the field of satellite dynamics. An overview is given below that includes a summary of selected highlights. This overview has been divided into parts addressing Low Earth Orbiting (LEO) satellite missions, Global Navigation Satellite Systems (GNSS), and solar system missions (to the Moon, Sun and planets, and inter-planetary).

Low Earth Orbiting satellites

The ESA *Envisat*, German DLR *CHAMP*, and NASA/CNES *Jason-1* satellites are providing fascinating results in the fields of geopotential modelling (Earth's gravity and magnetic fields), oceanography (altimeter-based), glaciology (for example by INSAR), seismology (also INSAR) and atmospheric research (radio occultation, SCIAMACHY). All these results have been enhanced by further improving the precise orbit determination

for these satellites, which has been achieved by a combination of better treatment of tracking data (GPS satellite-to-satellite tracking, DORIS, SLR), improved modelling of non-gravitational models (based on comprehensive satellite models and satellite-atmosphere interaction models) and also better understanding/treatment of space-borne accelerometer observations (*CHAMP*). The precision of determined orbits for these satellites seems to approach the 1 cm level, especially for the altitude (enhancing, for example, altimeter products and applications).

After 13 years in orbit, *Topex/Poseidon* ceased operation in October 2005. This mission has been an important catalyst for improved orbit determination techniques and dynamic force modelling. Starting from a pre-launch radial orbit precision requirement of about 10 cm, already quite soon after launch in 1992, this barrier was taken easily and a level of a few cm was reached. For the first time, the Global Positioning System (GPS) showed its enormous potential for very precise positioning of LEO satellites and for the derivation of dynamic models, the Earth's gravity field in particular.

The continuous release of more *CHAMP* data and, especially, the release of two years of high-quality *Grace* data in 2004 triggered many groups around the world to test and further improve not only conventional, but also many new, promising methods for precise orbit determination (dynamic, reduced-dynamic, kinematic) and gravity field determination (global, local). Significant progress was made in interpretation and processing of the observations taken by the *Grace* onboard KBR instrument, and accelerometers, leading to improved background modelling (tides, atmosphere, ocean mass changes), as well as in better estimation of both local and global time series of gravity field changes, which could be successfully attributed to, for example, continental hydrology, ocean mass redistributions, and tides in Arctic areas.

Despite the reduced operation in time of the laser altimeters onboard *Icesat*, amazing results have been obtained and synergies with the analyses of *Grace* and *Jason-1* data have been identified. *Icesat* would have formed a splendid tandem with ESA's *CryoSat* satellite if it was not for the dramatic failure to launch the spacecraft in October 2005, a failure which affected a large team of engineers from ESA and industry, as well as a large community of scientists. Immediately, it was realized that a *CryoSat*-type mission is crucial for understanding the system Earth, and a positive decision has already been made, that allows ESA to start activities that aim at building a follow-on, CryoSat-2, with a possible launch date around 2009.

The first *METOP* satellite (out of a series of three) was launched successfully on 19 October 2006. One of the objectives of the METOP constellation is to provide a fully operational, (near) real-time system for atmospheric profiling by radio occultation. To this aim, the METOP satellites are equipped with a newly-developed European GRAS receiver (GPS Receiver for Atmospheric Sounding). METOP offers a challenging environment for near real-time very precise orbit determination and will be operated by the EUMETSAT, with support from ESA, CNES and NOAA.

The US/Taiwan Province of China *Cosmic* constellation, consisting of six small satellites, was launched successfully on 14 April 2006 by a Minotaur rocket. The primary objective of *Cosmic* is to study the Earth's atmosphere and track climate change. Each of the six satellites carries a high-quality GPS receiver that allows a very precise orbit determination, a prerequisite for atmospheric profiling by GPS radio occultation. In addition, the constellation might offer unique opportunities for formation flying and relative positioning concepts.

Finally, intensive preparations are being made for ESA's *Gravity Field and Steady-State Ocean Circulation Explorer* (*GOCE*) mission. The aim of *GOCE* is to provide observations for modelling the Earth's (pseudo-static) gravity field with unprecedented precision and resolution making use of space-borne gravity gradiometry, based on an instrument that consist of an orthogonal triad of three pairs of accelerometers, and tracking by GPS. The launch of this very challenging satellite is foreseen to be in 2007.

Global Navigation Satellite Systems

A continuously growing number of users and applications benefit from the US Global Positioning System (GPS). The International GNSS Service (IGS) continues to provide, very reliably, precise ephemeris and clock products for the GPS satellites, and is continuously improving the precision of these products, decreasing the latency.

An important development is the commitment by the Russian Space Agency to re-establish the full GLONASS constellation in the coming years. This will open the possibility of enhancing the GPS system and further improving the reliability, integrity and precision of navigation by GNSS. This will be even more so after the implementation of the European Galileo system. An important milestone for Galileo was reached at the end of 2005 with the successful launch and deployment of the *Galileo In Orbit Validation Element* testing mission (*GIOVE-A*).

Solar system missions

Fascinating advances have been made in recent years in the field of precise orbit determination of Moon and Mars orbiters and in conjunction gravity field modelling of these celestial bodies. Analysis and re-analysis of Earth-based tracking of lunar and Mars orbiters has resulted in improved orbit solutions for *Clementine*, *Lunar Prospector* and *Mars Global Surveyor*. In addition, successful attempts were made to increase the resolution of lunar gravity field models and even to observe temporal variations of Mars's gravity field.

The Japanese *SELENE* (*SELenological and ENgineering Explorer*) mission to the Moon is currently scheduled for launch in the summer of 2007. *SELENE* will carry more than 10 instruments (including spectrometers for X-rays, gamma rays and charged particles, a multi-band imager and a laser altimeter) and the mission includes a number of sub-satellites that will contribute to modelling, for the first time, the global lunar gravity

field (including the far side) with high precision and resolution, making use of a combination of Earth-based and satellite-to-satellite tracking. Recent activities include the establishment of ground support and processing capabilities.

Tremendous challenges in orbit control and positioning were successfully met for the NASA/ESA *Cassini-Huygens* mission, resulting in the successful landing of the *Huygens* probe on Titan, one of Saturn's moons. Another major achievement was the close encounter with, plus landing on the asteroid Itokawa, in September 2005 by the Japanese *Hayabusa* satellite

A new regime of satellite dynamics will be opened by the new technology of satellite-to-satellite tracking by Laser Doppler Interferometry (LDI). Ranging precisions of the order of nano- to pico-metre might be achieved by this technology, possibily providing an opportunity to study new phenomena, especially in the field of fundamental physics. Currently, ESA and NASA are studying the *LISA* concept, a constellation of three satellites separated by some 5 million km (in a triangle with equal legs) flying in an Earth-like orbit at a distance of 1 AU from the Sun. Early studies indicate that *LISA* is not only a very challenging mission with respect to the required precision level for inter-satellite tracking, but also in relation to attitude and constellation control, and maintenance.

Outlook

Satellite dynamics and, in conjunction, precise orbit determination continue to play an important, if not crucial, role in the exploitation of artificial satellites, be it scientific or commercial. An important development is the design, development and realization of more and more multi-satellite missions, requiring not only absolute precise position solutions for single satellites, but also relative solutions for which the precision requirements are often more stringent. It is fair to state that many future satellite missions will rely on the availability of precise orbit solutions. For certain missions even further advances need to be made, not only in the field of precise orbit determination methodology, but also with respect to models (gravitational and non-gravitational) and tracking technology (both Earth-based and space-borne). Many efforts are currently being undertaken to achieve such improvements.

X. SCIENTIFIC BALLOONING

Scientific balloon programmes around the world in 2005-2006 continued to play a vital role in providing low-cost alternative vehicles for carrying out space research, using payloads lifted to heights of 20 – 50 km. The areas of research included atmospheric sciences, aeronomy, astrobiology, cosmic rays, and astronomy and astrophysics. Important improvements continue to be made in the development of materials and technologies to enable the extension of observing periods to several weeks, at the same time providing a low turn-around time for state of the art projects. With increasing world-wide concern about the Earth's atmosphere and environment, in situ monitoring via

scientific balloons has become an increasingly important activity. Balloon flights have maintained their role in providing a platform for the validation of new concepts for satellite missions in quasi space conditions. These programmes have also served as an excellent training ground for students and young researchers, and for public outreach activities.

Flight Programmes and Missions

The NASA balloon programme continues to provide high altitude platforms for science investigations and technology development. NASA's five standard balloon sizes range from 113,000 m^3 to 1,130,000 m^3, and support a maximum payload of 3600 kg. A total of 28 heavy payload flights were made in 2005-2006. The launch sites (and numbers of flights from each) included McMurdo Station, Antarctica (4), Fort Sumner, USA (18), Palestine, USA (2) and Kiruna, Sweden (4). The National Scientific Balloon Facility was renamed by US Congress as the Columbia Scientific Balloon Facility (CSBF) in commemoration of the crew of the Columbia Space Shuttle.

NASA brought new payload preparation facilities online at McMurdo to provide increased Long Duration Balloon (LDB) support capabilities at much reduced operating costs. NASA and ESRANGE (Kiruna, Sweden) completed expansion of the ESRANGE balloon launch pad to accommodate the launch of large heavy-lift balloons. Three ESRANGE-to-Canada LDB flights were flown in 2005-2006: the BLAST (Balloon-borne Large-Aperture Sub-millimeter Telescope) payload flew a 4-day LDB mission, while the TRACER and AESOP payloads each flew over five days from ESRANGE-to-Canada with experiments to measure energetic cosmic radiation and heavy cosmic ray nuclei. Future plans for NASA LDB and Ultra Long Duration Balloon (ULDB) missions include launches from the northern hemisphere between May and July, from Antarctica in December/January, and from southern hemisphere mid-latitude regions (i.e., Australia, Brazil) between November and February. Circum-global, LDB and ULDB missions maintain the latitude, within 5º, at which they are launched.

The Indian National Balloon Facility (INBF), located at Hyderabad, has increased its programme to develop and manufacture zero pressure balloons and associated flight control instrumentation. Four flights were conducted by INBF for studies in infrared and X-ray astronomy, and astrobiology, using balloons ranging from 32,613 m^3 to 422,149 m^3, carrying scientific instruments ranging in mass from 223 kg to 858 kg. All these flights were carried out using balloons that were manufactured in-house at the facility.

The Institute of Space and Astronautical Science/Japan Aerospace Exploration Agency (ISAS/ JAXA) conducted 18 balloon flights from the Sanriku Balloon Centre in Iwate. In addition to scientific observations in the fields of cosmic-ray physics, astronomy and geophysics, some technical verification of future space vehicles was carried out during the balloon flights. Some additional balloons were launched to investigate new technologies such as high altitude balloons fabricated from ultra-thin film, and prototypes of pumpkin-shaped super-pressure balloons.

The French Space Agency, Centre National d'Etudes Spatiales (CNES), continued a vigorous balloon programme for atmospheric chemistry and astronomical studies using different types of balloons, viz., Zero Pressure Balloon, Infra-Red Montgolfière, Stratospheric Pressurized Balloon and Boundary Layer Pressurized Balloon. CNES operates balloon launches from two facilities, Aire sur 1'Adour in south-west France, and Gap in south-east France. The latter facility is used only for summer campaigns. French balloons are also launched from Teresina (Brazil) and from Kiruna (ESRANGE). CNES carries out an average of 40 stratospheric balloon launches every year, with payloads ranging from a few kilograms to one tonne, reaching altitudes of up to 40 km. The scientific payloads/gondola are developed by laboratories of the Centre National de la Recherche Scientifique (CNRS).

Technology and Mission Concepts

Balloon technology development has been continued in order to meet a broad set of diverse and challenging science requirements. NASA's ULDB project continued toward the development of a heavy-lift super-pressure balloon, using a simplified design paradigm that increases the balloon's stability. New mathematical models, that predict stability, have been developed and refined in order to predict the behaviour of large-scale designs. NASA remains on track to provide a large ULDB balloon to carry 2700 kg aloft for long duration flights upwards of 100 days. A 170,000 m^3 ULDB test flight was flown from Kiruna, Sweden. This test balloon, built by Aerostar International, was incrementally pressurized during the test flight to a level 10% above the maximum design pressure. The system maintained a constant float altitude during the flight and was terminated by command.

NASA has also continued its planetary balloon development. As a successor to the Vega mission, a full-scale metallized fabric prototype of a Venus balloon was fabricated and successfully passed a two-week buoyancy test at JPL. To simulate inflation during planetary entry, two high altitude Mars balloon drop tests were completed, one with a Mylar sphere and the other with a pumpkin balloon design. A 25 m diameter Mars solar Montgolfière balloon was fabricated and flight tested. Testing of a guided control parachute system with applications for rover placement on Mars was completed by Global Solutions in Science and Learning (GSSL). A prototype blimp for Titan was fabricated out of cryogenic materials and was successfully tested at JPL down to 93K. A ~10 m long Titan blimp is now under construction for testing in the near future.

A team led by the US Southwest Research Institute successfully demonstrated powered flight of the HiSentinel stratospheric airship at an altitude of 22.5 km. The 45 metre long airship carried a 27 kg equipment pod and propulsion system for a 5-hour technology demonstration flight. HiSentinel is a development programme for a family of long-endurance autonomous solar-electric, stratospheric airships. These low-cost systems will be capable of lifting small- to medium-payloads (10 to 100 kg) to near-space altitudes for durations of longer than 30 days.

In India, the INBF has successfully upgraded several balloon flight control and support systems. These included load-line monitoring, quadrifilar antennae, S-band telecommand receivers, and GPS_sonde systems. The capability of the GPS-sonde systems to monitor the ozone profile was successfully tested to an altitude of 42 km. The INBF also redesigned and successfully tested an integrated load-line package that reduced the total load line package from 56 kg to 20 kg, while significantly reducing the load-line length. This design was achieved while increasing functionality to include S-band two-way communications, ranging, and flight termination capability.

ISAS/JAXA carried out a drop test of a deployable flexible structure capsule, which can be a re-entry vehicle with a significantly low ballistic coefficient for future planetary exploration. The capsule successfully separated from the balloon, and demonstrated that the flight model was stable in both the transonic and subsonic flow regimes and that its flight path and aerodynamic characteristics were in good agreement with the results of trajectory analysis and wind tunnel tests. ISAS/JAXA have also continued to develop ultra-thin polyethylene films of good homogenous quality. By using metalosen catalysis, a 2.8 μm film was successfully manufactured in 2004. A 5000 m^3 balloon was fabricated using this film, and was successfully tested to an altitude of 43 km. The production of much larger balloons capable of floating a payload up to 10 kg in the mesosphere is being considered. A super-pressure balloon system is also being developed for flights lasting several weeks. Modelling results have been confirmed by pressurized tests of a 1120 m^3 pumpkin-shaped super-pressure balloon on the ground. Several test flights of 10-day duration, flying from Brazil to Australia are scheduled over the next two to three years.

Scientific Research

The Cosmic Ray Energetics and Mass (CREAM) payload was flown twice by NASA on a conventional balloon from the Antarctica. The first flight lasted a record-breaking 42-days, while the second one a year later flew for 28 days. The accumulated 70 days of flight demonstrated the functionality of both science instruments and the ULDB support systems developed by NASA to extend balloon flights to 100 days. Scientific data were gathered to inaugurate CREAM's quest to explore a limit to the acceleration of cosmic rays in supernova blast waves.

NASA launched the Balloon-borne Large-Aperture Sub-millimetre Telescope (BLAST) payload as the first LDB flight to be flown from Kiruna, Sweden. It flew for four days from Kiruna to Canada, as the scientific and technical precursor to the Herschel Space Observatory that is scheduled for launch in 2008. The design of BLAST closely mirrors that of the *Herschel*-SPIRE imaging photometer, with a similar optical system and nearly identical filters and detector arrays. The four-day flight was too short to meet the entire objective, so the instrument has been refurbished as a LDB flight in Antarctica for launch in December 2006.

Two major science prizes were awarded in 2006, resulting from NASA balloon or balloon-related missions. Dr John Mather and Dr George Smoot received the 2006 Nobel

Prize in Physics for discoveries based on data observed from the *COBE* satellite. Much of the *COBE* instrument formulation had its beginnings on earlier scientific balloon payloads. Dr Andrew Lange and Dr Paolo de Bernardis received the 2006 Balzan Prize for Astronomy and Astrophysics for their contributions to cosmology, in particular the Boomerang Antarctic balloon experiment.

INBF launched two 4000 m^3 sounding balloons to measure the vertical profile of ozone in the stratosphere up to 42 km over Hyderabad, the launches being were to coincide with the transit of two aircraft carrying atmospheric science payloads of the German Meteorological Institute, flying between Germany and Australia via Hyderabad.

ISAS/JAXA flew the Micro-Segment Chamber, an electromagnetic shower calorimeter consisting of stacked emulsion films and thin lead plates, which was able to identify 49 primary electrons above 20 GeV. A prototype of a new X-ray detector, which can measure the polarization of hard X-rays, was successfully flight tested. In another stratospheric flight, seven microbes were collected which have been cultured in the laboratory, and are to be checked for their UV-tolerance.

ISAS/JAXA flew six Antarctic balloon flights in cooperation with the National Institute of Polar Research. The polar patrol balloon flight, which aimed at observing primary electrons in the cosmic radiation, flew for 13 days at 34.6 km. During this flight, about 100 primary electrons over 100 GeV were identified. Two balloon flights were dedicated to stratospheric cryogenic sampling. The remaining three flights were designed to observe ozone at over 41 km in the stratosphere.

Several balloon flights were carried out by ISAS/JAXA as part of international collaborative projects. Three flights to study auroral oxygen ion emission observations with an all-sky spectrograph were conducted at the Nordlysstasjonen, Norway, in 2004 and 2005, in cooperation with the Alfred Wegener Institute, Germany. In 2004, a payload for far-infrared spectroscopy of interstellar material was launched from Hyderabad, India, in collaboration with the Tata Institute of Fundamental Research. NASA, in collaboration with ISAS/JAXA, flew the Balloon-borne Experiment with Superconducting Spectrometer (BESS) polar spectrometer for an 8½-day Antarctic flight, searching for a possible excess of low energy antiprotons that could provide evidence for the existence of primordial black holes and other dark-matter candidates dating from the creation of the universe. This flight more than doubled the data collected over the previous decade with conventional (< 1-day) flights of the original BESS spectrometer in Canada. Nine million cosmic-ray events were recorded during the flight. While no anti-helium has ever been discovered in the cosmic radiation, the BESS-Polar flights will set new limits on a possible anti-helium flux.

CNES, in collaboration with ESA and DLR, organized two balloon campaigns from Terezina and Kiruna, Sweden. The focus of the programme was to continue the validation of stratospheric chemistry measurements, related to ozone loss, obtained by the MIPAS, GOMOS and SCIAMACHY payloads on-board the *Envisat* satellite. The

balloon payloads flown were LPMA, SPIRALE, SDLA, SAOZ, SALOMON, DOAS, MIPAS and TRIPLE.

CNES and the Laboratoire de Météorologie Dynamique (IPSL) carried out the Strateole-Vorcore stratospheric balloon campaign in September-October 2005, from McMurdo base in Antarctica. This campaign benefited from significant support of the NSF and the French Polar Institute (Institut Paul-Émile Victor). The main objective was to study the dynamics of the polar vortex when the ozone hole forms at the end of the winter. This includes the characterization of planetary waves and their role in particle dispersion and mixing in the vortex core, the description of shorter-scale gravity waves above Antarctica, and the study of the dynamical isolation of the vortex. The project's uniqueness comes from the observation system used to reach those objectives, i.e. a flotilla of long-duration closed, super-pressure spherical balloons, that are able to fly for several months in the lower stratosphere and carry a light meteorological payload. These balloons, of 8.5 - 10 m diameter, which were specifically developed by CNES for the campaign, stay on constant-density surfaces and therefore have the capability to perform quasi-Lagrangian flights.A broad international research community has commenced the analysis of more than 150,000 observations, corresponding to a total of 1575 flight days of the 25 balloons launched during the campaign.

The African Monsoon Multidisciplinary Analysis (AMMA) is a project led by the Institut de Recherché pour le Developpement (IRD) to improve understanding of the West African Monsoon and its influence on the physical, chemical and biological environment, and to provide the underpinning science to issues of health, water resources, food security and demography for West African nations. In support of the AMMA project, CNES carried out three balloon campaigns in 2006 from Cotonue (Benin), and Niamey and Zinder (Niger).

CNES is developing an original vehicle called AeroClipper to study the heat exchanges between the atmosphere and the oceans. It consists of a balloon system equipped with a guide rope, that is in contact with the surface of the ocean. The balloon, in lift deficit, is stabilized at the altitude of 60 m and its movement is driven by the surface wind. The instrumentation is divided into an atmospheric gondola, for the measurement of atmospheric parameters, and an oceanic gondola at the guide rope extremity to measure ocean salinity and surface temperature. During two Variabilité Atmosphérique intraSaisonnière et Couplage Océanique (VASCO) campaigns, 11 AeroClipper and 8 Boundary Layer Pressurized Balloons (BLPB) were released, resulting in 160 days of measurements.

XI. POTENTIALLY ENVIRONMENTALLY DETRIMENTAL ACTIVITIES IN SPACE

The following report by the COSPAR's Panel on Environmentally Detrimental Activities in Space (PEDAS) covers the time span from October 2004 to September

2006. It only addresses the space debris issues, which represent the current focus of PEDAS activities.

Most of the deterministic knowledge on objects orbiting the Earth is obtained from the US Space Surveillance Network (SSN), which can detect and track object down to 5 cm in low-Earth orbit altitudes (LEO), and down to about 1 m at geostationary orbit altitudes (GEO). Their unclassified catalogue in 2006 comprised about 9700 objects, of which no more than 6% were operational payloads, while about 40% were fragments from more than 200 break-up events. There were 53 successful launches in 2004, and 52 in 2005, the lowest number since 1961. In spite of the relatively low level of launch traffic, recent simulations conducted by NASA indicate that in the next 50 years, at altitude regions between 900 and 1000 km, long-term collisional cascading will prevail over the currently dominant explosions as a source of debris and create an accelerated population growth in those regions. It was concluded that this predicted trend, which was confirmed by members of the Inter-Agency Space Debris Coordination Committee (IADC), can only be prevented by actively removing large objects from this altitude regime. Three confirmed on-orbit collisions in 1991, 1996 and 2005, all of which occurred in the LEO region between 680 km and 980 km altitude, appear to support the model forecast. However, all events so far were non-catastrophic, producing only 6 additional catalogue objects in total.

The mean on-orbit fragmentation rate of spacecraft and orbital stages is about 4.5 per year, with no major change in the past years. Apart from two confirmed explosions in GEO, all other known events occurred in LEO orbits, or in orbits passing through the LEO region. Within two years, since October 2004, six explosions (with two for the same source object), two anomalous release events, and possibly one low-energy collision were noted. While this statistic confirms the historic mean annual fragmentation rate, the mean age of the source objects seems to have increased, which points to evidence of the implementation of mitigation measures in recent years, and their consequent effectiveness in limiting the creation of new space debris.

Observations of the GEO region with the 1 m ESA space debris telescope revealed ‘clouds’ of objects down to 15 cm in size. They seem to indicate the occurrence of up to 10 hitherto unnoticed explosion events in GEO, which emphasize the need for performing end-of-mission GEO re-orbiting to a graveyard orbit, about 300 km above the GEO ring, with subsequent passivation of the payload. In 2004 and 2005, a total of 29 GEO payloads reached their end of life. Of these, 15 were re-orbited according to international guidelines (e.g. IADC), 10 were insufficiently re-orbited, and four were left in libration orbits. Again, this seems to indicate a positive trend in mitigation practices, as in the past about one third of all disposals fell equally into to each of these three categories.

In order to reduce the risk of high-energy collisions, particularly in LEO, several space agencies perform an assessment of high-risk conjunction events between their payloads and the known catalogue objects. In response to such predictions, NASA performed an avoidance manoeuvre for their 4-ton *Terra* spacecraft which was predicted

to pass a Scout G-1 upper stage within about 500 m on 17 October 2005, and ESA executed two such manoeuvres for their 8-ton *Envisat* spacecraft to avoid a potential 200 m fly-by with the same type of upper stage on 20 June 2006, and to avoid a potential 150 m pass of a Zenith-2 rocket body fragment on 10 October 2004.

To improve our knowledge of the space debris environment, ground-based radar and optical observations are continuing on a world-wide basis. Radar observations of the LEO region can today detect objects down to 2 mm in diameter (Goldstone bi-static radar), while optical observations of the GEO regions cover object sizes down to 15 cm. Some of these space debris observation campaigns are coordinated within the framework of IADC. Recently, the European Incoherent Scatter Radar (EISCAT), normally used for ionospheric research, has started to contribute to such data. It can detect LEO objects down to 2 cm in size. At sub-mm sizes, in situ detectors and retrieved surfaces are the preferred space debris data sources: ESA's DEBIE-1 impact detector has been successfully operating on a Sun-synchronous LEO since October 2001, the *Hubble Space Telescope* (*HST*) solar arrays, retrieved during the third servicing mission in March 2002, have recently had their impact analysis completed, and NASA continues to examine Space Shuttle orbiters on a routine basis for debris and meteoroid impacts following their return to Earth. With one of the last Shuttle missions, NASA plans to deploy a large-area debris collector (LAD-C). Measurements across all relevant size regimes are generally in good agreement with the most widely used space debris and meteoroid environment models.

In Europe, consideration is being given to the possibilities for a space surveillance and space situational awareness capability based on a single bi-static radar, and a global network of telescopes. Supporting ESA studies have confirmed the feasibility of such a concept which builds on knowledge acquired in pilot programmes in France, the UK, and by ESA.

To preserve the long-term stability of the space debris environment, the removal (de-orbit) of mass from the LEO region is essential. Initially, this refers to operational payloads and rocket stages after their mission completion. Later, this should also include inert objects in orbit. For safe de-orbit operations, it is important to analyse the re-entry survival potential, in order to assess the risk on the ground. NASA has completed such analyses for the *Terra* spacecraft, and for the *HST*. ESA and CNES are performing similar assessments for Ariane stages and for the Automatic Transfer Vehicle (ATV).

Space debris is a global problem, which can only be solved by cooperation at an international level. The IADC, as coordinating body and initiator of technical research, is of paramount importance in this context. IADC has 11 members from all major space-faring nations. They meet annually to facilitate technical information exchange. The 23rd IADC meeting was held in April 2005 at ESOC, in Darmstadt, Germany, hosted by ESA. The 24th meeting was held in April 2006 at Tsukuba, Japan, hosted by JAXA. Major achievements in the past two years include the IADC Space Debris Mitigation Handbook, a comparison of different space debris environment models, the use of tethers for debris mitigation, and coordinated measurement campaigns with radars in LEO, and with

telescopes in GEO. In addition, IADC conducts annual re-entry prediction exercises so as to be prepared for high-risk re-entry events. In addition, the International Academy of Astronautics (IAA) contributes actively to progress in space debris research. In October 2005, the Academy published a position paper on 'Space Debris Mitigation – Implementing Zero Debris Creation Zones'.

In presentations at several international fora, the importance of the stability of disposal orbits for GEO and for semi-synchronous navigation constellation orbits was highlighted. New, more economical disposal recommendations with so-called 'eccentricity vector control' could be the result. Such options are also discussed at ISO, where standards for space debris mitigation are being developed.

Since 1994, space debris has been an official agenda item in the Scientific and Technical Sub-Committee (STSC) of the United Nations' Committee on the Peaceful Uses of Outer Space (UNCOPUOS). Several national delegations, as well as ESA and IADC, are regularly reporting on their space debris activities at the STSC. In 2003, in response to STSC requests, the IADC Space Debris Mitigation Guidelines were presented. Starting from the IADC Guidelines, several STSC delegations formed a working group to elaborate an alternative space debris mitigation document which was submitted for review as a conference room paper in 2006 (A/AC.105/C.1/2006/CRP.19). This document, with the title 'Space Debris Mitigation Guidelines of the STSC of UNCOPUOS', consists of a set of seven policy-level guidelines. It will be presented for acceptance at the February 2007 meeting of the STSC.

XII. RADIATION BELT ENVIRONMENT MODELLING

Radiation belt modelling is in continuous progress. This is mainly due to the increasing number of simultaneous multi-point in situ measurements and also due to the combination of complementary measurements (particles, waves, magnetic and electric fields).

In the last two years, the most noticeable progress in this field is the understanding of under which solar activity and solar wind conditions, relativistic electrons are accelerated to very high energies (known as killer electrons) in the radiation belts. From both observations and modeling, there is clear evidence that the chorus-waves (produced during the main phase of a magnetic storm) are responsible for electron acceleration in the core of the radiation belts. In some cases ambiguities still remain and have to be explained in the future. To make further progress, most efforts now concentrate on a better description of those waves and their detailed interactions with trapped electrons.

Thanks to enhanced exchanges between modellers and experimenters, several large datasets have been re-analysed in accord with new understandings. Significant progress has been made in improving the representation of in situ measurements, such as in the form of phase space densities at constant adiabatic invariants. These new analyses

are surely indebted to the increasing power of computers. As a result, new views emerge on particle dynamics. There are now many examples of magnetic storms, showing an internal (from the radiation belt point of view) relativistic electron build up.

The data assimilation techniques, adapted to the radiation belts, represents an important new topic, which has appeared over the past two years. Many scientist aspire to take advantage of the progress made in the recent past in oceanography and meteorology, to apply mature data assimilation methodology to the radiation belts. The first attempts have been made and the results are being continuously improved, as data analysis becomes better and the models more refined.

It is expected that new specification models, where data and physical models are combined, will be produced. Such new and conclusive attempts are expected to be seen by the time of the next COSPAR Assembly.

XIII. SPACE WEATHER

The importance of the space environment to our international assets, both to those situated in space as well as on the ground is increasingly being recognized. Contemporary societies increasingly rely upon orbiting satellites for applications, such as communication networks, global positioning for ship and airline navigation, and monitoring the Earth for research, weather forecasting, resource management and security. Astronauts now permanently inhabit the *International Space Station*. In parallel, the new frontiers in geophysical and heliophysical research include the exploration of the coupling processes between the traditionally studied regions (atmosphere, ionosphere, magnetosphere) at various time and spatial scales. Recent space weather progress has included substantial research activity and expansion of international programmes devoted to research and operational space weather.

On the operational side, the NOAA space-based assets (i.e. the space environment payloads onboard the *POES* and *GOES* spacecraft) have continued to provide publicly unique and invaluable continuous observation of high energy particles in space. The EUMETSAT spacecraft, *MetOp-A*, launched on 19 October 2006, which is also equipped with a space environment monitor system, is due to complete the *POES* constellation. Space environment surveillance services also rely on data collected by a ground- based network of observatories and from other ground- or space-based instruments, as for example the joint ESA-NASA *SOHO* mission, which has provided near real-time and continuous observation of the solar corona since 1995. The recent years have seen a rapid growth of internet-based data resources world-wide.

International collaboration in the development of space weather services is mainly supported by the International Space Environment Service (ISES). Several national weather agencies participate in ISES as well as two space agencies, NASA and ESA. The latter recently fostered the development of a European space weather service infrastructure through a 3 year pilot project.

On the scientific side, the International Living with a Star (ILWS) programme offers a framework for international collaboration in solar-terrestrial research. Within the ILWS advisory structure, a Task Group has been established to look at issues related to applications of the ILWS data. This 'end user' Task Group has been requested by the ILWS working group to examine the needs of space weather applications, to see to what extent the ILWS can help satisfy them, to recommend improvements which might be feasible, to recommend relationships with other activities to bolster applications, and to recommend further work. The NASA *STEREO* (*Solar Terrestrial RElations Observatory*) spacecraft, launched on 26 October 2006 will constitute a new resource for studying solar coronal phenomena.

SCOSTEP initiated in 2004 a new international scientific programme, CAWSES, aimed at significantly enhancing our understanding of the space environment and its impacts on life and society. The main functions of CAWSES are to help coordinate international activities in observations, modelling and applications, crucial to achieve this understanding, to involve scientists in both developed and developing countries, and to provide educational opportunities for students at all levels. The programme, which will last until 2008, includes four initial programme areas: solar influences on climate, space weather, climatology of the sun-Earth system, and atmospheric coupling processes. The first CAWSES campaign was held in March-April 2004 and involved more than 40 research activities.

A European funded initiative (COST 724 Action - Developing the Scientific Basis for Monitoring, Modelling and Predicting Space Weather) has been initiated and involves more than 17 countries in applied aspects of space weather research.

The Scientific Committee on Antarctic Research has recognized as an objective the need to address observation programmes for space weather research.

A number of activities are being coordinated in preparation for the 50th anniversary of the IGY 1957-58. This includes the International Heliophysical Year (IHY), the International Polar Year 2007-2008 and the electronic Geophysical Year (eGY). The IGY triggered the establishment of a world-wide system of data centres and physical observatories that are still in use today. Fifty years later, the new initiatives should provide a new impetus for space weather data acquisition and encourage the design of a prototype for a new operational space weather monitoring infrastructure.

An international organizing committee has been set-up and is preparing a plan for IHY. The objective of IHY is to discover the physical mechanisms at work, which couple the atmosphere of the Earth to events that drive them from the heliosphere. The systematic global study of this connection is to be the central theme of the IHY. In view of these aims, the following objectives have been proposed:

- to obtain a coordinated set of observations to study at the largest scale the solar-generated events which affect life and climate on Earth;

- to document and report the observations and provide a forum for the development of new scientific results utilizing these observations;
- to foster international cooperation in the study of heliophysical phenomena now and in the future;
- to communicate the unique scientific results of the IHY to the interested scientific community and to all the peoples of the Earth.

Involvement in the IHY is growing, and is being endorsed by many international agencies. In particular, the UN Office for Outer Space Affairs' (OOSA) Basic Space Science Programme dedicated the 2005 Moscow Workshop and its activities to the international coordination of IHY, particularly in developing countries. The IHY is likely to have a significant influence on the acquisition of data, and in the development of models for space weather applications.

The International Polar Year (IPY) will include research in both polar regions recognizing the strong links these regions have with the rest of the globe. It will involve a wide range of research disciplines, including the social sciences and the emphasis will be interdisciplinary in its approach and truly international in participation.

An International Association of Geomagnetism and Aeronomy (IAGA) task force has proposed that the world-wide scientific community should endorse and promote an electronic Geophysical Year (eGY) initiative. The IAGA task force strongly advocates: securing permission and release of existing data, creating access to information, and the conversion of relevant analogue data to digital form. The eGY would embrace all available and forthcoming geophysical data (e.g. atmospheric, ionospheric, geomagnetic, gravity) through the establishment of a series of 'virtual geophysical observatories' now being 'deployed' in an electronic network. The eGY would be based on the existing and continually developing computing/networking technologies and international information technology infrastructure.

XIV. PLANETARY PROTECTION

Planetary protection is concerned with biological interchange in the conduct of solar system exploration, including: (1) possible effects of contamination of planets other than the Earth, and of planetary satellites within the solar system by terrestrial organisms, and (2) contamination of the Earth by materials returned from outer space carrying potential extraterrestrial organisms. This area of space policy and its implementation accord with the provisions of Article IX of the United Nations Outer Space Treaty of 1967, which states that:

> "…parties to the Treaty shall pursue studies of outer space including the Moon and other celestial bodies, and conduct exploration of them so as to avoid their harmful contamination and also adverse changes in the environment of the Earth resulting from the introduction of extraterrestrial matter and, where necessary, shall adopt appropriate measures for this purpose…"

Although the existence of life elsewhere in the solar system has not been demonstrated, recent discoveries about the adaptations of Earth life to extreme environments, data suggesting the potential for liquid water existing on and near the surface of Mars in recent times, and the continuing evidence supporting the existence of a liquid water ocean on Europe suggest that the contamination of other solar system bodies is possible. Furthermore, the potential for life elsewhere in the solar system demands prudence in the planning and execution of missions that will return to Earth materials from other bodies in the solar system.

During the period from September 2004-September 2006, a variety of missions to other solar system bodies have been launched in compliance with the planetary protection policy that is maintained by COSPAR in support of the objectives of the Outer Space Treaty. Under the COSPAR policy, the concern for contamination is given from Category I (no concern) through to Category IV (greatest concern; landing spacecraft), with Category V reserved for Earth-return missions.

Significant Mission Events (Category II and Above Missions)

The NASA/ESA *Cassini* mission (Category II), in orbit around Saturn, had its first close encounter with Saturn's moon Titan in October 2004 and, on 14 January 2005, the ESA *Huygens* probe successfully entered the atmosphere of Titan and landed on its surface. The probe provided chemical and physical composition data about that moon, and images of the strange, cold (~95K) world hidden in Titan's dense (over 1.5 times the pressure of the Earth's) atmosphere. *Cassini* continues to discover new facts about the Saturnian system every day, with one of the more significant findings (for planetary protection) being that Saturn's moon Enceladus contains liquid water below its surface, and regularly jets that water into space by mechanisms that remain to be characterized and understood. Nonetheless, those interested in the evolution of organic chemistry in the solar system are intrigued by this frozen, yet active, world.

NASA's *Deep Impact* mission (Category II), launched on 12 January 2005, accomplished its planned impact of an instrumented projectile into comet P/Tempel 1 during the planned close encounter on 4 July 2005. The impact provided a unique look into the freshly exposed material and revealed data about what is hidden deep below the surface of the comet.

The NASA *Mars Reconnaissance Orbiter* (Category III), successfully launched from Cape Canaveral, Florida on 12 August 2005 aboard an Atlas-5 launch vehicle. The orbiter (*MRO*) contains a high resolution camera system and other instruments and, by September 2006 – after aerobraking in Mars orbit, attained its prime science orbit. This initial science orbit is incompatible with orbital lifetime restrictions, so *MRO* has had to meet total bioburden requirements, as per the COSPAR policy. In this implementation, portions of the spacecraft that, in the case of a premature orbital failure, will reach 500°C for over ½ a second as the spacecraft enters the Martian atmosphere will be exempted from bioburden accounting.

The JAXA-launched *Hayabusa* mission rendezvoused with asteroid 1998/Itokawa (formerly 1998 SF36) in August 2005 and, although there were some anomalies in the collection process, it is still possible that a sample of that asteroid will be returned to Earth sometime after 2007. The return phase of this mission (Category V) has been assessed as 'unrestricted Earth return' in the current COSPAR policy framework.

NASA's *Stardust* mission successfully returned its cargo of cometary dust particles to Earth on 15 January 2006, landing safely in the Utah desert. Stardust was a Category II/V mission under the COSPAR (and NASA) policy, being Category II outbound and Category V, 'unrestricted Earth return', inbound. Mission results are reshaping our view of what comets are, as well as where and how they formed.

On 19 January 2006 NASA's *New Horizons* mission to Pluto (Category II) was launched. The spacecraft will cross the orbits of all the planets from Earth to Neptune and fly by Pluto and Charon in July 2015. Seven science instruments on the piano-sized *New Horizons* probe will shed light on the surface properties, geology, interior makeup and atmospheres of Pluto and Charon, with a Jupiter gravity assist (and Jupiter observations) planned for February 2007, and an extended mission to investigate other Kuiper-Belt objects during the period 2016-2020.

Other Missions in Operation

Other missions currently in operation and of primary interest for planetary protection, showing their respective planetary protection categories, are listed below:

The NASA *Mars Global Surveyor* mission (Category III) continues in orbit around Mars, and remains active scientifically. The spacecraft is expected to meet its 50-year lifetime requirement in good order.

The NASA *Mars Odyssey* mission (Category III) continues its mission science phase in orbit around Mars. Additional results from *Odyssey* are documenting widespread hydrogen, interpreted as water ice, beneath the surface at medium to high Martian latitudes. The spacecraft continues to act as a communications relay for the Mars Exploration Rovers on the planet's surface. Over 80% of all rover data has been relayed through *Mars Odyssey*.

ESA's *Mars Express* orbiter (Category III) continues its mission science activities in polar orbit around Mars, providing high resolution views of Mars through its stereo camera system and other instruments, and sounding the Martian subsurface with its long-wave radar.

The two NASA Mars Exploration Rover missions (Category IVa) continue to operate on the Martian surface. Initial results from Opportunity demonstrated the past presence of standing liquid water on Mars, while Spirit, on the other side of Mars, has also detected liquid water in the distant past on Mars. The two spacecraft completed all

science objectives within their nominal (90 Sol) missions, and continue on extended missions now in their third Earth year.

The ESA *Rosetta* mission (Category II) is continuing on its 10½ year cometary odyssey to 67P/Churyumov-Gerasimenko. The mission will include the first soft landing, in situ analysis, and panoramic images from a comet's surface, reaching the four-kilometre (2.5-mile) diameter comet in May 2014.

The NASA MErcury Surface Space ENvironment, GEochemistry, and Ranging (*Messenger*) mission, set to become the first spacecraft to orbit the planet Mercury, continues en route, approaching the first of its two Venus flybys, with three Mercury flybys planned before it enters orbit around Mercury in March 2011. *Messenger* is the second spacecraft sent to Mercury, with the third (*BepiColombo*) being prepared by ESA for launch early in the next decade (2013).

Missions in Development/Planning

NASA's *Phoenix* mission (a Category IVc lander) is being developed for launch in 2007 by a Delta-II launch vehicle from Cape Canaveral, Florida. The mission will investigate sites of possible high ice concentrations in the northern plains of Mars. The mission plans to access the Martian subsurface via vertical mobility, and so its robot arm will be sterilized prior to launch and kept sterile until the probe reaches Mars.

Work is underway at NASA's Jet Propulsion Laboratory for a *Mars Science Laboratory* (Category IVc) scheduled for the 2009 launch opportunity to Mars. This multi-instrument-carrying rover is expected to make a soft landing on Mars in 2010. It, too, is intended to dig on Mars.

ESA's *Aurora* programme for future Mars exploration envisages a series of missions to land on Mars and ascertain its suitability for future human exploration. ESA has undertaken payload selections for a 'Pasteur' instrument suite for its *ExoMars* mission, now planned for the 2013 launch opportunity. *ExoMars* could end up being either Category IVc or Category IVb (mission planning life detection experiments that could be compromised by the presence of Earth organisms), but is expected to provide necessary ground truth for the presence of life-related organics on and below (up to 2 m depth) the Martian surface.

COSPAR Activities in Planetary Protection

Solar system exploration has entered a new era of activity and multinational cooperation. A number of the currently envisaged missions are targeted to bodies that have significant interest with respect to the origin of life and chemical evolution, and the potential for biological studies. In the past year three space agencies (ESA, JAXA and NASA) had spacecraft approaching or landing on Mars, and international cooperative missions are in operation to comets, asteroids, the giant planets and their moons.

COSPAR has an important role as the standard-setting international organization in the area of planetary protection, as it provides a necessary reference for international missions to such bodies. The Panel on Planetary Protection was formed in 1999 to consolidate and further develop the COSPAR planetary protection policy. As initially envisaged in the early 1960s, the COSPAR policy has come to form the basis for international agreements on provisions to protect other solar system bodies from Earth-source biological contamination, and to protect the Earth from potential extraterrestrial biological contamination. Accordingly, the Panel (with the assent of the COSPAR Bureau and Council) has become the forum within which the de facto international standard for planetary protection is forged and promulgated.

At its meeting during the 34th Scientific Assembly on 20 October 2002 in Houston, Texas, USA, the COSPAR Council adopted the revised and consolidated planetary protection policy that the Panel had developed in Williamsburg. In addition to providing specific guidelines that incorporated new policy requirements for Mars and Europa, the new COSPAR policy recommends that launching parties provide information to COSPAR about the procedures and computations used for planetary protection for each flight. One mark of its utility is that NASA has included the COSPAR policy as the basis for planetary protection measure to be undertaken consequent to any bilateral or multilateral agreements for joint solar-system exploration missions, and all international parties to date have accepted that basis, including ESA, CNES, DLR, CSA, RSA, and JAXA.

Recent activities of COSPAR focus on two areas of planetary protection activities. One area is further policy development and the explicit maintenance and promulgation of the existing COSPAR policy. Multilateral efforts are being made to define requirements for planetary bodies where emerging scientific evidence suggests that not only there exist contamination concerns, but that the body (Mars in particular) may have different prospects for Earth-source contamination depending on the specific location to be explored on the planet's surface. Coupled with new microbiological techniques to measure spacecraft cleanliness, new standards and requirements are to follow, based both on COSPAR's internal deliberations and on the recommendations of the US National Research Council's Committee on Preventing the Forward Contamination of Mars. The second area of planetary protection activities is the dissemination of knowledge about the COSPAR policy and its implementation. This has been undertaken under the broad charter of the Panel on Planetary Protection, which continues as an essential meeting ground for space agencies conducting solar system exploration missions on understanding the potential for life, and life-related molecules within Earth's own neighbourhood.

XV. CAPACITY BUILDING

Capacity Building Workshop programme

COSPAR's programme of Capacity Building Workshops is becoming well established. A workshop on X-ray astronomy was held at the University of KwaZulu-Natal in Durban, South Africa from 28 June to 9 July 2004. A second workshop was held in collaboration with the Centre Royale de Teledetection Spatiale (CRTS) from 19 to 30 September 2005, in Rabat, Morocco. This workshop broke new ground, as it was the first in the series on Easrth observation topics, in this case oceanography. Around the time of the Assembly in Paris, COSPAR conducted a major review of the activities of all its Commissions and Panels, that included the Panel on Capacity Building. One of the conclusions of the review was that capacity building workshops should cover the whole range of sciences in which the COSPAR community is active: the Rabat workshop was intended to give effect to that recommendation. Both of these workshops received grants from organizations in the host countries and were held in collaboration with, respectively, IAU and UN's Office of Outer Space Affairs (UN/OOSA) (Astronomy workshop), ESA, IFREMER, IRD, ISPRS, Medias-France, MERCATOR OCEAN, The MERSEA Project, the UK Meteorological Office, UNESCO/IOC, and the University of Plymouth (Oceanography workshop). COSPAR is indebted to the organizers of these workshops – Arthur Hughes and Peter Willmore (Durban) and Jean-Louis Fellous, Driss el-Hadani and Raymond Zaharia (Rabat) –for their sterling efforts.

It has already been remarked that, at its 35th Scientific Assembly in Paris, in 2004, the President of COSPAR, Professor R-M Bonnet, initiated a wide-ranging review of COSPAR's activities with a view to ensuring these are appropriately matched to today's requirements. In the case of Capacity Building, the review largely supported the current programme and the methods of effecting it. The programme is in the hands of the Panel for Capacity Building (Chair: A P Willmore); the Panel seeks proposals for new workshops from the COSPAR community, primarily at the biennial assemblies, in order to ensure that topics and locations are of genuine value to both the community and the host institutes. Seven proposals were received for the 2006-8 period, most of them having been submitted at the 2006 Scientific Assembly. A formal filtering process resulted in the selection of two proposals, both of which are for workshops in 2007 (there were none in 2006). The first of these is for a magnetosphere workshop (based on the *Cluster* mission) to be held in Sinaia, Romania, in June 2007. This workshop is now in a very advanced stage of planning and is being organized by Octav Marghitu, Thierry Dudok de Wit and Joachim Vogt. The second is for a Planetary Science workshop to be held in Montevideo, Uruguay, for which the planning is in progress (with Gonzalo Tancredi and Mike A'Hearns as organizers).

These workshops are intended to exploit the vast archives of data from space missions which now exist and are a most valuable resource for world class research. The archives are readily available over the internet, together with the software for all stage of data analysis. The workshop programme aims to ensure that scientists in the developing countries are aware of the opportunity which the archives and their associated software

offer them, and that they will receive practical training in using both data and software at the workshops. Details of the character and objectives of the workshops will be found at www.cosparhq.org/Meetings/Workshops.htm, together with accounts of previous workshops.

Discussion on Capacity Development at the 36th Scientific Assembly

The Panel organized a half-day discussion at the 36th Scientific Assembly in Beijing, China, under the title 'Opportunities for Capacity Building associated with the IHY', which focused mainly on activities connected with the International Geophysical Year in developing countries, and the opportunities which the IHY organization and facilities would present to scientists in developing countries. This meeting was organized by Peter Martinez.

The Panel held its usual business meeting, mainly to discuss its plans for the Montreal Assembly in 2008. The Beijing assembly was notable for the attendance, for the first time, of a number of 'graduates' from the COSPAR Capacity Building workshops, who were presenting papers at the scientific sessions. Two of these attended the business meeting (Diego Altamira of Argentina, and Urama Johnson of Nigeria), and described their experience at the workshops. Both remarked on the important effect which the workshops had had in developing their careers.

Conclusion

COSPAR's programme in the area of capacity building, though still being developed, is becoming well established. There is growing evidence that the particular workshop format used really makes them of lasting value to the participants. The workshop programmes involves a partnership with a wide range of international organizations, space agencies and research councils which have common goals to those of COSPAR in this area, and this collaboration is acknowledged. It also depends crucially on the efforts of the workshops organizers and the large number of lecturers who take part, and these also are gratefully acknowledged.

CONTRIBUTORS

The report submitted by the International Astronautical Federation (IAF) for Part One (Highlights in Space Technology and Applications for 2006) was prepared by Jerry Grey, President Emeritus of IAF (for Anne-Marie Mainguy, Vice-President, Technical Activities of IAF and Madhavan Nair, Vice-President, Scientific Activities of the International Academy of Astronautics (IAA) and was approved by James Zimmerman, President of the IAF. The International Institute of Space Law (IISL) contribution on international cooperation and space law was prepared by Sylvia Ospina, Member of the IISL Board of Directors, in cooperation with Ingo Baumann, DLR, Germany. Information was compiled from submissions of IISL Members and other sources. The IISL contribution is intended to highlight important events, and does not pretend to be all-inclusive. The IISL regrets any inconsistencies and/or omissions it may contain.

Part Two of the report (Progress in Space Research 2005-2006) was prepared by the Committee on Space Research (COSPAR) in response to a request from the Scientific and Technical Subcommittee of the United Nations Committee on the Peaceful Uses of Outer Space, and provides an overview of the progress in the various disciplines of space research science during the years 2005 and 2006. The report is organized in a manner that reflects the scientific domains of COSPAR's Scientific Commissions and Panels. Although many people contributed to this report, the major part of the scientific input was provided by the following persons:

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ACRONYMS, ABBREVIATIONS AND DEFINITIONS

Abdus Salam ICTP	Abdus Salam International Centre for Theoretical Physics
ACD	Atmospheric Chemistry Division
ACE	Advanced Composition Explorer
ACTIVE	Interkosmos 24 - ionosphere satellite mission launched in 1989
ADEOS	Advanced Earth Observing Satellite
AE-C/D/E	Atmospheric Explorer satellites
AEROS	Upper atmosphere & ionosphere study mission launched 1972
AESOP	Anti-Electron Sub-Orbital Payload
AFRL	Air Force Research Laboratory
AGILE	Astro-rivelatore Gamma a Immagini Leggero (ASI)
AIM	Aeronomy of Ice in the Mesosphere
Akari	Previously known as ASTRO-F or IRIS - InfraRed Imaging Surveyor (Japan)
AKEBONO	an aurora observation satellite (JAXA)
ALOMAR	Arctic Lidar Observatory for Middle Atmosphere Research
ALOS	Advanced Land Observing Satellite
Alouette	Ionospheric observatory satellite (Canada) launched in 1962
ALTAIR	Advanced Research Project Agency (ARPA) Long Range racking and Identification Radar
ALTEA	Anomalous Long Term Effects in Astronauts
AMIE	Asteroid-Moon Micro-Imager Experiment
AMISR	Advanced Modular Incoherent Scatter Radar
AMMA	African Monsoon Multidisciplinary Analyses
AMS	Alpha Magnetic Spectrometer
AMSU	Advanced Microwave Sounding Unit
APXS	Alpha Particle X-ray Spectrometer
Aqua	NASA Earth observation satellite
AquaHab	Closed Aquatic Habitat Research Facility
Ar	Argon
Ariane 5	Launch vehicle
ARPA	Advanced Research Project Agency
ASCAT	Advanced Scatterometer
ASGSB	American Society of Gravitational and Space Biology
ASI	Agenzia Spaziale Italiana
ASPERA	Energetic Neutral Atoms Analyser
ASR	Advances in Space Research (the official journal of COSPAR)
Astro F	See Akari
ASTROSAT	Planned multiwavelength astronomy satellite (India) (2007/2008)
Atlas-5	Launch vehicle
A-Train	Satellite constellation consisting of the Aqua, CloudSat, CALIPSO, PARASOL, and Aura satellite missions
ATV	Automatic Transfer Vehicle
AU	Astronomical Units
Aurora	ESA solar system exploration programme
AVHRR	Advanced Very High Resolution Radiometer
AVNIR	Advanced Visible and Near-Infrared Radiometer
BBF	Bursty Bulk Flows
BCAT	Binary Colloidal Alloy Test

BEAGLE-2	Geochemical lander module (UK)
Beijing-1	Imaging microsatellite (China)
BelKA	Belarusian Cosmic Aparatus
BepiColombo	Proposed ESA/JAXA Mercury orbiter (2012)
BESS	Balloon-borne Experiment with a Superconducting-magnet Spectrometer
BLAST	Balloon-borne Large Aperture Sub-millimetre Telescope
BLPB	Boundary Layer Pressurised Balloons
BLSS	Bioregenerative Life Support System
BXF	Boiling Experiment Facility
C	Carbon
CALIOP	Cloud-Aerosol Lidar with Orthogonal Polarization
CALIPSO	Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observation
CAM	Community Atmospheric Model
Cartosat	ISRO Remote Sensing Satellite
CASSINI	Joint NASA/ESA mission to study Saturn
CAWSES	Climate and Weather of the Sun-Earth System
CCD	Charge Coupled Device
CCM3	Community Climate Model
CD	Committee Draft
CDE	Cosmic Dust Experiment
CDM	Command Data Module
CEBAS	Closed Equilibrated Biological Aquatic System
CEDAR	Coupling Energetics and Dynamics of Atmospheric Regions
CEEF	Closed Ecology Experiment Facilities
CELSS	Controlled Ecological Life Support Systems
CERF	CERN-EU high-energy Reference Field
CERN	European Organisation for Nuclear Research
CFE	Capillary Flow Experiment
CHAMP	Challenging Mini-Satellite Payload for Geophysical Research and Applications
Chandra	X-Ray Observatory (NASA)
Chandrayaan-1	Lunar mission (India)
Chang'E1	Lunar orbiter (China)
Chang'E2	Lunar rover (China)
Chang'E3	Sample return mission (China)
CIP	Coordinated investment programme
CIPS	Cloud Imaging and Particle Size sensor
CIRA	COSPAR International Reference Atmosphere
CISM	Center for Integrated Space Weather Modelling
CIXS	Chandrayaan-1 Imaging X-Ray Spectrometer
Clementine	US Lunar orbiter
CloudSat	NASA/CSA satellite
CLUSTER	A mission consisting of four spacecraft designed to study the interaction between the solar wind and the magnetosphere
CMAM	Canadian Middle Atmosphere Model
CME	Coronal Mass Ejection
CNES	Centre Nationale d'Etudes Spatiales (France)
CNRS	Centre National de la Recherche Scientifique (France)
CNSA	China National Space Administration
COBE	Cosmic Background Explorer satellite

COLUMBUS	ISS laboratory module (ESA)
CONE	Combined sensor for Neutrals and Electrons
Constellation-X	Multi-satellite X-ray telescope (NASA)
CORONAS	Complex Orbital Near-Earth Observations of the Solar Activity (Russia)
Corot	Convection, Rotation & Planetary Transits space telescope (France)
COSMIC	Constellation Observing System for Meteorology, Ionosphere and Climate
COSMO	Constellation of small Satellites for Mediterranean Basin Observation
COSMOS 1809	Russian satellite launched in 1986
COSPAR	Committee on Space Research
COST	European Cooperation in the field of Scientific and Technical Research
CPP	Cold Plasma Probe
CPR	Cloud Profiling Radar
CREAM	Cosmic Ray Energetics and Mass
CRISM	Compact Reconnaissance Imaging Spectrometer
CRTS	Centre Royale de Teledetection Spatiale (Morocco)
CRYOSAT	Cryogenic Satellite (ESA satellite to measure Arctic ice) (lost during Oct. 2005 launch)
CSA	Canadian Space Agency
CSBF	Columbia Scientific Balloon Facility (formerly National Scientific Balloon Facility NSBF)
CSSTEAP	Centre for Space Science and Technology Education in Asia and the Pacific
CSU	Colorado State University
CTIM	Coupled Thermosphere-Ionosphere Model
CTIP	Coupled Thermosphere-Ionosphere Plasmasphere
CTX	Context Camera
CUTLASS	Co-operative UK Twin Auroral Sounding System
CW	Continuous Wave
Darwin	Infrared Space Interferometer
DAWN	A mission in the NASA Discovery Series designed to orbit and study asteroids Vesta and Ceres
D-CIXS	Demonstration of a Compact Imaging X-ray Spectrometer
DE	Dynamo Electric
DEBIE	First Standard Space Debris Monitoring Instrument
Deep Impact	A NASA Discovery-class mission designed to study the pristine material of a cometary nucleus
Delta II	US launch vehicle
DEMETER	Detection of Electro-Magnetic Emissions Transmitted from Earthquake Regions
DEOS	Department of Earth Observations and Space Systems
DIS	Draft International Standard
DLR	Deutsches Zentrum fuer Luft-und Raumfahrt (German Aerospace Centre)
DMC	Disaster Monitoring Constellation
DOAS	Differential Optical Absorption Spectroscopy
DOE	Department of Energy
DORIS	Doppler Orbitography and Radio-positioning Integrated by Satellite
Double Star	a joint ESA/Chinese project to study the effects of the Sun on the Earth's environment
EANA	European Astrobiology Network Association
ECMWF	European Centre for Medium Range Weather Forecasts

ECOMA	Existence and Charge State of Meteoric Dust Particles in the Middle Atmosphere
eGY	electronic Geophysical Year
EISCAT	European Incoherent Scatter Radar
ELGRA	European Low Gravity Research Association
ENVISAT	Environment Satellite
EO	Earth Observation (satellite)
EPDP	Electric Propulsion Diagnostic Package
EPEAD	Energetic Proton, Electron and Alpha Detector
EPIC	Equatorial Processes Including Coupling
EPS	EUMETSAT's Polar System
ERA	ECMWF Re-Analysis
ERS	European Remote Sensing Satellite
ESA	European Space Agency
ESI	Earth Surface Imager
ESOC	European Space Operations Centre
ESR	EISCAT Svalbard Radar
ESRANGE	Space operations centre of the Swedish Space Corporation
ESTEC	European Space Research and Technology Centre
EUMETSAT	European Organisation for the Exploitation of Meteorological Satellites
Eureca	European Rertrievable Carrier, a free-flying platform for space materials processing
EUV	Extreme Ultraviolet
eV	electron volts
ExoMars	ESA Exobiology mission to Mars (Planned launch 2011)
FAO	Federation of Astrobiology Organizations
Fe	Iron
FLEX	Flame Extinguishment Experiment
FLIP	Field Line Inter-hemispheric Plasma
FORMOSAT	Formosa Satellite Mission
FUSE	Far Ultraviolet and Spectroscopic Explorer (NASA)
g	Earth gravity
GAIA	Global Astrometric Interferometer for Astrophysics
GAIM	Global Assimilative Ionosphere Model
GALEX	Galaxy Evolution Explorer (NASA)
Galileo	European satellite radio navigation system
GCM	General Circulation Model
GCOS	Global Climate Observing System
GCPM	Global Core Plasma Model
GEM	Geospace Environment Modelling
Genesis	A NASA Discovery mission designed to collect solar wind
GEO	Geostationary Earth Orbit
GEO	Group on Earth Observations
GEOSS	Global Earth Observation System of Systems
Geotail	ISTP magnetotail mission (ISAS/NASA)
GERB	Geostationary Earth Radiation Budget
GHz	gigahertz
GI	Guest Investigator
GIOVE	Galileo In-Orbit Validation Element
GITM	Global Ionosphere Thermosphere Model

GLAST	Gamma-ray Large Area Space Telescope
GLONASS	Global Navigation Satellite System (Russia)
GNSS	Global Navigation Satellite System
GOCE	Gravity field and Ocean Circulation Explorer
GOES	Geostationary Orbiting Environmental Satellite
GOES	Geostationary Operational Environmental Satellite
GOME	Global Ozone Monitoring Experiment
GOMOS	Global Ozone Monitoring by Occultation of Stars
GP-B	Gravity Probe B
GPID	Global Plasmasphere Ionosphere Density
GPS	Global Positioning System
GRACE	Gravity Recovery and Climate Experiment
GRAS	Global Navigation Satellite System Receiver for Atmospheric Sounding
GRS	Gamma Ray Spectrometer
GSFC	NASA Goddard Space Flight Center
GSSL	Global Solutions in Science and Learning
GSWM	Global Scale Wave Model
GUVI	Global Ultraviolet Imager
H	Hydrogen
HAARP	High Frequency Active Auroral Research Program
Halca	Highly Advanced Laboratory for Communication and Astronomy (Japan) (formerly VSOP)
Hayabusa	An ISAS/NASA mission to bring back a sample of asteroid 1998/Itokawa. (Formerly MUSES-C)
HCl	Hydrogen Chloride (Hydrochloric Acid)
HCN	Hydrogen Cyanide
HDO	Hexanediol
Herschel	Formerly FIRST (Far Infra Red and Submillimeter Telescope) (ESA)
HETE-2	High Energy Transient Explorer (NASA)
HEUVAC	High-resolution version of the solar EUV irradiance model for aeronomic calculations
HF Radar	A decametric waves radar
HHP	Human Health and Performance
H-II A	JAXA launcher
HIMAC	Heavy-Ion Medical Accelerator in Chiba
Hinode	Observation mission with optical, X-ray and EUV telescopes (JAXA) (formerly Solar-B)
HiRISE	High Resolution Imaging Science Experiment
HIRS	High Resolution Infrared Radiation Sounder
HiSentinel	SWRI Stratospheric airship
hPa	hectoPascals
HRDI	High Resolution Doppler Interferometer
HRSC	High Resolution Stereo Camera
HST	Hubble Space Telescope (NASA/ESA)
HUYGENS	Probe of Saturn's moon Titan, included in the Cassini mission to Saturn
IAA	International Academy of Astronautics
IADC	Inter-Agency (space) Debris Coordination Committee
IAF	International Astronautical Federation
IAGA	International Association of Geomagnetism and Aeronomy
IALSWG	International Advanced Life Support Working Group

IAP	Institute of Atmospheric Physics (Germany)
IASF	Istituto di Astrofisica Spaziale e Fisica Cosmica
IASI	Infrared Atmospheric Sounding Interferometer
IAU	International Astronomical Union
IBER	Preliminary study of Investigations into Biological Effects of Radiation
IBMP	Institute of Biomedical Problems (Russia)
IBP	Institute of Biophysics (Russia)
ICCHIBAN	InterComparison for Cosmic-ray with Heavy Ion Beams At NIRS
ICESat	Ice, Cloud and Land Elevation Satellite
ICSU	International Council for Science (formerly International Council of Scientific Unions)
IES	Institute for Environmental Sciences (Japan)
IFREMER	Institut français de recherche pour l'exploitation de la mer
IGOS	Integrated Global Observing Strategy
IGS	International GNSS Service
IGY	International Geophysical Year
IHY	International Heliophysical Year
IIR	Imaging Infrared Radiometer
ILEWG	International Lunar Exploration Working Group
ILWS	International Living With a Star program
IMAGE	Imager for Magnetopause-to-Aurora Global Exploration
IMBP	Institute for Biomedical Problems (Russia)
IMP	Interplanetary Monitoring Platform
IMS	International Magnetospheric Study
INBF	Indian National Balloon Facility
INSAR	Interferometric Synthetic Aperture Radar
INTAS	International Association of New Independent States of the former Soviet Union
INTEGRAL	International Gamma Ray Astrophysics Laboratory imaging and spectroscopy project (ESA)
Interkosmos 19	Ionosonde satellite launched in 1979
IPSL	Institut Pierre Simon Laplace
IPY	International Polar Year
IR	Infrared
IRAS	Infrared Astronomical Satellite
IRD	Institut de recherche pour le développement
IRI	International Reference Ionosphere
ISAS	Institute of Space and Astronautical Sciences (Japan)
ISCS	International Solar Cycle Study
ISES	International Space Environment Service
ISIS	International Satellite for Ionospheric Studies
ISO	International Organization for Standardization
ISOLAB	International Symposium on Origins of Life and Astrobiology
ISPRS	International Society for Photogrammetry and Remote Sensing
ISR	Incoherent Scatter Radar
ISRO	Indian Space Research Organisation
ISRU	In-Situ Resource Utilization
ISS	International Space Station
ISSOL	International Society for the Study of the Origin of Life
ISTP	International Solar-Terrestrial Physics programme

ITM	Ionosphere, Thermosphere and Mesosphere
IZMIRAN	Russian Institute of Terrestrial Magnetism, Ionosphere and Radio wave Propagation
Jason	NASA/CNES ocean surface topography mission
JAXA	Japan Aerospace Exploration Agency
JB	Jacchia-Bowman Thermospheric Density Model
JERS	Japanese Earth Resources Satellite
JGU	Japan Geoscience Union
JPL	Jet Propulsion Laboratory
JSBSS	Japan Society for Biological Studies in Space
Juno	NASA Jupiter mission (launch scheduled 2010)
JWST	James Webb Space Telescope
K	Kelvin
K	Potassium
KATE	Ka-band Telemetry and Telecommand Experiment
KBO	Kuiper Belt Object
KBR	K-band ranging system
KEPLER	A NASA discovery-class mission consisting of a space telescope to search for Earth-like planets
keV	kilo electronvolts
KMCM	Kühlungsborn Mechanistic General Circulation Model
KOMPSAT	Korea Multi-Purpose Satellite
Koronas	See CORONAS
Koronas-Photon	See CORONAS. Mission aimed at detecting gamma-rays as well as neutrons (launch planned 2007)
Kr	Krypton
L1	Lagrange Point 1
L2	Lagrange Point 2
LAD-C	Large-Area Debris Collector
LASCO	Large Angle and Spectrometric Coronagraph experiment
LCROSS	Lunar Crater Observation and Sensing Satellite (NASA)
LDB	Long Duration Balloon flight operation
LDI	Laser Doppler Interferometry
LEO	Low Earth Orbit
LEO	Low Earth Orbiting (satellite)
LET	Linear Energy Transfer
LIDAR	Light Detection And Ranging
LIMA	Leibniz Institute Middle Atmosphere model
LISA	Laser Interferometer Space Antenna
LISA Pathfinder	Mission to test LISA technology
LPMA	Limb Profile Monitor of the Atmosphere
LSS	Life Support System
LTCS	Lower Thermosphere Coordinated Study
LTE	Local Thermodynamics Effect
Lunar Prospector	NASA Discovery Program mission
LUNAR-A	Japanese lunar penetrator mission (ISAS)
LWS	Living With a Star
MaCWAVE	Mountain and Convective Waves Ascending Vertically
MAGED	Magnetic Electron Detector
MAP	Middle Atmosphere Programme

MARCI	Mars Color Imager
MARIE	Martian Radiation Environment Experiment
MaRS	Mars Radio Science experiment
MARS EXPRESS	An ESA Mars exploration mission
Mars Global Surveyor	Mars orbiting mission (NASA)
Mars Pathfinder	NASA Mars Exploration mission
Mars Science Laboratory	Planned Mars rover mission (NASA)
MARSIS	Sub-Surface Sounding Radar/Altimeter
Matroshka	facility for radiation measurements under EVA conditions (ESA/Russia)
MB	Mössbauer Spectrometer
MCP	Meteorological Communications Payload
MCS	Mars Climate Sounder
MDI	Michelson Doppler Imager
MegaSIMS	A high-energy Secondary Ion Mass Spectromter (UCLA)
MELISSA	Micro-Ecological Life Support System Alternative
MERSEA	Marine Environment and Security for the European Area
MESSENGER	MEcury Surface Space ENvironment, GEochemistry, and Ranging
MetOp	Meteorological Operational satellite programme (ESA)
MF	Medium Frequency
MGS	Mars Global Surveyor (NASA)
MHD	MagnetoHydroDynamic
MHS	Microwave Humidity Sounder
MHz	mega hertz
MI	Microscopic Imager
Micro Segment Chamber	Electromagnetic shower calorimeter
MICROSCOPE	Microsatellite à traînée Compensée pour l'Observation du Principe d'Equivalence
MIDAS	Middle Atmosphere Dynamics And Structure
MINERVA	Micro/Nano Experimental Robot Vehicle for Asteroid (miniature rover of Hayabusa)
Mini-TES	Miniature Thermal Emission Spectrometer
MIPAS	Michelson Interferometer for Passive Atmospheric Sounding
MLT	Mesosphere and Lower Thermosphere
MM5	Meteorological simulation model
MMO	Mercury Magnetospheric Orbiter
MODIS	Moderate-resolution Imaging Spectro-radiometer
Monitor-E	Monitor Experimental (Russia)
MPO	Mercury Planetary Orbiter
MRO	Mars Reconnaissance Orbiter
MSE	Mesospheric Summer Echoes
MSG	Meteosat Second Generation
MSIS	Mass Spectrometer Incoherent Scatter
MST	Mesosphere/Stratosphere/Troposphere
MTSAT	Multi-function Transport Satellite
MU	Middle and Upper atmosphere
MUSES-C	See Hayabusa
M-V	JAXA launch vehicle
N	Nitrogen

Na	Sodium
NASA	National Aeronautics and Space Administration (USA)
NATO	North Atlantic Treaty Organization
NCAR	The National Center for Atmospheric Research (Boulder, CO, USA)
NCEP	National Centre for Environmental Prediction
Nd:YAG	neodymium-doped yttrium aluminium garnet
NEA	Near-Earth Asteroid
New Horizons	Mid-sized planetary exploration project (NASA)
NICMOS	Near IR Camera and Multi-Object Spectrometer
NLC	Noctilucent Cloud
NLTE	Non-local Thermodynamic Equilibrium
nm	nanometre
NOAA	National Oceanic and Atmospheric Administration
Nozomi	Japanese Mars orbiter
NPOESS	(US) National Polar-orbiting Operational Environmental Satellite System
NRL	Naval Research Laboratory
NRLEUV	EUV model at NRL
NRLMSIS	MSIS model completed at NRL
NRLMSISE-00	The new empirical model of the atmosphere
NSF	National Science Foundation
NSWP	National Space Weather Program
O	Oxygen
ODIN	1.1 m telescope to study interstellar chemistry and atmospheric ozone
Odyssey	NASA mission to map Mars
OGO-6	NASA magnetospheric study mission 1969-1979
OI	atomic oxygen
OMEGA	Visible and Infrared Mineralogical Mapping Spectrometer
OOSA	(UN) Office of Outer Space Affairs
Opportunity	A NASA Mars Explorer Rover mission
OSIRIS	Optical Spectrograph and Infrared Imaging System
PACIFICHEM	International Chemical Congress of Pacific Basin Societies
PALSAR	Phased Array type L-band Synthetic Aperture Radar
PAN	Panchromatic
Pancam	Panoramic Camera
Pasteur	ExoMars scientific payload
PCB	COSPAR Panel on Capacity Building
PDS	NASA Planetary Data System
PE	COSPAR Panel on Education
PEDAS	COSPAR panel on Potentially Environmentally Detrimental Activities in Space
PFS	Planetary Fourier Spectrometer
Phoenix	NASA Mars Lander
PI	Principal Investigator
PIP	Positive Ion Probe
Planck	Formerly COBRAS-SAMBA (Cosmic Background Radiation Anisotropy Satellite / Satellite for Measurement of Background Anisotropies)
Planet-C	Proposed JAXA mission to Venus (2009)
Plutino	A trans-Neptunian object in the 2:3 mean motion resonance with Neptune (e.g., Pluto, Orcus)
PMC	Polar Mesospheric Cloud

PMSE	Polar Mesospheric Summer Echoes
PMWE	Polar Mesosphere Winter Echoes
POD	Precise Orbit Determination
POES	Polar Orbiting Environmental Satellite
POLAR	NASA satellite designed to study the aurora and monitor space weather
PPARC	Particle Physics and Astronomy Research Council (UK)
PPP	COSPAR Panel on Planetary Protection
PRBEM	COSPAR Panel on Radiation Belt Environment Modelling
PRISM	Panchromatic Remote-sensing Instrument for Stereo Mapping
PSA	ESA Planetary Science Archive
PSB	COSPAR Panel on Technical Problems Related to Scientific Ballooning
PSC	Polar Stratospheric Cloud
PSD	COSPAR Technical Panel on Satellite Dynamics
PSLV	Polar Satellite Launch Vehicle
PSMOS	Planetary Scale Mesopause Observing System
PSW	COSPAR Panel on Space Weather
PVDF	Polyvinyldifluoride
RAPS	Reference Atmospheres for the Planetary System
RAT	Rock Abrasion Tool
Re	Earth radii
Resurs-DK1	Russian remote sensing satellite
RHESSI	Reuven Ramaty High Energy Solar Spectroscopic Imager
RMR	Rayleigh, Mie and Raman atmospheric scattering mechanism
RNA	RiboNucleic Acid
ROCSAT	Scientific satellite of Taiwan Province of China
ROMA	Rocket-borne Observations in the Middle Atmosphere
ROSE	Atmospheric model
ROSETTA	ESA mission to comet Wirtanen
Rossi-XTE	Rossi X-ray Timing Explorer (NASA)
RPI	Radio Plasma Imager
RSA	Russian Space Agency
RSIS	Radio Science Investigation with SMART-1
SABER	Sounding of the Atmosphere using Broad-band Emission Radiometry
SALOMON	Spectromètre d'Absorption Lunaire pour l'Observation des Minoritaires Ozone et Nox (CNRS/LPCE)
SAME	Smoke Aerosol Measurement Experiment
SAMPEX	Solar Anomalous and Magnetospheric Particle Explorer
SAOZ	Spectromètre d'Absorption par Observation Zénithale
SAR	Synthetic Aperture Radar
SARA	Sub-keV Atom Relecting Analyser
SBUV	Solar Backscatter Ultraviolet Radiometer
SC	Standing Committee
ScanSAR	Scanning Synthetic Aperture Radar
SCAR	Scientific Committee on Antarctic Research
SCIAMACHY	Scanning Imaging Absorption Spectrometer for Atmospheric Chartography
SCOSTEP	Scientific Committee on Solar-Terrestrial Physics
Scout	Launch vehicle (NASA)
SDLA	Senseur à Diode Laser
SDO	Solar Dynamics Observatory
SEE	Solar EUV Experiment

SELENE	Selenological and Engineering Explorer orbiter mission (JAXA)
SEM	Space Environment Monitor
SETI	Search for Extraterrestrial Intelligence
SEVIRI	Spinning Enhanced Visible and Infrared Imager
SHARAD	Shallow Radar
SIM	Space Interferometer Mission (NASA)
SIR	SMART-1 Infrared Spectrometer
SIR-2	Near-Infrared Spectrometer
SIRAL	Synthetic Aperture Interferometric Radar Altimeter
SIRTF	Space Infra-Red Telescope Facility, now Spitzer Observatory (NASA)
SJ-8	ShiJian-8, a Chinese seed-breeding satellite
SLR	Satellite Laser Ranging
SMART-1	Small Missions for Advanced Research in Technology (ESA)
SNOE	Student Nitric Oxide Explorer
SOFIE	Solar Occultation For Ice Experiment
SOHO	Solar and Heliospheric Observatory
Sojourner	Rover of Mars Pathfinder
Solar A	See Yohkoh
Solar B	See Hinode
Solar Orbiter	ESA solar mission to be launched in 2015
SOLAR-2000	Solar irradiance model
SORCE	Solar Radiation and Cloud Experiment
SOXS	Solar X-ray Spectrometer
Soyuz-Fregat	Launch vehicle
SPE	Solar Proton Event
SPEAR	Space Plasma Exploration by Active Radar
SPEDE	Spacecraft Potential, Electron and Dust Experiment
SPICAM	Ultraviolet and Infrared Atmospheric Occultation Spectrometer
SPICE	Smoke Point in Coflow Experiment
SPIRALE	Spectromètre InfraRouge pour l'étude de l'Atmosphère par Diodes Laser Embarquables (CNRS/LPCE)
SPIRE	Spectral and Photometric Imaging Receiver
Spirit	A NASA Mars Explorer Rover mission
Spitzer	NASA space infrared telescope facility
SPR	Surface Plasma Resonance
SRAMP	STEP Results, Applications and Modelling Phase
SRI	Stanford Research Institute
SROSS	Stretched Rohini Satellite Series (India)
SSN	Space Surveillance Network (USA)
SSOEL	Society for the Study of Origin and Evolution of Life (Japan)
SSW	Stratospheric Sudden Warming
STARDUST	NASA Discovery-class mission to fly past comet Wild 2
STEP	Satellite Test of the Equivalence Principle
STEP	Solar-Terrestrial Energy Programme
STEREO	Solar Terrestrial Relations Observatory
STIS	Space Telescope Imaging Spectrometer
STP	Space Test Program
STP	Solar Terrestrial Probes
STSC	Scientific and Technical Sub-Committee (of UNCOPUOS)
SunRISE	Radiative Inputs of the Sun to the Earth solar synthesis model

SuperDARN	Super Dual Auroral Radar Network
SUPIM	Sheffield University Plasmasphere Ionosphere Model
SURA	Southeastern Universities Research Association
Suzaku	Japanese X-ray astronomy satellite
SVALRAK	Sounding rocket launch facility (Norway)
SWAN	Solar Wind Anisotropies
Swift	Medium explorer, gamma-ray observation (NASA/UK/Italy)
SWRI	Southwest Research Institute
SXI	Solar X-ray Imager
T/I	Thermospheric/Ionospheric
TC	Chinese "Tan Ce", the Double Star spacecraft
TC	Technical Committee
TEC	Total Electron Content
Terrier-Orion	Sounding rocket (USA)
TG	Task Group
Th	Thorium
THEMIS	Thermal Emission Imaging System
TIDI	TIMED Doppler Interferometer
TIEGCM	(NCAR) Thermosphere-Ionosphere-Electrodynamic General Circulation Model
TIGER	Thermospheric-Ionospheric Geospheric Research
TIME	Thermosphere-Ionosphere-Mesosphere Electrodynamics
TIMED	Thermosphere-Ionosphere-Mesosphere Energetics and Dynamics
TOPEX	(Ocean) TOPographic Experiment
TOPEX/Poseidon	Joint US-French orbital mission, launched in 1992 to track changes in sea-level height with radar altimeters
TopSat	British topographical imaging microsatellite
TRACE	Transition Region and Coronal Explorer
TRACER	Transition Radiation Array for Cosmic Energetic Radiation
TRIPLE	3 instruments (Lyman alpha hygrometer, cryogenic whole air sampler and resonance fluorescence halogen oxide instrument)
TS	Technical Specification (ISO)
U	Uranium
UAE	United Arab Emirates
UARS	Upper Atmosphere Research Satellite
UHF	Ultra High Frequency
ULDB	Ultra Long Duration Balloon flight operation
ULYSSES	Joint ESA/NASA heliospheric mission
UN	United Nations
UNBSSI	UN Basic Space Science Initiative
UNCOPUOS	United Nations' Committee on the Peaceful Uses of Outer Space
UNESCO	United Nations Educational, Scientific and Cultural Organisation
UNESCO/IOC	UNESCO Intergovernmental Oceanographic Commission
UNOOSA	UN Office for Outer Space Affairs
URSI	Union Radio Scientifique International
US	United States
USC	University of Southern California
USU	Utah State University
UT	Universal Time (GMT)
UTC	Coordinated Universal Time

UV	UltraViolet
VASCO	Variabilité Atmosphérique Intrasaisonnière et Couplage Océanique (2002 oceanic observation campaign)
Vega	Venus balloon mission in 1985 (Russia)
VENUS EXPRESS	Venus explorer mission (2005)
VHF	Very High Frequency
VIS	Visible Imaging System
VITMO	Virtual Ionosphere Thermosphere Mesosphere Observatory
VLBI	Very Long Baseline Interferometry
VO	Virtual Observatory
VORCORE	Vortex Core
VSOP	VLBI Space Observation Programme (now Halca)
WACCM	Whole Atmosphere Community Climate Model
WD	Working Draft
WFC	Wide Field Camera
WG	Working Group
WIND	NASA spacecraft to study solar wind and terrestrial plasma
WMAP	Wilkinson Microwave Anisotropy Probe (NASA)
WRMISS	Workshop for Radiation Monitoring on the International Space Station
Xe	Xenon
XEUS	X-ray Evolving Universe Spectroscopy mission to detect black holes (ESA)
XMM-Newton	ESA X-ray Multi-mirror Mission
XRS	X-ray Sensor
Yohkoh	Solar activity observer (Japan)
ZBOT	Zero Boil-Off Tank Experiment

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