TECHNICAL REPORT
No. 2013-4

WIGOS

WMO Integrated Global Observing System

Implementation Plan for the Evolution of Global Observing Systems (EGOS-IP)

World Meteorological Organization
Weather • Climate • Water

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The development of this plan was led by the CBS Open Programme Area Group on the Integrated Observing System (OPAG-IOS), and is a contribution to the WMO Integrated Global Observing System (WIGOS)

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EXECUTIVE SUMMARY

Introduction

The purpose of this implementation plan is to outline the key activities to be implemented during the period 2012 to 2025 aiming at maintaining and developing all WMO component observing systems. These systems have a collective identity as the WMO Integrated Global Observing System (WIGOS), and the WIGOS vision is taken into account in this plan. The objective of the EGOS-IP is to address the observational requirements of WMO weather, climate and water applications in the most cost-effective way. The component observing systems will also make major contributions to the Global Earth Observation System of Systems (GEOSS) and to the Global Framework for Climate Services (GFCS). Some activities relate to co-sponsored observing systems and will have to be undertaken in close cooperation with partner organizations.

Observations support an increasingly wide range of applications in monitoring and forecasting of the atmosphere, and of the oceans and land surfaces, at different time scales. These activities support an increasing range of services with high socio-economic benefits. User requirements have become more stringent and new requirements have appeared with respect to these applications. More observation systems serve needs for real-time, near-real-time and non-real-time availability. Requirements for observations related to the WMO-IOC-UNEP-ICSU Global Climate Observing System (GCOS) and to the GFCS are expected to increase as well. In many cases, important improvements could be obtained by simply distributing, in a timely manner, observations that are already made for other purposes.

The actions developed in the present EGOS-IP are the results of several ongoing WMO activities, conducted in close cooperation with world experts in relevant disciplines:

- The “Vision for the Global Observing System (GOS) in 2025”, approved by EC-LXI (Geneva, 2009), which provides high-level goals to guide the evolution of global observing systems;
- The “Rolling Review of Requirements” (RRR), which has been carried out for several years. It compares observing systems capabilities with the user requirements in (currently) 12 different WMO application areas, and provides a “Statement of Guidance” (SoG) to identify key gaps;
- The results of impact studies, including observing system experiments and observing system simulation experiments, in some application areas.

Agents for implementation

For the surface-based observing systems the implementation actions rely mainly on national agencies such as National Meteorological Services (NMS) or National Meteorological and Hydrological Services (NMHS), although in several cases, *in-situ* observing networks are implemented by non-meteorological institutes or agencies in the context of an international programme or within a strong international cooperation. In some cases the networks are funded for research purposes and their sustainability is therefore a concern.

For the space-based observing systems, the agents are sometimes national agencies operating satellites for research and/or operational purposes, and sometimes multi-national agencies specialized in space observations.

For both surface and space-based systems, the level of international cooperation needed is high, justifying the existence of several international programmes sponsored or co-sponsored by WMO in partnership with other international organizations.

For land-based in-situ observing networks, the design and development is often carried out through Regional Associations (RAs) which have a key coordination role in their respective regions, using the guidelines of WMO Technical Commissions (TCs), primarily (but not only) CBS. A number of requirements are met through co-sponsored observing systems (GCOS, GOOS, GTOS). Concerning ocean in-situ observing networks, the Joint WMO-IOC Technical Commission for Oceanography and Marine Meteorology (JCOMM) is involved for all the observing systems making marine meteorological measurements at the surface, as well as oceanographic measurements at the ocean surface or at depth. Atmospheric chemistry observations are implemented through the Global Atmospheric Watch (GAW) Programme and its strategic plan and addendum. For space-based observing systems, there is a general tendency for the satellite observation to be global and less regional than in-situ observing networks. But the role of WMO is equally important, and WMO works in close cooperation with the Coordinating Group for Meteorological Satellites (CGMS), and with national and international agencies.

Some land-based observing networks have a crucial role in climate monitoring and have to be expanded. They are the surface radiation measurements which are complementary to the total solar irradiance obtained from satellite instruments, and all the variables which are necessary to monitor the carbon cycle of the Earth system, especially the soil carbon, and the fluxes of carbon dioxide and methane between the atmosphere, the ocean and the land surface. The GEO Carbon Strategy explains also which institutions are the agents for the implementation of these observations.

Over-arching and cross-cutting actions

In order to meet user needs, actions have to be taken to transfer some research-based observing systems, where they are mature and cost-effective, to an operational status. The changes to existing systems and the development of new systems have to be assessed continuously with the observation users. This is particularly important for several ocean observing systems which are currently maintained by research funding with limited durations. For some observing systems, improved cost-effectiveness is likely to be achieved through an adaptive mode which seeks to vary the observation set according to the meteorological situation.

The integrating role of WIGOS is important for the development of the “Vision for the GOS in 2025”. It is necessary to encourage all operators producing observations to adhere to the WIS and WIGOS standards. The continuity and consistency of data records for the key components of the observing system are also essential for many users.

Data policy actions must be taken to guarantee the continued availability of all essential observational data to all WMO Members, and to ensure a continued adherence to WMO data sharing principles irrespective of the data origin, including data produced by commercial entities. Data policies of Members and WMO need to evolve as user requirements and observing systems evolve to collect and exchange greater quantities and different types of data from a broader range of sources.

By 2025, technical developments will result in more automated procedures, much larger data volumes, and much higher data flow to be transmitted in real-time. Actions are needed to make sure the WIS capacities will be able to handle the observation volume and flow, and also to make sure the radio frequencies needed for WIGOS are protected.

Many developing countries and countries with economies in transition do not have the capabilities or the resources to provide the essential in-situ observations. It is important to tackle this by pursuing capacity building strategies for observing systems through projects funded by international organizations, bilateral partnerships and facilitation of regional cooperation. This may include the provision of guidelines and the organization of training and capacity-building events.

Surface-based observing system

In order to meet the different user requirements, many surface-based observing systems could be made more efficient without necessarily having to produce more observations. This can be realized by processing and exchanging more data, for example in the following ways:

- A global exchange of all hourly data which can be used in global applications, and a promotion of global exchange of sub-hourly data in support of relevant application areas;
- An exchange between different user communities (according to WIGOS standards) of observations coming from the atmosphere, ocean and terrestrial observing systems, with different pre-processing levels when needed.

The upper-air observing systems can be improved through various actions for radiosondes, aircraft data and profilers, such as:

- Making the upper-air global data coverage more uniform when considering all the observation systems together;
- Making a special effort to maintain isolated radiosonde sites or platforms (including Automated Shipboard Aerological Stations - ASAPs);
- Making a special effort to reactivate existing radiosonde sites which have stopped operations or which produce observations which are not transmitted;
- Developing an adaptive component for radiosondes and Aircraft Meteorological Data Relays (AMDARs), in order to produce some observations where and when they are most needed;
- Making a special effort to maintain the GCOS Upper-Air Network (GUAN) radiosonde sites and develop the GCOS Reference Upper-Air Network (GRUAN);
- Improving radiosonde processing and dissemination in order to make available data at a higher vertical resolution, together with position and time for each datum;
- Developing a consistent network of remote-sensing profiling stations on a regional scale;
- Developing and implementing humidity sensors as an integrated component of the AMDAR system.

Most of the surface observing systems over land would greatly benefit from the general actions on WIS/WIGOS standards (concerning the processing and the exchange of observations). Benefits are also expected from more frequent observations data becoming exchanged globally, including those from GAW stations, lightning detection systems and hydrological stations. A very cost-effective way to obtain more surface observations for the different users is to increase and broaden the exchange of observations serving specific applications such as road transport, aviation, agricultural meteorology, urban meteorology and energy production.

Specific actions are needed with respect to weather radar stations in order to:

- Improve the quality of quantitative precipitation estimates;
- Develop a weather radar data processing / exchange framework to serve all the users, achieving homogeneous data formats for international exchange.

Actions have to be taken concerning sea stations, Voluntary Observing Ships (VOS), moored buoys, drifting buoys and ice buoys, in order to improve the geographical coverage of ocean observations, particularly for measuring sea surface temperature, height, salinity, visibility, wave and surface wind.

For the ocean sub-surface, efforts are required in partnership with the Intergovernmental Oceanographic Commission (IOC) of UNESCO to produce more observations (temperature, salinity, etc.) with a high vertical resolution through profiling floats and Expendable Bathy-thermograph (XBT) instruments, and to disseminate all the data in real-time. In the deep ocean, it is challenging to obtain observations, and it is important to push the development of some emerging techniques.

Space-based observing system

The “Vision for the GOS in 2025” foresees an expanded space-based observing capability, an expanded community of space agencies contributing to WMO programmes, and an increased collaboration between them. More satellites should serve several applications rather than being dedicated to a single scientific activity.

One important issue for most of the space-based components is the continuity and the overlap of key satellite sensors which have to be guaranteed, together with both the real-time and delayed mode data processing and distribution, and also appropriate inter-comparison and inter-calibration procedures.

Continuous actions have to be taken to complement or maintain at least 6 operational geostationary (GEO) satellites separated ideally by no more than 70° of longitude, with at least:

- A visible / infra-red imager;
- A hyperspectral infra-red sounder;
- A lightning imager.

The Low Earth Orbit (LEO) satellite missions should include at least 3 operational sun-synchronous polar orbiting satellites (with equatorial crossing times around 13:30, 17:30 and 21:30 local time, to achieve an optimal global coverage). These orbiting platforms should be equipped with at least:

- A hyperspectral infra-red sounder;
- A microwave sounder;
- A high resolution multi-spectral visible / infra-red imager;
- A microwave imager.

Specific actions are needed for real-time transmission, pre-processing and dissemination to users of the high data volumes which are expected from LEO satellites.

In addition to the core meteorological satellite missions, several other satellite instruments need to be maintained or developed for weather, ocean, climate and other applications. Many of the following instruments serve more than one application area:

- Scatterometer: at least 2 satellites flying on well-separated orbits with a scatterometer onboard are needed;
- Global Navigation Satellite System (GNSS) receivers on LEO satellites: a radio-occultation constellation producing at least 10,000 occultations per day is needed;
- Altimeter: the user requirements call for a reference altimeter mission on a high-precision, non-sun-synchronous, inclined orbit, and 2 other instruments on well separated sun-synchronous orbits;
- Infra-red dual-angle view imager: such an imager onboard a polar orbiting satellite is needed in order to provide sea surface temperature measurements of climate monitoring quality;
- Narrow-band visible / near infra-red imagers: at least one imager of this type is needed for observing ocean colour, vegetation, surface albedo, aerosols and clouds;
- High-resolution multi-spectral visible / infra-red imagers: this type of instrument is important for agricultural meteorology, hydrology, land-use and the monitoring of floods and fires;
- Precipitation radars: associated with passive microwave imagers, these instruments are needed to support the Global Precipitation Measurement (GPM) mission;
- Broad-band visible / infra-red radiometers: this type of radiometer is necessary to monitor the Earth radiation budget (on at least one polar orbiting satellite);
- Various sounders (in the UV, visible and near-infra-red bands) on several GEO and LEO orbits, including a limb-sounding capability. This is mainly for atmospheric chemistry, monitoring of greenhouse gases and air pollution;
- Synthetic Aperture Radar (SAR): it is important to have at least one SAR on a polar orbiting satellite to monitor land surfaces, sea level, water level in flooded areas, etc., in order to contribute effectively to disaster management.

In addition to the instruments on the above list, there are several new or emerging instruments and technologies which should be tested and possibly implemented operationally before 2025. Examples of these on LEO satellites are lidars (for wind, clouds and aerosols) and low-frequency microwave radiometers (for soil moisture and ocean salinity). On GEO satellites, microwave and narrow-band visible / near-infra-red instruments should be demonstrated. Gravimetric sensors have the potential for monitoring the ground water. So far, no meteorological or oceanographic instrument has been flown on a Highly Elliptical Orbit (HEO), and a demonstration of this technology would be valuable.

Space weather

Space weather observations are required: to forecast the occurrence probability of space weather disturbances; to drive hazard alerts when disturbance thresholds are crossed; to maintain awareness of current environmental conditions; to determine climatological conditions for the design of both space-based systems (i.e., satellites and astronaut safety procedures) and ground based systems (i.e., electric power grid protection and airline traffic management); to develop and validate numerical models; and to conduct research that will enhance our understanding. A comprehensive space weather observation network must include ground based and space-borne observatories, with a combination of remote sensing and in-situ measurements.

Actions are needed in particular:

- To coordinate plans ensuring continuity of solar measurements, solar wind and interplanetary magnetic field measurements, and heliospheric imaging from space; to coordinate, standardize and expand the existing ground-based solar observation data; to improve ionospheric monitoring through expanded ground-based GNSS, improved timeliness of space-based GNSS radio-occultation measurements, and sharing of ground-based or space-based GNSS data among the meteorological and space weather communities in near-real-time through the WIS; to coordinate the use of dual-frequency radar altimeter observations by Space Weather community; to increase the availability of ground-based magnetometer data with high timeliness;
- To develop a plan for maintaining and improving space weather observations of the plasma and energetic particle environment.

Implementation strategy

Most of the actions of the document are expected to be feasible by 2025. The main exception is related to research and development actions on emerging observing systems: a lot of uncertainty is attached to some of them regarding their possible operational use by 2025.

The cross-cutting actions (which are not related to one particular observing system) are documented in sections 3 and 4 of this plan. The actions documenting the evolution of the ground-based observing systems are described in section 5, system by system. Those documenting the evolution of the space-based observing systems appear in section 6, also system by system, and those for space weather in section 7.

The implementation of the plan will be reviewed and assessed regularly under CBS guidance during the period 2012-2025, together with other documents, especially the "Vision for the GOS in 2025". This will require regular reporting of progress against the set of actions within the EGOS-IP.

A summary table of the actions proposed in this implementation plan is provided in Annex I.

Implementation Plan for the Evolution of Global Observing Systems (EGOS-IP)

1. INTRODUCTION

1.1. Preamble

By 2025, global observing systems will have developed considerably, building upon existing surface- and space-based sub-systems and capitalizing on existing and emerging technologies. They will be the central components of the WMO Integrated Global Observing System (WIGOS), which will provide an integrated and comprehensive system of observing systems in support of the WMO Member States' needs for information on weather, climate, water and related environmental matters. Existing components of the current WMO Global Observing System (GOS) will be interfaced with WMO co-sponsored and other, non-WMO observing systems. They will make major contributions to the Global Earth Observation System of Systems (GEOSS[1]) and to the newly created Global Framework for Climate Services (GFCS[2]). The space-based component will rely on enhanced collaboration through partnerships such as the Coordination Group for Meteorological Satellites (CGMS[3]) and the Committee on Earth Observation Satellites (CEOS[4]). Some observing sub-systems will rely on WMO partner organization systems: the Global Terrestrial Observing System (GTOS[5]), the Global Ocean Observing System (GOOS[6]) and others. Their climate components will be major contributors to the Global Climate Observing System (GCOS[7]).

These observing systems will address the observational requirements of a wide range of application areas across all WMO and WMO-sponsored Programmes, contributing to improved data, products and services from the National Meteorological Services (NMSs) and the National Meteorological and Hydrological Services (NMHSs). Although the observing systems will develop mainly by small incremental additions and technological changes, the scope of the evolution is expected to be major and to involve new approaches in science, data handling, product development and utilization, and training.

1.2. Context

There have been very significant improvements in the WMO Global Observing System (GOS) during the recent decades. They have led to a huge improvement in the range and quality of observations available for operational meteorological activities and hence to the quality of the services that they provide.

1 http://www.earthobservations.org/
2 In 2009, the World Climate Conference-3 (WCC-3) decided to establish a Global Framework for Climate Services (GFCS), to strengthen production, availability, delivery and application of science-based climate prediction and services. More details on: - http://www.wmo.int/gfcs
3 http://www.cgms-info.org/
4 http://www.ceos.org/
5 GTOS is co-sponsored by the FAO, ICSU, UNEP, UNESCO, and WMO - http://www.fao.org/gtos/
6 GOOS is co-sponsored by the ICSU, IOC of UNESCO, UNEP, and WMO - http://www.ioc-goos.org/
7 GCOS is co-sponsored by the ICSU, IOC of UNESCO, UNEP, and WMO - http://www.wmo.int/gcos

The evolution has been particularly significant for the space-based component of the GOS, which is now a composite of many different satellite instruments and systems contributing extensively to a wide range of applications.

In addition to playing their long-standing roles in operational meteorology and supporting rapid advances in numerical weather prediction (NWP), observations have started to support an increasingly wide range of applications, not only in real-time monitoring and forecasting of the atmosphere, but also of the oceans and the land surfaces, including in long-range forecasting at monthly and seasonal scales. User requirements have become more stringent, new requirements and new tools have appeared for these activities, models have progressed rapidly and so have their observational requirements. Altogether the observation requirements are becoming increasingly stringent and their evolution increasingly rapid.

The observing requirements take into account all relevant applications within WMO sponsored and co-sponsored programmes. Some are real-time applications, including weather and ocean forecasting. For those the observations are normally exchanged and processed on time-scales from a few minutes to a few hours (depending on the observing technique, on the user requirements and on the type of dissemination). Other applications are operational but can afford longer delays for collecting and using the observations. Others are research activities which are connected to real-time applications, but are not constrained by dissemination delays. Many observation systems serve both real-time and non-real-time needs. The GCOS activities and those of the GFCS have several requirements not affected by real-time constraints, although some aspects can be considerably helped by a real-time or near-real-time exchange of data. Requirements for observations (in terms of variables measured, spatial resolution, frequency of observation, etc.) related to provision of operational climate services under the GFCS are expected to increase as the users of these services become increasingly engaged[8.] In some cases, important improvements could be obtained by simply distributing in real-time observations which are already made for other purposes.

1.3. Background and purpose of the new plan

Under the auspices of the WMO Commission for Basic Systems (CBS), the Open Programme Area Group (OPAG) on the Integrated Observing System (IOS) and its Expert Team on the Evolution of Global Observing Systems (ET-EGOS) guide and monitor the evolution of global observing systems. The OPAG-IOS and the ET-EGOS have overseen the “Rolling Review of Requirements” (RRR) process. Under this process, requirements for observations are classified according to different application areas, and they are quantified in terms of data density (horizontal and vertical resolution), uncertainty (accuracy), observing cycle (frequency), and timeliness, for a comprehensive list of meteorological and environmental variables (wind, temperature, etc.). The RRR process regulates the management of a database[9] containing this information, which is reviewed and updated regularly. The RRR is currently conducted for 12 application areas: global NWP, high-resolution NWP, nowcasting and very short-range forecasting, seasonal to inter-annual forecasting, aeronautical meteorology, ocean applications (including marine meteorology), atmospheric chemistry, agricultural meteorology, hydrology, climate monitoring, climate applications and space weather. Other application areas are added

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8 Users of climate services in the context of the GFCS are a broad and highly diverse group including policymakers, managers, engineers, researchers, students and the public at large, in all sectors and socio-economic systems (including agriculture, water, health, construction, disaster risk reduction, environment, tourism, transportation, etc.), and the full extent of their requirements is not yet known.

9 http://www.wmo.int/pages/prog/www/OSY/RRR-DB.html

as necessary. For each application area, observation requirements are compared with the capabilities of current and planned observing systems through a “critical review” by experts in the application area. The critical review is also taking into account the results from impact studies. The main deficiencies in present/planned capabilities, in relation to user requirements, are summarized in a gap analysis or “Statement of Guidance” (SoG). The user requirements, the assessment of current and planned capabilities and the SoGs are the primary inputs which have contributed firstly to the “Vision for the GOS in 2025” and now to the analysis and Actions in this Implementation Plan.

The first version of EGOS-IP was developed during the period 2001-2003 and adopted by CBS in 2005. It contained a set of recommendations aimed at improving both the surface and space-based sub-systems of the GOS. This new plan is the result of a complete rewriting of the old plan. The rewriting has been necessary for the following reasons:

- From 2003, many comments and updates have been added on the top of the original recommendations, as part of the process of reporting progress on the EGOS-IP. These comments and updates are now mainly of historical interest and make the document difficult to read;
- Some recommendations are out-of-date;
- Some new recommendations have been added in the progress report, and many of these are still relevant to the new EGOS-IP;
- The “Vision for the GOS in 2025”[10], which was initiated by ET-EGOS in 2007 and adopted in 2009 by the sixty-first WMO Executive Council (EC-LXI), provides high-level goals for the evolution of observing systems. The new EGOS-IP is a comprehensive response to the new Vision and mirrors it in structure. WIGOS provides a new organizational framework for WMO observing systems, and it is necessary to place EGOS-IP within this framework and to include elements that are important within WIGOS, such as integration and interoperability;
- The new EGOS-IP is more specific concerning who has to take the different implementation Actions;
- The new EGOS-IP responds to the new version of the Implementation Plan for the Global Climate Observing System (GCOS-IP)[11], emerging requirements of the GFCS, and the Global Cryosphere Watch (GCW). In this Plan, Actions are included to emphasize and propagate GCOS requirements for high-quality observations of Essential Climate Variables (ECVs) and the observation practices set out in the GCOS Climate Monitoring Principles (GCMPs).

The purpose of the present EGOS-IP is to document a set of implementation Actions which are important for incremental improvement of global observing systems and for a convergence towards the 2025 Vision. Many of the Actions from the old version of the plan are reiterated and updated. In addition, the new Plan identifies the actors (organizations, bodies) who are responsible of each Action, the expected time-frame, the overall management and monitoring, as well as performance indicators. The performance indicators often refer to “number of observations” or “number of observing systems”. Although not specified for each individual Action, these figures should be read as, e.g., number of observations of acceptable quality, and

10 See http://www.wmo.ch/pages/prog/www/OSY/WorkingStructure/documents/CBS-2009_Vision-GOS-2025.pdf
11 See http://www.wmo.int/pages/prog/gcos/Publications/gcos-138.pdf

it is envisaged that the WMO Quality Management Framework (QMF), as applied to instruments and observation methods[12], will play an important role here (see section 2.1).

The new EGOS-IP describes the implementation Actions as they are envisaged in the early part of the decade 2010-2020, and it covers the period up to 2025. To monitor the Actions in this Implementation Plan, a progress report will be made regularly; it will describe the progress using this baseline EGOS-IP as reference.

When the existing planned activities appear sufficient to meet the requirements by 2025, no new Action is included in the corresponding sub-section. However, this does not preclude the addition of further Actions at a later date, if monitoring of progress on this Plan shows that the plans of implementing agents have changed and a “gap” has emerged.

Section 3 in this Plan deals with cross cutting Actions, and section 4 addresses special considerations in relation to developing countries. Actions are then documented separately for each observing system - for the surface-based observing systems in section 5, and the space-based observing systems in section 6. Finally section 7 documents the space weather.

2. THE STRATEGIC APPROACH TO IMPLEMENTATION

2.1. Overall approach and relationship to WIGOS

The present plan contains implementation Actions aimed at observing many variables describing the atmosphere and the environment in contact with the atmosphere (ocean, ice and land). It is intended that these Actions are challenging but feasible in the time-frame 2012-2025, although they may not be completed by 2025. These Actions are derived to a large extent from the gap analyses provided by the RRR process. The priority of the different actions is guided by the RRR in different application areas and by the corresponding SoGs.

The development of these Actions has been informed by a range of information, not only on the gaps between existing/planned observing capabilities and currently-stated user requirements, but also on the most cost-effective ways to fill these gaps. Where possible, guidance has been taken from experiments on the impact of real or hypothetical changes to observing systems. In particular, the results of Observing System Experiments (OSEs), Observing System Simulation Experiments (OSSEs) and other types of impact study performed by NWP centres have been taken into account.

The EGOS-IP Actions specified by this plan take into account the WIGOS vision, requirements, objectives and scope, specified by the WIGOS Development and Implementation Strategy (WDIS), adopted by Cg-XVI (2011), and also the WIGOS Implementation Plan (WIP) to be approved by EC-64 (2012) (see Website[13]):

WIGOS Vision and requirements

The WIGOS Vision calls for an integrated, coordinated and comprehensive observing system to satisfy, in a cost-effective and sustained manner, the evolving observing requirements of WMO Members in delivering their weather, climate, water and related environmental services. WIGOS

12 See CIMO Guide (http://www.wmo.int/pages/prog/www/IMOP/CIMO-Guide.html) Part III, Chapter 1 "Quality management"
13 See http://www.wmo.int/wigos

will provide a framework for enabling the integration and optimized evolution of WMO component observing systems, including WMO's contribution to co-sponsored systems.

To enable improved service delivery, there is a need to improve the existing observing capabilities, make them more cost-effective and sustain their operation. To ensure a coordinated, comprehensive, and sustainable system that meets the requirements of WMO and partners, improved governance, management and integration of observing systems is needed.

Integration must be pursued to ensure interoperability and facilitate optimization across observing components. A principal requirement for integration is the standardization in three key areas: Instruments and Methods of Observation; WMO Information System (WIS) information exchange and discovery; and data management consistent with the QMF.

Quality Management Framework (QMF)

WIGOS is expected to provide timely, quality-assured, quality-controlled and well-documented long-term observations. Implementing Quality Management procedures is required to enable better utilization of existing and emerging observing capabilities.

WIGOS will embrace QMF[14] procedures to ensure that observations, records and reports on weather, water, climate and other environmental resources, operational forecasts, warnings, related information and services are of identified quality, and in compliance with relevant joint standards agreed upon with other international organizations.

This should be based on agreed-upon quality assurance and quality control standards, with the goals of developing and implementing an integrated Quality Management System (QMS); in doing this, and only after effective national implementation, it will deliver reliable and timely data streams with adequate quality control and relevant metadata.

Coordinated Planning and Optimizing of Observing Systems

Within the WIGOS framework, the coordinated planning and optimization of observing systems will be performed through the RRR process, as described in section 1.3.

The development of WIGOS will draw benefits from various pilot projects which are expected to help the long-term development of global observing systems.

The EGOS-IP describes the implementation Actions proposed for each observing system. Other aspects of WIGOS - the management of networks, the relationships with partner organizations, coordination with WIS, etc. – whilst important, are outside the scope of EGOS-IP.

Several elements of the EGOS-IP strategic approach are also shared by the strategic approach of the GCOS-IP. These elements of the strategy are the following:

- Global coverage of surface-based in-situ and remote sensing observing networks. This largely involves improvements in existing networks to achieve the recommended technical, operational and maintenance standards, especially in developing countries;

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14 http://www.wmo.int/qmf

- Expansion of existing networks and especially improvement of the density and frequency of observations for data-sparse regions, such as the oceans, the tropics and the high latitudes and altitudes, and expansion to meet the emerging requirements of GFCS user communities;
- Improved data acquisition systems and data management procedures, with a goal of minimizing missing data, keeping consistency with the WIS and WIGOS concepts; this includes an adherence to internationally accepted standards for weather, climate, water and related environmental observations, and associated data exchange;
- Effective utilization of satellite data through continuous and improved calibration and/or validation, effective data management, and continuity of current high-priority satellite observations;
- Enhanced monitoring of data availability and quality (at all stages of processing, exchange and use) based on existing data systems;
- Continued generation of new capabilities through research, technical development and pilot-project demonstration.

2.2. Agents for implementation

For the surface-based observing systems the implementation Actions rely mainly on national agencies such as NMSs and NMHSs, although in several cases, in-situ observing networks are implemented by non-meteorological institutes or agencies in the context of an international programme or within a strong international cooperation. In some cases the networks are funded for research purposes and their sustainability is therefore a concern.

For the space-based observing systems, the agents are sometimes satellite operators and national agencies operating satellites for research and/or operational purposes, and sometimes multi-national agencies specialized in space observations.

For both surface and space-based systems, the level of international cooperation needed is high, justifying the existence of several international programmes sponsored or co-sponsored by WMO in partnership with other international organizations. For observing systems evolving from research to operational status, three WMO TCs have a leading role: the Commission for Basic Systems (CBS), the Commission for Atmospheric Sciences (CAS) and the Commission for Instruments and Methods of Observation (CIMO).

For land-based in-situ observing networks, the design and development is often carried out through RAs, which have a key coordination role in their respective regions, using the guidelines of TCs, primarily (but not only) CBS. A number of requirements are met through co-sponsored observing systems (GCOS, GOOS, GTOS). Concerning ocean in-situ observing networks, the Joint WMO-IOC Technical Commission for Oceanography and Marine Meteorology (JCOMM) is involved for all the observing systems making marine meteorological measurements at the surface, as well as oceanographic measurements at the ocean surface or at depth. Atmospheric chemistry observations are implemented through the Global Atmospheric Watch (GAW) Programme and its strategic plan and addendum (see web references given in section 5.3.1.4). For space-based observing systems, there is a general tendency for the observations to be global and less regional than in-situ observing networks. But the role of WMO is equally important, and WMO works in close cooperation with the Coordinating Group for Meteorological Satellites (CGMS), and with national and international agencies.

Some land-based observing networks have a crucial role in climate monitoring and have to be expanded. They are the surface radiation measurements which are complementary to the total solar irradiance obtained from satellite instruments, and all the variables which are necessary to monitor the carbon cycle of the Earth system, especially the soil carbon, the fluxes of carbon dioxide and methane between the atmosphere, the ocean and the land surface. The GEO Carbon Strategy[15] explains which institutions are the agents for the implementation of these observations.

3. OVER-ARCHING AND CROSS-CUTTING ACTIONS

This sections of the Implementation Plan follows closely the description of the general trends and issues, as they are documented in the "Vision for the GOS in 2025", and develops the general Actions which are necessarily associated with these trends and issues.

3.1. Response to user needs

Global observing systems will provide comprehensive observations in response to the needs of all WMO Members and Programmes for improved data, products and services, for weather, water, climate and related environmental matters. Through WIGOS, WMO will continue to provide effective global collaboration in the making and dissemination of observations, through a composite and increasingly complementary system of observing systems.

The sustainability of these observing systems may require partnerships between research and operational agencies. Observations of several variables are made in the context of research programmes or by space agencies whose primary mission is research and development. Once methods are sufficiently mature to guarantee a sustained set of observations to an acceptable level of accuracy, they need to be sustained into the future as an operational observing system if they fulfil the requirements of some user groups.

The operational system includes the observation process, the transmission to a pre-processing centre, and archiving and dissemination to users with procedures compatible with the WIS. These activities may or may not imply a transfer of responsibility from one organization to another. Whenever new or upgraded observing technologies or data processing systems are developed it is essential that there be interaction between the developers and the intermediate and end users to assess requirements and the impact of the new or evolving system before implementation. This will help ensure that all essential requirements are captured, including requirements for homogeneity of observations in time. Provisions should be made to enable users to prepare for new observing systems well in advance of system deployment in terms of data reception, processing and analysis infrastructure, and associated education and training.

At the same time, ongoing attention must continue for existing systems. Long-standing methods of observation remain valuable and should be employed for continuity and expansion of networks to meet user needs.

Action C1

Action: Meet growing user requirements for climate information by encouraging and assisting in expansion of traditional observing platforms for weather and climate observations.

Who: GCOS and CBS to lead the action, together with regional centres representing users and organizations operating component observing systems.

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15 http://www.earthobservations.org/documents/sbas/cl/201006_geo_carbon_strategy_report.pdf

Time-frame: Continuous.
Performance Indicator: Extent to which user needs are met.

Action C2

Action: Once relevant research-based observing systems are shown to be sufficiently mature and cost-effective, follow an appropriate migration methodology to become a sustained operational system.
Who: CBS, in collaboration with CIMO and CAS, to initiate and lead the evolution, with all organizations operating component observing systems.
Time-frame: Continuous. Timetable to be decided on a case by case basis.
Performance indicator: Number of sustained systems compared to the targets.

Action C3

Action: Ensure all operators producing observations adhere to the WIS standards[16].
Who: Organizations and agencies operating observing programmes. Action monitored by CBS.
Time-frame: Continuous.
Performance: Extent to which WIS standards are applied.

Action C4

Action: Careful preparation is required before introducing new (or changing existing) observing systems. The impact needs to be assessed through prior and ongoing consultation with data users and the wider user community. Also, data users need to be provided with guidance on data reception/acquisition, processing and analysis infrastructure, the provision of proxy data, and the provision of education and training programmes.
Who: All organizations operating component observing systems, following the best practices provided by CBS, CAS or other TCs and co-sponsored programmes
Time-frame: Continuous.
Performance Indicator: Extent to which user community concerns are captured.

Large parts of marine and ocean observing systems are currently maintained by research funding with limited duration. Considering the importance of continuous, long-term observations for key marine/ocean variables for many applications, including medium-range weather and seasonal climate forecasting, WMO Members should note potential gaps that may occur at the end of these research programmes unless ongoing funding for sustained observing networks is guaranteed. Such observing networks include: (i) the tropical moored arrays; (ii) Argo; (iii) a fraction of barometer upgrades on surface drifters (for weather forecasting); and (iv) altimeter, scatterometer, microwave sea surface temperature (SST) and sea ice measurements from research satellite missions.

Action C5

Action: Ensure sustained funding for the key marine/ocean observing systems (e.g. tropical moorings, Argo, surface drifters with barometers, as well as altimeter, scatterometer, SST from microwave radiometry, sea ice measurements from research satellite missions).

16 See http://www.wmo.int/pages/prog/wis/

Who: NMSs, NMHSs and partner national institutions, in collaboration with international organizations, TCs responsible for observing system coordination (e.g. JCOMM, CBS, and CIMO) and space agencies.
Time-frame: Continuous.
Performance Indicator: Percentage of observing networks funded through sustained mechanism.

Users require global observing systems to provide observations when and where they are needed in a reliable, stable, sustained and cost-effective manner. They require observations of specified spatial and temporal resolution, accuracy and timeliness. The user requirements will evolve in response to a rapidly changing user and technological environment, based on improved scientific understanding and advances in observational and data-processing technologies. Our ability to measure some key environmental variables is often limited by the lack of suitable techniques. These limitations can vary from the fundamental underlying observing technique to those associated with instrumentation, data processing, suitable calibration/validation techniques, spatial and/or temporal resolution, ease of operation and cost. As new remotely-sensed observations of environmental variables are made, it is critically important that the validation of both the measurements themselves and the retrieval methods used are carried out under a sufficient broad range of geophysical conditions. It is also important to derive observational products in a physically consistent way across ocean, land and atmosphere domains. The development of integrated products requires blending of different datasets or data sources, which needs to be consistent over time and space.

Some level of targeted observations will be achieved, whereby some observations are made or not made, in response to the local meteorological situation and the particular user needs. Their operation should be guided by and in collaboration with NMHSs to ensure interoperability and potential exchange of the data (see also section 5.3.1.1.1).

Action C6

Action: For each observing system proposed for operation in adaptive mode (i.e. a process which would vary the observation set according to the meteorological situation), investigate the feasibility, cost-effectiveness and side effects on the continuity of climate data records.
Who: Organizations operating observing networks on a routine basis. Process to be initiated and coordinated by CBS based on recommendations from CAS, other TCs, the RAs, and GCOS.
Time-frame: Continuous reviewing process of the feasibility and cost-effectiveness assessments.
Performance indicator: Number of networks operated with some level of targeting.

3.2. Integration

WIGOS will provide a framework for enabling the integration and optimized evolution of WMO observing systems (GOS, GAW, GCW, and WHYCOS), including WMO's contribution to co-sponsored systems (GCOS, GOOS, GTOS). Integration will be developed through the analysis of requirements and, where appropriate, through sharing observational infrastructure, platforms and sensors, across systems and with WMO Members and other partners. Surface and space-based observing systems will be planned in a coordinated manner to serve a variety of user needs with appropriate spatial and temporal resolutions in a cost-effective manner.

Data assimilation techniques have an important role to play with respect to a cost-effective integration of the different observing systems serving different applications across different disciplines. Data assimilation techniques are indeed able to add considerable value to observing systems by combining heterogeneous sets of information to provide complete and self-consistent sets of geophysical fields. Taken on its own, each observing system provides only a small sample of information with respect to the ensemble of global requirements as they are documented by the RRR process. However, combined in a global assimilation, the integration of their measurements is able to provide reliable global analyses for many variables, which are essential for many global applications.

For the achievement of this Implementation Plan, an important challenge is to find means for maintaining the long-term operation and the continuity of these observing systems. This does not mean that the continuity of each system should be guaranteed indefinitely; the strategy consists in making sure that the quality of the important variables is not degraded when an instrument or an observing system is replaced by another instrument or another observing system. Several applications use observations which are labelled “research” or “demonstration” for operational purposes. The border between “research” and “operations” is not well-defined and is moving all the time, mainly because it follows the scientific progress in applications and in data utilization methods. In this context, ensuring that observations of important variables are not degraded may mean ensuring the transition of research/demonstration systems into operational systems (which is recognized to be very challenging).

The integrating role of WIGOS is also supported by the strong complementarity between surface-based and space-based observations. Some examples:

- For observing the atmosphere, surface-based systems are more efficient in the boundary layer whereas satellite instruments are more efficient in the stratosphere and above the clouds;
- High horizontal resolution can be obtained with space-based imagers and sounders with global data coverage; this is impossible to achieve with in-situ observing networks which remain the best systems for high vertical resolution, especially in the lower atmosphere;
- The most accurate SST fields are obtained from a combination of satellite retrievals mixed with in-situ reference measurements.

Observations should be made available to the different users with a timeliness respecting their requirements. They should also be made available using standard practices for data processing, coding formats and dissemination, in order to facilitate the utilization.

Action C7

Action: Ensure time continuity and overlap of key components of the observing system and their data records, in accordance with user requirements, through appropriate change-management procedures.
Who: CBS to lead, in collaboration with other TCs, JCOMM, RAs, satellite agencies, NMSs and NMHSs, and organizations operating observing systems.
Time-frame: Continuous. Timetable to be decided on a case by case basis.
Performance indicator: Continuity and consistency of data records.

3.3. Data policy

The operating paradigm for the GOS has been built on WMO data sharing principles under which all essential data are shared openly among the WMO Members. This has been facilitated by the fact that, in the past, observational data have been provided primarily by national governments and international agencies. User requirements and observing systems have and will continue to evolve. Greater quantities and different types of data are being collected and exchanged, from a broader range of sources. Data policies of Members and WMO need to evolve accordingly.

The potential for an increased role in the future for commercial entities - e.g. hosting of instrument payloads or “data buys” and similar mechanisms - raises important issues regarding the continued availability to all WMO Members of data obtained under such arrangements.

Action C8

Action: For WMO and co-sponsored observing systems, ensure continued adherence to WMO data sharing principles irrespective of origin of data, including data provided by commercial entities.
Who: NMSs and NMHSs, and space agencies. Process monitored by CBS.
Time-frame: Continuous.
Performance indicator: Continued availability of all essential observational data to all WMO Members.

There is also great benefit from open sharing of data by other agencies and every opportunity should be taken to encourage such sharing.

3.4. Expansion

There will be an expansion in both the user applications served and the variables observed. This will include observations to support the production of datasets related to the GCOS essential climate variables (ECVs), adhering to the GCOS climate monitoring principles, and any additional observations required to implement operational climate services at global, regional and national scales under the GFCS. Atmospheric chemistry and hydrology are also two application types requiring an increasing number of variables to be observed from a greater number of stations.

The range and volume of observations exchanged globally will be increased. Several existing local observing systems are currently used only for local or regional applications; they will be used also in global applications as soon as they have proved they are able to bring additional value. The total volume of global data exchange will expand considerably because of new observed variables, because of existing local observations becoming exchanged globally, and because of increased resolutions (time and space) of global observing systems. The role of satellite and radar data sets will expand into applications requiring higher and higher horizontal resolution. This implies that the specialized data centres will have to serve a wider range of applications at all horizontal scales, from global to hectometre scale. This data volume expansion will put pressure on the data processing and dissemination processes which will be operated according to the WIS standards (especially important for real-time applications).

Action C9

Action: Evaluate the future evolution of data volumes to be exchanged and handled, based on the projected data volumes generated by the future space-based and surface-based sources.
Who: WMO/WIS to lead, in collaboration with TCs, JCOMM, RAs, satellite agencies, NMSs and NMHSs, and organizations operating observing systems.
Time-frame: Continuous.
Performance indicator: Evolution of the data volumes handled and exchanged.

Some observations of the land-based cryosphere are part of operational networks; others are part of research programmes and are not acquired in a consistent manner. There is a large and acknowledged gap internationally in the ability to measure reliably solid precipitation (snowfall, snow depth, ice, and rain water equivalent). Solutions should leverage new technologies and techniques for making in situ and remotely-sensed observations, and research is needed to integrate the two types of observations. For example, while snow depth is regularly measured at many land stations, lake ice cover and glacier mass balance are not. Improvements in snowfall observing practices and consistent and regular reporting are needed along with other variables. Some critical snow and ice properties, such as snowfall, snow water equivalent (SWE) and permafrost properties, are difficult to measure from space as well as in situ, though new technologies and satellite sensors are promising. The GCW will evaluate the surface and space-based cryosphere observing systems and will provide recommendations for reducing the gap between current capabilities and user needs.

3.5. Automation

The trend to develop fully automatic observing systems, using new observing and information technologies will continue, where it can be shown to be cost-effective and does not lead to degradation in respect of important requirements of some applications, e.g. climate monitoring. The access to real-time and raw data will be improved. More and more observing systems will have to produce different levels of data, from large volumes of raw data to highly processed data sets. A variety of users will be interested in one or more post-processing levels. It is important to have the different processing packages respecting a general set of WIS standards. Observational data will be collected and transmitted in digital forms, highly compressed where necessary. Data processing will be highly computerized.

A high degree of automation is especially required for observational networks covering areas highly exposed to severe weather phenomena. For nowcasting and risk mitigation in these areas, it is important to have a telecommunication infrastructure that is robust enough against these phenomena.

See related **Action G31** on data compatibility.

3.6. Interoperability, data compatibility, consistency and homogeneity

There will be an increased standardization of instruments and observing methods. There will be improvements in calibration of observations and the provision of metadata, to ensure data consistency and traceability to absolute standards. There will be an improved homogeneity of data formats and dissemination via the WIS, and also increased interoperability, between existing observing systems and with newly implemented systems. Metadata are essential for ensuring the quality, traceability and homogeneity of observations, therefore it is essential that an archive of rigorous metadata is maintained to support standardization, enable homogeneity assessments, and ensure data provenance and fitness for purpose.

To ensure consistency and homogeneity of the data sets, the monitoring principles for satellite data which are documented in the GCOS-IP for climatological purposes are all valid to some extent for other WMO applications, including the real-time applications. This is true for the recommendations which concern the time continuity, homogeneity and overlap of the observation, the orbit stability and sensor calibration, the data interpretation, processing and archiving. Global analyses for weather forecasting and other applications are dependent on several key observing systems. The long-term time continuity of these sensors is obviously very important for climate purposes, but it is almost as important for the other applications, including the real-time ones. All these sensors are used in a “synergetic” way, e.g. where one sensor helps in the evaluation of biases and drifts in other sensors. In this process the role of accurate in-situ observations is also important, supporting the GCOS requirements for the GCOS Reference Upper-Air Network (GRUAN).

By 2025 there will be improved methods of quality control and characterization of errors of all observations. Operational systems are needed that can track, identify and notify network managers and operators of observation irregularities, including time-dependent biases, as close to real-time as possible. Such feedback systems are already routine practices for several NWP centres, for the data which are assimilated in operational NWP models, and also for climate monitoring centres to ensure overall data quality. However there is a need to extend these monitoring activities to other applications and also to set up feed-back procedures for observed quantities which cannot be compared to any operational model. Also, even in the existing routine monitoring activities, there is a need to make more rapid and more efficient both the feedbacks to the operators and the correcting actions.

Action C10

Action: Monitor the flow of all essential data to processing centres and to users and ensure timely flow of feedback information to observing network management from monitoring centres.
Who: Data processing centres coordinated by appropriate TCs and international programmes (CBS to lead the process and initiate it when required).
Time-frame: Continuous.
Performance indicator: Usual monitoring criteria[17].

Action C11

Action: Achieve improved homogeneity of data formats for international exchange, by reducing to a smaller number of internationally coordinated standards.
Who: CBS to lead, in collaboration with other TCs.
Time-frame: Continuous.
Performance indicator: Number of data formats per data type.

3.7. Radio-frequency requirements

WIGOS components make use of a number of different radio applications.

17 Http://www.wmo.int/pages/prog/www/ois/monitor/introduction.html

Space-based passive sensing is performed in bands allocated to the Earth exploration satellite (passive) and meteorological satellite service. Passive sensing requires the measurement of naturally occurring radiation, usually of very low power levels and containing essential information on the physical process under investigation.

The relevant frequency bands are determined by fixed physical properties (molecular resonances) that cannot be changed or ignored. These frequency bands are, therefore, an important natural resource. Even low levels of interference received by a passive sensor may degrade its data. In addition, in most cases these sensors are not able to discriminate between natural and man-made radiation. In this respect, the International Telecommunication Union (ITU) Radio Regulations enable the passive services to deploy and operate their systems in the most critical frequency bands.

Several geophysical variables contribute, at varying levels, to natural emissions, which can be observed at a given frequency with unique properties. Therefore, measurements at several frequencies in the microwave spectrum must be made simultaneously in order to extract estimates of the variables of interest from the given set of measurements. Passive frequency bands should hence be considered as a complete system. Current scientific and meteorological satellite payloads are not dedicated to one given band but include many different instruments performing measurements in the entire set of passive bands. Also, full global data coverage is of particular importance for most weather, water and climate applications and services.

Also of great importance is the availability of sufficient and well-protected Earth exploration and meteorological satellite frequency spectrum for telemetry / telecommand, as well as for satellite downlink of the collected data.

The meteorological aids (MetAids) radiocommunication service is used for meteorological and hydrological observations and exploration, and provides the link between an in-situ sensing system (e.g. a radiosonde) for meteorological variables and a remote base station. The base station may be in a fixed or mobile location. Additionally, meteorological radars and wind profiling radars provide important observations. There are currently about 100 wind profiler radars and several hundred meteorological radars world-wide, which provide precipitation and wind information and play a crucial role in meteorological and hydrological alert processes.

The issues related to the above radio spectrum requirements and operation are addressed within WMO by the Steering Group on Radio Frequency Coordination (WMO SG-RFC). Within Europe, more than 20 National Meteorological Services and other relevant organizations have established the EUMETFREQ programme in order to coordinate their frequency protection activities. Frequency management and protection are particularly important for the WMO Space Programme and Space Agencies have established the Space Frequency Coordination Group (SFCG[18]) to coordinate their activities in this respect.

18 See http://www.sfcgonline.org/home.aspx

Action C12

Action: Ensure a continuous monitoring of the radio frequencies that are needed for the different components of WIGOS, in order to make sure they are available and have the required level of protection.

Who: WMO/SG-RFC to lead, in coordination with NMSs, NMHSs and national, regional and international organizations in charge of radio frequency management.

Time-frame: Continuous.

Performance indicator: Observation frequency bands available / not available with required level of protection.

4. CONSIDERATIONS FOR THE EVOLUTION OF OBSERVING SYSTEMS IN DEVELOPING COUNTRIES

Many developing countries and countries with economies in transition do not have the capabilities or the resources to provide the essential in-situ observations. This is a challenge for the consistency and the homogeneity of observations, especially at the global scale. The support needed by these countries and the mechanisms able to provide this support are the same as those described in the GCOS-IP (see its section on developing countries) for climate purposes, plus some support is often needed to disseminate in real-time observations which are already made, in the proper format, to the WIS.

More effort is needed to support these countries, especially Least Developed Countries (LDCs) and Small Island Developing States (SIDSs), by providing guidelines and organizing training and capacity-building events in the respective Regions. In many areas, including large parts of Africa, Asia and Latin America (Regions I, II, and III and some tropical areas between 25N and 25S), the current surface-based GOS provides insufficient observations. The evolution of observing systems in developing countries must address issues that fall in three categories: (a) lack of public infrastructure such as electricity, telecommunication, transport facilities, etc.; (b) lack of expertise from people to do the job, training, etc.; and (c) lack of funding for equipment, consumables, spare parts, manpower, etc. The lack of infrastructure and expertise may be the result of a lack of funding.

Evolution of observing systems must take into account upgrading, restoring, substitution and capacity building (especially in the use of new technologies). Two aspects need to be considered: the data production and the data use. It is possible that some countries do not and will not be able to produce data and will therefore only be users of data. To help developing countries produce data for international exchange, due consideration must be given to the three issues previously identified, i.e. public infrastructure, expertise and funding.

Possible approaches to observing system evolution in these conditions are the following. A first step should be to identify observing systems that are less dependent on local infrastructure. Where local infrastructure is sufficient, suitable expertise is available, and maintenance can be sustained, it may be possible to augment in-situ observations with other technologies such as satellite data, AMDAR, dropsondes and Automatic Weather Stations (AWS). Automated systems generally require a high level of technical competency and resources to maintain, repair and replace equipment when necessary. The ability to submit manual observations through a globally available web-based system could provide a further alternative for some LDCs and SIDSs.

A minimum set of reliable radiosondes is required as a backbone to the GCOS Upper-Air Network (GUAN). Members should do everything possible to fulfil the operational commitments of stations accepted within the GUAN. NWP impact studies[19] have shown the prominent importance of isolated radiosonde observations for both global and high resolution NWP.

Obtaining vertical profiles (of wind, temperature and, in the near future, humidity) by AMDAR in many data sparse areas appears as a natural way to obtain observations of some basic atmospheric variables in some countries with important airports and very few conventional atmospheric observations.

Capacity building in some countries continues to need attention. International responsibilities for data exchange may be supported by the migration toward the table-driven codes (BUFR[20] or CREX[21]) as a reliable representation of the data. More importantly, it will be necessary to develop and deploy systems for automatically generating messages (such as CLIMAT reports) and to ensure timely, efficient and quality-controlled flow of essential data, in keeping with the WIS implementation strategy.

Some countries have satellite receiving stations or receive satellite data through the Global Telecommunication System (GTS), but lack the expertise to utilize the information to their benefit. Some countries are acquiring Doppler radar but need training on how to process and interpret the information. For example, Region I has benefited with expanded access to conventional data and satellite imagery through the *Préparation à l'Utilisation de MSG en Afrique* (PUMA) project. This type of project should be expanded to include other data types for routine application (synoptic meteorology, aviation meteorology and nowcasting).

The following guidelines are proposed for the allocation of priorities for technical cooperation activities for the meteorological observing systems (by order of priority):

(a) Set up projects to improve/restore existing and to build new upper-air observational capabilities of the RBSN[22]/RBCN, with emphasis on the activation of silent upper-air stations and the improvement of coverage over data-sparse areas (in particular as regards the purchase of equipment and consumables, telecommunications and the training of staff);

(b) Extend AMDAR coverage to developing countries, LDCs and SIDS to supplement scarce upper-air observations or to provide a cost-effective alternative to countries that cannot afford costly upper-air sounding systems;

(c) Set up projects related to the improvement of data quality, regularity and coverage of surface observations of the RBSN/RBCN with emphasis to the activation of silent stations and the improvement of coverage over data-sparse areas;

(d) Set up projects related to the introduction and/or use of new observing equipment and systems including, where cost-effective, surface-based AWSs, AMDAR, ASAP and drifting buoys.

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19 See http://www.wmo.int/pages/prog/www/OSY/Reports/NWP-4_Geneva2008_index.html

20 FM 94 BUFR Global Telecommunication System (GTS) format - Binary universal form for the representation of meteorological data

21 FM 95 CREX GTS format - Character form for the representation and exchange of data

22 GCOS Surface Network (GSN) and GUAN stations are part of the RBSN (Regional Basic Synoptic Network)

Technical cooperation for achieving reliable communications would make a valuable contribution to ensure that observations data, once collected, can be widely exchanged.

Finally, the following recommendations should be taken into account when addressing the evolution of observing systems in developing countries:

- Define geographical areas to which priority for additional observations should be given, if additional funding were available;
- Prioritize where the needs are most pressing for WMO Voluntary Cooperation Programme (VCP) or other funding;
- Give high priority, in the Regions to maintaining a minimum radiosonde network with acceptable performance;
- Employ data rescue activities to preserve the historical observation record in developing countries, and make long-term datasets available for activities including reanalysis, research, adaptation, monitoring and other climate services;
- Encourage RAs in concert with CBS to define field experiments over data sparse areas, for a limited time, to evaluate how additional data would contribute to improve performance at the regional and global scale, following the example of the African Multidisciplinary Monsoon Analysis (AMMA[23]) field experiment;
- Examine the extent to which automated stations could become a viable, cost-effective alternative to manned stations for the surface network in the future, and investigate improved configurations of automated and manual stations;
- Follow the GCOS Climate Monitoring Principles (GCMP) and proper change-management practices when changes are made to the climate observing systems through close collaboration between observations managers and climate scientists;[24]
- For nowcasting and risk mitigation in vulnerable areas, the availability of a robust telecommunication infrastructure is an issue (robust against extreme weather conditions). Utilise robust telecommunication networks;
- Use the regional climate centre concept to provide access to specialists who could conduct training and maintenance of more complex systems including AWS.

Action C13

Action: Establish capacity building strategies for observing systems in developing countries through projects funded by International organizations, bilateral partnerships and facilitation of regional cooperation.

Who: NMSs/NMHSs with RAs, CBS, other TCs, in collaboration with international programmes.

Time-frame: Continuous.

Performance indicator: Substantial improvement in observational data return from developing countries.

23 See http://amma-international.org/

24 See WMO-TD No 1378 on: http://www.wmo.int/pages/prog/wcp/wcdmp/documents/WCDMPNo62.pdf

5. SURFACE-BASED OBSERVING SYSTEM

5.1. Introduction

The surface-based component of the GOS was developed originally to meet the requirements of operational meteorology without consideration of the new and emerging applications now covered by WMO Programmes. The surface-based systems generally provide traceable and temporally consistent observations which are an important historically consistent baseline for many observation systems. The issue of complementarity with the space-based component of the GOS started to be taken into account in the decade 1970-80.

For observing the upper atmosphere, the upper-air synoptic stations (consisting of rawinsondes, radiosondes, radio-wind and PILOT[25] balloon stations) were originally the unique surface-based observing system, until they were complemented by aircraft meteorological measurements and later by remotely-sensed observing systems (profilers and weather radars). The radiosonde station density has always been inadequate with respect to the meteorological requirements over remote areas including the oceans and deserts, and full implementation of the WWW has been a perpetual challenge for WMO even over land areas.

For observing the atmosphere near the surface, the surface observing station network is denser than for the upper-air. Over land it consists mainly of the manned and automatic surface stations. Over sea, it consists mainly of ships of the Voluntary Observing Ships scheme (VOS), fixed and mobile buoys. Many stations which originally served a single purpose (e.g., serving only synoptic or climatological, agricultural meteorology or aviation purposes) have evolved into multi-purpose stations serving multiple programmes and users.

Global synoptic and climatological networks are composed of the Regional Basic Synoptic and Regional Basic Climatological Networks (RBSN/RBCN). RBSN/RBCN should satisfy minimum regional requirements in order to permit WMO Members to fulfil their responsibilities within the World Weather Watch and for monitoring of climate.

Standard observing practices are included in the *Manual on the Global Observing System* (WMO-No. 544) and other Manuals. Recommended practices are included in several Guides, the *Guide to the Global Observing System* (WMO-No. 488) and the *Guide to Meteorological Instruments and Methods of Observation* (WMO-No. 8) and other Guides. Individual Actions in this Implementation Plan may result in changes of best practices and in a need to update the above WMO regulatory material. Evolving needs in areas of integration, automation, interoperability, data compatibility, consistency and homogeneity will have to be recognized in the WMO regulatory material. This will be addressed within the implementation of WIGOS and a development of the WIGOS Manual and Guide.

Observing the deep ocean remains a challenge: it cannot be done from space, and very few in-situ systems are available (expendable bathy-thermograph, XBT, instruments from ships, profiling floats). The observation of the ocean surface is less challenging as the satellites can contribute to a large extent, and the observation systems used for meteorology (ships, buoys) can also carry instruments for measuring surface variables like SST.

25 Upper-wind report from a fixed land station

For observing the land surface, some measurements may be made by surface synoptic stations (such as soil temperature at different levels, state of the ground snow depth and soil moisture). There is also a large variety of stations and networks developed independently for various applications, such as hydrology, urban meteorology, agriculture, monitoring of air pollution, electrical power production. They provide a large variety of variables which are potentially useful for several disciplines and which should be integrated.

Instruments need to be sufficiently robust to sample extremes in keeping with the climatology of the region in which they are deployed. For supporting improved forecasts and climate science, it is essential to withstand high winds, lightning strikes, and to adequately measure extremes in temperature and precipitation.

By 2025, there will be an increased tendency towards the integration of the surface-based observing systems of the three climate components: atmosphere, ocean and terrestrial system. This tendency to integration is natural in the context of the climate monitoring and prediction which require observations from the three components. “Integration” also means that there will be more multi-purpose instruments, stations and networks, and more progress on data interoperability, data exchange and data processing.

Data volumes for some observing systems, such as radiosondes or the surface stations, will stay relatively small. By contrast, for remote-sensing observing systems such as radar, the observed data volume is expected to grow fast (with similarities to satellite data), and the exchanged data volumes are expected to grow even faster.

In the following section (5.2), the generic issues concerning the surface-based global observing systems are put together, with the corresponding recommendations which are appropriate for its implementation in the period 2012-2025. Section 5.3 describes the recommended Actions for the different observing systems which should be used operationally by 2025, including some possible research / development activities which should be carried out, aiming at improving the observing systems.

5.2. Generic issues: representativeness, traceability, instrument calibration, data exchange

To guarantee data quality, especially for climate applications, instrument measurements should be traceable to the International System of Units (SI); that should be done through an unbroken chain of comparisons, quality assessments (including site representativeness) and calibrations of instruments and respective working international standards. Considering the rapid expansion in the number of different agencies operating observing networks (especially AWSs) and their potential contribution to WMO observing systems, evidence of traceability or quality management must be maintained over time. Where traceability to SI is not possible for some manual observations (e.g. cloud type), reference to published WMO standards should be required.

Action G1

Action: Ensure traceability of all meteorological observations and measurements to SI or WMO standards.

Who: NMSs/NMHSs, in coordination with WMO own and co-sponsored programmes, TCs, RAs, and other relevant organizations. CBS and RAs to lead and supervise.

Time-frame: Continuous.

Performance indicator: Number of stations that make measurements traceable to SI or WMO standards.

The increase of data volumes for some specific observing systems, such as radars and wind profilers, has to be accompanied by actions ensuring capability of WIS to cope with the corresponding increase of data exchange. This increase will be partly due to more frequent observations, e.g., through the automation, or to exchange of existing observations that were not exchanged internationally.

OSEs performed with NWP models have shown that global forecasts can be improved significantly by assimilating hourly data, even if the data are available only on a small portion of the globe, such as hourly atmospheric pressure observations from synoptic stations, radar data, and data from Global Navigation Satellite Systems (GNSS) receiving stations. Similarly, other applications, including climate and aviation, rely increasingly on sub-hourly data. Open and unrestricted access to all available data and their exchange would be needed to improve scope and quality of services provided by NMSs / NMHSs to their users.

Action G2

Action: Ensure, as far as possible, a global exchange of hourly data which are used in global applications, optimized to balance user requirements against technical and financial limitations.
Who: NMSs/NMHSs, RAs, in coordination with CBS and international programmes and agencies. CBS to lead the action.
Time-frame: Continuous. Timetable to be decided for each observing system.
Performance indicators: The standard monitoring indicators used in global NWP (see footnote no. 17 in section 3.6).

Action G3

Action: Promote a global exchange of sub-hourly data in support of relevant application areas.
Who: NMSs/NMHSs, in coordination with WMO own and co-sponsored programmes, TCs, RAs, and other relevant organizations. CBS to lead the action.
Time-frame: Continuous. Timetable to be decided for each observing system.
Performance indicator: A number of sub-hourly data types exchanged through WIS.

Climate modelling and seasonal forecasts also require an exchange of data between the different centres monitoring the atmosphere, the ocean and the terrestrial sub-system. Although the real-time constraints are less severe than for NWP, it is important to integrate these different observation systems, with common pre-processing and exchange rules, following the WIS and WIGOS standards. Such an action would improve considerably the benefits to the users without creating new observing systems. As the different users have different operational constraints and different requirements in data resolutions, this may imply, for some observing systems producing high data volumes, to organize the processing with different data levels (as done already for many satellite missions). The requirement for the validation of satellite products using surface-based observations can also be addressed by facilitating access to the data.

Action G4

Action: Ensure exchange of observations from atmosphere, ocean, terrestrial observing system, according to the WIGOS/WIS standards. If needed, organize different levels of pre-processed observations in order to satisfy different user requirements.

Who: NMSs/NMHSs, in coordination with WMO own and co-sponsored programmes, TCs, RAs, and other relevant organizations. CBS to lead the action.
Time-frame: Continuous. Timetable to be decided for each observing system.
Performance indicator: Statistics on the data made available to each application.

Action G5

Action: Surface-based observing network operators should facilitate access to observations suitable to support validation of space-based derivation of surface parameters.
Who: CBS to lead, in collaboration with NMSs and NMHSs.
Time-frame: Continuous.
Performance indicator: Quantity of surface-data made available for the validation of satellite products.

Mainly for the climate monitoring, but also for other applications, it is important:

- To maintain stations with long historically-uninterrupted observation records;
- To perform a regular calibration of instruments;
- To greatest extent possible, adhere to CIMO classification guidelines for siting and maintenance of the station environment;
- To test and intercompare different observing instrument/systems (e.g., radiosonde systems and remote-sensing systems providing different types of vertical profiles with a view of establishing the interoperability of their data);
- To collect and archive sufficient metadata to enable homogeneity assessments to be made and data provenance and fitness for purpose to be assessed;
- For all countries to maintain their GCOS (GSN, GUAN, and RBCN) stations and for these to provide observations on a continuing basis as long as possible.

For more details, see the Quality Management Framework (section 2.1 above).

Action G6

Action: Surface-based observing network operators should consider using space-based observations/products to monitor quality of data from surface-based networks.
Who: CBS to lead, with NMSs and NMHSs.
Time-frame: Continuous.
Performance indicator: Number of surface-based observing systems using satellite data for quality monitoring.

5.3. Issues specific to each observing system component

5.3.1. Upper-air observing systems over land

Upper-air profiles have long been collected using balloon-based methods. These methods are now complemented by a range of other sources over land, over the oceans and from space. WMO now adopts a composite approach, seeking to optimize the use of different methods to satisfy the requirements for upper-air observations. The following section addresses the contributions made by balloon-based upper-air stations, remote sensing profiling stations, aircraft observations, GAW stations and GNSS receiver stations. The contributions made over the oceans are addressed in section 5.3.5 and the contributions made from space are addressed in chapter 6.

5.3.1.1. Upper-air stations[26]

5.3.1.1.1. Radiosonde network and data coverage: optimization

NWP impact studies have consistently shown the importance of vertical profile data, particularly radiosonde data from isolated locations (see Section 4 of the proceedings of the fourth WMO Workshop on the Impact of Observations on NWP), and a network of upper-air measurements of sufficient coverage is required for climate monitoring. Inadequacies include some large continental regions that are not monitored by any radiosonde site. It is essential to reduce these big gaps in the radiosonde data coverage, or at least, to prevent these gaps from expanding.

It is essential to maintain operational radiosonde and pilot balloon stations in the least observed areas of Regions I, II and III, keeping in mind that the optimization of the radiosonde coverage cannot be done independently of aircraft and other observing systems.

Action G7

> **Action**: Expand radiosonde stations, or re-activate silent radiosonde stations, in the data sparse areas of Regions I, II and III which have the poorest data coverage. Make all possible effort to avoid closing of existing stations in these data sparse areas, where even a very small number of radiosonde stations can provide an essential benefit to all the users.
> **Who**: NMSs/NMHSs, in coordination with WMO own and co-sponsored programmes, TCs, RAs, and other relevant organizations. CBS to lead the action together with the RAs.
> **Time-frame**: Continuous.
> **Performance indicators**: The standard monitoring indicators used in NWP (see footnote no. 17 in section 3.6).

One of the highest priorities in terms of observation requirements is to add more profile observations in many data sparse areas. Thus all the AMDAR opportunities (see section 5.3.1.3) should be used to improve the wind and temperature data coverage, especially in data sparse areas like the inter-tropical regions or central and southern Africa. This implies collecting new wind and temperature profiles at certain airports by equipping some aircrafts flying regularly to these airports, and also acquiring data from cruise levels in these regions.

Action G8

> **Action**: Reconsider radiosonde network designs (e.g. by using isolated stations), taking into account other available sources of data, such as AMDAR and wind profilers.
> **WHO**: CBS through NWP impact studies and network design studies, in coordination with NMSs/NMHSs, WMO own and co-sponsored programmes, other TCs, RAs and other relevant organizations. CBS and RAs to lead the action.
> **Time-frame**: 2015 (or earlier) for a first redesign.
> **Performance indicator**: Design developed and implemented.

Several studies and campaigns (see reference to AMMA in the proceedings of the fourth WMO workshop on the impact of various observing systems on NWP[27]) have shown that in some cases NWP forecasts can be significantly improved by using additional targeted measurements in pre-computed sensitive areas (from operational NWP runs). Although the radiosonde network

26 Including radiosondes, pilot balloon, and dropsondes
27 http://www.wmo.int/pages/prog/www/OSY/Meetings/NWP-4-Geneva2008/Abridged_Version.pdf

is operated from fixed points, it has also been shown that increased effectiveness may be reached by varying the observation time or the launch frequency at some radiosonde sites, as confirmed by tests done by the Network of European Meteorological Services (EUMETNET) Composite Observing System (EUCOS[28]). Benefits can be drawn in the coming years by making the existing radiosonde network more adaptive or at least more optimal in time-space coverage.

The radiosonde network could be tuned in the following features: (i) the radiosonde observation time (e.g.: could it be switched from 00 and 12 UTC to other times in response to the local meteorology); (ii) the distance from the radiosonde sites to the airports (where AMDAR data can be easily obtained); (iii) the radiosonde time-series required by climate applications at fixed sites and regular times.

Action G9

Action: Continue the studies and tests on the usefulness of observations obtained by increasing the frequency of radiosonde launches at some observation sites, in relation with the meteorological situation in the area.
Who: NMSs/NMHSs, research institutions and other organizations operating radiosonde networks or organizing field-experiments, with the NWP centres. CBS and CAS to lead the action.
Time-frame: Continuous, with a time-table depending on regional campaigns.
Performance indicators: A number of radiosonde sites able to become “adaptive” together with the number of observations made (standard monitoring).

Action G10

Action: Investigate possibility to optimize the radiosonde network in order to make the upper-air conventional observation coverage more uniform taking into account all the user requirements in terms of space and time distribution; and make relevant recommendations to the CBS for updating Technical Regulations accordingly.
Who: NMSs/NMHSs, in coordination with WMO’s own and co-sponsored programmes, TCs, RAs and other relevant organizations. CBS and RAs to lead the action.
Time-frame: 2015, then continuous.
Performance indicators: Standard monitoring indicators.

5.3.1.1.2. GUAN and GRUAN stations

A selection of upper-air stations from RBSN/RBCN which are significant for both synoptic and climatological purposes form a baseline network called GCOS Upper-Air Network (GUAN). GUAN stations (currently 173) are also used to validate satellite data. GCOS is in the process of coordinating the implementation of an upper-air reference network for upper-air climate observations (GRUAN) that is expected to provide long-term, highly accurate measurements of atmospheric profiles, complemented by ground-based state-of-the-art instrumentation in order to fully characterize the properties of the atmospheric column and their changes. GRUAN is envisaged as a network of 30-40 high-quality, long-term, upper-air observing stations, building on existing observational networks, such as GUAN, the Global Atmospheric Watch (GAW), RBSN and GSN, and providing complete metadata for traceability of measurements. Because there is no other upper-air observing system able to provide a reference at fixed points (satellite and aircraft data are obtained at different positions from one day to another), it is very important to maintain the GUAN and develop the GRUAN (see also section 5.3.8.3).

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28 See http://www.eucos.net/

Action G11

Action: Improve quality, availability and sustainability of GUAN, ensuring maintenance of the existing network, and data quality.
Who: CBS to lead, in coordination with GCOS and with NMSs/NMHSs, TCs, RAs, and other relevant organizations.
Time-frame: Continuous.
Performance indicators: The standard monitoring indicators used in NWP.

Action G12

Action: Continue implementation of GRUAN through support and development of the initial 15 stations and eventual completion of the full 30-40 station network.
Who: CBS to lead in coordination with GCOS and with NMSs/NMHSs, TCs, RAs, and other relevant organizations.
Time-frame: Continuous.
Performance indicators: The standard monitoring indicators used in NWP and the indicators defined in the GRUAN Observation Requirements.

5.3.1.1.3. Improved dissemination

Data from some radiosonde stations are never internationally exchanged in real-time over the GTS, although they may be exchanged and archived locally and made available for climatological purposes. In some cases data exchange over the GTS has several hours delay, which reduces considerably their use for operational purposes. In many cases telecommunication hardware problems or software coding problems are responsible for unavailability of data.

Action G13

Action: Identify radiosonde stations that make regular measurements (including radiosondes operated during campaigns only), but for which data are not transmitted in real-time. Take actions to make data available.
Who: NMSs/NMHSs, in coordination with WMO own and co-sponsored programmes, TCs, RAs, and other relevant organizations. CBS and RAs to lead the action.
Time-frame: Continuous.
Performance indicator: A number of the above radiosonde stations providing data to GTS, plus standard monitoring indicators on radiosonde data availability and timeliness.

5.3.1.1.4. Reporting of high resolution observations

Many radiosonde observations are thinned (reduction of vertical resolution of the measured profiles) before they are internationally exchanged and assimilated in real-time. As a consequence, NWP and other applications do not have access to radiosonde data at high-vertical resolution, from which they could now derive significant benefits. Also, the user has no access to the exact position and time of each datum. The development of BUFR code for radiosonde data has been driven primarily by the need to address these problems and should help to solve most of the dissemination problems.

Action G14

Action: Ensure a timely distribution of radiosonde measurements at high vertical resolution, together with position and time information for each datum, and other associated metadata.

Who: NMSs/NMHSs, in coordination with WMO own and co-sponsored programmes, TCs, RAs, and other relevant organizations. CBS and RAs to lead the action.
Time-frame: Continuous.
Performance indicator: Number of radiosonde sites providing the high resolution profiles.

This Action consists of two sub-actions: (i) to code the radiosonde observation in high resolution BUFR (rather than low-resolution BUFR or TEMP[29]); and (ii) to transmit the position and time of each datum.

5.3.1.1.5. Observation of the stratosphere

Only 10 to 20% of the operational radiosonde profiles generally reach 10hPa (about 30km height). Except for some stations from the GRUAN network, whose role is also to serve as reference observations in the lower stratosphere, it may not be cost-effective to deploy radiosondes for measurements in the stratosphere due to the cost of reaching high altitude.

NWP impact studies have shown that the radiosonde data above 100hPa do have a positive impact on forecasts through NWP data assimilation, including on the forecast of tropospheric fields. However, these studies were conducted in a context where neither current satellite sounders nor the GNSS radio-occultation data were assimilated. The question of the usefulness of radiosonde data above 100 hPa should then be reassessed, while recognizing the requirement for continuity of data above 100hPa for climate monitoring.

Action G15

Action: Perform NWP impact studies to evaluate the impact of radiosonde data above 100hPa on global NWP, in the context of current observing systems (2012).
Who: NWP centres, coordinated by CBS/ET-EGOS in collaboration with CAS.
Time-frame: Before end of 2013.
Performance indicator: A number of independent studies carried out.

Observing System Simulation Experiments (OSSEs) are needed to evaluate the impact of a “perfect” atmosphere above 100hPa on the tropospheric forecasts. The idea is to give a quantitative estimate of the maximum benefit which could be obtained in NWP through improved observation of the stratosphere. OSSEs made with a variable number of radiosonde sites (providing data above 100hPa) could be compared to this upper limit.

Action G16

Action: Perform OSSEs to evaluate the impact of improved information above 100hPa on the tropospheric forecasts.
Who: NWP centres, coordinated by CBS/ET-EGOS in collaboration with CAS.
Time-frame: Before end of 2013
Performance indicator: A number of independent experiments of this kind carried out.

29 FM-35 TEMP GTS format : Upper-level pressure, temperature, humidity and wind report from a fixed land station

5.3.1.2. Remote-sensing upper-air profiling stations

A variety of remote sensing techniques are emerging for measuring some parts of the atmospheric profile of wind, temperature and humidity. Radar wind profilers are used operationally in many regions. Vertical profiles of wind are also derived from Doppler weather radars in many regions, while Doppler lidar and microwave radiometers are being introduced in some regions. Some devices can be used to measure aerosol, cloud properties and trace species in the atmosphere. Ceilometer data are used to monitor the height of the planetary boundary layer and volcanic ash. GALION (GAW Aeorosol Lidar Observing Network) is a network of regional lidar networks for the observation of atmospheric aerosols. See: http://alg.umbc.edu/galion/

Compared to the radiosonde measurements, the remotely sensed observations are providing data with much higher frequency. However they currently have a strong limitation in terms of data coverage. Only very few systems are technically able to measure atmospheric profiles from the boundary layer to the stratosphere. Most profilers measure only one variable in one part of the atmosphere, for example, the wind in the boundary layer. In future, the large variety of profiler instruments should be developed and used by an increasing number of applications. This is important from the point of view of complementing the radiosonde and aircraft profiles in the lower and upper troposphere. It would be an advantage to develop regionally a homogeneous network of remote-sensing profiling stations with a few sites integrating a large range of instruments and observing simultaneously (e.g.) wind, temperature and humidity.

In view of the future integrated observation system, in terms of temporal and spatial factors, Observing System Simulation Experiments (OSSEs) could be initiated to evaluate the impact of different remote-sensing profiling stations, in order to optimize upper-air observation profile observation, and in particular provide the guidance for integrated network design.

Action G17

Action: Develop networks of remote-sensing profiling stations on the regional scale in order to complement the radiosonde and aircraft observing systems, mainly on the basis of regional, national and local user requirements (although part of the measured data will be used globally).

Who: Organizations operating profiling stations in routine or research mode, in coordination with NMSs/NMHSs, RAs, TCs (mainly CAS, CBS and CIMO) and other regional institutions (e.g. EUMETNET in Europe). CBS to lead the action, in collaboration with CIMO, CAS and RAs.

Time-frame: Continuous. Detailed timetables to be set up by RAs at the regional level.

Performance indicator: A number of profiling stations providing quality-assessed data in real-time to WIS/GTS.

Global data assimilation schemes are able to assimilate observations which are produced every hour, or even more frequently, and they are able to draw benefits from such frequent observations even if they are produced by few limited profiling stations round the globe. It is useful to exchange globally data profiles produced on an hourly basis (or at least a subset). Appropriate data representation in BUFR should be available for this purpose.

Action G18

Action: Ensure, as far as possible, the required processing and the exchange of profiler data for local, regional and global use. When profiler data can be produced more frequently than 1 hour, a dataset containing only hourly observations can be exchanged globally following the WIS principles.

Who: Organizations operating profiling stations in routine or research mode, in coordination with NMSs/NMHSs, RAs, TCs (mainly CAS, CBS and CIMO) and other regional institutions (e.g. EUMETNET in Europe). CBS to lead the action together with the RAs.

Time-frame: Continuous. Detailed timetables to be set up by RAs at the regional level.

Performance indicator: A number of profiling stations exchanged globally.

5.3.1.3. Aircraft meteorological stations

In the northern hemisphere, meteorological data derived from aircraft stations, especially the automatic data produced by the AMDAR system, are an excellent complement to the data derived from the radiosonde network. This system produces vertical profile data in the vicinity of airports and single-level data when aircraft are flying at cruise levels. It has been shown through NWP impact studies that their impact on numerical forecasts has a magnitude similar to the impact of the radiosonde network. In the southern hemisphere and in the tropics the aircraft data coverage is very poor although there is some potential for developing it, preferably in a way that is complementary to existing AMDAR and radiosonde networks.

Extending aircraft observations data coverage is important and can be achieved through the extension of the programme to new airlines and aircraft operating in data-sparse areas. The programme coverage can also be improved greatly through an optimization process. This can be achieved through two general activities. Firstly, existing programmes can be extended so that internationally-operating aircraft are activated for reporting outside the national areas or regions that tend to be restricted by national programme constraints. Secondly, one can enhance the capabilities of programmes to control data output through the wider development and implementation of automated data optimization systems. Such systems, whilst allowing the efficient growth of the programme outside and across international boundaries with appropriate agreements in place, will also offer the potential to utilize the AMDAR system as an adaptive observing network (capability to change the reporting regime to serve the changing purposes of programme areas).

Action G19

Action: Improve AMDAR coverage over areas that currently have poor coverage, especially within Regions I and III, focussing on the provision of data at airports in the tropics and southern hemisphere where vertical profiles are most needed to complement current radiosonde data coverage and its likely evolution.

Who: NMSs, NMHSs in collaboration with commercial and other airlines, RAs. AMDAR Programme Management to lead the action.

Time-frame: Continuous.

Performance indicators: Number of airports where AMDAR measurements are taken. Amount of vertical profiles and AMDAR data in general, measured by the usual indicators of current AMDAR programmes.

Action G20

Action: Extend the AMDAR programme so as to equip and activate more internationally-operating fleets and aircraft (i.e. fleets and aircraft flying to and between international airports outside the country of origin) and extend the use of data optimization systems in support of improved upper-air observations coverage and efficiency, and also the adaptive functionality of the system.

Who: NMSs, NMHSs in collaboration with commercial and other airlines, RAs, CBS and AMDAR Programme Management. AMDAR Programme Management to lead the action.

Time-frame: Continuous.

Performance indicators: The number of airports where AMDAR measurements are taken and number of vertical profiles per day at each airport. The number of international airlines and aircraft equipped to provide AMDAR observations. The adaptability of the AMDAR programme.

Action G21

Action: Given the nature of the aircraft observing system as an increasingly critical and basic component of the Global Observing System, seek to establish agreements with airlines and the aviation industry to ensure that the system, infrastructure, data and communications protocols are supported and standardized within relevant aviation industry frameworks so as to ensure continuity and reliability of the system.

Who: NMSs, NMHSs in collaboration with national and other airlines and aviation industry, RAs, CBS and AMDAR Programme Management. AMDAR Programme Management to lead the action.

Time-frame: Continuous.

Performance indicators: Agreements made with aviation industry partners and organizations.

Data produced by humidity sensors are now used operationally from an increasing number of aircraft both in the USA and Europe, and it is critical and strategic to continue this development in order to converge to systems which measure humidity as well as air pressure (pressure altitude), temperature and wind as do radiosondes. Such an extension will provide an increased opportunity to restructure the upper-air observing systems for efficiency and improvement in coverage.

Action G22

Action: Continue the development and operational implementation of humidity sensors as an integrated component of the AMDAR system to ensure that humidity data is, processed and transmitted in the same way as wind and temperature.

Who: NMSs, NMHSs in collaboration with commercial and other airlines and TCs (CBS, CIMO) and AMDAR Programme Management. AMDAR Programme Management to lead the action.

Time-frame: Continuous.

Performance indicator: A number of aircraft providing humidity data in real-time.

The lower cost of aircraft observations in comparison to the radiosonde information as well as the reduced reliance on ground-based systems and infrastructure make it an ideal candidate system for rapid and reliable expansion of upper-air observations for developing countries in support of local, regional and global data users. Such an expansion should be undertaken in parallel with the necessary development action to facilitate the provision and utilization of data.

Observations of turbulence and icing are also made on some aircraft and it is desirable to expand this capability of the AMDAR system with these parameters in support of aviation operations and safety as well as other meteorological applications.

Action G23

> **Action**: Enhance and extend the capability to report observations of atmospheric turbulence and icing variables as an integrated component of the AMDAR system and in line with the requirements of the relevant programme areas and data users.
> **Who**: NMSs, NMHSs in collaboration with airlines and TC (CBS, CIMO) and AMDAR Programme Management l, RAs. AMDAR Programme Management to lead the action.
> **Time-frame**: Continuous.
> **Performance indicator**: A number of aircraft providing atmospheric turbulence and icing data in real-time.

Another source of important potential progress is the research and development actions associated with AMDAR systems for small aircraft, usually referred to as General Aviation (GA) aircraft. These aircraft tend to fly and generate level data in the middle troposphere whilst operating over shorter regional flight legs. This type of observation would be very useful for regional and local purposes and could also contribute to global data coverage. Priority should be placed on equipping aircraft operating on, to and out of isolated islands and remote sites where radiosonde observations are not available, e.g. deserts, islands and the Arctic. The impact of existing data sets (derived from deployment of the commercial communications and sensor system) on high resolution NWP models has been evaluated and compared to other observing systems such as profilers and radars. The results are encouraging: see for example Moninger et al. (2010) and Benjamin et al. (2010). In spite of several technical snags, AMDAR systems for GA aircraft do have potential for contributing to the improvement of data coverage of vertical profiles of AMDAR measurements (wind, temperature, humidity, turbulence and icing) in the lower troposphere and this development should be pursued whilst taking into account the potential associated with new and developing technologies such as ADS-B and Mode S.

Action G24

> **Action**: Develop and implement operational AMDAR systems which are adapted to small aircrafts operating at the regional scale and flying at low altitude in the troposphere.
> **Who**: Airlines operating small aircraft, NMSs, NMHSs in collaboration with RAs, CBS and AMDAR Programme Management. AMDAR Programme Management to lead the action.
> **Time-frame**: Continuous.
> **Performance indicator**: Number of small aircrafts providing AMDAR observations operationally in real-time.

Atmospheric composition measurements for several species, aerosols and volcanic ash are measured on some aircraft, but more in research than in operational mode. The actions related to atmospheric chemistry are documented in section 5.3.8.4.

5.3.1.4. Global Atmosphere Watch stations

Surface-based observations of atmospheric composition, complemented by aircraft measurements (see 5.3.8.4), will contribute to an integrated three-dimensional atmospheric chemistry observation network, together with a space-based component. Networks exist which are making regular measurements of ozone (profile and total) and many other gas species and aerosols (see GAW Strategic Plan[30] and addendum[31] for the complete list of variables). The tasks suggested for maintaining and enhancing the networks and for increasing the coverage in the tropics and southern hemisphere should be supported also for other applications. In addition, where appropriate the atmospheric composition observations are recommended to be processed and disseminated in near-real-time, in order to be used in several applications.

Action G25

Action: Encourage managers of national programmes of meteorological observations to extend the scope of these stations to include atmospheric chemistry observations.
Who: NMSs/NMHSs and respective organizations and research agencies conducting atmospheric composition observations, in coordination with TCs (especially with CAS and CBS) and RAs. CAS and CBS to lead the action with RAs.
Time-frame: Continuous. Timetable to be defined for each RA.
Performance indicator: Number of atmospheric composition stations.

5.3.1.5. GNSS receiver stations

In a similar way to the atmospheric profilers, networks of GNSS ground-based receiver stations have been operational in few regions around the world. The main application of these networks is generally not meteorological. Although they are very heterogeneous in quality and observing practices, the meteorological information has been extracted and collected in real-time from some stations. Starting in 2006, the meteorological information has been assimilated in operational NWP (both global and regional) either in the form of an Integrated Water Vapour (IWV = total water vapour integrated on the vertical), or in the form of a Zenith Total Delay (ZTD). The ZTD contains both the “wet delay” (due to the water vapour) and the “dry delay” directly related to the air density (air density directly related to surface pressure). The positive impact of GNSS ground-based meteorological observations on numerical forecasts has been shown (on the water vapour, precipitation and atmospheric pressure fields). See footnote referencing the workshop (on impact studies) in section 4 to access to a synthesis of OSEs.

The ground receiver stations in most countries are owned and operated by agencies other than the NMHSs. Hence the access to data, the processing to produce meteorological data, and permission to use and redistribute the data are all dependent on collaboration by the NMHS (individually or in multilateral groupings) with the owners/operators. In many cases it is not permitted for the NMHS (individually or in multilateral groupings) to exchange the data with other Members of WMO.

Concerning this observing system which is relatively new in meteorology, one important action is to exploit more the meteorological content of the existing GNSS receiver stations (in the form of IWV or ZTD). This action does not require deployment of new infrastructure. In addition, it would be very beneficial to improve the observation of upper-air humidity with denser receiver networks, taking into account all the other instruments that observe the upper-air humidity, and looking especially at areas for which the climatology is subject to rapid variations (in space and time) of the atmospheric water vapour content.

Total electron content (TEC) along a given propagation path can also be measured by tracking the time delay and phase shift of GNSS radio signals acquired by a ground receiver, for ionospheric monitoring. For example, high-rate ground GPS and GLONASS observations from

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30 ftp://ftp.wmo.int/Documents/PublicWeb/arep/gaw/gaw172-26sept07.pdf
31 http://www.wmo.int/pages/prog/arep/gaw/documents/FINAL_GAW_197.pdf

the International GNSS Service (IGS) are made every 15 minutes with a typical delay of 2-3 minutes. This is useful information for monitoring the space weather (see section 7).

Action G26

Action: Derive greater benefit from the existing GNSS receiver stations by establishing collaborative arrangements with station owners and operators for access, processing, and sharing of real-time data to derive meteorological or ionospheric information (ZTD or IWV, TEC).

Who: NMSs/NMHSs (individually or in multilateral groupings) will lead the Action and will need to collaborate with station owners/operators, with RAs (to determine exchange requirements), and with TCs (for relevant guidance).

Time-frame: Continuous.

Performance indicators: Number of GNSS receiver stations making available their data in real-time; number of stations which can be used in NWP according to the usual monitoring criteria (see footnote no. 17 in section 3.6).

Action G27

Action: Organize the global exchange of data from a subset of GNSS receiver stations, aiming at satisfying a frequency requirement of about one hour (for meeting requirements in global applications).

Who: Organizations and research agencies operating GNSS receiver stations, in coordination with NMSs/NMHSs, with RAs, TCs (especially CAS and CBS) and other international organizations (e.g. EUMETNET). CBS to lead the action with RAs.

Time-frame: Continuous.

Performance indicator: A number of GNSS receiver stations whose data are exchanged globally in real-time.

Action G28

Action: Optimize the upper-air water vapour observation over land, considering the collaborative establishment of additional GNSS receiver stations, and also the other humidity observing systems.

Who: Organizations and research agencies operating GNSS receiver stations, in coordination with NMSs/NMHSs, with RAs, TCs (especially CAS and CBS) and other international organizations (e.g. EUMETNET). NMSs/NMHSs to lead the action with RAs.

Time-frame: Continuous.

Performance indicators: Number of GNSS receiver stations making available their data in real-time; number of stations which can be used in NWP according to the usual monitoring criteria (see footnote no. 17 in section 3.6).

5.3.2. Surface observing systems over land

5.3.2.1. Surface synoptic and climate stations

“Synoptic” stations are observing stations originally developed to address the needs for synoptic meteorology and other applications (e.g. aeronautical meteorology, climate monitoring, severe weather and disaster risk reduction), “synoptic” meaning that they belong to an ensemble of stations providing observations at the same time, allowing a weather analysis on a large geographical area at a given time.

Land-surface observations come from a wide variety of in-situ networks, and they serve the requirements of many application areas. Surface synoptic and climatological stations provide measurements at the interface between the atmosphere and the land surface, and also other qualitative or quantitative observations related to atmospheric or environmental phenomena, such as visibility, present weather, cloud height, cloud type, thunderstorms, lightning and type of precipitation, which are increasingly important for emerging environmental societal applications. For initializing NWP models the important variables are surface pressure, surface wind, air temperature and humidity, precipitation and the state of the ground, including snow depth and soil moisture. Most of these variables can be assimilated in NWP models with an hourly frequency, therefore, the global exchange of these data should be adapted accordingly. There are also many variables that serve the full needs of the climate services community, and there is a growing requirement for high frequency measurements and near-real-time transmission and data collection. These include, but are not limited to, ECVs listed in the GCOS-IP. In addition climate reference stations are being established to provide the highest quality observations for climate monitoring while also supporting forecasting through hourly data transmission. The monitoring of the surface radiation budget is very dependent on the surface stations of the BSRN (Baseline Surface Radiative Network)[32].The BSRN should be expanded and secured. Radiation and energy flux measurements (e.g. from Fluxnet) have to be considered as well.

Action G29

> **Action**: Extend the BSRN to achieve global coverage.
> **Who**: NMSs/NMHSs, and research organizations, RAs and TCs, coordinated by CBS.
> **Time-frame**: Continuous.
> **Performance indicator**: Number of BSRN stations.

Action G30

> **Action**: Ensure, as far as possible, global exchange of variables measured by surface observing stations (including climatological stations) with at least one hour frequency and in real-time.
> **Who**: NMSs/NMHSs, RAs and TCs, coordinated by CBS.
> **Time-frame**: Continuous.
> **Performance indicator**: A percentage of observations exchanged globally with a one hour frequency (with respect to the number of stations observing hourly).

An increasing number of variables are measured automatically with required quality. The trend to automation is encouraged, as it could improve the data compatibility and the data coverage, especially from remote locations, and the frequency and availability of data in real-time. Currently, many observations made routinely are not distributed in real-time, although requirements are documented in the RRR, and automation does provide new opportunities for disseminating variables that were in the past collected but not shared in real-time.

In addressing the increasing trend in automation of observations, CBS and CIMO have developed guidelines and procedures for the transition from manual to Automatic Weather Stations (land and marine). Once published, they will be available on the WMO Website[33].

Action G31

> **Action**: Improve data compatibility, availability (also with higher frequency) and data coverage of surface observations (including climatological) through quality management, automation and exchange of data in real-time, as far as possible from all operational stations.

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32 http://www.bsrn.awi.de/
33 http://www.wmo.int/pages/prog/www/IMOP/publications-IOM-series.html

Who: NMSs/NMHSs, RAs and TCs, coordinated by CBS.
Time-frame: Continuous.
Performance indicator: A percentage of stations distributing quality-assessed observations in real-time over WIS/GTS (with respect to the number of stations producing observations).

Several observations are made and transmitted routinely, but they are exchanged in formats that are not adequate to contain metadata needed for appropriate use in data assimilation and in other tools. This is particularly true for the atmospheric pressure which is usually measured with a very good accuracy, but cannot be used without accurate information of the barometer altitude. Another example of needed metadata information is the height (above the surface) where the wind measurement is taken. Other variables including temperature and precipitation and other elements for climate services are sometimes also transmitted without adequate metadata.

Actions aiming at improving the quality, the consistency and the availability of the surface observations (including climatological) are particularly important for climate applications and will contribute to building long-term series of observations and re-analyses. All the actions of the GCOS-IP (section dealing with the surface observations of the atmospheric domain) must also be supported for non climate applications.

Action G32

Action: Ensure variables measured by surface stations (including climatological) are exchanged together with access to relevant metadata according to WIGOS and WIS standards. Special attention should be given to the barometer altitude uncertainty.
Who: NMSs/NMHS, RAs and TCs, coordinated by CBS.
Time-frame: Continuous.
Performance indicators: Usual monitoring indicators (see footnote no. 17 in section 3.6).

Action G33

Action: Improve design of the Regional Basic Synoptic Network (RBSN) and the Regional Basic Climatological Network (RBCN), making every effort to retain climatically significant stations.
Who: CBS leading the action through the appropriate NWP impact studies and network design studies, in coordination with NMSs/NMHSs, WMO-owned and co-sponsored programmes, other TCs, RAs and other relevant organizations.
Time-frame: 2015.
Performance indicator: Design developed and implemented.

5.3.2.2. Global Atmosphere Watch stations

Surface observations of atmospheric composition contribute to an integrated three-dimensional atmospheric chemistry observation network, together with upper-air measurement stations (ground-based, aircraft, balloons, see 5.3.1.4 and 5.3.8.4) and with a space-based component. Surface observations of CO_2 and CH_4 for example are very important for identifying sources and sinks of these components and for understanding the radiative influences on climate (see references to the GAW documents in section 5.3.1.4, and also the GCOS-IP). Surface observing network for atmospheric chemistry variables is clearly insufficient for global observing requirements. Priorities for different tasks for surface-based trace gases and aerosol observations are laid out in the GAW Strategic Plan and its addendum (see also references of section 5.3.1.4).

By 2025, models used for NWP and climate and atmospheric composition modelling will become increasingly important for climate projection and chemical weather forecast. In support of this, it will be important to progressively integrate the corresponding observing networks, so that atmospheric composition observations are made available in near-real-time.

Action G34

Action: Implement as soon as possible a near-real-time exchange of the atmospheric composition observations which are made at surface stations. Follow the GAW recommendations and WIGOS and WIS practices for implementing this dissemination, and the standard quality assessment practices.
Who: Organizations and research agencies operating atmospheric composition observations, in coordination with NMSs/NMHSs, the RAs and TCs. CAS and CBS to lead the action with RAs.
Time-frame: Continuous. Timetable to be established for each RA.
Performance indicator: A number of surface atmospheric composition stations making quality-assessed data available in real-time.

5.3.2.3. Global Cryosphere Watch stations

The recently established Global Cryosphere Watch (GCW) programme will set up a comprehensive cryosphere observing network called "CryoNet", a network of reference sites or "super-sites" in cold climate regions, operating a sustained, standardized programme for observing and monitoring as many cryospheric variables as possible at each site. Initially, it will build on existing cryosphere observing programmes or add standardized cryospheric observations to existing facilities as part of super-site environmental observatories. As encouraged by GCOS, GCW will facilitate the establishment of high-latitude super-sites with co-located measurements of key variables, especially permafrost and snow cover, thus enhancing GCOS/GTOS Networks for Permafrost (GTN-P), Glaciers (-G) and Hydrology (-H). GAW stations in cold climates are logical candidates. CryoNet reference sites will provide long-term data sets for monitoring climate variability and change, improved model parameterization of cryospheric processes, and support for development and validation of satellite products and forecast, climate, hydrologic and cryospheric models. The CryoNet Team of the GCW Observing Systems Working Group will develop formal procedures for establishing the GCW network, evaluate potential supersites, and determine data availability.

Action G35

Action: Implement as soon as possible a comprehensive cryosphere observing network of reference sites "CryoNet".
Who: Organizations, institutes and research agencies conducting cryosphere observation and monitoring, in coordination with NMSs/NMHSs, the RAs and TCs, as required. CryoNet Team will lead the action. GCW Advisory Board and Management Board will oversee the action.
Time-frame: 2014.
Performance indicator: Number of reference sites taking part in CryoNet.

Action G36

Action: Provide, as far as possible, a real-time or near-real-time exchange of the cryospheric data from CryoNet. Follow the GCW, WIGOS and WIS practices for implementing this dissemination, and the standard quality assessment practices and archiving.

Who: Organizations, institutes and research agencies conducting cryosphere observations and monitoring, in coordination with NMSs/NMHSs, the RAs and TCs, as required. CryoNet Team will lead the action. GCW Advisory Board and Management Board will oversee the action.
Time-frame: 2014.
Performance indicator: Number of CryoNet stations making quality-assessed data available.

5.3.2.4. Lightning detection systems

Ground-based (total or only “cloud to ground”) real-time lightning detection and tracking systems have demonstrated their value as an early indicator of the location and intensity of developing convection, and also of the motion of thunderstorms. Especially for nowcasting, severe weather warning and aviation applications, these observing systems may increase the warning lead time associated with severe thunderstorms. For aviation the data coverage requirement is almost global. Advanced lightning systems also provide the 3D structure of the electricity activity for aviation.

In 2025 one can foresee long-range lightning detection systems providing cost-effective, homogenized global data, with high location accuracy, significantly improving the data coverage in data-sparse areas. High resolution lightning detection systems should be also deployed in some specific areas, for special applications, with higher location accuracy, and with cloud-to-cloud and cloud-to-ground discrimination.

Action G37

Action: Improve global lightning detection efficiency by extending the deployment of long-range lightning detection systems and introducing more of these systems. Priorities should be given to filling gaps in populated areas and along commercial airline routes.
Who: NMSs/NMHSs and agencies operating long-range lightning detection systems RAs and TCs, coordinated by CBS and CIMO, leading the action jointly.
Time-frame: Continuous.
Performance indicator: Data coverage for this type of observations.

Action G38

Action: Develop and implement techniques for the integration of lightning detection data from different systems, including from surface- and space-based systems, to enable composite products to be made available.
Who: NMSs/NMHSs and agencies operating lightning detection systems, RAs and TCs, coordinated by CBS and CIMO, leading the action jointly.
Time-frame: Continuous.
Performance indicator: Level of integration of the lightning systems.

Action G39

Action: Improve the exchange of lightning detection data in real-time by establishing and implementing agreed protocols for the exchange of data.
Who: NMSs/NMHSs and agencies operating lightning detection systems, NMSs, NMHS, RAs and TCs, coordinated by CBS and CIMO.
Time-frame: Continuous.
Performance indicator: A percentage of observations exchanged regionally and globally.

5.3.2.5. Surface-based stations serving specific applications

Many specific observing networks have been developed (and are still being developed) to monitor local applications such as the weather variables alongside the roads, motorways or railway tracks, within and around cities and airports, for agricultural or horticultural crops or those needed for electrical power generation. This ensemble of networks is very heterogeneous in terms of observed variables, observing practices, standards, as well as frequency of observations. However these data are essential elements for meeting climate service requirements and are very useful not only for their main application but also for many other larger-scale applications documented in the RRR, including for global and high resolution models.

In the coming years, specific attention needs to be paid to the measurements in the urban environment, for at least two reasons: (i) the monitoring of the climate variability and change is important in such areas where specific issues of adaptation arise; and (ii) the verification and validation of local NWP and air quality models which are likely to be run operationally over limited areas centred over big cities; these models are likely to become an important instrument of the climate variability and change monitoring in addition to their role in meteorological and air-pollution short-range forecasting.

Such specific observations and models are likely to be needed not only in the vicinity of big urban agglomerations, but also in the vicinity of important airports, where the aviation requirements may imply the development of specific high resolution networks for monitoring and nowcasting severe phenomena.

Most of these specific observing systems are fully automatic; they use up-to-date technologies and often produce observations with high frequency. In order to have these systems serving a wider range of users, there should be a coordinated planning on appropriate data representation and codes and reporting practices, approved QM/QA[34] standards for data and metadata. In addition, standards should be developed for the data processing in order to produce derived sets of observations required by different users (local, national, regional, global).

Mutual benefits can be derived from cooperation with the renewable energy installations, which require monitoring of their environment. For the clean energy sources (wind, solar, hydroelectric, geothermal energy), weather and climate information is an essential part of development and operational activities, and they require a continuing assessment of efficiency and environmental impacts.

Action G40

Action: Ensure, as far as possible in real-time, exchange of observations, relevant metadata, including a measure of representativeness made by surface-based stations serving specific applications (road transport, aviation, agricultural meteorology, urban meteorology, etc.).

Who: Agencies operating stations serving specific applications, NMSs/NMHSs, RAs and TCs, coordinated by CBS.

Time-frame: Continuous.

Performance indicator: A percentage of observations from the above stations exchanged regionally and globally in real-time.

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34 Quality Management and Quality Assessment

Action G41

Action: Enhance observations in candidate areas to support studies associated with the development and operations of renewable energy installations, and also to understand the influence of these installations on local weather and climate phenomena related to the operation of the renewable technologies.
Who: Agencies operating stations serving renewable energies, NMSs/NMHSs, RAs and TCs, coordinated by CBS.
Time-frame: Continuous.
Performance indicator: Number of observations supporting of renewable energies.

5.3.3. Hydrological observing systems over land

5.3.3.1. Hydrological reference stations

Concerning the global exchange of hydrological variables, GCOS, through its co-sponsored Terrestrial Observation Panel for Climate (TOPC), has established the Global Terrestrial Network for Hydrology (GTN-H), with the objective of designing and implementing the baseline networks, and in order to demonstrate the value of integrated global hydrological products. The activities of the GTN-H and of the WMO/CHy include the global monitoring of rivers, lakes, ground water and water use. The monitoring programme requirements led to the establishment of GCOS/GTOS baseline networks for river runoff and lake level.

The Global Runoff Data Centre (GRDC) has a mandate to collect river discharge data, but long delays can occur before the data are actually collected and distributed. In addition there is a tendency to reduce the number of stations in the existing observing networks, and there is a strong concern over this continuous decline of hydrological networks, especially the closure of climate-relevant stations.[35]

Action G42

Action: For climate purposes, maintain the existing hydrological stations of the GCOS/GTOS baseline network, and facilitate their global exchange.
Who: All hydrological services operating these reference stations, WMO TCs (CHy and CBS), GCOS. CBS and GCOS to lead the action.
Time-frame: Continuous.
Performance indicator: Percentage of hydrological reference stations exchanging globally quality-assessed data.

More details about specific actions on hydrological reference stations can be found in relevant sections of the GCOS-IP. A general description of all the elements contributing to hydrology, water resources and water cycle can also be found in the WHYCOS document[36].

5.3.3.2. National hydrological network stations

For monitoring the Earth water cycle, many variables are measured by national hydrological networks and other stations from heterogeneous networks: liquid and solid precipitation, snow depth, snow water content, lake and river ice thickness, dates of freezing and break-up, water level, water flow, water quality, soil moisture, soil temperature, sediment loads. Some of them

35 See the paragraph on the exchange of hydrological data in the GCOS-IP.
36 http://www.whycos.org/IMG/pdf/WHYCOSGuidelines_E.pdf

are not relevant to any real-time applications, but some others require a rapid data exchange (e.g. precipitation and river discharges in case of flood event). A small subset requires global exchange whereas most of them need to be exchanged only at the national and local level.

The TOPC has identified hydrometeorological variables with a high observation priority.[37] Several of these variables have an in-situ observation component which is complemented by a satellite component; still, there are important identified gaps in the different hydrology networks which have to be filled. In general there is an insufficient access to hydrological variables.

The observation of hydrological variables on global and regional scales, performed in a continuous and consistent way will require integrated observing systems (both in-situ and satellite-based) and used in support of several application areas. Observations include those of hydrological variables such as evaporation, soil moisture, snow, and surface and groundwater, as defined in GCOS-IP terrestrial actions.

Action G43

> **Action**: Include observations of key hydrological variables (liquid and solid precipitation, evaporation, snow depth, snow water content, lake and river ice thickness, water level, water flow, soil moisture) into an integrated system for a consistent observation, processing and exchange, following the WIGOS standards.
> **Who**: Hydrological services, GCOS, WMO TCs (CHy and CBS) leading the action.
> **Time-frame**: Continuous.
> **Performance indicator**: percentage of hydrological data integrated in this system.

5.3.3.3. Ground water stations

Ground water has an important role in the environment and its management, although it is less important for many applications covered by the RRR (especially the forecasting applications). It is used as a primary source of drinking water and also in agricultural and industrial activities. Ground water resources need to be protected as, in many regions, withdrawal rates exceed recharge rates. Once modified or contaminated, ground water can be very costly and difficult to restore.

Ground water monitoring is a continuous standardized process involving in-situ, satellite and air-borne observations. The groundwater monitoring includes both its quantity and its quality (analysis of selected physical and chemical variables).

According to a world-wide inventory of ground water monitoring compiled by the International Ground water Resources Assessment Centre (IGRAC), in many countries, a systematic monitoring of ground water quantity and quality is minimal or non-existing.

Action G44

> **Action**: To continue and expand existing programmes of ground water observation and monitoring, including expansion of the IGRAC.
> **Who**: Hydrological services in collaboration with WMO/CHy, the Food and Agriculture Organization (FAO) and GTOS (especially its Global Terrestrial Network for Groundwater - GTN-GW – component). WMO/CHy and GTOS to lead the action.
> **Time-frame**: Continuous.

37 See SoG on Hydrology

Performance indicator: number of ground water stations operating.

The ground water actions described in the GCOS-IP should be supported, especially those aimed at establishing a prototype global monitoring information system with the GTN-GW.

5.3.4. Weather radar stations

Weather radars are acquiring an increasing importance in weather forecasting and warning, in hydrology and many applications depending on weather forecasting, e.g. aeronautical meteorology (wind shear). This increased importance is partly related to the development of NWP models at kilometre scale (which progressively become able to assimilate weather radar data) and of other ad hoc tools for nowcasting and short-range forecasting. Weather radars have the capacity to observe several variables related to precipitation: precipitation intensity and geographical distribution, hydrometeor size distribution, phase and type of precipitation. They can also locate sand and dust storms, and they can measure wind components through the Doppler technique, and also humidity through the refractivity. The deployment of polarimetric weather radars contributes to the improvement of quantitative precipitation estimates (QPE), to a better detection of large hail, and to an improved identification of rain/snow transition regimes in winter storms. VHF radars have been tested and can provide observations at higher resolution, but only at shorter range. All these weather phenomena are especially important for aviation and severe weather forecasting and warning for public.

Advances in NWP, climate modelling, and severe weather warnings and disaster mitigation have led to new requirements for precipitation products of high quality constructed from data from one or more radar networks. Also, recent advances in radar technology and in signal and data processing have brought the field to the brink of operational readiness for these products and their quantitative use for various operational applications. In the past, radars were perceived to address only regional and local applications but this view is rapidly changing as telecommunication networks allow vast amounts of data to be transferred and archived.

The weather radar coverage was improved considerably during the last decades in some regions of the world, with some data exchanged across the national borders (on at least some composite products).

There is still a lot of potential progress which should come before 2025 from improved technology, standardization of observing procedures, and increase of data exchange, including at the global level. Currently (in 2012), in the areas that are well covered by weather radars, there is a lot of heterogeneity in technology deployed, the observing practices, the calibration and processing techniques, and the form of the data presentation and exchange. In the developing countries, the radar coverage is poor or non-existent, including in the areas where the storm nowcasting (and very short-range forecasting - VSRF) is extremely important. A special effort has to be organized for these areas, not only in terms of weather radar deployment, but also in terms of nowcasting tools combining a limited number of weather radars with other sources of information (satellite products, propagation of GNSS signals or of other electromagnetic signals).

Action G45

Action: Increase the deployment, calibration and use of dual polarization radars in those regions where it is beneficial.
Who: CBS to lead the action in collaboration with CIMO, RAs and NMSs/NMHSs.
Time-frame: Continuous.

Performance indicator: Data coverage obtained from this type of radar for each Region.

Action G46

Action: Perform comparison of weather radar software with the objective to improve quality of the quantitative precipitation estimates (QPE).
Who: CIMO in collaboration with NMSs/NMHSs and agencies operating weather radars.
Time-frame*:* Continuous.
Performance indicator: Guidance provided to the operators and Members.

Action G47

Action: For areas in developing countries which are sensitive to storms and floods, a special effort has to be made to establish and maintain weather radar stations.
Who: NMSs/NMHSs, agencies operating weather radars, in collaboration with RAs and TCs (CBS, CIMO and CHy). CBS to lead the action.
Time-frame: Continuous.
Performance indicator: The number of operational weather radar stations in the above areas.

Concerning the use and impact of observations in NWP, the Proceedings of the 2008 WMO workshop states (see reference in footnote no. 19 of section 4): "Radar data have demonstrated their positive impacts on regional data assimilation systems, and on some occasions also on global systems". By 2025, it is expected that most of the operational global data assimilation systems for NWP (and re-analyses) will assimilate some radar data, at least in the form of Doppler winds. Therefore, a global exchange of selected radar data should be introduced.

Radar information is also important for climate applications. It will be used in the future for (e.g.) regional re-analyses and monitoring of the water cycle. See GCOS-IP – executive summary.

Action G48

Action: Define weather radar data to be exchanged at regional and global levels, propose frequency of exchange of those data and develop a weather radar data processing framework, in concert with development of products based on national, regional, global requirements.
Who: CBS (leading the action), CIMO, CHy in coordination with NMSs/NMHSs, agencies operating weather radars, in collaboration with RAs.
Time-frame: Continuous.
Performance indicator: Volume of radar data which are exchanged globally and regionally.

5.3.5. Upper-air observing system over the oceans. Automated Shipboard Aerological Programme (ASAP) ships

All the Actions documented in section 5.3.1.1 related to radiosonde observations over land, except those for GRUAN (5.3.1.1.2), are relevant for ASAP. These Actions refer to:

- The importance of isolated radiosonde data for removing the biggest gaps in data coverage;
- The appropriate coding of the total radiosonde information in the vertical, followed by a rapid real-time dissemination;

– The possibility to optimize the data coverage by adapting the launching time, taking into account the ensemble of the radiosonde network, but also other observation systems providing vertical profile observations (AMDAR for example).

For the North Atlantic area (with very few islands which can provide fixed radiosonde sites), EUMETNET[38] has developed a European component of the Automated Shipboard Aerological Programme (ASAP), called E-ASAP (EUMETNET – ASAP). See information on E-ASAP by going to the home page of EUMETNET. Between 15 and 20 ships regularly operate radiosonde launches in the North Atlantic on commercial line services from Western Europe to North and Central America. These ASAP ships contribute to about 10 to 15 radiosonde observations per day on average (situation of 2012), most of these observations being made at 00 or 12 UTC (possibility to make them at a different time, in order to optimize space-time coverage). In the year 2011, the E-ASAP programme contributed about 4500 radiosonde launches over the Atlantic Ocean. Concerning the impact of ASAP ships on numerical forecasts, the Proceedings of the 2008 WMO workshop states (see reference in footnote of section 4): "Even a very limited number of radiosondes located in data sparse regions in the oceans can have a significant impact on the forecast". The North Atlantic ASAP network has not only a direct impact on forecasts, but it helps the use of satellite data by providing in-situ reference observations with a lot of vertical details. More than 80% of the total ASAP launches in 2011 were performed in the Atlantic Ocean. Therefore, for other oceanic areas, and especially for the North Pacific and Indian Ocean, there is potential for improving very significantly the overall quality of the composite observing system through the development of a very limited number of observing stations (typically 10 or 20). Dropsondes launched from reconnaissance aircrafts are an equivalent system which is used both in the Pacific and in the Atlantic, but very irregularly, to support severe storms forecasts.

Action G49

Action: Maintain and optimize the existing ASAP network over North Atlantic, and develop similar programmes for the North Pacific and the Indian Ocean.
Who: NMSs, NMHSs, in collaboration with companies operating commercial ships, RAs, JCOMM, CBS and CAS. JCOMM to lead.
Time-frame: Continuous.
Performance indicator: Volume of ASAP data available in real-time (usual NWP monitoring indicators).

5.3.6. Surface observing systems over the oceans

Important ocean variables to measure at the ocean-atmosphere interface include the surface pressure, the SST, the Sea Surface Height (SSH), the Sea Surface Salinity (SSS), the surface wind, the wave characteristics, the ocean surface current and the visibility. Additional variables are needed near the coasts and also when the ocean is covered with ice. Variables related to ocean acidity, ocean colour, nutrients and phytoplankton are important ECVs which are documented in the GCOS-IP.

The uneven geographical coverage of the in-situ ocean observing network is an ongoing issue for ocean applications. Considering the regional variability in requirements, varied deployment logistics (including from remote regions, and insecurity-prone regions), and the difficulty to ensure optimized planning for observing networks with limited resources, WMO Members should

38 http://www.eumetnet.eu/

note the need for studies on geographical variability in spatial/temporal resolution for ocean observations.

Most of the actions documented in the following sub-sections are aimed at improving the geographical coverage of ocean observing systems, particularly for measuring surface pressure, SST, SSH, SSS and visibility, along with higher resolution geometry. This can be done by extending open-ocean and coastal observing networks, or developing existing observing sites into multi-purpose stations, or also using emerging remote-controlled in-situ observation technologies to cover inaccessible regions.

5.3.6.1. High Frequency (HF) coastal radars

HF coastal radars are a very powerful observing technique for monitoring the sea state and the surface ocean current within a few hundred kilometres of the coasts. These radars can measure both waves (significant height) and current within a kilometric horizontal resolution. For many of the HF radar systems now in use, a triangulation technique using two radars is required to remove directional ambiguities in waves and currents.

The purpose of this radar observing system is not to achieve a good global coverage of the ocean coasts, but to improve the horizontal resolution and the quality with respect to other oceanic observations in the coastal areas which are very sensitive to the weather and oceanic phenomena (for environmental or economical reasons): populated areas near the coasts, harbours with a lot of ship traffic and risk of pollution (for both the terrestrial and the marine wildlife). By 2025, it is likely that specific atmospheric and oceanic Limited Area Models (LAM) will be operated on many coastal areas with a horizontal resolution between 100 and 1000m, in order to help the real-time monitoring of these sensitive areas. HF coastal radars should then become an important source of information to be assimilated in these models. They are already an important source of information for the production of real-time maps of ocean surface currents and significant wave height for ship traffic and for search and rescue operations.

5.3.6.2. Sea stations (ocean, island, coastal and fixed platforms)

The sea observing stations provide the same surface variables as land surface stations (see 5.3.2.1): surface pressure, temperature, humidity, wind, visibility, cloud amount, type and base height, precipitation, past and present weather. With respect to surface stations over land, their role is increased for two reasons:

- They also observe a set of marine variables: SST, wave direction, period and height, sea-ice, etc.;
- They are generally situated either in sensitive coastal areas or on isolated sites like islands and oil platforms, and so they are more important in terms of their contribution to global data coverage.

The recommendations of section 5.3.2.1, valid for land surface stations, apply also to sea stations. The isolated islands which have already a long climate record are particularly important to maintain for climate monitoring.

The sea station networks are very insufficient to meet the different marine and oceanic requirements, especially for SSH, SST, SSS, and wave measurements.[39] A general improvement in measurement capabilities and data accessibility is needed, which has to rely not only on sea stations, but also on ships, buoys, tide stations and profiling floats.

Action G50

Action: Ensure state-of-art technologies are employed to improve accuracy for all measurements made at sea stations. Develop visibility measurement capabilities over the ocean.
Who: NMSs, NMHSs and national partner institutions, in collaboration with international organizations and space agencies. JCOMM, CBS, and CIMO to lead the action.
Time-frame: Continuous.
Performance Indicators: Usual monitoring indicators on availability and quality of marine observations.

5.3.6.3. Voluntary Observing Ships Scheme (VOS)

The list of meteorological and marine variables which is normally observed by VOS ships is the same as the one observed by sea stations (5.3.6.2.). The main practical difference is that ships are mobile: this can be an advantage for a better space-time data coverage, but it is a drawback for climate users interested in long time series.

Many recommendations made for land surface synoptic stations are also valid for VOS ships, especially those concerning: global exchange of hourly data (**Action G30**) and coding and transmission of metadata (**Action G32**). For the atmospheric pressure measurement onboard ships, a particular attention should be given to the barometer height, its correct value, correct coding and correct transmission. Indeed atmospheric pressure (often reduced to sea level in this case) is the most important ship observation for NWP, and it is also very important for marine and aviation applications, as well as synoptic meteorology and nowcasting. The global NWP monitoring of ship data shows that some ship observations are affected by important biases in atmospheric pressure measurements, which is obviously linked to incorrect barometer heights (and/or erroneous reduction to sea level). There are also potential improvements on the quality of ship air temperature, SST and wind observations, improvements which could be obtained by more regular interactions of the observation operators with the NWP monitoring centres. See for example the UK Metoffice Website[40].

Action G51

Action: Improve the quality of ship observations by more regular interactions with the NWP monitoring centres and more regular checks on the instruments onboard.
Who: Port Meteorological Officers (PMOs), NMSs, NMHSs and other NWP monitoring centres in collaboration with companies operating commercial ships. CBS and JCOMM to lead the action.
Time-frame: Continuous.
Performance indicators: Usual NWP monitoring indicators.

39 See SoG on Marine Applications)
40 http://www.metoffice.gov.uk/research/monitoring/observations/marine

5.3.6.4. Moored and drifting buoys

The moored and drifting buoys normally provide observations for a subset of the following variables: surface pressure, temperature, humidity, wind, visibility, SST, ocean current, 3D wave spectrum, wave direction, period and height and precipitation. As they are fully automatic systems, this observed subset is reduced compared to what can be observed by ships or synoptic sea stations (e.g. clouds and present/past weather are not observed by buoys). There is a large variety of buoys which are deployed operationally, and sometimes the observed subset is reduced to one or two variables on the simplest buoy types. The advantage of the fully automatic systems is that the observation frequency can be quite high for some buoys (observed data every 10 minutes, for example). Drifting buoys move away from their deployment point shortly after being put into the water. They have a limited operational lifetime for reasons such as battery life, sensor failure, transmitter failure, running ashore, etc. The Data Buoy Cooperation Panel (DBCP) of JCOMM strives to maintain a global network of 1250 drifting buoys deployed to meet a grid spacing of 5 degrees by 5 degrees. New buoys have to be redeployed regularly to maintain oceanic data coverage which is complemented by ship data coverage (commercial sailing lines). For the mid-latitude part of the north Atlantic, a good data coverage (and a good complementarity with ships) has been achieved in the years 2000-2010 mainly through the EUMETNET Surface Marine Programme (E-SURFMAR[41]). However, continuous efforts are needed to maintain this coverage as it is still below the requirements in some small areas of the North Atlantic where the deployment is difficult. In addition, in many other areas of the globe, the buoy data coverage is not as good; it presents significant gaps in (e.g.) the southern oceans and the North Pacific. The operational data coverage (for buoys and other observing systems) can be checked on a daily basis on (e.g.) the ECMWF web[42]. The maps showing the monthly buoy coverage (for different types of instruments, different observed variables) can be seen on the DBCP web[43].

For NWP, the most important variable (among those observed by buoys) is surface pressure, and it is important to improve its data coverage. In data assimilation it is used in synergy with space-based surface wind measurements (scatterometers, microwave instruments). A good SST global coverage is important both for NWP and ocean applications. Ocean current information is valuable for oceanographic analysis and forecasting. The wave information is very important for marine services and applications.

Moored buoys provide a richer and more geographically stable data set than drifting buoys for climate time series which are difficult to build with moving platforms. However, even for climate monitoring, the drifting buoys contribute indirectly through their use in meteorological and ocean data assimilation, and in the re-analyses.

The recommendations G30, G31 and G32 made for synoptic sea stations also apply for moored and drifting buoys. The global collection and exchange of buoy observations should be hourly as a minimum. It is recognized that the limitations of satellite telecommunications limit the timeliness of data collection for a significant number of drifting buoys.

Given the importance of a good atmospheric pressure data coverage and of the technological capacities for measuring pressure, the recommendation of GCOS-IP on buoys should be

41 http://www.eumetnet.eu/e-surfmar
42 http://www.ecmwf.int/products/forecasts/d/charts/monitoring/coverage/dcover/
43 http://www.jcommops.org/dbcp/

strongly supported. It calls for the implementation of pressure sensors on all the buoys by 2014. Another GCOS recommendation which should be supported calls for all the buoys of the Ocean Reference Mooring Network (a data buoy subset of the Ocean Sustained Interdisciplinary Timeseries Environment observation System - OceanSites[44]) to be equipped with precipitation measurement instruments. Observations of precipitation are particularly important for the interpretation of satellite data over the oceans. The GCOS recommendation for the implementation of a wave measurement component as part of the Surface Reference Mooring Network is important because of the limited number of marine reference sites providing information on the waves and because of the limitations of satellite-based wave measurements.

In summary, ocean buoy data are useful for weather and ocean forecasts and for climate monitoring, and additionally can be used to complement or validate remotely-sensed data and operational models.

Action G52

Action: Support the DBCP in its mission to maintain and coordinate all components of the global network of over 1250 drifting buoys and 400 moored buoys, which provides measurements such as SST, surface current velocity, air temperature and wind speed and direction.
Who: NMSs, NMHSs, national oceanographic institutions, in collaboration with JCOMM, international organizations and companies operating oceanic buoys, CBS and CIMO. CBS and JCOMM to lead the action.
Time-frame: Continuous.
Performance indicators: Volume of quality-controlled moored and drifting buoy data available in real-time (usual NWP monitoring indicators).

Action G53

Action: Install barometer on all newly deployed drifting buoys.
Who: NMSs, NMHSs, national oceanographic institutions, in collaboration with JCOMM, international organizations and companies operating oceanic buoys, CBS and CIMO. CBS and JCOMM to lead the action.
Time-frame: Continuous.
Performance indicator: Availability of surface pressure observations from drifting buoys.

Action G54

Action: In the tropical Indian Ocean, extend the existing network of moored buoys to a data coverage similar to those of the Atlantic and Pacific tropics.
Who: NMSs, NMHSs, national oceanography institutions, in collaboration with JCOMM, international organizations and companies operating oceanic buoys, CBS and CIMO. CBS and JCOMM to lead the action.
Time-frame: Continuous.
Performance indicators: Number and data coverage of moored buoys available in the Indian Ocean tropics (usual monitoring indicators).

44 http://www.oceansites.org/

5.3.6.5. Ice buoys

Ice buoys observe some of the following variables: surface pressure, temperature, wind, ice thickness, and upper ocean temperature and salinity. Sea ice motion is derived from their movement. Some buoys measure only air temperature, surface pressure, and position (therefore motion). More robust measurements are made by ice mass balance (IMB) buoys, which can measure snow depth, ice thickness, the ice temperature profile, ice motion, and some meteorological variables. In 2012, about 50 buoys were in service in the Arctic Ocean at any time, though fewer than ten measure ice and snow thickness. As with buoys deployed in the open ocean, surface pressure is a very important variable for NWP, and this is especially true for the northern polar cap which is otherwise a gap in the data coverage. Ice thickness, snow depth, and temperature are also key variables to monitor in the context of climate change, and also for many marine applications.

Action G55

Action: Increase ice buoy data coverage on the northern polar cap through a regular deployment of new drifters.

Who: NMSs, NMHSs, national oceanographic and polar institutions, in collaboration with JCOMM, international organizations and companies operating ice buoys, CBS and CIMO. CBS and JCOMM to lead the action.

Time-frame: Continuous.

Performance indicators: Volume of ice buoy data available in real-time (usual NWP monitoring indicators).

5.3.6.6. Tide stations

They measure the sea water height. In some cases other variables such as surface pressure, wind, sea water temperature and salinity are measured at the same site. The main role of the Global Sea Level Observing System (GLOSS) is to provide oversight and coordination for global and regional sea level networks in support of oceanographic and climate research related to tide and mean sea level applications (both real-time and not real-time). The main component is the GLOSS Core Network (GCN), an evenly distributed set of about 300 coastal and island tide gauge stations that serves as the backbone of the global network.

There is a need to complete and sustain the GCN network of tide gauges to monitor the coastal sea level changes. The GCN stations should be linked to continuous GNSS stations where possible (either directly at the gauge or levelling to nearby continuous GNSS stations) to enable determination of vertical land motion near GCN stations and thereby absolute sea level change. This is important in the context of the climate change to support the adaptation planning. In this context, the recommendation in the GCOS-IP concerning the GCN should be supported.

The GCN remains a main focus of the GLOSS programme. Stations at roughly 1000 km intervals along the continental margins and at all the major island groups provide sufficient global coverage for a range of oceanographic applications. A denser station network is typically needed for regional/local applications. When instruments are renewed or upgraded multiple use of the sea level stations should be considered where possible (i.e. tsunami, storm surge and wave monitoring).

Action G56

Action: Ensure global availability of in situ sea level data (tide gauges, tsunameters).
Who: NMSs, NMHSs, and national partner institutions, in collaboration with international organizations and space agencies. JCOMM, CBS, and CIMO to lead the action.
Time-frame: Continuous.
Performance Indicator: Amount of tide gauge data available globally.

5.3.7. Sub-surface oceanic observing systems

5.3.7.1. Profiling floats

In the ocean sub-surface, profiling floats measure some of the following variables: temperature, salinity, dissolved oxygen, ocean acidity and pCO_2. The Argo[45] profiling floats provide global coverage of temperature and salinity profiles down to 2000m. “Deep-Argo” floats are under development and will be able to go down to about 3000m. Data are assimilated in ocean models and used for Seasonal to Inter-Annual (SIA) forecasts, for monitoring the ocean sub-surface and for other marine applications. Higher resolution in the observing network would be needed in some active oceanic areas. Some of these profiling float data are also delivered with delays which are inadequate for real-time applications. Although designed to provide long records of data, most of the national programmes contributing to the Argo programme are currently funded for research purposes, and would benefit from transitioning them to operational mode.

The important actions of the GCOS-IP (concerning profiling floats) should be strongly supported: (i) the appropriate number of floats required for enhancing and sustaining an adequate network; and (ii) a pilot project for putting oxygen sensors on some floats. The main reason is the need to monitor carefully the quantity of dissolved oxygen in the oceans, in relation with the climate evolution and the impact on ocean biochemistry and marine life.

Action G57

Action: For ocean and weather forecasting purposes, transition of the Argo profiling float network from research to operational status, and ensure timely delivery and distribution of high vertical resolution data for sub-surface temperature and salinity.
Who: NMSs, NMHSs, national oceanographic institutions, in collaboration with Argo project, JCOMM, international organizations and companies operating profiling floats, CBS and CIMO. JCOMM to lead the action in cooperation with CBS.
Time-frame: Continuous.
Performance indicators: Volume of profiling float data available in real-time (usual monitoring indicators).

5.3.7.2. Ice-tethered platforms

The ice-tethered platforms move at the speed of the ocean ice cover (slowly) while observing the temperature, the salinity and the current underneath. Because of the lack of other techniques for monitoring the deep polar oceans that are frozen at the surface, the ice-tethered platforms have an important role with respect to the global data coverage of oceanic data.

In the context of research projects dedicated to the Arctic Ocean, pCO_2 (ocean acidity) and CH_4 sensors have been also used on ice-tethered platforms. [46]

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45 http://www.argo.net
46 http://www.whoi.edu/science/PO/arcticgroup/projects/ipworkshop_report.html

5.3.7.3. Ships of opportunity

With XBT instruments, ships of opportunity can provide oceanic temperature profile data with a good vertical resolution (about 1m) down to 1000m. They are used by several applications in the same way as profiling floats (see 5.3.7.1), and there is also a lot of potential to improve their real-time delivery.

Action G58

> **Action**: For ocean and weather forecasting purposes, improve timely delivery and distribute high vertical resolution data for sub-surface temperature from Ships/XBT.
> **Who**: NMSs, NMHSs, national oceanographic institutions, in collaboration with JCOMM, international organizations and companies operating ships of opportunity, CBS and CIMO. JCOMM to lead the action in cooperation with CBS.
> **Time-frame**: Continuous.
> **Performance indicators**: Volume of XBT data available in real-time (usual monitoring indicators).

The action of the GCOS-IP, aimed at improving and sustaining the existing network and coverage of the ships of opportunities should be supported.

5.3.8. Research & development and operational pathfinders

Research efforts are ongoing to observe better details of the atmospheric boundary layer, and these efforts are likely to be required for several years. The observation requirement is primarily for wind, temperature and humidity profiles. It is also for aerosols, some chemical species and cloud properties. Indeed, the lack of detailed vertical profiles in the boundary layer (especially wind profiles) is one of the big weaknesses of the current GOS. It is probably the biggest gap which appears by comparing the RRR with the current observing facilities (see for example the SoG for global NWP). For temperature, water vapour and other atmospheric gases, satellite sounders are unable to observe the boundary layer profiles because of inadequate vertical resolutions, and often also (for infra-red sounders) because of the presence of clouds. (See, for example, the user requirements and SoGs for high resolution NWP, nowcasting and aviation). The only routine surface-based observing system which has currently the capacity of measuring the boundary layer profile is the radiosonde network, but with severe limitations on the data coverage and on the observation frequency (every 12h most of the time). Ground-based wind profilers and profiling stations integrating wind, temperature and humidity are the best hope for high frequency observations of the boundary layer, at least locally, and perhaps also at the regional level, but research efforts are still needed before the implementation of operational networks. Technological progress for profiling techniques is also dependent on the existence of a small number of reference observatory stations, as suggested by GCOS with the GRUAN. Long periods of intercomparison between reference stations and new types of profilers are sometimes necessary to calibrate properly the new instruments (see 5.3.1.2). The CIMO Testbed and Lead Centres sites will contribute to improve the performance of profilers in the atmospheric boundary layer, see: http://www.wmo.int/pages/prog/www/IMOP/Testbeds-and-LC.html

There are at least two other domains which are poorly observed with respect to the RRR and where technological developments are needed to achieve significant progress:

- In the atmosphere, a better observation of clouds (with their large variety of water and ice particles – especially important for aviation), of aerosols and chemical species. It is important that manual cloud observations should be continued at representative stations.

Manual observations need to be retained at least until technological advances are sufficient to ensure automated measurements can satisfactorily replace manual observations;

- In the ocean sub-surface, where it is difficult to obtain observations, ocean gliders and instrumented marine animals are two observing options which are in development (see 5.3.8.5 and 5.3.8.6 below). The GCOS recommendation about promotion of new improved technologies, in support of the GOOS for climate applications is the important one to activate.

Another general tendency affecting meteorological and environmental observations is the move to more automatic and highly computerized systems. It leads to the production of more frequent data and higher volumes of raw data. The pre-processing of the observations tends also to become fully automatic. This requires higher integration between the observation and the data processing. In order to satisfy different types of user, the observation pre-processing will become more complex and more flexible, and it will follow the same tendency as the satellite data: the necessity to produce 2 or 3 different levels of data for different users. The levels will differ by the amount of pre-processing applied to the raw data and by the data volume.

The tendency to more automation is a factor which contributes to a tendency towards “more observing systems of opportunity”. The best example of opportunity in meteorology (which came in the 1990s and the first decade of this century) is the use of GNSS signals propagating through the atmosphere to extract meteorological information. If research actions are carried out towards new opportunities, one can expect the development of other surface-based observing systems based on technologies and capabilities which are designed primarily for non meteorological purposes. Basically, many telecommunication signals propagating in the atmosphere are potentially able to bring indirectly information about the atmospheric state. This has been already successfully tested for estimating the precipitation rate from the attenuation of the Global System for Mobile Communications (GSM) signals of mobile telephones, see Messer (2007). Wind turbines used for electricity power production is another potential opportunity for getting local information on the wind. The electricity power production is obviously dependent on the wind; this dependence can then be inverted in a way that derives the wind information from the power production. In addition, an ensemble of windmills is an opportunity to have a 100m mast which can be instrumented with meteorological sensors at different heights, to provide high vertical resolution profiles from the first 100m in the atmospheric boundary layer. Such an action requires a cooperation between the wind turbine operators and instrument experts from NMSs or NMHSs.

A third tendency for the period 2010-2025, which is true in many disciplines, is to obtain, transmit and use more and more information presented in the form of images. Intense weather phenomena, clouds, amount and type of precipitation on the ground (rain, snow, hail), visibility, sea state, etc., are already exchanged on the Internet through digital pictures or videos. Potentially they can provide the same information as the qualitative information which is in the SYNOP[47] code (with more details). However a lot of research and development is needed to exploit objectively this information which is generally not presented in a standard form, and which is difficult to quantify into environmental variables. This requires retaining manual capabilities at a sufficient number of stations both as a basic reference for representative stations, and for calibration purposes.

47 FM-12 SYNOP GTS format - Report of surface observation from a fixed land station

The technologies summarized below are observing systems that are still at the stage of research and development, and which could become part of global observing systems by 2025. This list is not intended to be comprehensive.

5.3.8.1. Unmanned Aeronautical Vehicles (UAVs)

UAVs have been used in several meteorological campaigns for obtaining detailed information on temperature, humidity and wind, on some limited geographical areas, in the lower troposphere. (See Mayer et al. (2010)). Unlike a normal aircraft, they can fly up and down, and they can provide vertical profiles of meteorological variables. As the atmospheric boundary layer is an important gap in terms of meteorological profiles, UAVs are well adapted to fill this gap locally, but they are difficult to use in routine mode.

UAVs could become an adaptive element of a composite observing system by 2025. Research has to be continued both on technological aspects and on the development of cost-effective means (for operating UAVs regularly). UAVs are also an excellent opportunity for integrating atmospheric chemical measurements and standard meteorological measurements on the same platform. Also aviation regulations need attention before UAVs can be used on a regular basis.

5.3.8.2. Driftsonde balloons (gondolas)

The driftsonde technique consists in launching a constant level balloon, flying in the stratosphere with several dropsondes (stored in a gondola) which can be dropped on demand, providing a vertical profile of temperature, humidity and wind (like normal radiosondes or dropsondes launched from an aircraft). They have been used in several meteorological campaigns, like the AMMA campaign in Africa (see footnote reference to AMMA in section 4) and the THORPEX/Concordiasi[48] experiment in Antarctica (see Rabier et al. (2010)).

These gondolas look very well adapted to meteorological campaigns which are limited in time (a few weeks), but difficult to use in routine as a key element of the composite observing system (also because of the aviation regulations, like UAVs). Currently it is not possible to recommend any development plan for an operational use of this system.

5.3.8.3. GRUAN stations

The GRUAN is neither a new technology nor a new observing system. It is a concept initiated by GCOS (see section 5.3.1.1.2 of this report), consisting in maintaining a small number of observing sites (up to 40) operating high quality radiosondes, reaching the mid stratosphere (about 30 or 40 km as maximum height). In addition to their role in climate monitoring and as a reference for the GUAN stations, these observing sites should act as “small observation laboratories” in which atmospheric vertical profiles are observed through different techniques (surface-based sounders, profilers radars and lidars, etc.) and inter-compared. These atmospheric profiles should be as complete as possible and should integrate a larger number of variables (compared to ordinary radiosondes), including the measurement of clouds, aerosols and concentration of chemical species. Developing GRUAN sites is a simple way and a good opportunity to stimulate research on new observing technologies.

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48 Concordiasi is an international project of the THORPEX-IPY cluster within the International Polar Year effort to provide validation data to improve the usage of polar-orbiting satellite data over Antarctica

5.3.8.4. Aircraft atmospheric measurements

Automated aircraft measurements of wind and temperature have been operational in meteorology for more than two decades. Measurement of humidity from aircraft stations commenced operations around 2010 (see 5.3.1.3).

Atmospheric chemistry measurements from aircraft commenced two decades ago but are limited to a small number of aircraft and not integrated with the other meteorological measurements: see for example the documentation on the IAGOS project (IAGOS = Integration of routine Aircraft observations into a Global Observing System). Different ranges of atmospheric chemistry monitoring packages have been developed (e.g. CARIBIC, CONTRAIL). Atmospheric composition measurements for several gas species and aerosols, including volcanic ash, are made on some aircraft, but more in research than in operational mode. For the future it is important to converge to a more integrated operational system which would measure all these variables on some aircraft, process them consistently and make them available in near real-time where possible, including for models in which chemistry is simulated, for aviation meteorology, and for global and high-resolution NWP.

Action G59

> **Action**: Where possible and appropriate, integrate automatic aircraft measurements of atmospheric composition with measurements of wind, temperature and humidity, with processing and dissemination performed, according to GAW and other relevant standards.
> **Who**: Organizations involved in atmospheric measurements from aircraft platforms, NMSs, NMHSs in collaboration with commercial and other airlines, WMO TCs (CBS, CIMO, CAS) and AMDAR panel. CBS, CAS and AMDAR Panel to lead the action.
> **Time-frame**: Continuous.
> **Performance indicator**: A number of aircraft producing both meteorological observations and atmospheric composition measurements in real-time.

5.3.8.5. Instrumented marine animals

Marine animals provide opportunities for oceanographers to make observations, in the sense that the ensemble of sensors attached to an animal moving in the sea can be used for observing both the animal itself and its environment. Boehlert et al. (2001) stated: “Biological autonomous sampling systems have immense potential to contribute oceanographic data in a cost-effective manner”. Ten years later, around 2010, only modest progress has been noted in the use of this technique, which is limited by its lack of time continuity and its poor data coverage (limited to some coastal areas). Efforts should continue, especially to improve the exchange of data with all the users of ocean measurements, to make it more rapid and more standard.

5.3.8.6. Ocean gliders

The observing role played by UAVs in the atmosphere is similar to the one taken by ocean gliders in the ocean. This type of observations has been used in the past for oceanographic campaigns: see Rudnick et al. (2004) and Davis et al. (2002). They have the same capacity and the same flexibility to target a specific area of the ocean and to observe it in its 3 dimensions. Wave gliders and ocean gliders have been used in several field experiments. Wave gliders could be used on a routine basis in some parts of the world by 2015.

Research and developments should be pursued in at least two directions: on new instruments able to observe more ocean variables, and on the standardization of the data exchange.

6. SPACE-BASED OBSERVING SYSTEM

6.1. Introduction

For several decades two types of satellites have been used in meteorology: geostationary satellites (GEO) and Low Earth Orbiting (LEO) satellites. The GEO satellites are deployed along the equator, with their longitudes chosen to optimize the data coverage. The main advantage of a GEO satellite is the high observation frequency of 15 or 30 minutes. The main drawback is that it cannot observe the polar caps (polarward of about 60° of latitude). LEO satellites are generally deployed on a polar sun-synchronous orbit, although other orbits are used for specific applications. The main advantage of sun-synchronous orbits is the global coverage which can be achieved in 12h with many scanning instruments. The data coverage is quite good near the poles where new observations can be produced at each orbit (i.e. about every 100 minutes). The main drawback is the observation frequency in low latitude regions, where observations are produced generally every 12h for a single platform. A rapid and continuous data collection by the ground segments is also more difficult to organize than for geostationary satellites.

Some satellite series have been operational for several decades, like the American Geostationary Operational Environmental Satellite (GOES) or the European METEOSAT (geostationary satellites), or the American NOAA[49] series of polar orbiting satellites. The main instruments operated on these operational satellites are imagers (visible and infra-red) and atmospheric sounders (infra-red or microwave). Research satellites have played a major role in complementing operational satellites, and they will continue to play a major role in the future, although they cannot guarantee the continuity of observation. Some platforms have different instruments serving different applications, and the tendency to develop multi-user platforms is likely to continue. Some user requirements will be met through constellations of satellites (e.g. the COSMIC[50] constellation for radio-occultation measurements). The data volumes and the variety of instruments which are used routinely for many applications have been increased considerably over the last 20 years. Nowadays, many satellite observing systems (including research satellites) bring a very significant contribution to operational weather and climate monitoring. Data continuity, which is essential for climate monitoring as well as for operational applications, is being threatened by the potential end of satellite missions before follow-on platforms are launched. Space agencies are encouraged to prolong the lifetime of currently flying instruments on relevant satellite missions.

A detailed description of the current satellites and instruments contributing to global observing systems (or are likely to contribute in the period 2012-2025) can be found in the WMO Website[51] satellite observing capabilities database. This information set contains a “gap analysis”, i.e. the more critical gaps which lead to recommendations on the development/improvement of satellite observing systems. For the coming 15 years, one can expect an expanded space-based observing capability, an expanded community of space agencies contributing to WMO

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49 National Oceanic and Atmospheric Administration (USA)
50 Constellation Observing System for Meteorology, Ionosphere and Climate
51 http://www.wmo.int/pages/prog/www/OSY/RRR-DB.html: this WMO web page contains a comprehensive database on past, present and future satellites with their instruments.

Programmes and an increased collaboration between them. One can expect also a tendency to have more and more satellites serving several applications.

In the following section (6.2), generic issues concerning the space-based component of global observing systems are described, with corresponding recommendations for implementation in the period 2012-2025. Section 6.3 describes the recommended Actions for the different observing systems classified in the following components (as foreseen in the Vision 2025):

- Operational geostationary satellites (sub-section 6.3.1);
- Operational polar-orbiting satellites on sun-synchronous orbits (6.3.2);
- Miscellaneous operational satellite missions, with various instruments on various orbits (6.3.3), which complement the previous two components, the ensemble being the backbone of the space-based observing systems;
- R&D satellite missions, operational pathfinders and technology demonstrations (6.3.4) whose role within composite observing systems in 2025 is uncertain, but which are likely to have an operational contribution by then.

It is noted that observations for space weather are discussed separately in section 7.

6.2. Generic issues: data calibration, data exchange, product generation, data stewardship, education and training

There will be a tendency towards higher spatial, temporal and spectral resolution for all satellite observing systems. It will enhance the information available, particularly to monitor and predict rapidly-evolving small-scale phenomena. It will increase the demand on data exchange and on processing capabilities. The spatial, temporal and spectral resolutions of the satellite data used in operational forecasting are generally coarser than the resolutions of the instruments, because of limitations in computer resources and in data assimilation methodologies. The resolution of the satellite data which are actually assimilated in meteorological and oceanic models is expected to increase faster than the instrument resolutions, by 2025, because of improvements in data assimilation techniques.

6.2.1. Data availability and timeliness

The progress on instrument capabilities and on the use of satellite information will be fully successful only if it is accompanied by actions aiming at improving the availability and the timeliness of the data for the different users and the different applications, from global assimilation in meteorological or oceanic models to the local use in nowcasting. This is more critical for LEO satellites than for GEO. For LEO satellites, direct readout capabilities should be provided wherever possible. In combination with direct readout, the development of the RARS (Regional ATOVS[52] Re-transmission Systems) has improved the timely delivery of data. This type of “quick re-transmission” action on satellite radiances for polar orbiting sounders has considerably helped NWP in recent years, and it will help more and more regional and local forecast systems in the future. Applying such concepts to other data, e.g. imagery, would be beneficial to many other application areas. For GEO satellites, the data delivery is easier within the geographical area corresponding to the Earth disk which is observed directly by each satellite. The main challenge is the rapid processing and the rapid and global exchange of processed data (such as atmospheric motion vectors, AMVs) which are needed for global NWP

52 Advanced TIROS Operational Vertical Sounder

with an hourly frequency at least. Other applications have identified different requirements for data timeliness.

User-friendly data dissemination techniques (internet, Digital Video Broadcast) should be provided as appropriate. These various techniques all contribute to the WIS and should also be used to disseminate products and training material.

6.2.2. User information, training and data stewardship

Provisions should be made to enable effective use of the capabilities provided by the space-based GOS, and to prepare users for new satellite capabilities well in advance of system deployment. This includes guidance on data reception, processing and analysis infrastructure, including software.

Users relying on satellite-based datasets and products require sufficient information on their quality (e.g., accuracy), the algorithms used, and fitness for purpose. Satellite operators should provide full description of all steps taken in the generation of satellite products, including algorithms used, specific satellite datasets used, and characteristics and outcomes of validation activities. This should be in adherence with the QMF procedure (see section 2.1). Metadata should follow the WMO core metadata profile and compliant with internationally-agreed formats recognized by WMO (see WMO Guidelines on the use of metadata for WIS, 2010[53]).

For climate monitoring and studies of other long-term phenomena, extended satellite time-series (e.g., Fundamental Climate Data Records) are needed. Long-term data stewardship under scientific guidance is necessary to achieve homogeneous long-term records, which should include regular reprocessing (roughly every five years). User-friendly arrangements for access to data archives should be put in place.

As part of continuous improvement in Members' capacity, preparation should include the necessary provision of education and training to users, for example through the CGMS Virtual Laboratory for Education and Training in Satellite Meteorology (VLab) and its Centres of Excellence. The user requirements related to satellite data, products, infrastructure and training should be regularly assessed on global and regional level, as appropriate, in order to monitor the effectiveness of the Actions proposed.

Action S1

Action: Enable Members, as appropriate, to fully benefit from evolving satellite capabilities through guidance on data reception and dissemination systems, including the necessary infrastructure upgrades.
Who: CBS leading the action in consultation with CGMS and satellite operators.
Time-frame: Continuous.
Performance Indicator: Level of positive response to survey of Members' user needs.

Action S2

Action: Satellite operators to provide full description of all steps taken in the generation of satellite products, including algorithms used, specific satellite datasets used, and characteristics and outcomes of validation activities.
Who: Satellite operators in CGMS and CEOS.

53 http://wis.wmo.int/2010/metadata/version_1-2/WMO%20Core%20Metadata%20Profile%20v1-2%20Guidance%20Documentation%20v0.1%20%28DRAFT%29.pdf

Time-frame: Continuous.
Performance Indicator: Number of products fully documented, adhering to the QMF procedure.

Action S3

Action: Satellite operators to ensure long-term data preservation and scientific stewardship of data, including regular reprocessing (roughly every five years).
Who: Satellite operators, in coordination with GCOS.
Time-frame: Continuous.
Performance Indicator: Existence of long-term satellite data archives, with regular reprocessing.

Action S4

Action: Members should be enabled to benefit from evolving satellite capabilities through adequate, application-oriented education and training activities (including distance learning).
Who: CGMS through its Virtual Laboratory (VLab), including Centres of Excellence, and partners.
Time-frame: Continuous.
Performance Indicator: Level of positive response to survey of Members' training needs.

Action S5

Action: Regions should determine and maintain requirements for satellite datasets and products.
Who: RAs and satellite operators through their regional task teams and VLab Centres of Excellence.
Time-frame: Continuous.
Performance Indicator: Completeness and currency of set of regional requirements.

6.2.3. Calibration matters

Because almost all satellite instruments need other instruments or other measurements to improve their calibration, the role of the Global Space-based Inter-calibration System (GSICS) becomes increasingly important with the increase in the number of observing systems and in their variety. It is also essential to combine in-situ observations into the process of calibration, tuning and validation. These activities will be carried out by satellite agencies, national laboratories and major NWP centres, helped by WMO, CGMS and CEOS. These activities cover:

- Earth-based reference sites (such as especially-equipped ground sites and ad hoc field campaigns) used to monitor the satellite instrument performance;
- Extra-terrestrial calibration sources (sun, moon, stars) which are stable calibration targets for monitoring the instrument calibration;
- Model simulations which allow the standard monitoring comparison "observed values vs. model values";
- Benchmark measurements of the highest accuracy by special satellite and ground-based instruments.

There should be common spectral bands on GEO and LEO sensors to facilitate intercomparisons and calibration adjustments. Globally distributed GEO sensors should be routinely inter-calibrated using a given LEO, and a succession of LEO sensors in a given orbit should be routinely inter-calibrated with a given GEO sensor.

Action S6

> **Action**: Maintain and develop the GSICS intercomparisons and inter-calibrations between GEO and LEO sensors on an operational basis.
> **Who**: GSICS.
> **Time-frame**: Continuous.
> **Performance indicator**: Number of instruments calibrated in accordance with GSICS standards.

Instruments should be inter-calibrated on a routine basis against reference instruments or calibration targets, using common methodologies. At least two infra-red and two high-quality visible and, ultimately, ultra-violet and microwave instruments should be maintained in LEO orbits to provide reference measurements for inter-calibration of operational instruments in geostationary or LEO orbit.

For most applications, and especially for climate monitoring, the time continuity of the key satellite sensors has to be planned and organized at the international level. In order to ensure continuity and consistency of data records, there is a need for: (i) continuity of observations; and (ii) overlap of key reference sensors that are needed to provide traceability, as articulated in the GCOS Climate Monitoring Principles (GCMPs)[54].

Action S7

> **Action**: Ensure continuity and overlap of key satellite sensors, keeping in mind both real-time processing and processing in delayed mode for consistency of climate records, re-analyses, research, recalibration or case studies.
> **Who**: CGMS leading the action, with TCs, satellite agencies and satellite data processing centres.
> **Time-frame**: Continuous.
> **Performance indicator**: Continuity and consistency of data records.

6.3. Issues specific to each observing system component

6.3.1. Operational geostationary satellites

For geostationary meteorological satellites, one key feature is to have them distributed approximately uniformly along the equator, in order to have no gap between their respective observation disks in the tropics and mid-latitudes, so that they can provide a global, frequent (15-30 minutes) continuous data coverage, except for the polar caps (approximately poleward of 60° latitude). To meet the (current and future) different requirements, at least 6 operational geostationary satellites are needed, with an interval of ideally no more than 70° longitude for their positions along the equator. During recent decades the continuity of coverage over the Indian Ocean has been the main concern. Currently, the interval along the equator between GOES-W and MTSAT, 80 to 85°, is also larger than recommended.

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54 See: http://www.wmo.int/pages/prog/gcos/aopcXVI/8.9_RecognitionDatasets.pdf

Action S8

Action: Ensure and maintain a distribution of at least 6 operational geostationary satellites along the equator, ideally separated by no more than 70° of longitude. Improve the spatial and temporal coverage with GEO satellites over the Pacific.

Who: CGMS leading the action, with TCs, satellite agencies and satellite data processing centres.

Time-frame: Continuous.

Performance indicator: Quality of the global coverage by the different instruments of operational geostationary satellites.

6.3.1.1. High-resolution multi-spectral visible/infra-red imagers.

Visible/infra-red imagers are currently available on all the geostationary satellites. The number of channels and the imagery resolution are variable from one satellite to the other. The GEO imagers are used in several applications, primarily for nowcasting and VSRF. They are very useful for detecting dangerous weather phenomena and for monitoring their rapid development and motion. They observe the clouds (amount, type, temperature of the top). From tracking clouds and water vapour features on image time series, wind observations are derived: atmospheric motion vectors (AMVs). Surface temperature is derived over sea and over land, as well as atmospheric stability indices. The GEO imagery is also used to detect precipitation, aerosols, snow cover, vegetation cover, including Leaf Area Index (LAI) and Fraction of Absorbed Photosynthetically Active Radiation (FAPAR), fires and volcanic ash.

By 2025, an increased space/time resolution is expected for most of the GEO satellite imagers, and it is important to improve the data collection and the data exchange accordingly.

Action S9

Action: On each operational geostationary satellite, implement and maintain at least one visible/infra-red imager with at least 16 channels providing full disk coverage, with a temporal resolution of at least 15 minutes and a horizontal resolution of at least 2km (at sub-satellite point).

Who: CGMS leading the action, with TCs and satellite agencies.

Time-frame: Continuous.

Performance indicator: Number of geostationary satellites equipped with high resolution imagers.

Action S10

Action: For each geostationary satellite, organize the scanning strategy and the processing of the imagery (together with other instruments or other sources of information) in order to produce AMV with at least a 1h frequency.

Who: CGMS leading the action, with TCs, satellite agencies and data processing centres.

Time-frame: Continuous.

Performance indicator: Number of geostationary satellites producing AMVs operationally.

6.3.1.2. Hyper-spectral infra-red sounders

Infra-red sounders have been used for a long time on LEO satellites. Hyper-spectral infra-red sounders are now operational on some LEO satellites (e.g. IASI on the Metop satellite) but not on GEO. The evaluation of the potential of hyper-spectral sounders on GEO was performed with the GIFTS mission, which was considered by the USA.

Several operators of geostationary satellites have firm plans to include hyper-spectral infra-red sounders for the next series of satellites. Detailed plans for the different series of GEO satellites are given in the WMO Database of Observational User Requirements and Observing Systems Capabilities (see footnote reference in section 6.1 of this report).

These planned sounders put the emphasis on high horizontal resolution (better than 10km), and on high vertical resolution (about 1km). Their main objective is to provide frequent information on the 3D structure of atmospheric temperature and humidity, for the whole Earth disk seen by the satellite (except in and below clouds). They will be used, together with the imagers, to produce high resolution winds (AMVs from clouds or water vapour features), to track rapidly evolving phenomena, and to determine surface temperature (sea and land). They are also designed to have an important role in the frequent observation of atmospheric chemical composition.

Action S11

> **Action**: All meteorological geostationary satellites should be equipped with hyper-spectral infra-red sensors for frequent temperature and humidity soundings, as well as tracer wind profiling with adequately high resolution (horizontal, vertical, time).
> **Who**: CGMS leading the action, with TCs, satellite agencies and data processing centres.
> **Time-frame**: Continuous for the mission planning and preparation; 2015-2025 for making the instruments operational.
> **Performance indicator**: Number of geostationary satellites equipped with hyper-spectral sounders.

6.3.1.3. Lightning imagers

A lightning imaging satellite mission has no heritage from any current or past geostationary mission. It is intended to provide a real-time lightning detection and location (with an accuracy of 5 to 10km) capability, primarily in support to nowcasting and VSRF. It is designed to detect cloud-to-cloud and cloud-to-ground strokes with no discrimination between the two types.

As lightning is strongly correlated with storms and heavy precipitation, another objective of a lightning mission is to serve as proxy for intense convection and convective rainfalls. It could serve as proxy for diabatic and latent heating to be assimilated in NWP models. It will also help the generation of a complete lightning climatology, together with the surface-based lightning observing systems (see 5.3.2.4). Finally, lightning plays a significant role in generating nitrogen oxides, and lightning observations could be an important source of information for atmospheric chemistry models.

A lightning imaging mission is planned before 2025 for most of the geostationary satellite programmes: the European MTG (LI: Lightning Imager), the American GOES, from GOES-R onwards (GLM: Geostationary Lightning Mapper), the Russian GOMS[55] and the Chinese FY-4[56].

55 Geostationary Operational Meteorological Satellite
56 FengYun 4 Meteorological Satellite

Action S12

Action: All meteorological geostationary satellites should be equipped with a lightning imager able to detect cloud-to-cloud and cloud-to-ground strokes.
Who: CGMS leading the action, with TCs, satellite agencies and data processing centres.
Time-frame: Continuous for the mission planning and preparation; 2015-2025 for making the instruments operational.
Performance indicator: Number of geostationary satellites equipped with a lightning imager.

6.3.2. Operational polar-orbiting sun-synchronous satellites

For achieving good global data coverage, the Vision-2025 envisages at least 3 operational polar orbiting satellites (with a minimum set of instruments) plus other satellites on various orbits. The Equatorial Crossing Time (ECT) of the 3 satellites is envisaged at 13:30, 17:30 and 21:30 (local solar time). The orbit ECT choice for the 3 operational satellites (and for all the other polar orbiting satellites) must be permanently monitored through an international cooperation.

Action S13

Action: Ensure the orbit coordination for all core meteorological missions in LEO orbit, in order to optimize temporal and spatial coverage, while maintaining some orbit redundancy. The LEO missions should include at least 3 operational sun-synchronous polar orbiting satellites with ECT equal to 13:30, 17:30 and 21:30 (local time).
Who: CGMS leading the action, with TCs and space agencies.
Time-frame: Continuous.
Performance indicators: Number and orbit distribution of contributing LEO satellite missions.

These orbiting platforms (with ECT equal to 13:30, 17:30 and 21:30) should be equipped with at least a hyper-spectral infra-red sounder, a microwave sounder and a high resolution multi-spectral visible/infra-red imager.

Compared with geostationary satellites, it is more difficult with polar platforms to implement a rapid data collection (from the platform to the ground segment), and then for the data delivery to meet the timeliness requirements of the several user applications.

Action S14

Action: Improve timeliness of LEO satellite data, especially of the core meteorological missions on the three orbital planes, by developing communication and processing systems which achieve delivery in less than 30 minutes (as done with the RARS network for some data sets).
Who: CGMS leading the action, with TCs, satellite agencies and data processing centres.
Time-frame: Continuous.
Performance indicator: Timeliness of LEO satellite data, as judged by the usual monitoring scores.

Action S15

Action: Improve local access in real-time to LEO satellite data, especially to the core meteorological missions on the three orbital planes, by maintaining and developing direct read-out communication and processing systems.

Who: CGMS leading the action, with TCs, satellite agencies and data processing centres.
Time-frame: Continuous.
Performance indicator: volumes of LEO satellite data accessible by direct read-out.

6.3.2.1. Hyper-spectral infra-red sounders.

The current (2012) experience on hyper-spectral sounders is based on the use of IASI on the Metop[57] satellite, and of AIRS on AQUA[58]. Compared to the previous infra-red sounders, they provide much more detail in the vertical on the temperature and humidity structure. Their main drawback is that they are limited to sample the clear-sky atmosphere and the portion which is above the clouds. But they are also a significant source of information for sea/land surface temperature, atmospheric composition and cloud variables. Impact studies have shown that they have a strong positive impact on global NWP. They are also expected to have an important role for complementing microwave instruments in the preparation of climate data records (see next section 6.3.2.2 on microwave sounders).

One difficulty for the users of hyper-spectral infra-red sounders is the huge volume of redundant data to process. Each user is interested in the information from a specific subset of this huge volume, and this subset varies from one application to another. For example, global NWP is interested in a representation of the data that gives most information on the temperature and humidity profiles, whilst the atmospheric composition community is interested in information on specific atmospheric constituents. It is a challenge for the centres pre-processing these observations to provide a satisfactory data delivery to all users in an operational context.

Action S16

Action: Design the ground segments for hyper-spectral infra-red sounders in order to define and implement a data reduction strategy which optimizes the information content accessible within the timeliness and cost constraints, whilst addressing the needs of different user communities.
Who: CGMS leading the action, with TCs, satellite agencies and data processing centres.
Time-frame: Continuous.
Performance indicator: Volume and timeliness of the different data sets distributed to the users of hyper-spectral sounders.

6.3.2.2. Microwave sounders

Microwave sounders have been used in meteorology since the decade 1970-1980, mainly from the American NOAA series of satellites, equipped first with the Microwave Sounding Unit (MSU), then with the Advanced Microwave Sounding Unit (AMSU). They provide information on the atmospheric vertical profiles of temperature and humidity, but with a coarser vertical resolution compared to hyper-spectral infra-red sensors. Their main advantage on infra-red sounders is their capacity to observe in and below the clouds. Currently (2012), they are available for meteorological operations on several satellites (5), and they provide a backbone for large-scale global assimilation systems. NWP impact studies have shown that these observations provide a very strong positive contribution.

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57 EUMETSAT Polar Orbiting Operational Meteorological Satellite
58 http://aqua.nasa.gov/

In addition to their key role for the observation of atmospheric temperature and humidity, microwave sounders provide information on cloud water content and precipitation.

Specific microwave radiance data from satellites, especially from the MSU and AMSU instruments, have become key elements of the historical climate record, and they need to be continued in the future to sustain a long-term record. A GCOS-IP action aims at ensuring the continued derivation of microwave radiance data for climate data records. This climate recommendation is reinforced by the key role taken by the microwave sounders in global re-analyses.

Action S17

Action: Fill the gap in planned coverage of microwave sounders in the early morning orbit.
Who: CGMS leading the action, with TCs and satellite agencies.
Time-frame: Continuous.
Performance indicator: Number of microwave sounders planned for satellites in early morning orbit.

6.3.2.3. High resolution multi-spectral visible/infra-red imagers

Visible/infra-red imagers have been used since the beginning of satellite meteorology in the decade 1960-1970. At this time they provided very useful qualitative information for meteorologists, especially on the type and position of clouds and weather systems. Since then, a lot of technological progress has been performed on imagers, particularly on their horizontal resolutions and on the number of channels. Imagers on LEO satellites complement very well those on GEOs, by observing the middle and high latitudes, although their observation frequency is limited by their orbit configurations.

The observational capabilities of imagers onboard LEO satellites are very similar to those on geostationary satellites. They observe the clouds (amount, type, temperature of the top). Surface temperature is derived over sea and over land. The LEO imagery is also used to detect precipitation, aerosols, snow cover, vegetation cover (including LAI and FAPAR), fires and volcanic ash). They are most useful for nowcasting and VSRF in the polar areas. They can also be exploited for producing AMVs (cloud-tracked winds or water-vapour-tracked winds). MODIS[59] winds have been used in operational NWP for several years, and a very significant positive impact has been demonstrated, probably due to the lack of other types of upper-air wind observations over the polar caps.

Action S18

Action: Use the imagers of all operational polar orbiting platforms to produce AMVs from the tracking of clouds (or water vapour features).
Who: CGMS leading the action, with TCs, satellite agencies and data processing centres.
Time-frame: Continuous.
Performance indicator: Volume and timeliness of the different data sets produced operationally on the polar caps.

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59 MODIS: MODerate-resolution Imaging Spectrometer (onboard AQUA and TERRA satellites).

Action S19

Action: Implement a water vapour channel (e.g. 6.7 µm) on the imager of all core meteorological polar-orbiting satellites to facilitate the derivation of polar winds from water vapour motion.
Who: CGMS leading the action, with TCs, satellite agencies and data processing centres.
Time-frame: Continuous.
Performance indicator: Number of core meteorological polar-orbiting satellites with a water vapour channel in its imager.

6.3.2.4. Microwave imagers

The microwave imagers are similar to the passive microwave sounders discussed in 6.3.2.2, except they have different characteristics in wavelengths and spatial resolution which make them more appropriate for the observation of the land or sea surface. Over the oceans they provide information on sea-ice, surface wind speed and sea surface temperature. Over land they observe surface temperature, soil moisture and snow water equivalent. They also provide information on the precipitation and total column atmospheric water vapour. Polarimetric imagers also provide information on sea surface wind direction.

Since the decade 1990-2000, the total column water vapour and the surface wind speed information provided by the Special Sensor Microwave Imager (SSM-I) instrument onboard the American satellites DMSP[60] have been used widely for weather and climate applications. Initially the use of the data was limited to the ocean, but more recently a lot of progress has been achieved on the use of microwave satellite information over land. The role of these microwave sensors is also important for monitoring the sea ice limits around the polar caps. Due to the continuity of the DMSP/SSM-I observations during the last 20 years, these sensors make important contributions both to climate monitoring and to global re-analyses.

To meet the different user requirements, at least 3 satellites with microwave imagers are needed on well separated orbits. According to current plans most requirements are expected to be met, except possibly for all-weather SST.

Action S20

Action: Ensure availability of microwave imagers with all necessary channels to monitor SST.
Who: CGMS with satellite operators.
Time-frame: Continuous.
Performance Indicator: Number of LEO satellites with a microwave SST sensor.

6.3.3. Additional operational missions in appropriate orbits

In addition to the imagers and sounders listed above and operated on GEO and LEO orbits, several other satellite instruments are used for weather, ocean, climate and other applications. Many of them (but not all) are operated on polar orbiting sun-synchronous satellites. Several instruments serve the needs of more than one application.

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60 DMSP: Defence Ministry Satellite Programme (from the USA): among the different instruments onboard DMSP satellites, the SSM-I is the Special Sensor Microwave Instrument (used in operational meteorology).

6.3.3.1. Scatterometers

Unlike microwave imagers which are passive instruments, scatterometers onboard satellites are an active observing system. Scatterometers provide information mainly on the oceanic surfaces (sea surface wind speed, ice cover) and also for the land surface (soil moisture).

The first scatterometer data to be assimilated in operational global NWP models were the oceanic wind observations of the European ERS-1[61] satellite in the decade 1990-2000. Since then, scatterometers have been provided to NWP and other applications, from satellites like ERS-2, QuikScat[62], Metop (and its ASCAT[63] instrument) - see the WMO Database of Observational User Requirements and Observing Systems Capabilities for a list of instruments and missions. They generally provide a very good global data coverage (with some limitations on the maximum wind speed, or over sea ice) which helps considerably to meet the meteorological and oceanic requirements in terms of surface wind. Over land the use of scatterometer data is not as mature, but a lot of progress has recently been achieved on the use of soil moisture information.

At least two satellites flying on well-separated orbits with a scatterometer onboard are needed and should be maintained in the future. According to the present plans the requirements are expected to be met.

6.3.3.2. Radio-occultation constellation

The use of radio-occultation in meteorology is a good example of observing systems based on an opportunity: (i) the continuous availability of GNSS radio signals emitted by about 30 GNSS satellites (probably around 60 in 2015-2025), orbiting at an altitude of about 22000 km; and (ii) the perturbing role of the atmosphere which slows down the signal propagation, and generates atmospheric refraction. Then, by installing GNSS receivers on other satellites (ad hoc constellation or operational meteorological satellites, generally in LEO), it becomes possible to measure the delays of the signals due to their propagation through the atmosphere. These delays are mainly dependent on the air density, and they provide useful information on temperature, especially in the stratosphere and upper troposphere, and on humidity in the lower troposphere.

Radio-occultation measurements have been assimilated in operational NWP models since about 2005 from several satellites: CHAMP[64], GRACE-A[65], Metop (with its GRAS[66] instrument), the COSMIC constellation[67] (see Poli et al., 2009). Their impact on the analyses and forecasts has been evaluated by several NWP centres, and the main results have been discussed in the 4th WMO workshop on impact studies (see footnote reference in section 4). Taking into account the very indirect character of the observing system through instruments which were not primarily designed for meteorology, this positive impact has been found surprisingly large. In addition, the data coverage obtained from a constellation of receiving satellites is global and quite uniform. The system offers absolute measurements (self-calibrated), not contaminated by clouds, which

61 ERS = Earth Resource Satellite; ESA mission (ERS-1 started in 1991 and was followed by ERS-2)
62 Quick Scatterometer (NASA)
63 Metop's Advanced SCATterometer
64 CHAllenging Minisatellite Payload
65 GRACE: Gravity Recovery And Climate Experiment
66 GNSS Receiver for Atmospheric Sounding
67 http://www.cosmic.ucar.edu/

is a big advantage with respect to: (i) the general inter-calibration of satellite data; and (ii) the creation of climate data records.

Most of the existing satellites currently providing radio-occultation measurements to operational applications are not operational satellites and do not belong to any satellite programme whose future continuity is guaranteed. For the period 2012-2025, it is important to plan the continuity of a sufficient number of receiving satellites, to avoid losing the benefits of the important investments made on the production of radio-occultation measurements and on their use in operational meteorology. It should be noted that the amount of information delivered by a radio-occultation sensor depends on the number of on-board antennas and the number of GNSS systems it is compatible with (e.g. GPS, GLONASS, Galileo).

Action S21

Action: Ensure and maintain a radio-occultation constellation of GNSS receivers onboard platforms on different orbits producing at least 10,000 occultations per day (order of magnitude to be refined by the next Action). Organize the real-time delivery to processing centres.
Who: CGMS to lead the action, with TCs, satellite agencies and data processing centres.
Time-frame: Continuous.
Performance indicator: Number of GNSS occultations per day that are processed in near-real-time.

Action S22

Action: Perform an Observing System Simulation Experiment (OSSE) to evaluate the impact of different numbers of occultations per day, and to estimate the optimal number of daily occultations required.
Who: NWP centres, in coordination with CBS (to lead the action) and CAS.
Time-frame: Before end 2013.
Performance indicator: A number of OSSEs carried out.

Another application of the GNSS signals and radio-occultation is the measurement of electron density in the ionosphere. Therefore the future radio-occultation constellations will contribute also to the space weather applications (see section 7).

6.3.3.3. Altimeter constellation

SSH is one of the key variables to observe for ocean analysis and forecasting and for coupled ocean-atmosphere modelling. SSH has been observed through a series of satellite altimeters since the beginning of the decade 1990-2000: ERS-1 and 2, JASON-1[68] and 2, ENVISAT[69], GEOSAT[70], etc. - see the WMO Database of Observational User Requirements and Observing Systems Capabilities, for documentation on these satellites and their instrument characteristics. Satellite altimeters provide measurements of the ocean topography and of the significant wave height with a global coverage and a good accuracy. The interest of wide-swath altimeters could be highlighted. The surface wind can also be estimated from the wave observation. However the horizontal and temporal resolutions are limited by the instrument producing observations only at the nadir of the satellite (for most instruments). The horizontal resolution can be good along the

68 Ocean Surface Topography mission (USA/France)
69 ESA Environmental Satellite mission
70 GEOdetic SATellite

satellite track, and the main limitation is "across-track" in mid-latitudes: there is generally a 300km gap between measurements from two consecutive orbits.

Several altimeters are also able to provide measurements on ice topography (over sea and land) and on the lake levels (applications to glacier monitoring and hydrology). Unfortunately, there is a gap in laser altimetry between NASA's first and second ICESat satellites. While the radar altimeter on Cryosat-2 is also for sea and land ice measurements, the ideal altimeter constellation would have both laser and radar altimeters. The combination would provide greater accuracy in sea ice thickness estimates, and might provide information on the depth of snow on the ice.

In the future, several altimeter instruments (planned or already flying) will continue to support these applications: ALT on HY-2A[71], AltiKa[72] on SARAL[73] - see WMO Database of Observational User Requirements and Observing Systems Capabilities. In the period 1990-2010, the number of operational altimeters has varied from 1 to 4. It is generally agreed that a minimum of two satellites on sun-synchronous orbits, plus one reference mission, will be necessary to meet the requirements of operational oceanography.

Action S23

> **Action**: Implement an altimeter constellation comprising a reference mission on high-precision, not sun-synchronous, inclined orbit, and two instruments on well separated sun-synchronous orbits.
> **Who**: CGMS leading the action, with TCs, JCOMM, satellite agencies and data processing centres.
> **Time-frame**: Continuous.
> **Performance indicator**: Number and orbit geometry of satellites providing altimetry in real-time.

6.3.3.4. Infra-red dual-angle view imager

For climate monitoring purposes it is important to have continuous records of very accurate measurements of SST. In the GCOS-IP an action states: "Continue the provision of best possible SST fields based on a continuous coverage-mix of polar orbiting and geostationary infra-red measurements, combined with passive microwave coverage and appropriate in-situ networks". To achieve the required quality of SST fields it is important to have at least one infra-red instrument with a dual view for accurate atmospheric corrections. Such instruments have already been used: ATSR[74] on ERS, AATSR[75] on ENVISAT - see the WMO Database of Observational User Requirements and Observing Systems Capabilities. Another one is planned for the Sentinel 3 mission: the SLSTR (Sea and Land Surface Temperature Radiometer).

Action S24

> **Action**: Ensure and maintain in operation at least one infra-red dual-angle view imager onboard a polar orbiting satellite in order to provide SST measurements of climate monitoring quality.

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71 HaiYang ocean satellite mission (China)
72 High accurate oceanography altimeter
73 Environment monitoring mission (India/France)
74 Along Track Scanning Radiometer
75 Advanced Along-Track Scanning Radiometer

Who: CGMS leading the action, with TCs, JCOMM, satellite agencies and data processing centres.
Time-frame: Continuous.
Performance indicator: Operational availability of dual-angle view imagers.

The high-quality SST fields obtained through these infra-red imagers will also be useful for applications other than climate monitoring, in operational meteorology and oceanography. Also these imagers will contribute to the observation of aerosols, clouds, and fires.

6.3.3.5. Narrow-band high-spectral and hyper-spectral visible/near infra-red imagers

Remote-sensed observations of the ocean colour and related geophysical variables (e.g. phytoplankton, and nutrients) are useful for detecting several types of marine pollution, they can provide images of biological variables of the marine life with a high horizontal resolution (a few hundred metres). Observations of ocean colour are required for several marine applications and for the validation of ocean models.

The observations of ocean colour require passive imagers with narrow bands in the visible and near-infra-red spectrum. Several instruments of this type have already been operated, like the COCTS[76] on the Chinese HY-satellite series, the GOCI[77] on the Korean COMS[78] satellite, the MERIS[79] on the European ENVISAT satellite, or the OCM on the ISRO Oceansat-1 and Oceansat-2 satellites. For the future, other instruments are planned, like the OCS[80], or the OLCI[81] on the Sentinel-3[82].

The narrow-band imagers operated in the visible and near-infra-red are also useful for observing the vegetation (including LAI, FAPAR and the monitoring of burnt areas), the surface albedo, the aerosols and the clouds.

This narrow-band mission is currently well covered by LEO satellites.

6.3.3.6. High-resolution multi-spectral visible/infra-red imagers

For vegetation classification, land use monitoring and flood monitoring, visible/infra-red imagers are needed with characteristics emphasizing high horizontal resolution. These high-resolution instruments are normally applicable only on LEO satellites. The LAI is one of the main variables sought for agricultural meteorology from satellite data for use in crop simulation models. Although the LAI can be retrieved from several imagers, the highest resolution is achieved through the instruments of the LANDSAT[83] and SPOT[84] series. The land surface is observed with a horizontal resolution of dam order of magnitude. With instruments like the CHRIS onboard PROBA-2[85], the resolution can reach 2.5m on some specific targeted areas.

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76 Chinese Ocean Colour and Temperature Scanner
77 Geostationary Ocean Colour Imager
78 Communication, Ocean and Meteorological Satellite
79 MEd Resolution Imaging Spectrometer
80 Ocean Colour Scanner on the Russian Meteor Satellite
81 Ocean Land Colour Imager
82 A multi-instrument ESA satellite mission contributing to the Global Monitoring for Environment and Security (GMES)
83 Earth-observing satellite mission (NASA/USGS)
84 Satellite Pour l'Observation de la Terre
85 CHRIS = Compact High Resolution Imaging Spectrometer, onboard the PROBA-2 (PRoject for OnBoard Autonomy) satellite. PROBA-2 (after PROBA) is a demonstration mission of ESA, which has more and more routine users.

It is essential to continue this type of satellite mission in the future on order to guarantee the continuity of the existing series. This is important for agricultural meteorology, hydrology, land use, careful monitoring of disasters (floods, fires) and the very high-resolution imagers will have several other specific utilizations.

6.3.3.7. Precipitation radars with passive microwave imagers

Estimating the global field of precipitation amount (with precipitation type) at different time-scales is one of the more challenging tasks in weather and climate applications. One reason is related to the high variability in space and time of precipitation: in convective situations, flooding rains may affect one area with no precipitation at all a few kilometres away; the accumulated rainfalls (on 1h, 1 day, 1 month or 1 year) varies by one or two orders of magnitude between the equator and the poles. A second reason is that there is no hope to obtain a global coverage of precipitation observation through surface-based rain gauges and radars: in spite of the efforts made for expanding and improving the surface-based radar networks (see section 5.3.4.), the coverage will always be limited. However a proper estimation of precipitation fields is essential at all time-scales, from those required by the climate monitoring (several years, globally) to the local estimate of rainfall accumulated on 1h or less (flood monitoring). An ad hoc space-based precipitation observing system is very important to achieve this goal.

The concept of Global Precipitation Measurement (GPM) missions combines active precipitation measurements (made from space-based radars) with a constellation of passive microwave imagers (discussed in 6.3.2.4). The GPM constellation is planned to include a core mission with a 65° inclination orbit (with respect to the equator), plus several satellites developed by several national or international agencies. Its objective is to provide a global coverage of precipitation data at 3h intervals, and 8 satellites are needed to achieve this objective. The satellites will be equipped with active precipitation radars, or passive microwave instruments, or generally both. The characteristics of the existing and planned radars can be found on the WMO Database of Observational User Requirements and Observing Systems Capabilities search for example the CPR (Cloud and Precipitation Radar) or the DPR (Dual-frequency Precipitation Radar) in the Database.

This type of measurement has already proven its value, first on the TRMM[86] mission (satellite launched in 1997), and on the CLOUDSAT[87] mission, launched in 2006 by the USA, as part of the "A-Train"[88], to monitor the water cycle of the Earth, and also clouds and aerosols. The MEGHA-Tropiques Mission (MTM[89]), prepared through collaboration between France and India, launched in 2011, also contributes to this project whose emphasis is put on precipitation and water cycle. Several satellites (planned or already flying) will have a low orbital inclination from the equator. For example, the MTM satellite flies between 20S and 20N. In this way, they will provide more frequent data near the equator, compared to the usual polar orbiting satellites whose inclination is close to 90°. This is important for a better understanding and modelling of the diurnal cycle in the tropics. The data availability in real-time is also important for nowcasting and operational hydrology.

86 Tropical Rainfall Measuring Mission
87 NASA EOS mission to observe clouds
88 The A-Train includes several satellites flying in formation: AQUA, AURA, CLOUDSAT, CALIPSO, PARASOL (The OCO launch failed in February 2009)
89 CNES/ISRO Megha-Tropiques Mission to observe the water cycle and energy budget in the tropics

Action S25

Action: To implement at least one Precipitation Radar mission on an inclined orbit, and a follow-on operational mission.
Who: CGMS leading the action, with TCs, satellite agencies and data processing centres.
Time-frame: 2014 (initial) and continuous (follow-on)
Performance indicator: Availability of one mission.

Action S26

Action: In support of GPM, implement at least one passive MW mission on a low-inclination orbit.
Who: CGMS leading the action, with TCs, satellite agencies and data processing centres.
Time-frame: Continuous.
Performance indicator: Availability of one passive MW satellite mission on a low-inclination orbit.

Action S27

Action: Organize the delivery of GPM data in real-time to support nowcasting and operational hydrology requirements.
Who: CGMS leading the action, with TCs, satellite agencies and data processing centres.
Time-frame: Continuous.
Performance indicator: Extent to which availability requirements for nowcasting and operational hydrology are met.

6.3.3.8. Broad-band visible/infra-red radiometers for Earth radiation budget

The Earth Radiation Budget (ERB) measures the overall balance between the incoming energy from the sun and the outgoing thermal (long-wave) and reflected (short-wave) energy from the Earth. It can only be measured from space, thus the continuity of observations is an essential issue for climate applications (see GCOS-IP, section about ERB).

In addition to imagers and sounders on LEO and GEO satellites, and to aerosols and cloud properties measurements (see sections above from 6.3.2), the ERB requires at least one polar orbiting satellite equipped with a broad-band visible/infra-red radiometer and a sensor for measuring the total solar irradiance.

Broad-band radiometers were available in the past on the ERB Satellite (ERBS) and are available on the TERRA and AQUA satellites. The SCARAB[90] instrument flying on MTM also contributes to the ERB.

Action S28

Action: Ensure the continuity of ERB type global measurements by maintaining operational broad-band radiometers and solar irradiance sensors on at least one LEO polar orbiting satellite.
Who: CGMS leading the action, with TCs, satellite agencies and data processing centres.

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90 Scanning radiative budget instrument

Time-frame: Continuous.
Performance indicator: Number of polar orbiting satellites contributing to the ERB.

6.3.3.9. Atmospheric composition instrument constellation

Measurements of variables related to atmospheric composition are important for a diverse range of applications such as monitoring of the stratospheric ozone layer, monitoring and forecasting of air quality including long-range transport of pollution, investigation into the interaction between atmospheric composition and climate change and monitoring of episodic events such as volcanic eruptions and biomass burning. As mentioned above (5.3.1.4), a number of atmospheric constituents have an important role in climate forcings and feedbacks. This is the case for ozone, methane, CO_2 and others. Details can be found in the GAW Strategic Plan (see footnote references to GAW documents in section 5.3.1.4) and the GCOS-IP. Several of these constituents will also become important variables of NWP and atmospheric chemistry models (or already are, like ozone). The observations of these variables should become fully integrated in the WIGOS and then exchanged in real-time to meet the requirements of the full range of atmospheric chemistry applications, including air quality monitoring, and NWP.

There is a long established tradition, dating back to the 1970's when the ozone hole was first discovered, of monitoring stratospheric ozone from space. Since that time many space-based instruments have contributed to the measurements of atmospheric ozone, reactive trace gases, aerosols and more recently green house gases such as CO_2 and CH_4. The Japanese GOSAT, specifically addresses the observation of key Greenhouse Gas (GHG) for climate change.

Other examples of instruments devoted or largely contributing to atmospheric chemistry are: TOMS (flown on board Nimbus 7, Meteor 3, Earthprobe), SAGE I (flown on AEM-B), SAGE II (flown on ERBS), SBUV/2 (flown on board 6 NOAA satellites including current NOAA-19), GOME (flown on ERS-2), SMR & OSIRIS (flown on ODIN), SCIAMACHY, MIPAS & MERIS (flown on Envisat), MLS (flown on UARS and EOS-Aura), OMI & TES (flown on EOS-Aura), MODIS (on EOS-Terra and EOS-Aqua), MISR & MOPITT (on EOS-Terra), AIRS (on EOS-Aqua), GOME-2 and IASI (flown on 3 Metop satellites), AIRS (on EOS-Aqua), CrIS, OMPS & VIIRS (on Suomi NPP), CALIOP (on CALIPSO), TANSO-FTS (flown on GOSAT). In addition, multispectral imagers as described in 6.3.1.1 and 6.3.2.3 can be used in support of aerosol monitoring.

Looking towards the next generation of operational missions, OMPS-nadir[91] is present on Suomi-NPP and planned for its follow-on JPSS-1. It will measure ozone, but also NO_2, SO_2 and other trace gases. The OMPS-limb, also present on Suomi-NPP, performs high vertical resolution sounding in the stratosphere. In the European GMES[92] programme, the missions called Sentinel-4 and Sentinel-5 consist of ultra-violet and visible (and in the case of Sentinel-5 near-infra-red) sounders for supporting atmospheric chemistry to be flown on MTG (GEO) and EPS-SG (LEO) respectively. See the WMO Database of Observational User Requirements and Observing Systems Capabilities for more details.

Action S29

Action: For atmospheric chemistry applications including monitoring of ozone, reactive species relevant to air quality and air pollution, and of greenhouse gases, ensure the operational continuity of ultra-violet/visible/near-infra-red sounders, including high

91 OMPS: Ozone Mapping and Profiler Suite
92 GMES: Global Monitoring for Environment and Security

spectral resolution ultra-violet/visible sounders on GEO, and at least one ultra-violet/visible sounder on 3 well-separated polar orbits. Ensure also the continuity of limb-sounding capability.
Who: CGMS leading the action, with TCs, satellite agencies and data processing centres.
Time-frame: Continuous.
Performance indicator: Number of GEO and LEO ultra-violet/visible/infra-red sounders contributing to atmospheric chemistry.

For more details about the operational continuity of some atmospheric composition sounders, see GCOS-IP, section dealing with atmospheric chemistry.

6.3.3.10. Synthetic Aperture Radar (SAR)

Compared with a normal radar, the SAR processes the series of images in a special way, in order to increase considerably the spatial resolution locally, which implies some trade-offs on other geometrical variables of the radar measuring technique: scanning angle, swath size, etc. With SAR observing systems onboard LEO satellites, one can obtain locally very high resolution observations of land surface (including above ground biomass), wave heights (directions plus spectra), sea level (especially near the coasts), water level in flooded areas, sea ice caps, ice sheets and icebergs.

The SAR technology has been used on several satellites: ERS-1, ERS-2, ENVISAT (with its Advanced Synthetic Aperture Radar (ASAR) instrument), ALOS[93] (JAXA[94] satellite with its PALSAR[95] instrument). The ESA satellite CRYOSAT-2[96] has been launched in 2010 with its SAR instrument called SIRAL[97]. These SAR instruments have been used for both research and operational applications. For the future, several SAR missions are planned as well; for example the planning and development of the SAR-C instrument (radar in C band) on the GMES Sentinel-1 mission would be a very good step towards integration of the SAR observing system into the operational observing systems. The future Radarsat Constellation Mission (RCM) planned for 2015-2023 will include 3 satellites phased on the same orbit, enabling a 4-day revisit time.

It is not feasible to obtain in real-time a global coverage of SAR data. In addition the SAR processing delays are important, which often prevents a rapid delivery. However it is important to have at least one operational SAR satellite mission whose continuity is guaranteed, and integrated in the WIGOS, with proper mechanisms to ensure a rapid delivery of data at the regional and local scales, in order to cope efficiently with high-risk phenomena and disaster management. Because of the local character of the SAR-targeted areas and of the high volume of data to process, it is actually desirable to have more than one satellite mission complying with these operational characteristics.

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93 Advanced land observing Satellite "Daichi"
94 Japan Aerospace Exploration Agency
95 Phased Array L-band Synthetic Aperture Radar
96 ESA ice mission
97 Synthetic Aperture Interferometric Radar Altimeter

6.3.4. Operational pathfinders and technology demonstrators

It is important to pursue investigations on some new satellite instruments and some new space technologies even if the final operational success is not guaranteed, provided these new systems are expected to help significantly for meeting the user requirements. In the past, several research or demonstration missions produced a beneficial operational outcome much more quickly than expected originally by the potential users. Several pathfinders and technology demonstrators are discussed below. They are all challenging but achievable by 2025, with a good chance to be an operational part of global observing systems by 2025 for some of them, and a reduced chance for some other systems.

6.3.4.1. Lidars on LEO satellites

Lidar instruments flying on satellites have been used in meteorology or are planned to be used as demonstration satellite missions. The lidar can be designed to observe some of the following atmospheric components: profiles of wind components (from Doppler shifts), aerosols, cloud-top and cloud-base height, and water vapour profile. Space-borne lidars are also used in altimetry (see 6.3.3.3).

a) Doppler wind lidars

Space-borne Doppler wind lidars are the best hope for filling a big gap in the global data coverage: the lack of wind profile measurements which are currently too dependent on a single observing system, the radiosonde network.

An ESA demonstration mission, ADM-AEOLUS, is planned from 2013 to 2015 to test wind profile measurements made from the ultra-violet lidar, ALADIN[98]. ADM-AEOLUS[99] will be operated from a polar orbiting satellite and will provide global observations of wind profiles. It is very important to have these data delivered in real-time to the main NWP centres to check rapidly (the estimated life-time of ADM-AEOLUS is only 3 years) to what extent they can improve weather forecasts.

Following a successful demonstration mission, it will become a priority to plan and design an operational system based on wind lidars, using the experience accumulated in the demonstration mission, to decide on the appropriate number of satellites and the instrument characteristics.

Action S30

Action: Use the experience of demonstration missions (like the ADM-AEOLUS one) to plan and design an operational observing system based on Doppler wind measurements (providing a global coverage of wind profiles).

Who: CGMS leading the action, with TCs, ESA and other satellite agencies, data processing and NWP centres.

Time-frame: As soon as possible after data have been provided by demonstration missions.

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98 See http://www.esa.int/esaLP/LPadmaeolus.html; see also Stoffelen et al. (2005)

99 Earth Explorer Atmospheric Dynamics Mission

Performance indicator: Number and quality of Doppler wind lidar profiles (made from space) available to the users.

b) Cloud and aerosol lidars

Cloud and aerosol lidar systems can provide accurate measurements of cloud top height and can also observe cloud base height in some cases (e.g.: stratocumulus). They are also able to provide an accurate observation of aerosol layers in the atmosphere.

The CALIOP[100] instrument has been available on CALIPSO since 2006, and the ATLID[101] instrument should fly on the EARTH-CARE[102] mission prepared by ESA and Japan, and planned for 2013[103]. Given the potential of these lidars, the data should be delivered for evaluation in operational centres (mainly forecasting and atmospheric chemistry applications). For the design of a possible operational system based on cloud/aerosol lidar, it is important to note that a Doppler wind lidar like the ADM-AEOLUS has also the capacity to observe clouds and aerosols, which raises the possibility of designing an operational system which would integrate wind, cloud and aerosol measurements.

For an efficient evaluation of the lidar data (as soon as the instrument is operated), it is important to have these data distributed in real-time, so that they can be used (or at least evaluated) in operational numerical models dealing with atmospheric chemistry and weather forecasting.

Action S31

Action: Deliver cloud/aerosol lidar data produced from satellite missions to operational data processing centres and users. Use this experience to decide about a possible cloud/aerosol operational mission (integrated or not with an operational Doppler wind lidar mission).
Who: CGMS leading the action, with TCs, satellite agencies, data processing centres, forecasting and atmospheric chemistry users.
Time-frame: Continuous with a special effort phased with the EARTH-CARE mission.
Performance indicator: Data volume produced by space-based cloud/aerosol lidars and used by operational applications.

c) Water vapour lidars

Feasibility studies have been carried out on the measurement of atmospheric water vapour profiles from lidars onboard LEO satellites. The objective has been found highly challenging, and no demonstration mission is currently planned for a water vapour lidar. It is still worth keeping a research activity on such an observing system, and worth planning a demonstration mission when appropriate.

6.3.4.2. Low-frequency microwave radiometer on LEO satellites

Microwave radiometers on LEO satellites have a capacity to observe ocean salinity and soil moisture, but with a limited horizontal resolution. At large scales, the salinity information will be

100 Cloud-Aerosol Lidar with Orthogonal Polarisation
101 ATmospheric LIDar
102 Earth Clouds, Aerosols and Radiation Explorer - see http://www.esa.int/esaLP/LPearthcare.html
103 For more details on CALIPSO, CALIOP, EARTH-CARE and ATLID, see the WMO database referenced in section 6.1. http://www.wmo.int/pages/prog/sat/gos-intro_en.php

useful in ocean applications, in seasonal and inter-annual forecasting and in climate monitoring. The soil moisture produced from these microwave instruments should also be useful in NWP, seasonal and inter-annual forecasting, hydrology and climate monitoring. The horizontal resolution provided by these instruments may be marginal for meeting the user requirements in the coastal areas and for high-resolution marine applications.

The SMOS[104] satellite was launched in January 2009 and is expected to provide data until 2014. The Argentinean/NASA mission[105] SAC-D is expected to provide similar data between 2012 and 2016. Such research data sets should be delivered to operational meteorological, hydrological and oceanographic centres for near-real-time evaluation. If the benefits are judged sufficiently significant, an operational mission should be planned.

Action S32

> **Action**: Study the benefits brought by satellite demonstration missions like SMOS (missions based on low-frequency microwave radiometers) on atmospheric, hydrological and oceanic models, in a quasi operational context, and decide if a similar operational mission can be designed.
> **Who**: CGMS leading the action, with TCs, JCOMM, satellite agencies, data processing centres, meteorological, hydrological and oceanic modelling centres.
> **Time-frame**: As soon as possible for impact studies, from 2013 onwards to decide on new missions.
> **Performance indicator**: Improvement brought by using these microwave data on different models.

Ocean salinity and soil moisture are variables whose variations are important to consider at the climate scale. The archiving of data series is important; see recommendations in the ocean part of the GCOS-IP.

6.3.4.3. Microwave imagers/sounders on GEO satellites

Using microwave imagers and sounders from geostationary satellites could provide very frequent precipitation observations, together with cloud properties (liquid water and ice content), and atmospheric temperature/humidity profiles. However such instruments are highly challenging for several technical reasons. One reason is the need for very large antennas to be operated on GEO orbits.

The potential benefit of such satellite instruments would be very high in terms of global estimation of precipitation fields (at all time scales). They would be very good complements to the same type of instruments on LEO satellites (see sections 6.3.2.4 and 6.3.3.7 about microwave imagers, GPM and precipitation fields). Therefore there is a good case to plan a demonstration mission with microwave instruments onboard a geostationary satellite.

Action S33

> **Action**: Plan and design a demonstration mission with microwave instruments onboard a geostationary satellite, aiming at a significant improvement in terms of real-time observation of clouds and precipitation.

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104 SMOS: Soil Moisture and Ocean Salinity; satellite demonstration mission led by ESA, see: http://www.esa.int/esaLP/ESAMBA2VMOC_LPsmos_0.html
105 See http://aquarius.nasa.gov/

Who: CGMS leading the action, with TCs, satellite agencies, data processing centres, meteorological and hydrological modelling centres.
Time-frame: As soon as possible, taking into account the maturity of technology.
Performance indicator: Success of a microwave instrument onboard a GEO satellite, then improvement brought by the data to meteorological and hydrological forecasting.

6.3.4.4. High-resolution, multi-spectral, narrow-band, visible/near-infra-red on GEO satellites

Such instruments on GEO satellites would be the natural complement of the visible/near-infra-red instruments onboard LEO satellites (presented in section 6.3.3.5). They would contribute to the observation of ocean colour, vegetation, clouds and aerosols, and they would help disaster monitoring, with the usual advantage of GEO versus LEO: the frequency of images which makes the observation almost continuous on the Earth disk seen by the satellite. However their implementation is much more challenging than on LEO because of the high altitude of the geostationary orbit.

Action S34

Action: Plan and design a demonstration mission with high-resolution visible/near-infra-red instruments onboard a geostationary satellite, aiming at improving significantly the observation of ocean colour, vegetation, clouds and aerosols with multi-spectral narrow-band sensors.
Who: CGMS leading the action, with TCs, satellite agencies, data processing centres, meteorological, oceanic and environmental centres.
Time-frame: As soon as possible, taking into account the maturity of technology.
Performance indicator: Success of this type of instrument onboard a GEO satellite, then improvement brought by the data to meteorology, oceanography and environmental science.

6.3.4.5. Visible/infra-red imagers on satellites in high inclination and Highly Elliptical Orbit (HEO)

The HEO has never been used in meteorology and oceanography. Its main advantage is that the satellite can stay close to the vertical of one particular region of the Earth (at high altitude) for several hours, and only a reduced time on the opposite side of the Earth. When the orbit inclination on the equator is high, it almost offers the observation continuity similar to that of a geostationary satellite but in a polar region. With visible/infra-red sensors onboard, a HEO satellite would offer an almost continuous observation of the large number of meteorological and oceanic variables normally observed by this type of sensors: clouds (and AMVs) at high latitudes, surface temperature, sea-ice, ash plumes, vegetation, fires and snow cover.

Action S35

Action: Plan and design a demonstration mission with visible/infra-red instruments onboard a HEO satellite with a highly elliptical orbit and a high inclination over the equator, in order to target a polar area. The aim is to obtain the same environmental observations with a quality similar to those obtained from GEO satellites.
Who: CGMS leading the action, with TCs, satellite agencies, data processing centres, meteorological and environmental centres.
Time-frame: As soon as possible, taking into account the maturity of technology.

Performance indicator: Success of a visible/infra-red instrument onboard a HEO satellite, then improvement brought by the data to meteorology and environmental science.

6.3.4.6. Gravimetric sensors

Satellites have been used for gravity field measurements for several decades. Several gravity field sensors are currently flying, like the USA GRACE[106] mission or the ESA GOCE[107] satellite.

Their instruments can measure the Earth gravity field and follow its variations in space and time. From these variations, one can detect information on the ground water mass, or on the mass of water in some lakes and rivers. Thus they contribute to the monitoring of the ground water, together with a set of in-situ observing systems described in 5.3.3.3.

Note that gravity instruments are often flying on multi-user platforms: for example GNSS receivers embarked on any gravity field measurement platform, if properly set up, can be used for radio-occultation of the atmosphere, contributing to forecasting and climate applications, as described in 6.3.3.2.

7. SPACE WEATHER

Space Weather refers to the physical processes occurring in the space environment, driven by the Sun and Earth’s upper atmosphere, and ultimately affecting human activities on Earth and in space. In addition to the continuous ultra-violet (UV), visible and infra-red (IR) radiation which provides radiative forcing to our weather and climate at the top of the atmosphere and maintains the ionosphere, the Sun emits a continuous flow of solar wind plasma which carries the Sun's embedded magnetic field, and releases energy in an eruptive mode, as flares of electromagnetic radiation (radio waves, IR, visible, UV, X-rays), energetic particles (electron, protons, and heavy ions), and high speed plasma through coronal mass ejections. The solar wind and the eruptive disturbances (i.e. solar storms) propagate out into interplanetary space and impact interplanetary space and Earth’s environment.

The electromagnetic radiation travels at the speed of light and takes about 8 minutes to move from Sun to Earth, whereas the energetic particles travel more slowly, taking from tens of minutes to hours to move from Sun to Earth. At typical speeds, the background solar wind plasma reaches Earth in about four days, while the fastest coronal mass ejections can arrive in less than one day. The solar wind and the solar disturbances interact with the Earth's magnetic field and outer atmosphere in complex ways, causing strongly variable energetic particles and electric currents in the magnetosphere, ionosphere and thermosphere. These can result in a hazardous environment for satellites and humans at high altitudes, ionospheric disturbances, geomagnetic field variations, and the aurora, which can affect a number of services and infrastructure at the Earth’s surface, or airborne or space-borne in Earth orbit. The threats of space weather are certain to increase, both in the near term as solar maximum approaches and in the far term as our dependence on technologies impacted by space weather continues to expand.

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106 Gravity Recovery and Climate Experiment - http://www.csr.utexas.edu/grace/
107 Gravity field and steady-state Ocean Circulation Explorer - http://www.esa.int/esaLP/LPgoce.html

Space weather observations are required: to forecast the occurrence probability of space weather disturbances; to drive hazard alerts when disturbance thresholds are crossed; to maintain awareness of current environmental conditions; to determine climatological conditions for the design of both space based systems (i.e., satellites and astronaut safety procedures) and ground based systems (i.e., electric power grid protection and airline traffic management); to develop and validate numerical models; and to conduct research that will enhance our understanding. The vastness of space and the wide range of physical scales which control the dynamics of space weather demand that numerical models be employed to characterize the conditions in space and to predict the occurrence and consequence of disturbances. In order to obtain the maximum benefit from sparse measurements, space weather observations have to be used through assimilation into empirical or physics-based models. A comprehensive space weather observation network must include ground-based and space-borne observatories. Both the ground-based and the space-based segments shall contain a combination of remote sensing and in-situ measurements.

Today, services relying on operational and research observing assets can help all WMO Members to monitor disturbances and to warn of oncoming storms. The space environment, however, is vastly undersampled. Significant gaps in our observing capabilities limit our ability to provide a comprehensive characterization of the important physical parameters, and limit the accuracy of our predictive models. Existing ground-based and space-based assets have not all been integrated into a coordinated observing network. These include a number of Global Navigation Satellite System (GNSS) receiver sites, ground measurements of Earth's magnetic field, and satellite measurements of energetic particles and magnetic field in space. Furthermore, continuity of some essential space-based monitoring missions is not planned.

In the framework of the WMO Information System (WIS) and the WMO Integrated Global Observing System (WIGOS), existing observing systems and service centres can be expanded and further integrated, thus improving the capability to deliver a broad range of services. Space weather is a global challenge requiring coordinated global preparedness. All Members have the opportunity to contribute to future capabilities, and are encouraged to improve the collection and open dissemination of ground-based and space-based space weather data. Working together, we can achieve global preparedness for space weather hazards and response.

Action W1

> **Action**: To develop and implement a coordinated plan ensuring continuity of solar measurements, solar wind and interplanetary magnetic field measurements, and heliospheric imaging, including measurements at different locations such as at the L1 Lagrange point, the Sun-Earth line upstream from the L1 point, the L5 Lagrange point, as well as the required global network of ground-based antennas for data reception and processing.
> **Who**: ICTSW[108], CGMS and space agencies.
> **Time-frame**: End 2014.
> **Performance indicator**: Availability of coordinated plans for continuity until 2030.

Action W2

> **Action**: To coordinate and to standardize the existing ground-based solar observation data, and to expand them where required for redundancy, and to develop a common data portal or virtual observatory within the WIS.

108 Inter-programme Coordination Team on Space Weather (ICTSW)

Who: ICTSW and all Members performing solar observations from the surface.
Time-frame: Continuous.
Performance indicator: Availability of data template for ground-based solar observation.

Action W3

Action: To increase the spatial resolution of ground-based GNSS ionospheric observations (TEC and scintillation), either by deploying additional receivers in regions with sparse coverage (e.g. Africa), making the data from existing receivers accessible, or by utilizing different means of receiving GNSS data, such as aircraft-mounted receivers, to reduce gaps over the oceans.
Who: ICTSW and all Members operating or planning ground-based GNSS networks.
Time-frame: continuous.
Performance indicator: Number of ground-based GNSS receivers providing near-real-time data.

Action W4

Action: To improve the timeliness of space-based GNSS measurements from LEO satellites to get near-real-time information about the 3D electron density distribution of the ionosphere/plasmasphere system. (e.g. by use of a RARS concept or other network of satellite ground stations for rapid transmission).
Who: ICTSW, CGMS, relevant space agencies, and WMO Members who support ground stations.
Time-frame: Continuous.
Performance indicator: Number of occultations per day available with a timeliness to meet user requirements.

Action W5

Action: To foster sharing of ground-based GNSS data and GNSS Radio-Occultation among the meteorological and space weather communities, and to facilitate the near-real-time access to these data through WIS.
Who: ICTSW, IROWG[109] and WMO/WIGOS project office.
Time-frame: Continuous.
Performance indicator: Agreement on data sharing.

Action W6

Action: To coordinate the use of dual-frequency radar altimeter observations by Space Weather community to improve or validate ionospheric models and for operational TEC monitoring over the oceans.
Who: ICTSW, WMO Space Programme and altimetry satellite operators.
Time-frame: Continuous.
Performance indicator: Number of satellite altimeters providing data for space weather.

Action W7

Action: To increase the availability of ground-based magnetometer data with high timeliness. This can be accomplished by: (i) deployment of magnetometers in regions with limited coverage; (ii) dissemination of data from existing magnetometers within WIS; and (iii) agreement with data providers for their data to be used in space weather products.

109 International Radio Occultation Working Group (IROWG)

Who: ICTSW and magnetometer observatories.
Time-frame: Continuous.
Performance indicator: Number of magnetometer data sources available with timeliness to meet user requirements.

Action W8

Action: Develop a plan for maintaining and improving space weather observations of the plasma and energetic particle environment along the following priorities: (1) maintain long-term continuity, and if possible improve the spatial resolution, of measurements at all altitudes from LEO through GEO orbits; (2) improve the sharing of existing and planned plasma and energetic particle measurements; (3) include energetic particle sensors on HEO satellites; and (4) conduct research to incorporate the plasma and energetic particle data into numerical models to give flux estimates at all locations where our satellites are in orbit.
Who: ICTSW, CGMS and space agencies.
Time-frame: End of 2014.
Performance indicator: Availability of a plan for space weather observation of plasma and energetic particle environment.

ANNEX I - REFERENCES

Benjamin, S.G., B.D. Jamison, W.R. Moninger, S.R. Sahm, B.E. Schwartz, and T.W. Schlatter, 2010: Relative short-range forecast impact from aircraft, profiler, rawinsonde, VAD, GPS-PW, METAR and mesonet observations via the RUC hourly assimilation cycle. Mon. Wea. Rev., 138, pp.1319-1343.

Boehlert, G.W., D.P. Costa, D.E. Crocker, P. Green, T.O'Brien, S. Levitus, B.J. Le Boeuf, 2001: Autonomous Pinniped Environmental Samplers: Using Instrumented Animals as Oceanographic Data Collectors. *J. Atmos. Oceanic Technol.*, 18, 1882–1893.

Davis, R.E., C.E. Eriksen and C.P. Jones, 2002. Autonomous buoyancy-driven underwater gliders. The Technology and Applications of Autonomous Underwater Vehicles. G. Griffiths, ed, Taylor and Francis, London. 324 pp.

Mayer, S., A. Sandvik, M. Jonassen and J. Reuder, 2010: Atmospheric profiling with the UAS SUMO: A new perspective for the evaluation of fine-scale atmospheric models. Meteorology and Atmospheric Physics, DOI 10.1007/s00703-010-0063-2.

Messer, H., 2007: Rainfall monitoring using cellular networks. IEEE Signal Proc. Mag., 24, 142–144.

Moninger, W.R., S.G. Benjamin, B.D. Jamison, T.W. Schlatter, T.L. Smith, and E.J. Szoke, 2010: Evaluation of Regional Aircraft Observations using TAMDAR . Weather and Forecasting, vol.25, N°2, pp. 627-645.

Poli P., S.B. Healy, F. Rabier, and J. Pailleux, 2009 : Preliminary Assessment of the Scalability of GPS Radio Occultation Impact in Numerical Weather Prediction. Geophysical Research Letters, 35.

Rabier F., A. Bouchard, E. Brun, A. Doerenbecher, S. Guedj, V. Guidard, F. Karbou, V.-H. Peuch, L. El Amraoui, D. Puech, C. Genthon, G. Picard, M. Town, A. Hertzog, F. Vial, P. Cocquerez, S. Cohn, T. Hock, H. Cole, J. Fox, D. Parsons, J. Powers, K. Romberg, J. Van Andel, T. Deshler, J. Mercer, J. Haase, L. Avallone, L. Kalnajs, C. R. Mechoso, A. Tangborn, A. Pellegrini, Y. Frenot, J.-N. Thépaut, A. McNally, G. Balsamo and P. Steinle, 2010 : The Concordiasi project in Antarctica. Bull. Amer. Meteor. Soc. (BAMS), vol. 91, 1, 69-86.

Rudnick, D. L., R. E. Davis, C. C. Eriksen, D. M. Fratantoni, and M. J. Perry, 2004: Underwater gliders for Ocean Research. *J. Mar. Tech. Soc.,* 38, 73-84.

Stoffelen, A., J. Pailleux, E. Källen, J.M. Vaughan, L. Isaksen, P. Flamant, W. Wergen, E. Andersson, H. Schyberg, A. Culoma, R. Meynart, M. Endemann and P. Ingmann, 2005 : The atmospheric dynamics mission for global wind field measurement Bull. Amer. Meteor. Soc., January 2005, 73-87.

ANNEX II - SUMMARY TABLE OF ACTIONS

No.	***Action***	***Agent for implementation***	***Time frame***	***Performance indicator(s)***
C1	Meet growing user requirements for climate information by encouraging and assisting in expansion of traditional observing platforms for weather and climate observations.	GCOS and CBS to lead the action, together with regional centres representing users and organizations operating component observing systems.	Continuous.	Extent to which user needs are met.
C2	Once relevant research-based observing systems are shown to be sufficiently mature and cost-effective, follow an appropriate migration methodology to become a sustained operational system.	CBS, in collaboration with CIMO and CAS, to initiate and lead the evolution, with all organizations operating component observing systems.	Continuous. Timetable to be decided on a case by case basis.	Number of sustained systems compared to the targets.
C3	Ensure all operators producing observations adhere to the WIS standards.	Organizations and agencies operating observing programmes. Action monitored by CBS.	Continuous.	Extent to which WIS standards are applied.
C4	Careful preparation is required before introducing new (or changing existing) observing systems. The impact needs to be assessed through prior and ongoing consultation with data users and the wider user community. Also, data users need to be provided with guidance on data reception/acquisition, processing and analysis infrastructure, the provision of proxy data, and the provision of education and training programmes.	All organizations operating component observing systems, following the best practices provided by CBS, CAS or other TCs and co-sponsored programmes	Continuous.	Extent to which user community concerns are captured.
C5	Ensure sustained funding for the key marine/ocean observing systems (e.g. tropical moorings, Argo, surface drifters with barometers, as well as altimeter, scatterometer, SST from microwave radiometry, sea ice measurements from research satellite missions).	NMSs, NMHSs and partner national institutions, in collaboration with international organizations, TCs responsible for observing system coordination (e.g. JCOMM, CBS, and CIMO) and space agencies.	Continuous.	Percentage of observing networks funded through sustained mechanism.
C6	For each observing system proposed for operation in adaptive mode (i.e. a process which would vary the observation set according to the meteorological situation), investigate the feasibility, cost-	Organizations operating observing networks on a routine basis. Process to be initiated and coordinated by	Continuous reviewing process of the feasibility and cost-effectiveness	Number of networks operated with some level of targeting.

No.	Action	Agent for implementation	Time frame	Performance indicator(s)
	effectiveness and side effects on the continuity of climate data records.	CBS based on recommendations from CAS, other TCs, the RAs, and GCOS.	assessments.	
C7	Ensure time continuity and overlap of key components of the observing system and their data records, in accordance with user requirements, through appropriate change-management procedures.	CBS to lead, in collaboration with other TCs, JCOMM, RAs, satellite agencies, NMSs and NMHSs, and organizations operating observing systems. RAs.	Continuous. Timetable to be decided on a case by case basis.	Continuity and consistency of data records.
C8	For WMO and co-sponsored observing systems, ensure continued adherence to WMO data sharing principles irrespective of origin of data, including data provided by commercial entities.	NMSs and NMHSs, and space agencies. Process monitored by CBS.	Continuous.	Continued availability of all essential observational data to all WMO members.
C9	Evaluate the future evolution of data volumes to be exchanged and handled, based on the projected data volumes generated by the future space-based and surface-based sources.	WMO/WIS to lead, in collaboration with TCs, JCOMM, RAs, satellite agencies, NMSs and NMHSs, all organizations operating observing systems.	Continuous.	Evolution of the data volumes handled and exchanged.
C10	Monitor the flow of all essential data to processing centres and to users and ensure timely flow of feedback information to observing network management from monitoring centres.	Data processing centres coordinated by appropriate TCs and international programmes (CBS to lead the process and initiate it when required).	Continuous.	Usual monitoring criteria
C11	Achieve improved homogeneity of data formats for international exchange, by reducing to a smaller number of internationally coordinated standards.	CBS to lead, in coordination with other TCs.	Continuous.	Number of data formats per data type
C12	Ensure a continuous monitoring of the radio frequencies which are needed for the different components of WIGOS, in order to make sure they are available and have the required level of protection.	WMO/SG-RFC to lead, in coordination with NMSs, NMHSs and national, regional and international organizations in charge of radio frequency management.	Continuous.	Observation frequency bands available/not available with required level of protection.
C13	Establish capacity building strategies for observing systems in developing countries through projects funded by international organizations, bilateral partnerships and facilitation of regional cooperation.	NMSs/NMHSs with RAs, CBS, other TCs, in collaboration with international programmes.	Continuous.	Substantial improvement in observational data return from developing countries.
G1	Ensure traceability of meteorological observations	NMSs/NMHSs, in coordination	Continuous.	Number of stations that make

No.	Action	Agent for implementation	Time frame	Performance indicator(s)
	and measurements to SI or WMO standards.	with WMO own and co-sponsored programmes, TCs, RAs, and other relevant organizations. CBS and RAs to lead and supervise.		measurements traceable to SI or WMO standards.
G2	Ensure, as far as possible, a global exchange of hourly data which are used in global applications, optimized to balance user requirements against technical and financial limitations.	NMSs/NMHSs, RAs, in coordination with CBS and international programmes and agencies. CBS to lead the action.	Continuous. Timetable to be decided for each observing system.	The standard monitoring indicators used in global NWP[17].
G3	Promote a global exchange of sub-hourly data in support of relevant application areas.	NMSs/NMHSs, in coordination with WMO own and co-sponsored programmes, TCs, RAs, and other relevant organizations. CBS to lead the action.	Continuous. Timetable to be decided for each observing system.	A number of sub-hourly data types exchanged through WIS.
G4	Ensure exchange of observations from atmosphere, ocean, terrestrial observing system, according to the WIGOS standards. If needed, organize different levels of pre-processed observations in order to satisfy different user requirements.	NMSs/NMHSs, in coordination with WMO own and co-sponsored programmes, TCs, RAs, and other relevant organizations. CBS to lead the action.	Continuous. Timetable to be decided for each observing system.	Statistics on the data made available to each application.
G5	Surface-based observing network operators should facilitate access to observations suitable to support validation of space-based derivation of surface parameters.	CBS to lead, in collaboration with NMSs and NMHSs.	Continuous.	Quantity of surface-data made available for the validation of satellite products.
G6	Surface-based observing network operators should consider using space-based observations/products to monitor quality of data from surface-based networks.	CBS, NMS, NMHS	Continuous.	Number of surface-based observing systems using satellite data for quality monitoring
G7	Expand radiosonde stations, or re-activate silent radiosonde stations, in the data sparse areas of Regions I, II and III which have the poorest data coverage. Make all possible effort to avoid closing of existing stations in these data sparse areas, where even a very small number of radiosonde stations can provide an essential benefit to all the users.	NMSs/NMHSs, in coordination with WMO own and co-sponsored programmes, TCs, RAs, and other relevant organizations. CBS to lead the action together with the RAs.	Continuous.	The standard monitoring indicators used in NWP[17].
G8	Reconsider radiosonde network designs (e.g. by using isolated stations), taking into account other	CBS through NWP impact studies and network design	2015 (or earlier) for a first redesign.	Design developed and implemented.

No.	Action	Agent for implementation	Time frame	Performance indicator(s)
	available sources of data, such as AMDAR and wind profilers.	studies, in coordination with NMSs/NMHSs, WMO own and co-sponsored programmes, other TCs, RAs and other relevant organizations. CBS and RAs to lead the action.		
G9	Continue the studies and tests on the usefulness of observations obtained by increasing the frequency of radiosonde launches at some observation sites, in relation with the meteorological situation in the area.	NMSs/NMHSs, research institutions and other organizations operating radiosonde networks or organizing field experiments, with the NWP centres. CBS and CAS to lead the action.	Continuous, with a time-table depending on regional campaigns.	A number of radiosonde sites able to become “adaptive” together with the number of observations made (standard monitoring).
G10	Investigate possibility to optimize the radiosonde network in order to make the upper-air conventional observation coverage more uniform taking into account all the user requirements in terms of space and time distribution; and make relevant recommendations to the CBS for updating Technical Regulations accordingly.	NMSs/NMHSs, in coordination with WMO own and co-sponsored programmes, TCs, RAs and other relevant organizations. CBS and RAs to lead the action.	2015, then continuous.	Standard monitoring indicators
G11	Improve quality, availability and sustainability of GUAN, ensuring maintenance of the existing network, and data quality.	CBS to lead in coordination with GCOS and with NMSs/NMHSs, TCs, RAs, and other relevant organizations.	Continuous.	The standard monitoring indicators used in NWP.
G12	Continue implementation of GRUAN through support and development of the initial 15 stations and eventual completion of the full 30-40 station network.	CBS to lead in coordination with GCOS and with NMSs/NMHSs, TCs, RAs, and other relevant organizations.	Continuous.	The standard monitoring indicators used in NWP and the indicators defined in the GRUAN Observation Requirements.
G13	Identify radiosonde stations that make regular measurements (including radiosondes operated during campaigns only), but for which data are not transmitted in real-time. Take actions to make data available.	NMSs/NMHSs, in coordination with WMO own and co-sponsored programmes, TCs, RAs, and other relevant organizations. CBS and RAs to lead the action.	Continuous.	A number of the above radiosonde stations providing data to GTS, plus standard monitoring indicators on radiosonde data availability and timeliness.
G14	Ensure a timely distribution of radiosonde measurements at high vertical resolution, together with position and time information for each datum, and other associated metadata.	NMSs/NMHSs, in coordination with WMO own and co-sponsored programmes, TCs, RAs, and other relevant	Continuous.	Number of radiosonde sites providing the high resolution profiles.

No.	***Action***	***Agent for implementation***	***Time frame***	***Performance indicator(s)***
		organizations. CBS and RAs to lead the action.		
G15	Perform NWP impact studies to evaluate the impact of radiosonde data above 100hPa on global NWP, in the context of current observing systems (2012).	NWP centres, coordinated by CBS/ET-EGOS and CAS.	Before end of 2013.	A number of independent studies carried out.
G16	Perform OSSEs to evaluate the impact of improved information above 100hPa on the tropospheric forecasts.	NWP centres, coordinated by CBS/ET-EGOS and CAS	Before end of 2013.	A number of independent experiments of this kind carried out.
G17	Develop networks of remote-sensing profiling stations on the regional scale in order to complement the radiosonde and aircraft observing systems, mainly on the basis of regional, national and local user requirements (although part of the measured data will be used globally).	Organizations operating profiling stations in routine or research mode, in coordination with NMSs/NMHSs, RAs, TCs (mainly CAS, CBS and CIMO) and other regional institutions (e.g.: EUMETNET in Europe). CBS to lead the action with CIMO, CAS and RAs.	Continuous. Detailed timetables to be set up by RAs at the regional level.	A number of profiling stations providing quality-assessed data in real-time to WIS/GTS.
G18	Ensure, as far as possible, the required processing and the exchange of profiler data for local, regional and global use. When profiler data can be produced more frequently than 1 hour, a dataset containing only hourly observations can be exchanged globally following the WIS principles.	Organizations operating profiling stations in routine or research mode, in coordination with NMSs/NMHSs, RAs, TCs (mainly CAS, CBS and CIMO) and other regional institutions (e.g. EUMETNET in Europe). CBS to lead the action together with the RAs.	Continuous. Detailed timetables to be set up by RAs at the regional level.	A number of profiling stations exchanged globally.
G19	Improve AMDAR coverage over areas that currently have poor coverage, especially within Regions I and III, focussing on the provision of data at airports in the tropics and southern hemisphere where vertical profiles are most needed to complement current radiosonde data coverage and its likely evolution.	NMSs, NMHSs in collaboration with commercial and other airlines, RAs. AMDAR Programme Management to lead the action.	Continuous.	Number of airports where AMDAR measurements are taken. Amount of vertical profiles and AMDAR data in general, measured by the usual indicators of current AMDAR programmes.
G20	Extend the AMDAR Programme so as to equip and activate more internationally-operating fleets and aircraft (i.e. fleets and aircraft flying to and between international airports outside the country of origin) and extend the use of data optimization systems in support of improved upper air observations coverage	NMSs, NMHSs in collaboration with commercial and other airlines, RAs, CBS and AMDAR Programme Management. AMDAR Programme Management to lead the action.	Continuous.	The number of airports where AMDAR measurements are taken and number of vertical profiles per day at each airport. The number of international airlines and

No.	Action	Agent for implementation	Time frame	Performance indicator(s)
	and efficiency, and also the adaptive functionality of the system.			aircraft equipped to provide AMDAR observations. The adaptability of the AMDAR programme.
G21	Given the nature of the aircraft observing system as an increasingly critical and basic component of the Global Observing System, seek to establish agreements with airlines and the aviation industry to ensure that the system, infrastructure, data and communications protocols are supported and standardized within relevant aviation industry frameworks so as to ensure continuity and reliability of the system.	NMSs, NMHSs in collaboration with national and other airlines and aviation industry, RAs, CBS and AMDAR Programme Management. AMDAR Programme Management to lead the action.	Continuous.	Agreements made with aviation industry partners and organizations.
G22	Continue the development and operational implementation of humidity sensors as an integrated component of the AMDAR system to ensure that humidity data is, processed and transmitted in the same way as wind and temperature.	NMSs, NMHSs in collaboration with commercial and other airlines and TCs (CBS, CIMO) and AMDAR Programme Management. AMDAR Programme Management to lead the action.	Continuous.	A number of aircraft providing humidity data in real-time.
G23	Enhance and extend the capability to report observations of atmospheric turbulence and icing variables as an integrated component of the AMDAR system and in line with the requirements of the relevant programme areas and data users.	NMSs, NMHSs in collaboration with airlines and TC (CBS, CIMO) and AMDAR Programme Management, RAs. AMDAR Programme Management to lead the action.	Continuous.	A number of aircraft providing atmospheric turbulence and icing data in real-time.
G24	Develop and implement operationally AMDAR systems which are adapted to small aircrafts operating at the regional scale and flying at low altitude in the troposphere.	Airlines operating small aircraft, NMSs, NMHSs in collaboration with RAs, CBS and AMDAR panel. AMDAR Programme Management to lead the action.	Continuous.	Number of small aircrafts providing AMDAR observations operationally in real-time.
G25	Encourage managers of national programmes of meteorological observations to extend the scope of these stations to include atmospheric chemistry observations.	NMSs/NMHSs and respective organizations and research agencies conducting atmospheric composition observations, in coordination with TCs (especially with CAS and CBS) and RAs. CAS and CBS to lead the action with	Continuous. Timetable to be defined for each RA.	Number of atmospheric composition stations.

No.	Action	Agent for implementation	Time frame	Performance indicator(s)
		RAs.		
G26	Derive greater benefit from the existing GNSS receiver stations by establishing collaborative arrangements with station owners and operators for access, processing, and sharing of real-time data to derive meteorological or ionospheric information (ZTD or IWV, TEC).	NMSs/NMHSs (individually or in multilateral groupings) will lead the Action and will need to collaborate with station owners/operators, with RAs (to determine exchange requirements), and with TCs (for relevant guidance).	Continuous.	Number of GNSS receiver stations making available their data in real-time; number of stations which can be used in NWP according to the usual monitoring criteria[17].
G27	Organize the global exchange of data from a subset of GNSS receiver stations, aiming at satisfying a frequency requirement of about one hour (for meeting requirements in global applications).	Organizations and research agencies operating GNSS receiver stations, in coordination with NMSs/ NMHSs, with RAs, TCs (especially CAS and CBS) and other international organizations (e.g., EUMETNET). CBS to lead the action with RAs.	Continuous.	A number of GNSS receiver stations whose data are exchanged globally in real-time.
G28	Optimize the upper-air water vapour observation over land, considering the collaborative establishment of additional GNSS receiver stations, and also the other humidity observing systems.	Organizations and research agencies operating GNSS receiver stations, in coordination with NMSs/ NMHSs, with RAs, TCs (especially CAS and CBS) and other international organizations (e.g. EUMETNET). NMSs/NMHSs to lead the action with RAs.	Continuous.	Number of GNSS receiver stations making available their data in real-time; number of stations which can be used in NWP according to the usual monitoring[17].
G29	Extend the BSRN to achieve global coverage.	NMSs/NMHSs, and Research organizations, RAs and TCs, coordinated by CBS.	Continuous.	Number of BSRN stations.
G30	Ensure, as far as possible, global exchange of variables measured by surface synoptic and climatological stations with at least one hour frequency and in real-time.	NMSs/NMHSs, RAs and TCs, coordinated by CBS.	Continuous.	A percentage of observations exchanged globally with a one hour frequency (with respect to the number of stations observing hourly).
G31	Improve data compatibility, availability (also with higher frequency) and data coverage of surface	NMSs/NMHSs, RAs and TCs, coordinated by CBS.	Continuous.	A percentage of stations distributing quality-assessed

No.	Action	Agent for implementation	Time frame	Performance indicator(s)
	synoptic and climatological observations through quality management, automation and exchange of data in real-time, as far as possible from all operational stations.			observations in real-time over WIS/GTS (with respect to the number of stations producing observations).
G32	Ensure variables measured by surface synoptic and climatological stations are exchanged together with access to relevant metadata according to WIGOS and WIS standards. Special attention should be given to the barometer altitude uncertainty.	NMSs/NMHS, RAs and TCs, coordinated by CBS.	Continuous.	Usual monitoring indicators[17].
G33	Improve design of the Regional Basic Synoptic Network (RBSN) and the Regional Basic Climatological Network (RBCN), making every effort to retain climatically significant stations.	CBS leading the action through the appropriate NWP impact studies and network design studies, in coordination with NMSs/NMHSs, WMO own and co-sponsored programmes, other TCs, RAs and other relevant organizations.	2015.	Design developed and implemented.
G34	Implement as soon as possible a near-real-time exchange of the atmospheric composition observations which are made at surface stations. Follow the GAW recommendations and WIGOS and WIS practices for implementing this dissemination, and the standard quality assessment practices.	Organizations and research agencies operating atmospheric composition observations, in coordination with NMSs/NMHSs, the RAs and TCs. CAS and CBS to lead the action with RAs.	Continuous. Timetable to be established for each RA.	A number of surface atmospheric composition stations making quality-assessed data available in real-time.
G35	Implement as soon as possible a comprehensive cryosphere observing network of reference sites “CryoNet”.	Organizations, institutes and research agencies conducting cryosphere observation and monitoring, in coordination with NMSs/NMHSs, the RAs and TCs, as required. CryoNet Team will lead the action. GCW Advisory Board and Management Board will oversee the action.	2014.	Number of reference sites taking part in CryoNet.
G36	Provide, as far as possible, a real-time or near-real-time exchange of the cryospheric data from CryoNet. Follow the GCW, WIGOS and WIS practices for implementing this dissemination, and the standard quality assessment practices and archiving.	Organizations, institutes and research agencies conducting cryosphere observations and monitoring, in coordination with NMSs/NMHSs, the RAs and	2014.	Number of CryoNet stations making quality-assessed data available.

No.	Action	Agent for implementation	Time frame	Performance indicator(s)
		TCs, as required. CryoNet Team will lead the action; GCW Advisory Board and Management Board will oversee the action.		
G37	Improve global lightning detection efficiency by extending the deployment of long-range lightning detection systems and introducing more of these systems. Priorities should be given to filling gaps in populated areas and along commercial airline routes.	NMSs/NMHSs and agencies operating long-range lightning detection systems RAs and TCs, coordinated by CBS and CIMO, leading the action jointly.	Continuous.	Data coverage for this type of observations.
G38	Develop and implement techniques for the integration of lightning detection data from different systems, including from surface- and space-based systems, to enable composite products to be made available.	NMSs/NMHSs and agencies operating lightning detection systems, RAs and TCs, coordinated by CBS and CIMO, leading the action jointly.	Continuous.	Level of integration of the lightning systems.
G39	Improve the exchange of lightning detection data in real-time by establishing and implementing agreed protocols for the exchange of data.	NMSs/NMHSs and agencies operating lightning detection systems, NMSs, NMHS, RAs and TCs, coordinated by CBS and CIMO.	Continuous.	A percentage of observations exchanged regionally and globally.
G40	Ensure, as far as possible in real-time, exchange of observations, relevant metadata, including a measure of representativeness made by surface-based stations serving specific applications (road transport, aviation, agricultural meteorology, urban meteorology, etc.).	Agencies operating stations serving specific applications, NMSs / NMHSs, RAs and TCs, coordinated by CBS.	Continuous.	A percentage of observations from the above stations exchanged regionally and globally in real-time.
G41	Enhance observations in candidate areas to support studies associated with the development and operations of renewable energy installations, and also to understand the influence of these installations on local weather and climate phenomena related to the operation of the renewable technologies.	Agencies operating stations serving renewable energies, NMSs/NMHSs, RAs and TCs, coordinated by CBS.	Continuous.	Number of observations supporting of renewable energies.
G42	For climate purposes, maintain the existing hydrological stations of the GCOS/GTOS baseline network, and facilitate their global exchange.	All hydrological services operating these reference stations, TCs (CHy and CBS), GCOS. CBS and GCOS to lead the action.	Continuous.	Percentage of hydrological reference stations exchanging globally quality-assessed data.

No.	Action	Agent for implementation	Time frame	Performance indicator(s)
G43	Include observations of key hydrological variables (liquid and solid precipitation, evaporation, snow depth, snow water content, lake and river ice thickness, water level, water flow, soil moisture) into an integrated system for a consistent observation, processing and exchange, following the WIGOS standards.	Hydrological services, GCOS, TCs (CHy and CBS) leading the action.	Continuous.	Percentage of hydrological data integrated in this system.
G44	To continue and expand existing programmes of ground water observation and monitoring, including expansion of the IGRAC.	Hydrological services in collaboration with WMO/CHy, the Food and Agriculture Organization (FAO) and GTOS (especially its Global Terrestrial Network for Groundwater - GTN-GW – component). WMO/CHy and GTOS to lead the action.	Continuous.	Number of ground water stations operating.
G45	Increase the deployment, calibration and use of dual polarization radars in those regions where it is beneficial.	CBS to lead the action in collaboration with CIMO, RAs and NMSs/NMHSs.	Continuous.	Data coverage obtained from this type of radar for each Region.
G46	Perform comparison of weather radar software with the objective to improve quality of the quantitative precipitation estimates (QPE).	CIMO in collaboration with NMSs/NMHSs and agencies operating weather radars.	Continuous.	Guidance provided to the operators and Members.
G47	For areas in developing countries which are sensitive to storms and floods, a special effort has to be made to establish and maintain weather radar stations.	NMSs/NMHSs, agencies operating weather radars, in collaboration with RAs and TCs (CBS, CIMO and CHy). CBS to lead the action with each RA.	Continuous.	The number of operational weather radar stations in the above areas.
G48	Define weather radar data to be exchanged at regional and global levels, propose frequency of exchange of those data and develop a weather radar data processing framework, in concert with development of products based on national, regional, global requirements.	CBS (leading the action), CIMO, CHy in coordination with NMSs/NMHSs, agencies operating weather radars, in collaboration with RAs.	Continuous.	Volume of radar data which are exchanged globally and regionally.
G49	Maintain and optimize the existing ASAP network over North Atlantic, and develop similar programmes for the North Pacific and the Indian Ocean.	NMSs, NMHSs, in collaboration with companies operating commercial ships, RAs, JCOMM, CBS and CAS. JCOMM to lead RAs	Continuous.	Volume of ASAP data available in real-time (usual NWP monitoring indicators).
G50	Ensure state-of-art technologies are employed to	NMSs, NMHSs and national	Continuous.	Usual monitoring indicators on

No.	Action	Agent for implementation	Time frame	Performance indicator(s)
	improve accuracy for all measurements made at sea stations. Develop visibility measurement capabilities over the ocean.	partner institutions, in collaboration with international organizations and space agencies. JCOMM, CBS, and CIMO to lead the action.		availability and quality of marine observations.
G51	Improve the quality of ship observations by more regular interactions with the NWP monitoring centres and more regular checks on the instruments onboard.	Port Meteorological Officers (PMOs), NMSs, NMHSs and other NWP monitoring centres in collaboration with companies operating commercial ships. CBS and JCOMM to lead the action.	Continuous.	Usual NWP monitoring indicators.
G52	Support the DBCP in its mission to maintain and coordinate all components of the global network of over 1250 drifting buoys and 400 moored buoys, which provides measurements such as SST, surface current velocity, air temperature and wind speed and direction.	NMSs, NMHSs, national oceanographic institutions, in collaboration with JCOMM, international organizations and companies operating oceanic buoys, CBS and CIMO. CBS and JCOMM to lead the action.	Continuous.	Volume of quality-controlled moored and drifting buoy data available in real-time (usual NWP monitoring indicators).
G53	Install barometer on all newly deployed drifting buoys.	NMSs, NMHSs, national oceanographic institutions, in collaboration with JCOMM, international organizations and companies operating oceanic buoys, CBS and CIMO. CBS and JCOMM to lead the action.	Continuous.	Availability of surface pressure observations from drifting buoys.
G54	In the tropical Indian Ocean, extend the existing network of moored buoys to a data coverage similar to those of the Atlantic and Pacific tropics.	NMSs, NMHSs, national oceanography institutions, in collaboration with JCOMM, international organizations and companies operating oceanic buoys, CBS and CIMO. CBS and JCOMM to lead the action.	Continuous.	Number and data coverage of moored buoys available in the Indian Ocean tropics (usual monitoring indicators).
G55	Increase ice buoy data coverage on the northern polar cap through a regular deployment of new drifters.	NMSs, NMHSs, national oceanographic and polar institutions, in collaboration with JCOMM, international organizations and companies operating ice buoys, CBS and	Continuous.	Volume of ice buoy data available in real-time (usual NWP monitoring indicators).

No.	Action	Agent for implementation	Time frame	Performance indicator(s)
		CIMO. CBS and JCOMM to lead the action.		
G56	Ensure global availability of in situ sea level data (tide gauges, Tsunameters).	NMSs, NMHSs, and national partner institutions, in collaboration with international organizations and space agencies. JCOMM, CBS, and CIMO to lead the action.	Continuous.	Amount of tide gauge data available globally.
G57	For ocean and weather forecasting purposes, transition the Argo profiling float network from research to operational status, and ensure timely delivery and distribution of high vertical resolution data for sub-surface temperature and salinity.	NMSs, NMHSs, national oceanographic institutions, in collaboration with Argo project, JCOMM, international organizations and companies operating profiling floats, CBS and CIMO. JCOMM to lead the action in cooperation with CBS.	Continuous.	Volume of profiling float data available in real-time (usual monitoring indicators).
G58	For ocean and weather forecasting purposes, improve timely delivery and distribute high vertical resolution data for sub-surface temperature from Ships/XBT.	NMSs, NMHSs, national oceanographic institutions, in collaboration with JCOMM, international organizations and companies operating ships of opportunity, CBS and CIMO. JCOMM to lead the action in cooperation with CBS.	Continuous.	Volume of XBT data available in real-time (usual monitoring indicators).
G59	Where possible and appropriate, integrate atmospheric composition measurements together with the measurements of wind, temperature and humidity, with processing and dissemination performed according to the GAW and other relevant standards.	Organizations involved in atmospheric measurements from aircraft platforms, NMSs, NMHSs in collaboration with commercial and other airlines, TCs (CBS, CIMO, CAS) and AMDAR panel. CBS, CAS and AMDAR Panel to lead the action.	Continuous.	A number of aircraft producing both meteorological observations and atmospheric composition measurements in real-time.
S1	Enable Members, as appropriate, to fully benefit from evolving satellite capabilities through guidance on data reception and dissemination systems, including the necessary infrastructure upgrades.	CBS leading the action in consultation with CGMS and satellite operators.	Continuous.	Level of positive response to survey of Members' user needs
S2	Satellite operators to provide full description of all steps taken in the generation of satellite products,	Satellite operators in CGMS and CEOS.	Continuous.	Number of products fully documented, adhering to the

No.	Action	Agent for implementation	Time frame	Performance indicator(s)
	including algorithms used, specific satellite datasets used, and characteristics and outcomes of validation activities.			QMF procedure
S3	Satellite operators to ensure long-term data preservation and scientific stewardship of data, including regular reprocessing (roughly every five years).	Satellite operators, in coordination with GCOS.	Continuous.	Existence of long-term satellite data archives, with regular reprocessing
S4	Members should be enabled to benefit from evolving satellite capabilities through adequate, application-oriented education and training activities (including distance learning).	CGMS through its Virtual Laboratory (VLab), including Centres of Excellence, and partners.	Continuous.	Level of positive response to survey of Members' training needs
S5	Regions should determine and maintain requirements for satellite datasets and products.	RAs and satellite operators through their regional task teams and VLab Centres of Excellence.RAs	Continuous.	Completeness and currency of set of regional requirements
S6	Maintain and develop the GSICS inter-comparisons and inter-calibrations between GEO and LEO sensors on an operational basis.	GSICS.	Continuous.	Number of instruments calibrated in accordance with GSICS standards.
S7	Ensure continuity and overlap of key satellite sensors, keeping in mind both real-time processing and processing in delayed mode for consistency of climate records, re-analyses, research, recalibration or case studies.	CGMS leading the action, with TCs, satellite agencies and satellite data processing centres.	Continuous.	Continuity and consistency of data records.
S8	Ensure and maintain a distribution of at least 6 operational geostationary satellites along the equator, ideally separated by no more than 70° of longitude. Improve the spatial and temporal coverage with GEO satellites over the Pacific.	CGMS leading the action, with TCs, satellite agencies and satellite data processing centres.	Continuous.	Quality of the global coverage by the different instruments of operational geostationary satellites.
S9	On each operational geostationary satellite, implement and maintain at least one visible/infra-red imager with at least 16 channels providing full disk coverage, with a temporal resolution of at least 15 minutes and a horizontal resolution of at least 2km (at sub-satellite point).	CGMS leading the action, with TCs and satellite agencies.	Continuous.	Number of geostationary satellites equipped with high resolution imagers.
S10	For each geostationary satellite, organize the scanning strategy and the processing of the imagery (together with other instruments or other sources of information) in order to produce AMV with at least a 1h frequency.	CGMS leading the action, with TCs, satellite agencies and data processing centres.	Continuous.	Number of geostationary satellites producing AMVs operationally.

No.	Action	Agent for implementation	Time frame	Performance indicator(s)
S11	All meteorological geostationary satellites should be equipped with hyper-spectral infra-red sensors for frequent temperature and humidity soundings, as well as tracer wind profiling with adequately high resolution (horizontal, vertical, time).	CGMS leading the action, with TCs, satellite agencies and data processing centres.	Continuous for the mission planning and preparation; 2015-2025 for making the instruments operational.	Number of geostationary satellites equipped with hyper-spectral sounders.
S12	All meteorological geostationary satellites should be equipped with a lightning imager able to detect cloud-to-cloud and cloud-to-ground strokes.	CGMS leading the action, with TCs, satellite agencies and data processing centres.	Continuous for the mission planning and preparation; 2015-2025 for making the instruments operational.	Number of geostationary satellites equipped with a lightning imager.
S13	Ensure the orbit coordination for all core meteorological missions in LEO orbit, in order to optimize temporal and spatial coverage, while maintaining some orbit redundancy. The LEO missions should include at least 3 operational sun-synchronous polar orbiting satellites with ECT equal to 13:30, 17:30 and 21:30 (local time).	CGMS leading the action, with TCs and space agencies.	Continuous.	Number and orbit distribution of contributing LEO satellite missions.
S14	Improve timeliness of LEO satellite data, especially of the core meteorological missions on the three orbital planes, by developing communication and processing systems which achieve delivery in less than 30 minutes (as done with the RARS network for some data sets).	CGMS leading the action, with TCs, satellite agencies and data processing centres.	Continuous.	Timeliness of LEO satellite data, as judged by the usual monitoring scores.
S15	Improve local access in real-time to LEO satellite data, especially to the core meteorological missions on the three orbital planes, by maintaining and developing direct read-out communication and processing systems.	CGMS leading the action, with TCs, satellite agencies and data processing centres.	Continuous.	Volumes of LEO satellite data accessible by direct read-out.
S16	Design the ground segments for hyper-spectral infra-red sounders in order to define and implement a data reduction strategy which optimizes the information content accessible within the timeliness and cost constraints, whilst addressing the needs of different user communities.	CGMS leading the action, with TCs, satellite agencies and data processing centres.	Continuous.	Volume and timeliness of the different data sets distributed to the users of hyper-spectral sounders.
S17	Fill the gap in planned coverage of microwave	CGMS leading the action, with	Continuous.	Number of microwave

No.	Action	Agent for implementation	Time frame	Performance indicator(s)
	sounders in the early morning orbit.	TCs and satellite agencies.		sounders planned for satellites in early morning orbit.
S18	Use the imagers of all operational polar orbiting platforms to produce AMVs from the tracking of clouds (or water vapour features)	CGMS leading the action, with TCs, satellite agencies and data processing centres.	Continuous.	Volume and timeliness of the different data sets produced operationally on the polar caps.
S19	Implement a water vapour channel (e.g. 6.7 µm) on the imager of all core meteorological polar-orbiting satellites to facilitate the derivation of polar winds from water vapour motion.	CGMS leading the action, with TCs, satellite agencies and data processing centres.	Continuous.	Number of core meteorological polar-orbiting satellites with a water vapour channel in its imager.
S20	Ensure availability of microwave imagers with all necessary channels to monitor SST.	CGMS with satellite operators.	Continuous.	Number of LEO satellites with a microwave SST sensor.
S21	Ensure and maintain a radio-occultation constellation of GNSS receivers onboard platforms on different orbits producing about 10000 occultations per day (order of magnitude to be refined by the next Action). Organize the real-time delivery to processing centres.	CGMS to lead the action, with TCs, satellite agencies and data processing centres.	Continuous.	Number of GNSS occultations per day that are processed in near-real-time.
S22	Perform an Observing System Simulation Experiment (OSSE) to evaluate the impact of different numbers of occultations per day, and to estimate the optimal number of daily occultations required.	NWP centres, in coordination with CBS (to lead the action) and CAS.	Before end 2013.	A number of OSSEs carried out.
S23	Implement an altimeter constellation comprising a reference mission on high-precision, not sun-synchronous, inclined orbit, and two instruments on well separated sun-synchronous orbits.	CGMS leading the action, with TCs, JCOMM, satellite agencies and data processing centres.	Continuous.	Number and orbit geometry of satellites providing altimetry in real-time.
S24	Ensure and maintain in operation at least one infra-red dual-angle view imager onboard a polar orbiting satellite in order to provide SST measurements of climate monitoring quality.	CGMS leading the action, with TCs, JCOMM, satellite agencies and data processing centres.	Continuous.	Operational availability of dual-angle view imagers.
S25	To implement at least one Precipitation Radar mission on an inclined orbit, and a follow-on operational mission.	CGMS leading the action, with TCs, JCOMM, satellite agencies and data processing centres.	2014 (initial) and continuous (follow-on).	Availability of one mission.
S26	In support of GPM, implement at least one passive MW mission on a low-inclination orbit.	CGMS leading the action, with TCs, satellite agencies and data processing centres.	Continuous.	Availability of one passive MW satellite mission on a low-inclination orbit.
S27	Organize the delivery of GPM data in real-time to	CGMS leading the action, with	Continuous.	Extent to which availability

No.	Action	Agent for implementation	Time frame	Performance indicator(s)
	support nowcasting and operational hydrology requirements.	TCs, satellite agencies and data processing centres.		Requirements for nowcasting and operational hydrology are met.
S28	Ensure the continuity of ERB type global measurements by maintaining operational broad-band radiometers and solar irradiance sensors on at least one LEO polar orbiting satellite.	CGMS leading the action, with TCs, satellite agencies and data processing centres.	Continuous.	Number of polar orbiting satellites contributing to the ERB.
S29	For atmospheric chemistry applications including monitoring of ozone, reactive species relevant to air quality and air pollution, and of greenhouse gases, ensure the operational continuity of ultra-violet/ visible/near-infra-red sounders, including high spectral resolution ultra-violet/visible sounders on GEO, and at least one ultra-violet/visible sounder on 3 well-separated polar orbits. Ensure also the continuity of limb-sounding capability.	CGMS leading the action, with TCs, satellite agencies and data processing centres.	Continuous.	Number of GEO and LEO ultra-violet/visible/infra-red sounders contributing to atmospheric chemistry.
S30	Use the experience of demonstration missions (like the ADM-AEOLUS one) to plan and design an operational observing system based on Doppler wind measurements (providing a global coverage of wind profiles).	CGMS leading the action, with TCs, ESA and other satellite agencies, data processing and NWP centres.	As soon as possible after data have been provided by demonstration missions.	Number and quality of Doppler wind lidar profiles (made from space) available to the users.
S31	Deliver cloud/aerosol lidar data produced from satellite missions to operational data processing centres and users. Use this experience to decide about a possible cloud/aerosol operational mission (integrated or not with an operational Doppler wind lidar mission).	CGMS leading the action, with TCs, satellite agencies, data processing centres, forecasting and atmospheric chemistry users.	Continuous with a special effort phased with the EARTH-CARE mission.	Data volume produced by space-based cloud/aerosol lidars and used by operational applications.
S32	Study the benefits brought by satellite demonstration missions like SMOS (missions based on low-frequency microwave radiometers) on atmospheric, hydrological and oceanic models, in a quasi operational context, and decide if a similar operational mission can be designed.	CGMS leading the action, with TCs, JCOMM, satellite agencies, data processing centres, meteorological, hydrological and oceanic modelling centres.	As soon as possible for impact studies, from 2013 onwards to decide on new missions.	Improvement brought by using these microwave data on different models.
S33	Plan and design a demonstration mission with microwave instruments onboard a geostationary satellite, aiming at a significant improvement in terms of real-time observation of clouds and precipitation.	CGMS leading the action, with TCs, satellite agencies, data processing centres, meteorological and hydrological modelling centres.	As soon as possible, taking into account the maturity of technology.	Success of a microwave instrument onboard a GEO satellite, then improvement brought by the data to meteorological and hydrological forecasting.

No.	***Action***	***Agent for implementation***	***Time frame***	***Performance indicator(s)***
S34	Plan and design a demonstration mission with high-resolution visible/near-infra-red instruments onboard a geostationary satellite, aiming at improving significantly the observation of ocean colour, vegetation, clouds and aerosols with multi-spectral narrow-band sensors.	CGMS leading the action, with TCs, satellite agencies, data processing centres, meteorological, oceanic and environmental centres.	As soon as possible, taking into account the maturity of technology.	Success of this type of instrument onboard a GEO satellite, then improvement brought by the data to meteorology, oceanography and environmental science.
S35	Plan and design a demonstration mission with visible/infra-red instruments onboard a HEO satellite with a highly elliptical orbit and a high inclination over the equator, in order to target a polar area. The aim is to obtain the same environmental observations with a quality similar to those obtained from GEO satellites.	CGMS leading the action, with TCs, satellite agencies, data processing centres, meteorological and environmental centres.	As soon as possible, taking into account the maturity of technology.	Success of a visible/infra-red instrument onboard a HEO satellite, then improvement brought by the data to meteorology and environmental science.
W1	To develop and implement a coordinated plan ensuring continuity of solar measurements, solar wind and interplanetary magnetic field measurements, and heliospheric imaging, including measurements at different locations such as at the L1 Lagrange point, the Sun-Earth line upstream from the L1 point, the L5 Lagrange point, as well as the required global network of ground-based antennas for data reception and processing.	ICTSW, CGMS and space agencies.	End 2014	Availability of coordinated plans for continuity until 2030
W2	To coordinate and to standardize the existing ground-based solar observation data, and to expand them where required for redundancy, and to develop a common data portal or virtual observatory within the WIS.	ICTSW and all Members performing solar observations from the surface.	Continuous.	Availability of data template for ground-based solar observation.
W3	To increase the spatial resolution of ground-based GNSS ionospheric observations (TEC and scintillation), either by deploying additional receivers in regions with sparse coverage (e.g. Africa), making the data from existing receivers accessible, or by utilizing different means of receiving GNSS data, such as aircraft-mounted receivers, to reduce gaps over the oceans.	ICTSW and all Members operating or planning Ground-based GNSS networks.	Continuous.	Number of ground-based GNSS receivers providing near-real-time data.
W4	To improve the timeliness of space-based GNSS measurements from LEO satellites to get near-real-time information about the 3D electron density distribution of the ionosphere/plasmasphere system.	ICTSW, CGMS, relevant space agencies, and WMO Members who support ground stations.	Continuous.	Number of occultations per day available with a timeliness to meet user requirements.

No.	Action	Agent for implementation	Time frame	Performance indicator(s)
	(e.g. by use of a RARS concept or other network of satellite ground stations for rapid transmission).			
W5	To foster sharing of ground-based GNSS data and GNSS Radio-Occultation among the meteorological and space weather communities, and to facilitate the near-real-time access to these data through WIS.	ICTSW, IROWG and WIGOS project office.	Continuous.	Agreement on data sharing.
W6	To coordinate the use of dual-frequency radar altimeter observations by Space Weather community to improve or validate ionospheric models and for operational TEC monitoring over the oceans.	ICTSW, WMO Space Programme and altimetry satellite operators.	Continuous.	Number of satellite altimeters providing data for space weather.
W7	To increase the availability of ground-based magnetometer data with high timeliness. This can be accomplished by: (i) deployment of magnetometers in regions with limited coverage; (ii) dissemination of data from existing magnetometers within WIS; and (iii) agreement with data providers for their data to be used in space weather products.	ICTSW and magnetometer observatories.	Continuous.	Number of magnetometer data sources available with timeliness to meet user requirements.
W8	Develop a plan for maintaining and improving space weather observations of the plasma and energetic particle environment along the following priorities: (1) maintain long-term continuity, and if possible improve the spatial resolution, of measurements at all altitudes from LEO through GEO orbits; (2) improve the sharing of existing and planned plasma and energetic particle measurements; (3) include energetic particle sensors on HEO satellites; and (4) conduct research to incorporate the plasma and energetic particle data into numerical models to give flux estimates at all locations where our satellites are in orbit.	ICTSW, CGMS and space agencies.	End of 2014.	Availability of a plan for space weather observation of plasma and energetic particle environment.

ANNEX III - ACRONYMS

3D	Three Dimensional
AATSR	Advanced Along-Track Scanning Radiometer
ACM	Atmospheric Chemistry Model
ADM-Aeolus	Earth Explorer Atmospheric Dynamics Mission
AIRS	Atmospheric Infrared Sounder
ALADIN	Atmospheric Laser Doppler Instrument
ALOS	Advanced land observing Satellite "Daichi"
Altika	High accurate oceanography altimeter onboard SARAL mission
AMDAR	Aircraft Meteorological Data Relay Programme
AMMA	African Monsoon Multidisciplinary Analyses
AMSU	Advanced Microwave Sounding Unit
AMV	Atmospheric Motion Vector
AQUA	Aqua satellite mission - http://aqua.nasa.gov/
Argo	International profiling float programme (not an acronym)
ASAP	Automated Shipboard Aerological Programme
ASAR	Advanced Synthetic Aperture Radar
ASCAT	Metop's Advanced SCATterometer
ATLID	ATmospheric LIDar
ATOVS	Advanced TIROS Operational Vertical Sounder
ATSR	Along Track Scanning Radiometer
AWS	Automatic Weather Station
BSRN	Basic Surface Radiation Network
BUFR	FM 94 BUFR GTS format - Binary universal form for the representation of meteorological data
CALIOP	Cloud-Aerosol Lidar with Orthogonal Polarisation
CALIPSO	Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observation
CAS	WMO Commission for Atmospheric Sciences
CBS	WMO Commission for Basic Systems
CCD	Charge-Coupled Device
CCl	WMO Commission for Climatology
CEOS	Committee on Earth Observation Satellites
CGMS	Coordination Group for Meteorological Satellites
CHAMP	CHAllenging Minisatellite Payload
CHRIS	Compact High Resolution Imaging Spectrometer
CHy	WMO Commission for Hydrology
CIMO	WMO Commission for Instruments and Methods of Observation
CLARREO	Climate Absolute Radiance and Refractivity Observatory
CLOUDSAT	NASA EOS mission to observe clouds
CNES	Centre National d'Etudes Spatiales (France)
COCTS	Chinese Ocean Colour and Temperature Scanner
COMS	Communication, Ocean and Meteorological Satellite (Rep. of Korea)
Concordiasi	An international project of the THORPEX-IPY cluster within the International Polar Year effort to provide validation data to improve the usage of polar-orbiting satellite data over Antarctica
COSMIC	Constellation Observing System for Meteorology, Ionosphere and Climate
CPR	Cloud and Precipitation Radar
CREX	FM 95 CREX GTS format - Character form for the representation and exchange of data
CRYOSAT	ESA ice mission

DEMETER	Detection of Electro-Magnetic Emissions Transmitted from Earthquake Regions
DMSP	Defence Meteorological Satellite Program (USA)
EARS	EUMETSAT ATOVS Re-transmission Systems
EARTH-CARE	Earth Clouds, Aerosols and Radiation Explorer
E-ASAP	EUMETNET ASAP
EC	WMO Executive Council
ECT	Equatorial Crossing Time
ECV	Essential Climate Variable
EGOS-IP	Implementation Plan for the Evolution of Global Observing Systems
ENVISAT	ESA Environmental Satellite mission
EOS	NASA Earth Observing System
EPS-SG	EUMETSAT Polar System – Second Generation
ERB	Earth Radiation Budget
ERBS	The Earth Radiation Budget Satellite
ERS	Earth Resource Satellite (ESA)
ESA	European Space Agency
ET-EGOS	CBS Expert Team on the Evolution of Global Observing Systems
EUCOS	EUMETNET Composite Observing System
EUMETNET	Network of European Meteorological Services
FAO	Food and Agriculture Organization
FAPAR	Fraction of Absorbed Synthetically Active Radiation
FDHSI	Full Disk High Spectral resolution Imagery
FLS	fixed land station
FY-4	FengYun 4 Meteorological Satellite (China)
GAW	Global Atmosphere Watch Programme
GCMP	GCOS Climate Monitoring Principles
GCOS	Global Climate Observing System
GCOS-IP	Implementation Plan for the Global Climate Observing System
GDRC	Global Runoff Data Centre
GEO	Geosynchronous satellite
GEO	Group on Earth Observations
GEOS	Geostationary Operational Environmental Satellite (USA)
GEOSAT	GEOdetic SATellite
GEOSS	Global Earth Observing System of Systems
GFCS	Global Framework for Climate Services
GHG	Green-House Gas
GLAS	Geoscience Laser Altimeter System
GLOSS	Global Sea Level Observing System
GMES	Global Monitoring for Environment and Security
GNSS	Global Navigation Satellite Systems
GOCE	Gravity field and steady-state Ocean Circulation Explorer
GOCI	Geostationary Ocean Colour Imager
GOME	Global Ozone Monitoring Experiment
GOMOS	Global Ozone Monitoring by Occultation of Stars
GOMS	Geostationary Operational Meteorological Satellite (Russian Federation)
GOOS	WMO/IOC/UNEP/ICSU Global Ocean Observation System
GOS	Global Ocean Observing System
GOS	WMO Global Observing System
GOSAT	Greenhouse gas Observing Satellite
GPM	Global Precipitation Measurement
GRACE	Gravity Recovery And Climate Experiment

GRAS	Metop's GNSS Receiver for Atmospheric Sounding
GRUAN	GCOS Reference Upper-Air Network
GSICS	Global Space-based Inter-calibration System
GSM	Global System for Mobile Communications
GSN	GCOS Surface Network
GTN	Global Terrestrial Network
GTN-G	Global Terrestrial Network for Glaciers
GTN-GW	Global Terrestrial Network for Groundwater
GTN-H	Global Terrestrial Network for Hydrology
GTN-P	Global Terrestrial Network for Permafrost
GTOS	Global Terrestrial Observing System
GTS	WWW Global Telecommunication System
GUAN	GCOS Upper-Air Network
HEO	Highly Elliptical Orbit satellite
HF	High Frequency
HRFI	High Resolution Fast Imagery
HY-2A	HaiYang ocean satellite mission (China) 2A
IAGOS	Integration of routine Aircraft observations into a Global Observing System
IASI	Infra-red Atmospheric Sounding Interferometer
ICSU	International Council for Science
ICTSW	Inter-programme Coordinating Team on Space Weather
IGRAC	International Ground water Resources Assessment Centre
IOC	Intergovernmental Oceanographic Commission of UNESCO
IOS	Integrated Observing System
IROWG	International Radio Occultation Working Group
IRS	Infra-red Sounder
ISRO	Indian Space Research Organisation
ISS	International Space Station
ITU	International Telecommunication Union
IWV	Integrated Water Vapour
JASON	Ocean Surface Topography mission (USA/France)
JAXA	Japan Aerospace Exploration Agency
JCOMM	Joint WMO-IOC Technical Commission for Oceanography and Marine Meteorology
LAI	Leaf Area Index
LAM	Limited Area Model
LANDSAT	Earth-observing satellite missions (NASA/USGS)
LDC	Least Developed Countries
LEO	Low Earth Orbit satellite
MERIS	MEd Resolution Imaging Spectrometer
METEOSAT	EUMETSAT Geostationary Meteorological Satellite
Metop	EUMETSAT Polar Orbiting Operational Meteorological Satellite
MODIS	MODerate-resolution Imaging Spectrometer (onboard AQUA and TERRA satellites)
MSU	Microwave Sounding Unit
MTG	Meteosat Third Generation
MTM	CNES/ISRO Megha-Tropiques Mission to observe the water cycle and energy budget in the tropics
NASA	National Aeronautics and Space Administration
NMHS	National Meteorological and Hydrological Services
NMS	National Meteorological Services

NPOESS	National Polar-orbiting Operational Environmental Satellite System (USA)
NWP	Numerical Weather Prediction
OceanSites	Ocean Sustained Interdisciplinary Timeseries Environment observation System
OCS	Ocean Colour Scanner on the Russian Meteor Satellite
OLCI	Ocean Land Colour Imager
OMPS	Ozone Mapping and Profiler Suite
OPAG	Open Programme Area Group
OPAG-IOS	OPAG on the IOS
OPERA	Operational Programme for the Exchange of weather RAdar information
OSE	Observing System Experiment
OSSE	Observing System Simulation Experiment
PALSAR	Phased Array L-band Synthetic Aperture Radar
PILOT	FM-32 PILOT GTS format: Upper-wind report from a fixed land station
PMO	Port Meteorological Officer
POAM	Polar Ozone and Aerosol Measurement
PROBA	PRoject for OnBoard Autonomy
PUMA	Préparation à l'Utilisation de MSG en Afrique
QA	Quality Assurance
QM	Quality Management
QMF	Quality Management Framework
QMS	Quality Management System
QuickSCAT	Quick Scatterometer (NASA)
R&D	Research and Development
RA	WMO Regional Association
RBCN	Regional Basic Climatological Network
RBSN	Regional Basic Synoptic Network
RRR	Rolling Review of Requirements
SAR	Synthetic Aperture Radar
SARAL	Environment monitoring mission (India/France)
SBUV	Solar Backscatter Ultraviolet Radiometer
SCARAB	Scanning radiative budget instrument onboard MTM
SCIAMACHY	Scanning Imaging Absorption Spectrometer for Atmosphere Chartography
Sentinel-3	A multi-instrument ESA satellite mission contributing to GMES
SIA	Seasonal to Inter-Annual
SIDS	Small Island Developing States
SIRAL	Synthetic Aperture Interferometric Radar Altimeter
SLSTR	Sea and Land Surface Temperature Radiometer
SMOS	Soil Moisture and Ocean Salinity
SoG	Statement of Guidance
SPOT	Satellite Pour l'Observation de la Terre
SSH	Sea Surface Height
SSM-I	Special Sensor Microwave Imager
SSS	Sea Surface Salinity
SST	Sea Surface Temperature
SYNOP	FM-12 SYNOP GTS format - Report of surface observation from a fixed land station
TAMDAR	Tropospheric Airborne Meteorological Data Reporting
TC	WMO Technical Commission
TEC	Total Electron Content
TEMP	FM-35 TEMP GTS format - Upper-level pressure, temperature, humidity and wind report from a fixed land station

TERRA	Terra satellite mission - http://terra.nasa.gov/
THORPEX	The Observing system Research and Predictability Experiment
TOPC	Terrestrial Observation Panel for Climate
TOMS	Total Ozone Mapping Spectrometer
TRMM	Tropical Rainfall Measuring Mission
UAV	Unmanned Aeronautical Vehicle
UNEP	United Nations Environment Programme
UNESCO	United Nations Educational, Scientific and Cultural Organization
USA	United States of America
USGS	US Geological Survey
UTC	Coordinated Universal Time
UV	Ultra-violet
VCP	WMO Voluntary Cooperation Programme
VSRF	Very Short Range Forecasting
VOS	Voluntary Observing Ships Scheme
WCRP	World Climate Research Programme (WCRP)
WHYCOS	World Hydrological Cycle Observing System
WIGOS	WMO Integrated Global Observing System
WIP	WIGOS Implementation Plan
WIS	WMO Information System
WMO	World Meteorological Organization
WWW	WMO World Weather Watch
XBT	Expendable Bathythermograph
ZTD	Zenith Total Delay