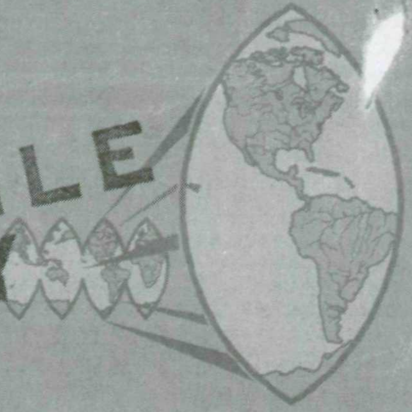
NASA SP-293

EXAMETNET

Experimental InterAmerican
Meteorological
Rocket
Network



THE FIRST FIVE YEARS, 1966-1970

Sponsored by the EXAMETNET Executive Committee
of the participating National Scientific Organizations

ARGENTINA	Comisión Nacional de Investigaciones Espaciales
BRAZIL	Comissão Nacional de Atividades Espaciais
UNITED STATES	National Aeronautics and Space Administration

NASA SP-293

EXAMETNET: THE FIRST FIVE YEARS, 1966-1970

Scientific and Technical Information Office 1972
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
Washington, D.C.

FOREWORD

Meteorological sounding rockets were first utilized in significant numbers in the late 1950's and the coordinated launching of these sounding rockets was essentially confined to the Northern Hemisphere. In the mid-1960's, Argentina, Brazil, and the United States established a cooperative program of coordinated launches to overcome this obvious inequity in our knowledge of the upper atmospheric structure and behavior with regard to the Southern Hemisphere. The purpose of the program was to provide synoptic information of stratospheric and lower mesospheric winds and temperatures up to an altitude of about 60 km in both hemispheres. These data, when combined with those from other observational techniques, would form a base for the study of various meteorological phenomena such as mid- and high-latitude warmings, tropical oscillations, interrelations between different regions of the atmosphere, large scale circulation patterns, and inter-hemispheric relations in the upper atmosphere.

After planning and organizational meetings in 1965, the Experimental Inter-American Meteorological Rocket Network (EXAMETNET) began launching meteorological sounding rockets in January 1966 and has continued on a coordinated schedule. Each year representatives of each country convene to review the activities of the past year and plan for the coming year. At the last meeting in Rio de Janeiro, Brazil, in October 1970, it was felt that the completion of five years of operation was a milestone at which it would be appropriate to assess the efforts of a half decade and that the assessment might assist in the formation of future plans.

This document is a report of this assessment. It describes the formation of the network, international and national relations, technology, data procedures and techniques, and their improvements and the research that has been accomplished as a result of this international cooperative effort.

While this is a self-assessment and an internally prepared document, there was a deliberate effort to maintain objectivity as the various aspects were reviewed. It is hoped that this goal was achieved and that this report may be of some interest and utility to other organizations and groups engaged in or planning meteorological sounding rocket observations and the coordination of such activities with others to enhance the scientific utility of the information.

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INTRODUCTION

The meteorological rocket, first utilized in significant numbers in the late 1950's, is now recognized as a standard means of gathering atmospheric data above the upper limit of the balloon-borne radiosonde (about 30 km). Indeed, much valuable information has become available from rocketsonde observations for use in a variety of research studies, as well as for the derivation of high-altitude climatological and model atmospheres. Typical of the research studies are those concerned with wintertime stratospheric warmings, which predominantly occur over the middle and polar latitudes. No complete explanations have yet emerged with regard to the cause and the full effect of this phenomenon. Also of prime importance are studies concerning the less dramatic quasi-biennial and semi-annual oscillations at low latitudes.

Once the explanations for these phenomena are forthcoming, more study will be required to determine the interactions between warmings and tropical oscillations, as well as in defining the coupling mechanism between various layers of the troposphere and stratosphere. This general problem area has long interested meteorologists, since some feel it may be possible to gain insight into tropospheric conditions, especially large-scale relatively long-range changes, from close inspection of stratospheric conditions and changes.

Until the middle 1960's, rawinsonde and rocketsonde observations provided only a limited amount of high-altitude data and these were concentrated mainly in the Northern Hemisphere. Most of the rocketsonde observations came from the cooperative organization of launching sites called the Meteorological Rocket Network (MRN). Although much was being learned about the Northern Hemisphere stratosphere, some researchers felt that the full meteorological significance of its behavior would also require Southern Hemisphere data. Before this time the most popular assumption was to consider the Southern Hemisphere stratospheric circulation a mirror image of that of the Northern Hemisphere.

Clear evidence of differences between the hemispheres began to emerge after analysis of stratospheric rawinsonde data in the Southern Hemisphere became a reality during the International Years of the Quiet Sun (IQSY), 1964-1965. Hemispheric dissimilarities in circulation patterns were most apparent over polar regions during the winter season, but differences could also be perceived at the lower latitudes.

There was, therefore, ample motivation for acquiring more meteorological information on the stratosphere in the Southern Hemisphere. Cooperative scientific efforts utilizing observational data extending to the highest possible altitude could be initiated to gain knowledge of the hemispheric circulation in the stratosphere and, consequently, to determine similarities and differences between the two hemispheres.

Any observational program involving rockets must be limited in scope. The planners of the Experimental Inter-American Meteorological Rocket Network (EXAMETNET) representing the governments of Argentina, Brazil and the United States, fully realizing the limitations, decided that a meridional-type network would provide valuable information for many types of research. Thus, the original EXAMETNET of three rocketsonde stations in the Americas between 40°N and 40°S was formed. The principle objective of the network was to provide information on stratospheric temperature and wind up to about 60 km, so that comparisons could be made of the measured parameters in both hemispheres and the tropics and the results related to the structure and dynamics of the upper atmosphere. The present sites are Mar Chiquita, Argentina (37.8°S), Natal, Brazil (5.9°S) and Wallops Island, Virginia (37.8°N).

Because of the limited number of launch sites, EXAMETNET cannot provide the large volume of observations needed spatially to delineate the high-level circulation. It is, therefore, logical that network data must be combined with other observations in order to carry out many studies. The network was formed with this point in mind. Additionally, it is extremely important that a high degree of cooperation, on a national level as well as international, be maintained, especially in terms of coordination of launch schedules between network and other stations. This philosophy of cooperation takes full account of the number of observations available from the world-wide rawinsonde network as well as from other rocket stations, and more recently, thermodynamic data from the satellite-borne atmospheric sounding instrumentation.

FORMATION OF NETWORK

A. Organization

Establishment of the EXAMETNET resulted from a suggestion made by Argentina in 1965 to set up, on an experimental basis, a number of launch sites in South America with the capability of growing into a coordinated network of launching facilities in the Western Hemisphere extending from the Arctic to the Antarctic [Ref. 1]. To initiate this research network, Memoranda of Understanding for cooperative projects were concluded by the Argentine and Brazilian space agencies with the U.S. space agency. These agencies are: the Comisión Nacional de Investigaciones Espaciales (CNIE-Argenina), the Comissão Nacional de Atividades Espaciais (CNAE-Brazil), and the National Aeronautics and Space Administration (NASA-United States). The memoranda established project responsibility of each country.

In August 1965, a meeting took place at Wallops Island, Virginia, U.S.A., bringing together representatives from various countries interested in participating in the EXAMETNET. Views were exchanged on the overall objectives and conduct of the network. To achieve success in all phases of this experimental program, each participating country designated personnel to be responsible for the technical and scientific aspects; namely, a Project Manager to assure project implementation and coordination, a Scientific Coordinator to review the data and provide for the analysis, and an Experimenter to conduct research with the data.

In addition, an organization was established within which these designated personnel can carry out their assigned functions and responsibilities. The basic organization (Fig. 1) consists of an EXAMETNET Executive Committee (EEC) for providing guidance and advice. This Committee is served by two working groups: the Technical Working Group (TWG) coordinates and implements the experimental program and the Scientific Working Group (SWG) provides the scientific plans, recommendations, launch schedules and data procedures.

The Executive Committee, consisting of a representative from each national participating organization, has the overall responsibility for the implementation of the program. It provides guidance and advice to the Technical and Scientific Working Groups on its own initiative or when consulted by those groups. It approves plans and recommendations of the Scientific and Technical Working Groups for launch schedules for synoptic observations and commits its individual national organizations to this support.

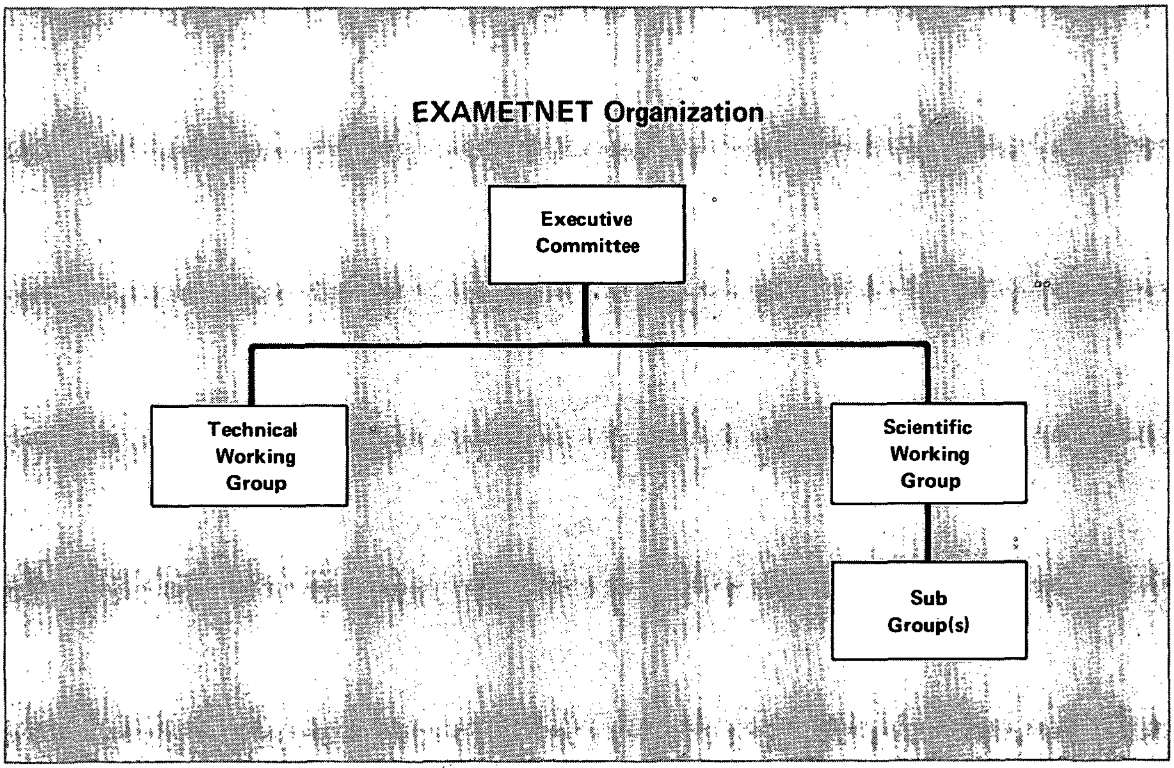


Figure 1.—Basic EXAMETNET organization.

The Technical Working Group provides technical recommendations and plans to the national scientific organizations participating in the EXAMETNET. Under the direction of the Executive Committee, the TWG plans, coordinates, reviews and implements facility and operational requirements necessary for carrying out the established scientific needs of the network.

The Scientific Working Group provides the scientific recommendations and plans to the national scientific organizations participating in the EXAMETNET. Under the direction of the Executive Committee the SWG determines and reviews requirements, network schedules, data dissemination, exchange, and utilization, and recommends scientific analysis and research areas associated with EXAMETNET.

Implementation of EXAMETNET has involved the major areas of observational scheduling (Fig. 2), facilities and equipment preparation, training, launch site preparation, and finally the logistics and operation of the network (Fig. 3), including data processing. Initial operations began in early 1966.

The systems and facilities used by the EXAMETNET participants (Fig. 4) are generally defined by the Memoranda of Understanding between each country and the United States. Argentina and Brazil provided the range facilities, within their respective countries, including launcher foundations, blockhouses, support buildings, utilities, safety devices, etc., and the personnel for conducting the network launches. The United States provided the procurement, construction, rehabilitation and modification of meteorological rocket training and data acquisition systems on loan to or for training of.

B. Criteria for Membership

Agencies from other countries may be considered for regular membership in EXAMETNET provided the following primary criteria are met:

(1) The proposed member agency should have the sponsorship of, or be a part of an appropriate civilian scientific central governmental agency (or governmental designated agency) within its home country.

(2) The proposed member agency must have a demonstrated scientific and technical capability as determined by the EXAMETNET Executive Committee (EEC). The details of this requirement can be made known to prospective member agencies during the exchange of correspondence with the EEC.

No. of rockets		Jan					Feb				Mar					Apr				May				Jun				Jul					Aug				Sep					Oct				Nov					Dec		No. of remaining rockets	Percentage of remaining rockets
																								Week of year																														
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52		
15			1				1				1				1					1				1				1					1				1				1					1				1			3	20
26			1				1		1		1		1		1		1			1				1				1			1		1		1		1		1		1		1	1		1		1		1			5	19
30			1				1		1		1		1		1		1			1		1		1		1		1		1	1		1		1		1		1		1		1	1		1		1		1			6	20
40			1		1		1		1	1	1		1		1		1			1		1		1		1		1		1	1		1		1		1	1	1	1	1	1	1	1	1	1	1	1		1	1		8	20
50			1		1		1	1	1	1	1	1	1	1	1		1			1		1		1		1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1		1	1		10	20
60			1		1		1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1		12	20
70	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	18	26
80	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	28	35

Flexible matrix launching schedule

Figure 2.—Suggested launching schedule for EXAMETNET stations based on number of available rocketsondes for yearly use.

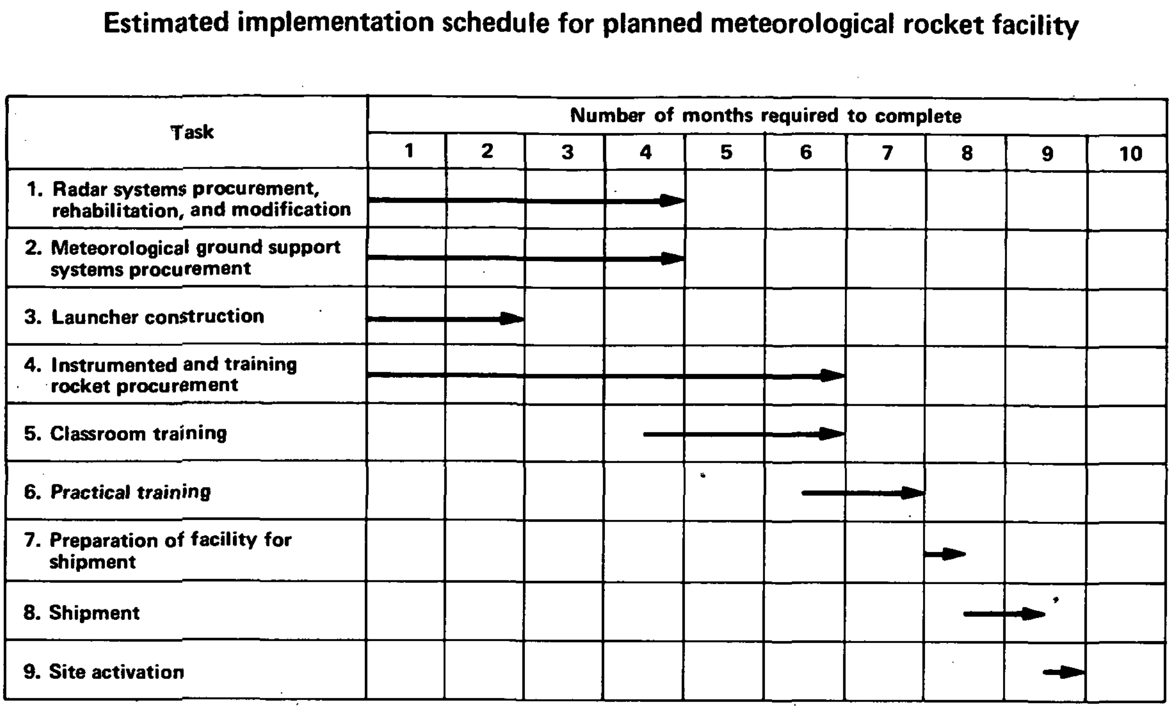
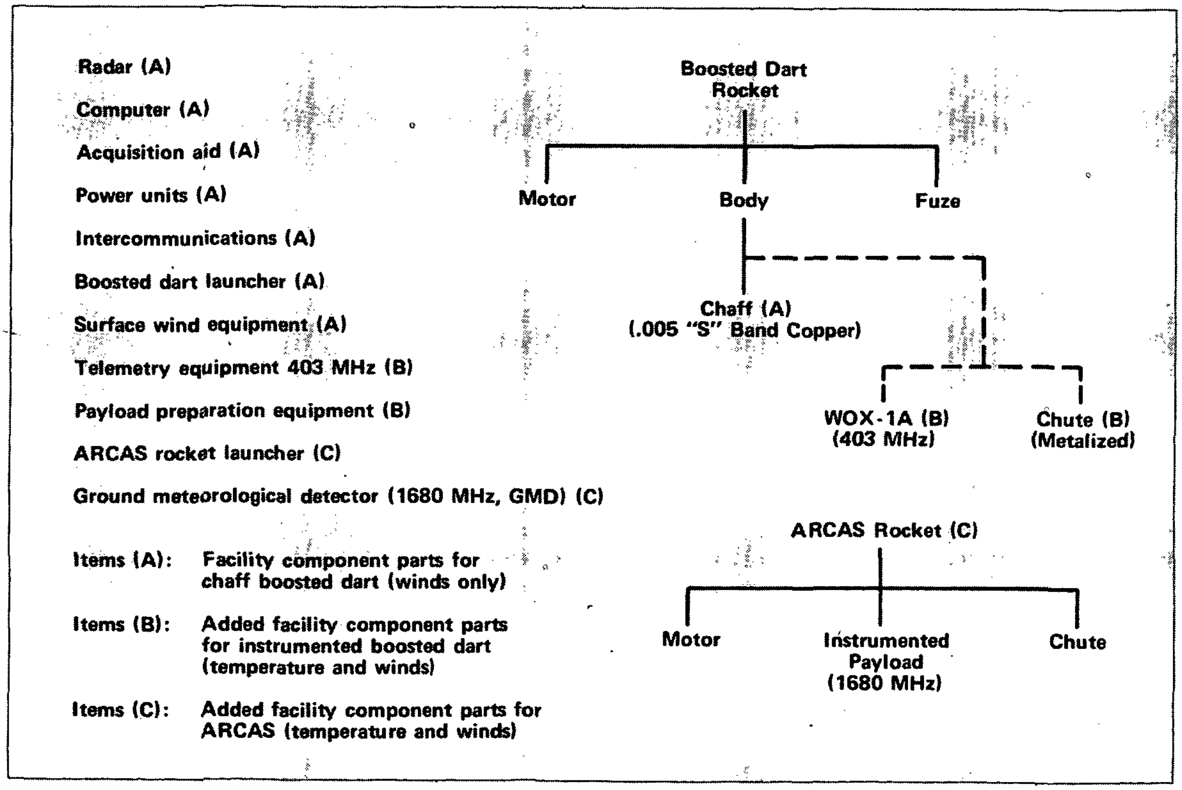


Figure 3.—Time schedule in months to activate new rocket launch facilities.



Radar (A)
Computer (A)
Acquisition aid (A)
Power units (A)
Intercommunications (A)
Boosted dart launcher (A)
Surface wind equipment (A)
Telemetry equipment 403 MHz (B)
Payload preparation equipment (B)
ARCAS rocket launcher (C)
Ground meteorological detector (1680 MHz, GMD) (C)

Items (A):	Facility component parts for chaff boosted dart (winds only)
Items (B):	Added facility component parts for instrumented boosted dart (temperature and winds)
Items (C):	Added facility component parts for ARCAS (temperature and winds)

Figure 4.—Equipment used at EXAMETNET launch sites.

(3) The proposed member agency should be from the Americas, or have facilities located in the Americas.

However, upon meeting criteria (1) and (2), a country could be accepted into the network as an Adjunct Member.[1] This Adjunct Member could participate in EXAMETNET activities such as: coordination of rocket launching schedules, exchange of data in accepted format and other activities. Adjunct Members participate in the activities of the Scientific Working Group and the Technical Working Group at the Annual EXAMETNET Meetings.

At the 6th Annual Meeting held in Rio de Janeiro, Brazil, October 1970, Spain was affirmed by the EEC to become the first Adjunct Member of EXAMETNET. This was a natural consequence of several years of cooperation between Spain and regular EXAMETNET members. For example, a cooperative program of small meteorological rocket launchings by Spain (Comisión Nacional de Investigaciones de Espacio, CONIE) was agreed upon via a Memorandum of Understanding with the United States (NASA) in 1966. EXAMETNET implementation procedures were utilized for providing the rocket tracking and data acquisition systems on loan to and for training of the Spanish team. Spain provided the range facilities, including launcher foundations, blockhouses, 403 MHz telemetry, equipment, support buildings, utilities, safety devices, etc., and the personnel for conducting their launches.

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[1] The concept and criteria for Adjunct Membership were established during the 5th Annual EXAMETNET Meeting at Mar del Plata, Argentina in 1969.

INTERNATIONAL AND NATIONAL RELATIONS

A. International

While EXAMETNET is a regional international endeavor with its activities generally confined to the Americas, it has become part of the world-wide community with its relations and activities spreading outside the Western Hemisphere.

The EXAMETNET participation in the international community has had a number of aspects. One was in the establishment of an international format for reporting data from meteorological sounding rocket launchings. The Committee on Space Research (COSPAR) recognized the need for a common standard data format and formed an ad hoc working group for its development. The EXAMETNET representatives were part of this ad hoc working group which incorporated many of the features and procedures of the previously adopted EXAMETNET format. Subsequently, the World Meteorological Organization (WMO) adopted the format. The World Data Center-A (WDC-A) was asked to issue instructions for preparing the format and requested that all countries adhere to them.

EXAMETNET, using this standard international format, now submits data to World Data Center-A for inclusion in the publication of meteorological sounding data along with those of the other organizations and countries for use by the scientific community.

The EXAMETNET participants are members of Panel C (Meteorological Rocket Observations and Networks) of COSPAR Working Group 6 so that network activities are a part of this international group's deliberations. At the COSPAR Meeting XIII in Leningrad, USSR, during May 1970, Panel C stressed the very considerable advantage derived from coordinated soundings and urged every possible effort be made to secure such coordination, especially in neighboring regions. Coordinated launches have always been a basic premise in EXAMETNET operations.

The EXAMETNET sites, at present, form a meridional chain or network of stations. At the XIII Meeting of COSPAR, the USSR discussed a proposal that two meridional chains be organized, one in the Eastern Hemisphere and one in the Western and that EXAMETNET might serve as the basis for the Western Hemisphere meridional network. The data from these two networks would be exchanged for studies of the stratospheric circulation, the semi-annual, annual, and biennial oscillations in the atmosphere and related atmospheric research.

The WMO has recognized the increased use of sounding rockets, the different types launched, and the need to determine the comparability of the data from these different systems in order to enhance the scientific utility of measurements. To fulfill the need for comparability, the WMO is organizing a program of intercomparison of rocketsondes at the Indian range at Thumba during 1972. The EXAMETNET members are considering participation in this program, although several intercomparison, reliability, and repeatability of measurement tests have already been accomplished. These include comparisons of the Arcasonde system with two types of Boosted-Dart systems (i.e., WOX-1A and the PWN-8B), as well as individual reliability and repeatibility tests of the three systems.

EXAMETNET data are disseminated to over 200 recipients in the international scientific community. In addition, member countries have responded to requests for special launches and for compilation of their sounding rocket data. For example, the organization honored a request from India for launches from as many EXAMETNET sites as possible in coordination with Indian launches scheduled for certain days in March 1970. Also for use in upper atmosphere research, EXAMETNET provides data from its network to the Free University of Berlin.

B. National

(1) Argentina

The EXAMETNET program in Argentina is under the responsibility of CNIE. The evaluation of the data as well as that of the scientific correlations and results is performed by the National Meteorological Service (Servicio Meteorológico Nacional), and the operations are carried out by Argentine Air Force personnel. In addition to submitting data to WDC-A, the processed data are made available to universities and scientific organizations.

(2) Brazil

CNAE is the national agency responsible for the Brazilian participation in EXAMETNET. A portion of the operations is executed by the Groupo Executivo de Trabalhos e Estudos de Projetos Espaciais (GETEPE) of the Ministry of Aeronautics for CNAE under an agreement between these organizations. Other agencies make use of the data and are kept informed of the plans. Among those are the Meteorological Office of the Ministry of Agriculture and the Meteorology Laboratory of the Aeronautics Technical Center. Contact has also been established with the WMO sponsored meteorological project in northeastern Brazil.

(3) United States

While NASA is the national agency directly charged with fulfilling the United States commitment to the EXAMETNET Program, other national organizations are directly and indirectly involved. At NASA request, the Upper Air Branch, National Meteorological Center, National Oceanic and Atmospheric Administration (formerly the Environmental Science Services Administration) accepted the function of the U. S. Experimenter to carry out research with the EXAMETNET measurements and other related data.

Since the coordination of meteorological rocket soundings and the enhancement of the utility of the data is one of the goals of EXAMETNET, it was appropriate to maintain contact with the activities of the cooperative Meteorological Rocket Network. This is accomplished through the NASA membership in an organization which has the function of reviewing the total plans of the U. S. Government agencies for meteorological research and services. This is the Office of the Federal Coordinator for Meteorological Services and Research (OFCM). OFCM is divided into a number of committees and groups staffed mainly by members of various government agencies. Meteorological sounding rocket activities are assigned to the Scientific Advisory Group (SAG) of the Interagency Committee for Applied Meteorological Research (ICAMR). EXAMETNET is represented through the NASA member on SAG. The SAG, which reports to ICAMR, is kept informed of the EXAMETNET plans and accomplishments and reviews how these plans merge with those of the other agencies.

Additionally, the Meteorological Working Group of the Inter-Range Instrumentation Group (IRIG/MWG) initiates and coordinates the cooperative activities of the various national ranges. It is through this medium that the IRIG/MWG and national ranges are kept informed of the improvements, developments, procedures and accomplishments of EXAMETNET.

TECHNOLOGY

A. Introduction

The following general requirements help to insure that EXAMETNET data meet the highest possible standards called for by the research community: (1) the use of uniform equipment and procedures at the various stations, (2) the use of qualified flight systems to meet launch schedules, (3) the continual development of reliable communications so that data are distributed in the most efficient manner, and (4) the maintenance of a high level of proficiency of operations personnel.

B. Training

The participants of EXAMETNET carried out a program of technical and operational training before network operations began (Fig. 5). Included were the areas of radar operation and maintenance, rocket preparation and launching, payload preparation, data reduction, and telemetry equipment maintenance. In addition to insuring the development of uniform procedures throughout EXAMETNET, the training provided the basis for each participating agency to conduct such programs of their own, to maintain proficiency in the event of personnel changes and for future growth.

C. Developments and Improvements

Shortly after the formation of the network, both Argentina and Brazil integrated the Arcas meteorological rocket (Fig. 6) into their facilities. Recently, Argentina has added the Space Data Corporation Datasonde system (Fig. 7) to its inventory. Brazil also plans procurement and initial use of this system during the late 1970 - early 1971 period. Consistent with the concept of cooperation between EXAMETNET members, Argentina will provide assistance to Brazil in familiarizing personnel with this new system.

Spain has included in its inventory the SKUA meteorological rocket system developed by the United Kingdom [Ref. 2]. This system, which provides temperature data as well as wind data, is used in addition to a number of chaff rockets.

Development of new systems as well as reliability testing and modification of operational rockets has been carried out by member countries. Pertinent results include:

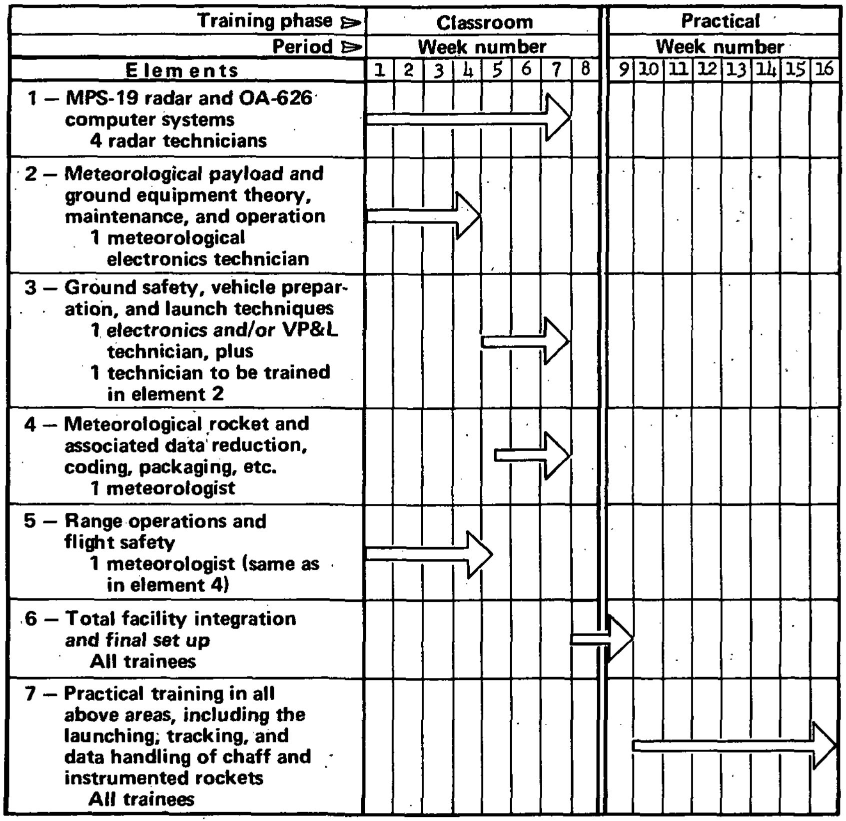

Figure 5.—General training schedule for EXAMETNET.

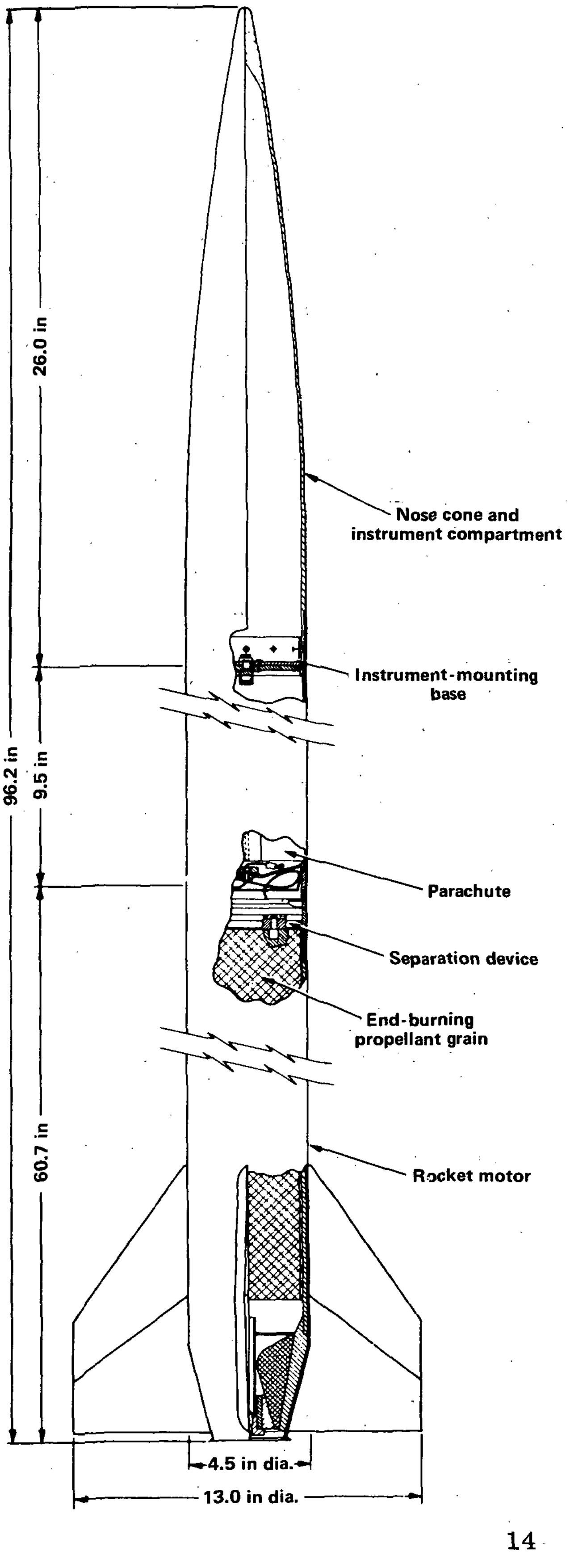

Figure 6. —Arcas rocket.

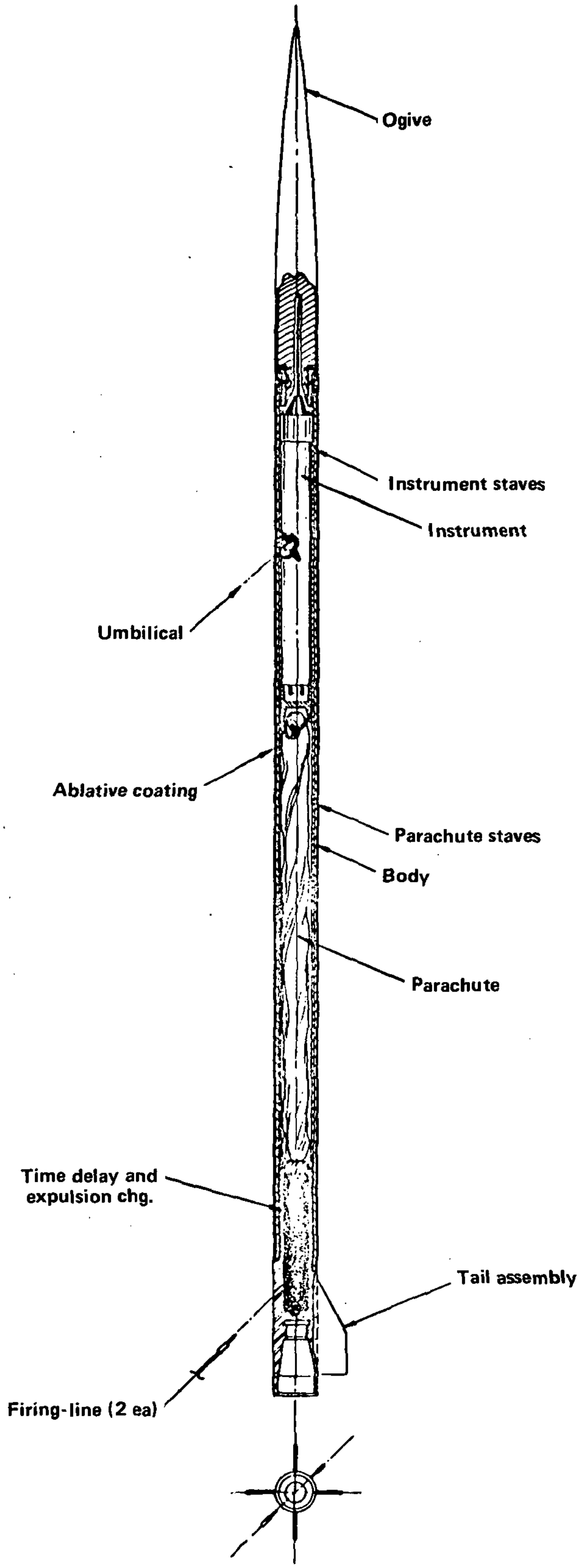

Figure 7. —Datasonde system (dart only).

(1) Argentina

At the request of CNIE, several years ago, IIAE (Instituto de Investigación Aeronáutica y Espacial) of Argentina started designing a meteorological rocket system. The result of this effort is the DIM (Dardo de Investigación Meteorológica) which is a boosted dart system equipped with a chaff payload. Several operational launchings have already been carried out from Mar Chiquita and it is expected that the system will be officially put into operation in 1971.

(2) Brazil

At the request of GETEPE of the Ministry of Aeronautics, a new meteorological sounding rocket system is being developed in Brazil by private companies specifically to conform to EXAMETNET requirements. This system is called the SONDA-1. The rocket motor has already been developed and work on the payload is continuing. The entire system is expected to be ready for testing during 1971.

Some of the modifications mentioned in the U. S. section (see next section) have also been implemented at the Natal range, namely those contained in items b, c, and d.

(3) United States

In the United States, availability and reliability of performance of various flight systems, such as the WOX-1A, Arcasonde, and SDC Datasonde, are constantly monitored. In addition, as new systems are developed they are tested and studied to determine their usefulness in terms of the EXAMETNET objectives. In particular, the Datasonde system was found to be an effective and relatively inexpensive tool for EXAMETNET. It has replaced the Arcasonde for many operations.

Other improvements have been made to ground and flight equipment. Some of these are:

(a) Addition of improved Boosted-dart motor to the flight hardware.
(b) Changing of the 403-MHz telemetry recorder speed from 1/2 inch per minute to 5 inches per minute to improve the resolution of the analog data.
(c) Addition of a helical antenna to the 403-MHz receiving system to improve the received signal.
(d) Addition of an AGC recorder to the mobile MPS-19 radars to monitor radar signal strength.
(e) Addition of digital computer methods to the data reduction techniques.

D. Tests

Numerous tests and comparisons have been conducted to determine the reliability of various rocket systems. Included were:

(1) A determination of the WOX-1A system's reliability for routine utilization. Results were disappointing as only 22 percent of the systems tested by EXAMETNET provided temperature.

(2) Comparisons of Datasonde payloads to determine their repeatability [Ref. 3], as well as the quality of the thermistors and thermistor mounts [Ref. 4]. Results showed an average root-mean-square temperature difference of about 1°C for 5 pairs. The importance of quality control for each individual instrument was highlighted as one pair, containing an instrument with a cracked glass thermistor coating, exhibited an RMS difference of 2.8°C.

(3) Comparisons of data gathered by meteorological rockets with temperature and geopotential height information derived from satellites [Ref. 5]. These comparisons have just been started, and it is hoped that much information can eventually be gained regarding the accuracy of rocketsondes as well as the utility of satellite data at stratospheric levels.

(4) Determination of quality control techniques for application to rocket wind [Ref. 6] and temperature data. Real-time quality control methods are feasible and worthwhile (for example, through radar plot-board monitoring of fall rates just after parachute ejection) and through their use, faulty hardware or erratic sensor behavior can be distinguished. These methods have been established by determining realistic limits for fall rates, as well as the altitude of first usable data after ejection. Rocketsonde temperature measurements can also be evaluated by noting rocketsonde-radiosonde temperature differences in the region of data overlap.

DATA PROCEDURES AND TECHNIQUES

The value of the EXAMETNET data is highly dependent on the success and efficiency of launch site operations as well as the rapid dissemination of the observational information in a suitable format. With regard to launch site operations, it was recognized that uniform procedures had to be established before network operations began. Thus, standardized data reduction methods were developed, resulting in compatible data presentation from all stations. Standardization is extremely important in reduction of rocketsonde data since it is possible to make many subjective decisions in deriving data from the various instruments tracking any given flight system.

A manual of the EXAMETNET data reduction procedures has been published and this technical report is continually updated by the network participants as necessary [Ref. 7]. It should be noted that uniform procedures have not been developed for all other non-network launch sites. Quite possibly these varied reduction procedures could inject a significant bias in the final data presentations.

Additionally, a centralized data checking technique was developed at Wallops Station where network observations are examined for accuracy. The information is then processed by electronic computer and placed on magnetic tapes which are then submitted to WDC-A for international distribution.

Also developed within the EXAMETNET was a new technique for wind determination from the radar information. The procedure, though simple, yields a wind measurement at every whole kilometer of height, providing a definite advantage for climatological calculations. Additionally a new smoothing technique for the wind data has yielded more consistent results than the method formerly used [Ref. 8].

At the inception of the network, it was recognized that the rocketsonde data reduction procedures, as well as the format for data publication used at that time, did not completely satisfy the needs of the scientific community. To correct obvious deficiencies, the EXAMETNET revised the existing data publication format and the revised format was used for EXAMETNET annual reports. Although this new format allowed the presentation of data in a form which provided much information to the user, a less desirable result was the addition of a new data format considerably different from that used for the monthly publications. Two different formats were impractical since World Data Center-A was to assume the responsibility of publishing all rocket observations on a monthly basis. This problem stimulated requests for a common rocketsonde data format which was mentioned earlier. The resulting format is indicated in Fig. 8. While this new data presentation

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87689                                   Y  M  D  GMT   TR  WS  TS  AC  BC WC TC
 MAR CHICUITA, ARGENTINA
  37.8S 057.4W                         69 05 15 2201 -166 102 010 000 000 00 00

                                         QUESTIONABLE DATA
 BASE DATA
  GEOM HGT    1446 DECAMTRS   WHT  WHB  THT  THB SQ  SHT  SHB   RT   RP
  PRESSURE 139.0C MBS
 TEMP       -64.5 DEGC                                          21   00

SOUNDING                                (HGT IN GEOMETRIC DECAMTRS)

 HGT          WIND             FV  TEMP   TC   PRES     DENSITY  SOS SPC  SPC

        POLAR   COMPONENT
                                                           -3
        DEG MPS   N-S  E-W  MPS  DEGC           MB       G M     MPS  A    B

05822                                -029           2.472-1  3.529-1  313
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05500   272 070  -002  070  100  -020           3.816-1  5.251-1  319
05400   270 074   000  074  088  -017           4.354-1  5.924-1  321
05300   270 078   000  078  088  -014           4.960-1  6.674-1  323
05246   271 073  -001  073  088  -013           5.319-1  7.115-1  324
05200   271 069  -001  069  086  -013           5.645-1  7.568-1  323
05100   267 074   004  074  080  -015           6.426-1  8.661-1  322
05000   261 074   012  073  074  -016           7.320-1  9.919-1  321
04900   258 075   016  073  071  -017           8.345-1  1.137+0  321
04800   260 065   011  064  064  -019           9.521-1  1.304+0  320
04700   262 066   009  065  058  -020           1.087+0  1.497+0  319
04600   269 065   001  065  052  -022           1.242+0  1.720+0  318
04520   271 056  -001  056  050  -023           1.383+0  1.923+0  317
04500   271 054  -001  054  050  -022           1.420+0  1.972+0  318
04400   275 053  -005  053  050  -020           1.624+0  2.237+0  319
04334   278 055  -007  054  046  -019           1.772+0  2.430+0  320
04300   279 056  -009  055  045  -021           1.854+0  2.559+0  319
04200   279 046  -007  045  040  -026           2.122+0  2.985+0  315
04173   277 045  -006  045  039  -027           2.201+0  3.113+0  315
04100   273 043  -002  043  037  -028           2.433+0  3.450+0  314
04060   276 045  -004  044  036  -028           2.570+0  3.651+0  314
04000   279 047  -007  046  036  -026           2.790+0  3.935+0  315
03929   282 053  -011  052  031  -024           3.073+0  4.297+0  316
03900   283 055  -012  054  030  -024           3.196+0  4.474+0  316
03810   276 045  -005  045  030  -025           3.612+0  5.074+0  316
03800   275 044  -004  044  030  -026           3.661+0  5.160+0  315
03700   285 043  -011  042  033  -034           4.206+0  6.124+0  310
03652   287 042  -012  040  030  -038           4.503+0  6.663+0  308
03600   290 040  -014  038  028  -039           4.853+0  7.225+0  307
03500   280 034  -006  033  024  -042           5.611+0  8.455+0  305
03478   278 033  -005  033  023  -043           5.794+0  8.755+0  304
03400   270 030   000  030  022  -044           6.498+0  9.869+0  304
03300   285 028  -007  027  021  -045           7.532+0  1.152+1  303
03200   290 020  -007  019  020  -047           8.741+0  1.346+1  302
03185   289 020  -006  019  019  -047           8.939+0  1.378+1  301
03100   280 019  -003  019  017  -045           1.015+1  1.551+1  303
03048   276 021  -002  020  017  -044           1.096+1  1.667+1  303
03000   272 022  -001  022  017  -046           1.177+1  1.806+1  302
02900   264 022   002  022  016  -050           1.367+1  2.137+1  299
02800   270 023   000  023  013  -054           1.594+1  2.536+1  297
02789   271 023   000  023  013  -055           1.621+1  2.585+1  296
02700   277 019  -002  019  013  -056           1.861+1  2.984+1  296
02600   268 015   001  015  010  -057           2.176+1  3.508+1  295
02515   258 014   003  014  009  -058           2.487+1  4.029+1  294
02500   256 014   003  014  009  -058           2.547+1  4.116+1  294
02441   254 014   004  013  008  -056           2.793+1  4.476+1  296
02408   252 014   004  013  008  -062           2.942+1  4.848+1  292
02400   252 014   004  013  008  -062           2.980+1  4.911+1  291
02300   256 015   004  015  007  -062           3.499+1  5.774+1  291
02200   275 010  -001  010  006  -062           4.109+1  6.790+1  291
02100   249 008   003  007  006  -063           4.826+1  7.988+1  291
02000   230 014   009  011  005  -063           5.671+1  9.400+1  291
01929   261 014   002  014  005  -063           6.360+1  1.055+2  290
01900   272 015  -001  015  005  -063           6.665+1  1.105+2  291
01826   274 007   000  007  005  -063           7.511+1  1.243+2  291
01800   277 004   000  004  005  -063           7.832+1  1.296+2  291
01700   262 016   002  016  004  -063           9.205+1  1.526+2  291
01600   270 026   000  026  004  -063           1.082+2  1.797+2  290
01561                                004  -064           1.153+2  1.915+2  290
01500                                004  -065           1.273+2  2.130+2  289
01497                                004  -065           1.279+2  2.141+2  289
```

```
SOUNDING CONSTANT PRESSURE LEVELS (HGT IN GEOPOTENTIAL DECAMTRS)

 HGT          WIND             FV  TEMP   TC   PRES     DENSITY  SOS SPC  SPC

        POLAR   COMPONENT
                                                           -3
        DEG MPS   N-S  E-W  MPS  DEGC           MB       G M     MPS  A    B

05413   271 071  -002  071       -020           4.000-1  5.511-1  318
04992   263 074   009  073       -015           7.000-1  9.434-1  322
04724   261 065   011  065       -018           1.000+0  1.366+0  320
04212   279 050  -008  050       -023           2.000+0  2.787+0  316
03919   281 051  -010  050       -025           3.000+0  4.204+0  316
03556   288 039  -012  037       -040           5.000+0  7.458+0  306
03329   277 029  -004  029       -044           7.000+0  1.066+1  303
03092   281 019  -004  019       -046           1.000+1  1.531+1  302
02641   273 017  -001  017       -056           2.000+1  3.211+1  295
02385   252 014   004  013       -062           3.000+1  4.943+1  291
02069   243 009   004  008       -063           5.000+1  8.273+1  290

RAWINSONDE                              (HGT IN GEOPOTENTIAL DECAMTRS)

02081   255 016   004  015       -060           5.000+1
02000   255 016   004  015       -060           5.720+1
01900   287 012  -003  011       -060           6.700+1
01800   268 012   000  011       -061           7.880+1
01700   265 020   001  019       -062           9.220+1
01649   260 032   005  031       -062           1.000+2
01600   280 030  -005  029       -060           1.077+2
01568   288 029  -008  027       -058           1.140+2
01507   280 022  -003  021       -064           1.270+2
01500   257 032   007  031       -064           1.273+2
01443   267 044   002  043       -065           1.390+2
01419   268 038   001  037       -067           1.450+2
01100   294 047  -019  042       -048           2.400+2
01030   288 042  -012  039       -043           2.680+2
01000   288 038  -011  036       -041           2.797+2
00900   282 030  -006  029       -035           3.230+2
00800   295 020  -008  018       -028           3.720+2
00700   304 018  -010  014       -020           4.265+2
00600   306 015  -008  012       -013           4.856+2
00535   280 012  -002  011       -008           5.290+2
00500   280 013  -002  012       -006           5.525+2
00441   274 012   000  011       -005           5.960+2
00400   260 015   002  014       -002           6.285+2
00300   295 018  -007  016        004           7.110+2
00200   298 008  -003  007        011           8.040+2
00100   333 009  -008  004        018           9.085+2
00079   335 008  -007  003        020           9.310+2
00062   354 010  -009  001        015           9.500+2
00028   360 006  -006  000        015           9.890+2
00002   005 004  -003  000        015           1.015+3
```

ROCKETSONDE - - - SUPPLEMENTAL DATA - - - RADIOSONDE
MOTOR ARCAS PERFORM GOOD RADIOSONDE TYPE VAISALA RS-13
PAYLOAD ARCASONDE 1A PERFORM GOOD PRESS SENSOR ANEROID
RADAR TYPE MPS-19 GR EQUIP GMD-2B TEMP ELMNT WIRE
EF AZ ANG 124 EF EL ANG 83 BALLOON SIZE 2000 GRAMS
PAYLOAD ACQUIS ALT 68580 TIME 122 GRND EQUIP VAISALA
WIND SENSOR 15 FT CHUTE REMARKS:
TEMP SENSOR .010 IN BEAD THERM
SPEC SENSOR NONE

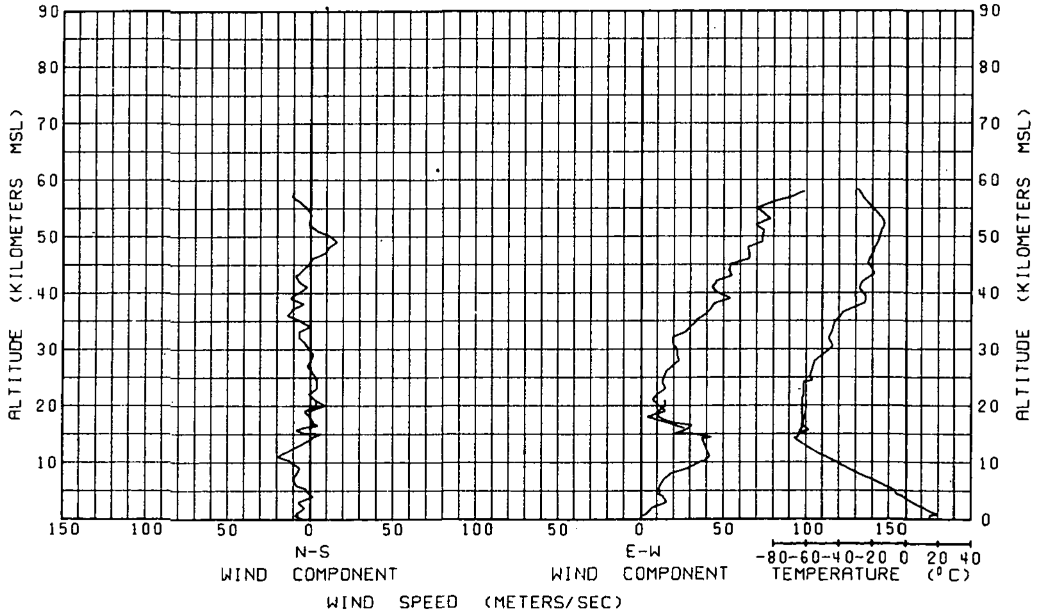

Figure 8.—Example of World Data Center-A high-altitude data format.

has been in publication only a short time, response from the scientific community indicates that the value of the rocketsonde data publications has been considerably enhanced.

RESEARCH RESULTS

A. Introduction

It has been shown clearly within the last decade that the stratospheric layer is one in which dramatic meteorological changes can occur, and there is evidence that some of the changes may be linked to the tropospheric circulation. These fundamental findings, coupled with recently derived requirements for meteorological support of supersonic transport and space shuttle operations, will demand a comprehensive knowledge of the stratosphere (15 to 55 km) and perhaps even the mesosphere (55 to 80 km). This knowledge would include, among countless other items: (1) the behavior of the circulation regimes at all altitudes in both the Northern and Southern Hemispheres and the differences that may, for example, be brought on by the different land-sea distributions; (2) the possible interactions between the circulation patterns in both hemispheres; and perhaps most important, (3) the interactions between the upper and lower layers of the atmosphere.

Complete information on the above-mentioned items would normally require a vast system of high-altitude observing stations capable of obtaining temperature and wind data from the surface to above 60 km. However, the expense of such a system, designed for in situ measurements, is completely prohibitive, and thus the planning of such a network would be only an academic exercise. This is especially true in the Southern Hemisphere, where ocean areas would further restrict the distribution of observational sites.

Since we cannot hope for the large volume of data needed to describe the entire atmosphere, we must find other less costly ways for acquiring the necessary information. It is important to reemphasize that EXAMETNET was formed with the expectancy of maximum data acquisition from a minimal rocket network. This philosophy dictated the establishment of carefully derived firing schedules at rocket stations oriented in a general north-south line. However, the philosophy also takes full account of the number of observations available from the worldwide rawinsonde network as well as from other rocket stations, and more recently, thermodynamic data from the satellite atmospheric sounding instrumentation.

It is the purpose here to review the salient contributions of the EXAMETNET to the meteorological community. In doing so, we shall attempt to evaluate the scientific usefulness of the line of meridional type of network, extending across the equator into both hemispheres, so that judgements can be made as to the need for additional networks.

Experience has shown that the difficult task of sounding the atmosphere with meteorological rockets must be complemented by a parallel effort to evaluate the accuracy of the measured data. This evaluation is a basic function of the EXAMETNET research. We will first review the results of these data accuracy studies, which, as mentioned earlier, included comparisons between observations by different types of rocketsonde data and between rocketsonde measurements and temperatures derived from satellite radiance measurements.

B. Data Accuracy Studies

(1) Separation of diurnal variation from instrumental errors

The determination of the diurnal tide in the stratosphere (from 30 to 60 km) is closely linked to the evaluation of instrumental errors. In fact, in many cases it is nearly impossible to separate the two, although many attempts have been made [Refs. 9, 10]. As a result, there are still considerable differences of opinion as to the true amplitude and phase of the tide. Before the formal establishment of EXAMETNET, experiments were sponsored in order to gain insight on this problem. One was carried out in September 1965 at Wallops Island [Ref. 11]. The results of the data analysis, which involved a comparison of the temperature variation inferred geostrophically from the tidal wind data with the temperature variation measured directly by the rocketsondes, was by no means conclusive. There was a suggestion, however, that the rocketsonde observations contained error due to direct solar radiation affecting the sensors or some critical portion of the instrument package. Thus, it became mandatory that future tests be conducted with the objective of determining the accuracy of rocketsonde measurements.

(2) Small-scale variability

As is the case for any observational series, if the data points are sufficiently close together in space and/or time, then the validity of any individual observation can be "verified" by comparing it against the surrounding values. On the other hand, when the observations are in a region generally void of other data points, then each report must be accepted at its face value and the need for utmost accuracy is relatively increased.

In view of certain inherent difficulties in the measurement of atmospheric temperature with rocketsonde instrumentation (i.e., aerodynamic heating, etc.), an extensive program of testing and evaluation has been in progress to insure that the most reliable systems possible are being employed by the EXAMETNET participants. The use of such equipment in sparse data areas (for example, in the Southern Hemisphere) is especially desirable, since comparisons with measurements made close by in space and/or time cannot be as readily accomplished as in areas where observational data are relatively plentiful.

Several experiments have been carried out to determine the compatibility of both wind and temperature profiles measured with different types of rocketsondes launched within periods of several minutes to several hours of each other, and placed in nearly the same spatial positions [Refs. 3, 12, 13]. Results generally indicate that the small-scale structure of the wind and temperature fields can be repeatedly discriminated. A good example of the small-scale repeatability between the zonal wind component as measured by the Arcasonde 1A and the Japanese Mt-135 is shown in Fig. 9. However, these early experiments did raise some questions. For example, although the small-scale perturbations of the temperature profiles were repeatable, in some cases the smoothed temperatures were as much as 5-8° at variance over a period of a few hours especially at the higher altitudes. The question arises as to whether these large-scale differences are a function of instrumental bias or real atmospheric variation.

In response to the questions raised above, the EXAMETNET has sponsored two additional experiments. The first entailed a concentrated series of launchings of the Datasonde instrument [Ref. 3], while the second involved a comparison of several rocketsonde instrument types with each other and against measurements obtained by the various temperature-profile-radiometer instruments aboard the Nimbus III and IV experimental satellites [Ref. 5].

The results of the first experiment conducted on June 20, 1969 indicate that temperatures measured by the Datasonde instrument are generally repeatable to within 2°C, but that substantial large-scale variability (variability in the mean temperature throughout a given layer) can exist, apparently as a result of a real atmospheric change. For example, a temperature change of over 7°C within 2 hours at about the stratopause was verified by several soundings. These results are important since they indicate an increasing meso-scale stratospheric variability which probably peaks at the stratopause. More investigation should indicate whether the amplitude of this variability increases during the winter season.

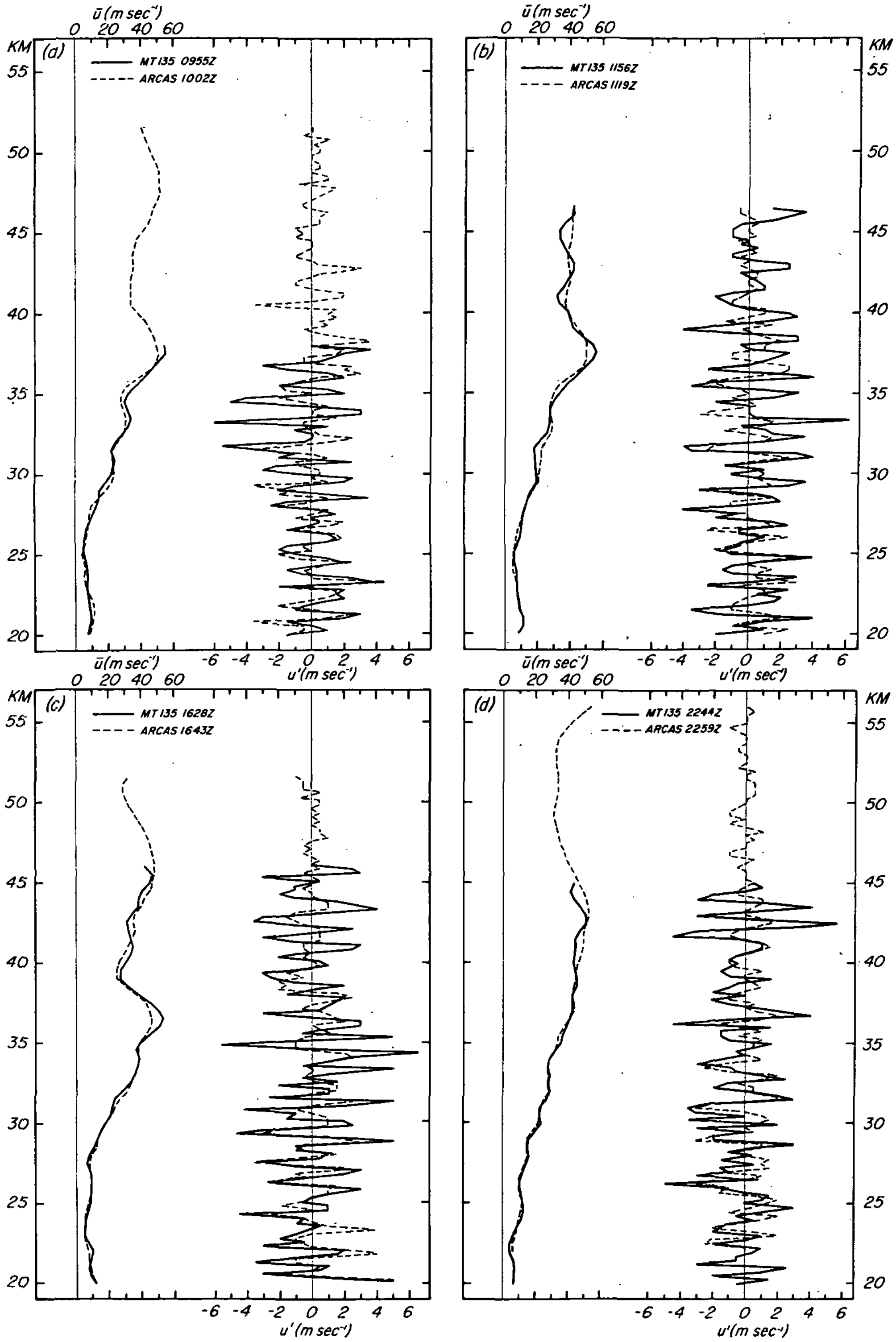

Figure 9.—Smoothed (U) and perturbation (U') zonal wind profiles for United States-Japan comparison tests on April 4, 1967 [Ref. 12].

(3) Rocketsonde-satellite sounder comparisons

The rocketsonde-satellite sounder experiment was recommended at the Fifth Annual Meeting of EXAMETNET. In accordance with these recommendations, NASA conducted the experiment at Wallops Station. Essentially this is a comparison between satellite derived temperatures from the temperature-profile-radiometer or spectrometer instruments and those measured by rocketsondes. This comparison is afforded by scheduling rocketsonde observations at the approximate time of satellite overflight. A significant amount of data has already been obtained at Wallops Island. Although no firm conclusions have yet been reached, there are indications that several of the transmittance functions used for deriving the satellite temperature profiles may not be correct. These results may provide an important method of adjusting the transmittances which were originally derived in a theoretical manner.

Another preliminary indication from the rocketsonde-satellite comparison is that in certain configurations of thermistor placement, the Datasonde rocketsonde instrument (used for a portion of the comparisons) yields temperatures that are biased toward the warm side. This bias was also suggested in earlier comparisons with other instruments.

C. Circulation Studies

There were several attempts to obtain high-level information for cross-sectional type analysis of the Southern Hemisphere before the actual start of the EXAMETNET launch operations. Perhaps the most prominent was the NASA Mobile Launch Expedition aboard the USNS Croatan [Refs. 14, 15] which provided an outstanding amount of data up to 60 km while the ship cruised a route southward across the equator and along the west coast of South America. Examples of how such data can be used are shown in Figs. 10 and 11. A north-south cross section of wind and temperatures along 78°W in the Southern Hemisphere is shown in Fig. 10. Although the observations were taken during a period of about two weeks, they were combined to show the general features of the circulation.

Another method of presenting cross-sectional type data is shown in Fig. 11. These segments of analyses up to 0.4 mb can be used for limited comparisons of circulation regimes during analogous seasons of the Northern and Southern Hemispheres. The Northern Hemisphere segments here were taken from synoptic analyses [Ref. 16], and those of the Southern Hemisphere were again derived from data taken from the Croatan over a period of about 2 weeks.

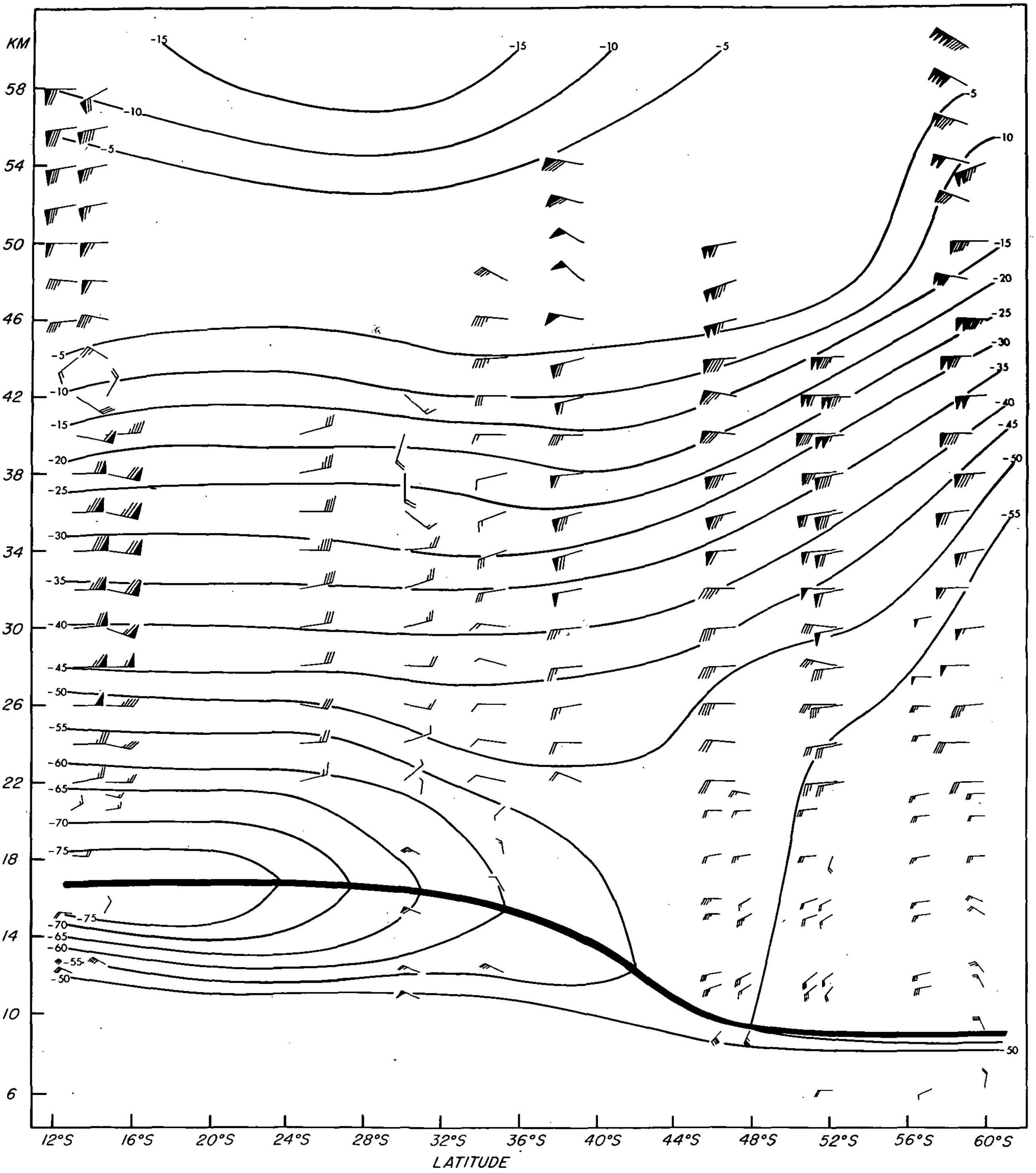

Figure 10.—Space-time cross-section of wind and temperature from 12°S to 60°S along 78°W for March and April 1965 [Ref. 14]. Rocketsonde winds (kt) are denoted by large symbols, temperature (°C) by upright numerals, and support rawinsonde data by small wind symbols; isotherms at 5°C intervals.

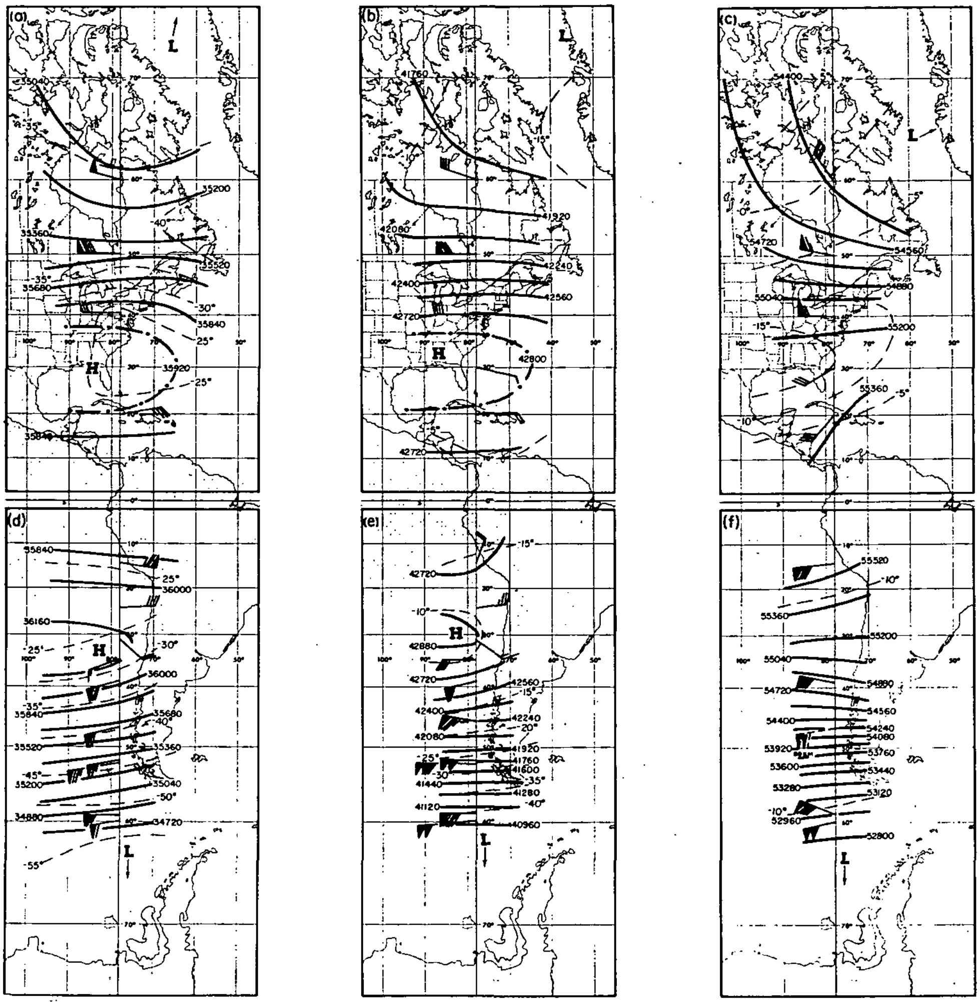

Figure 11.—(a) 5-mb, (b) 2-mb, (c) 0.4-mb analyses (Northern Hemisphere) centered on 78°W for April 7, 1965, with interpolated geostrophic winds (after Ref. 11); (d) 5-mb, (e) 2-mb, (f) 0.4-mb analyses (Southern Hemisphere) centered on 78°W and April 9, 1965, based on Croatan data. Rocketsonde winds in knots; contours at 160-M intervals; isotherms at 5°C intervals [Ref. 14].

Because of the generally large scale of the synoptic systems in the stratosphere and the fact that they very likely slope with height, it has long been considered that the optimum way of studying the stratospheric circulation at rocketsonde heights is to construct a map analysis at lower altitudes (height and temperature at a constant-pressure level) utilizing all information available (rawinsonde, rocketsonde, constant-level balloon, satellite). That map can then be utilized as a base chart into which the relatively few higher-altitude rocket observations can be meaningfully integrated to at least infer the circulation at higher levels.

For the initial attempt at this type of analysis in the Southern Hemisphere [Ref. 17], rawinsonde data and constant-level balloon information were used to construct weekly analyses for the 30-mb level for the month of June 1967 (the analysis for June 14 is shown in Fig. 12). Rocketsonde information from Chamical,[2] Argentina; Natal, Brazil; and Ascension Island indicated (rocket reports from Chamical and Natal also for June 14 are shown in Fig. 13) that a subtropical ridge, present in the lower stratosphere, diminished with height. In addition, the data suggested that the polar westerlies extended equatorward with increasing height. These results are consistent with those which had been derived previously from Northern Hemisphere data.

More recently [Ref. 18], research efforts have concentrated on the question of whether stratospheric warmings occur with the same frequency and intensity in the Southern Hemisphere as they do in the Northern Hemisphere. The Southern Hemisphere winter of 1969 was notable in that several warming pulses occurred throughout the season, although these warmings could not be classified as strong by Northern Hemisphere standards and were not accompanied by major circulation changes. An example of the circulation pattern during such a warming in mid-August is shown in Fig. 14. The available rocket reports and high-level radiosonde reports (a time section of temperature and wind showing the effect of the warming at Mirny, A USSR station in the Antarctic, is shown in Fig. 15) suggest that the warming was somewhat more pronounced in the higher portions of the stratosphere. However, the results strengthen the concept that the polar regions of the hemispheres react quite differently during warming periods. Increasing evidence indicates, for example, that mid-winter stratosphere circulation breakdowns (i.e., wind reversals), may never occur in the Southern Hemisphere at least at the lower levels because the strength of the wintertime polar cyclone is significantly greater than that of the Northern Hemisphere.

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[2] Earlier site of Argentine rocket station, before the move to Mar Chiquita.

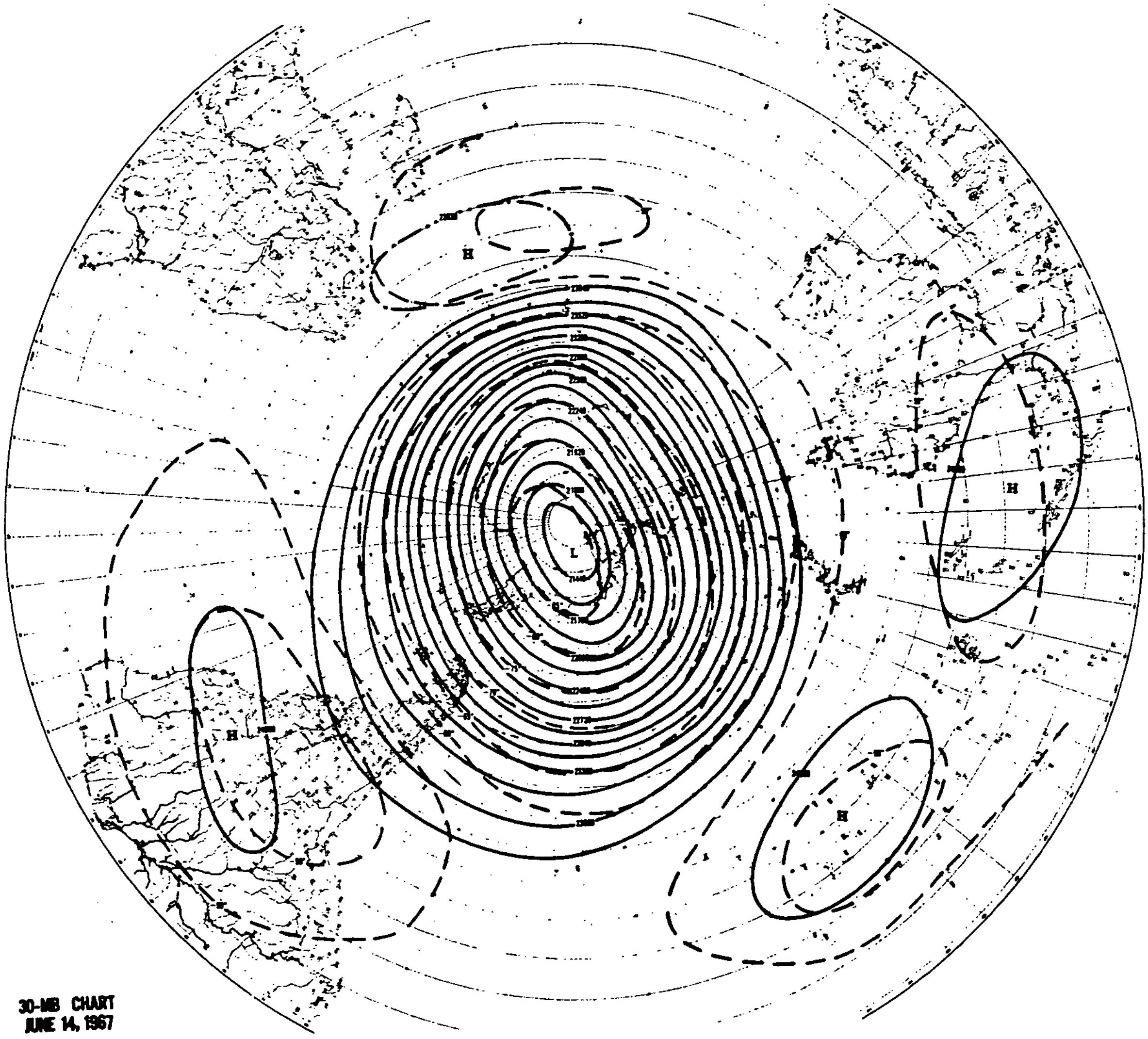

Figure 12.—Southern Hemisphere 30-mb analysis for the week of June 14, 1967. Units: geopotential meters and degrees Celsius. Contour intervals: 160 gpm, 5°C [Ref. 17].

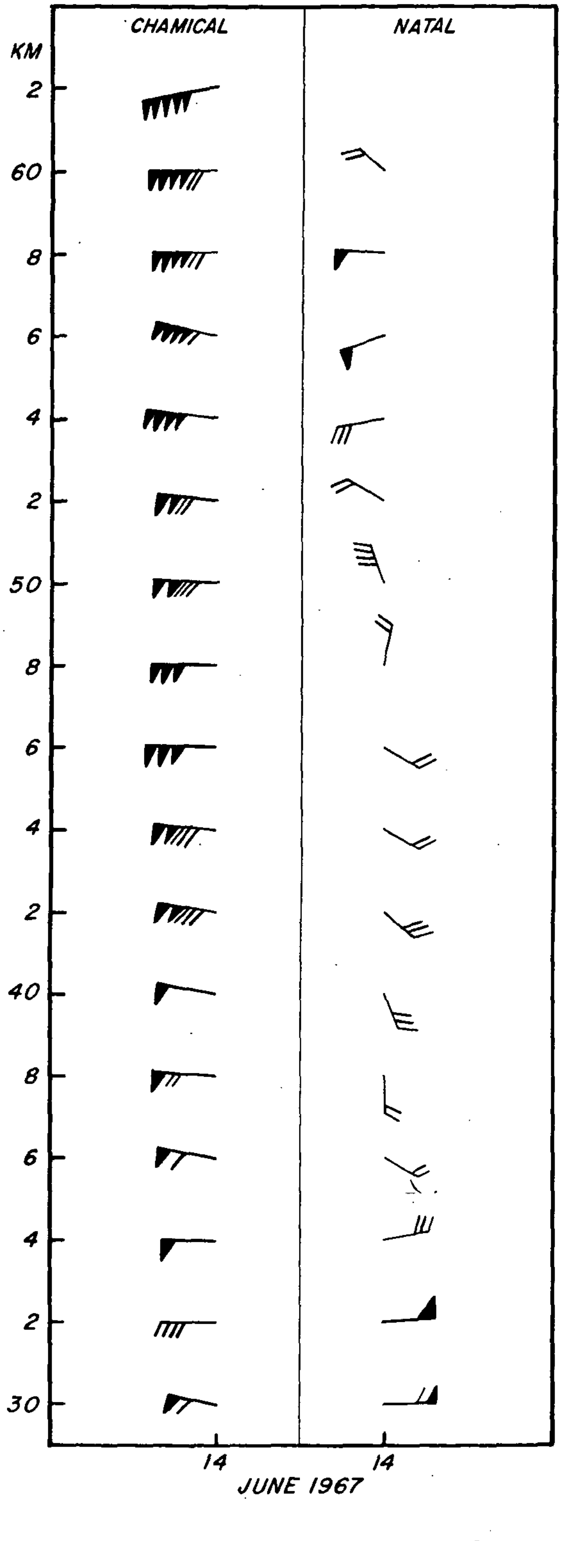

Figure 13.—Observed rocketsonde winds (knots) for Chamical, Argentina, 30°22'S-66°17'W, and Natal, Brazil 5°55'S-35°10'W; June 14, 1967. A full barb represents 10 knots; a pennant, 50 knots [Ref. 17].

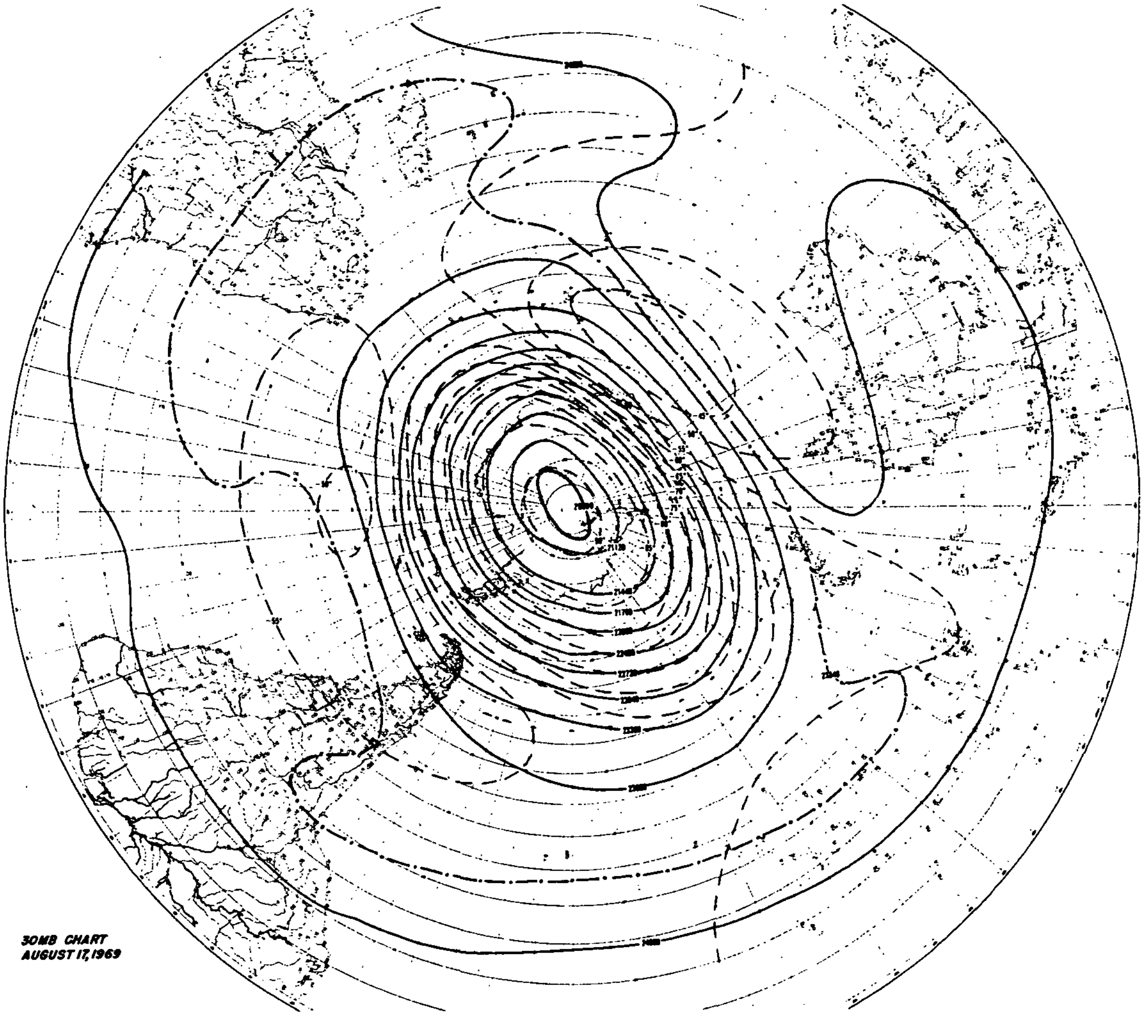

Figure 14.—Southern Hemisphere 30-mb analysis for August 17, 1969. Units: geopotential meters and degrees Celsius. Contour intervals: 320 gpm, 5°C [Ref. 18].

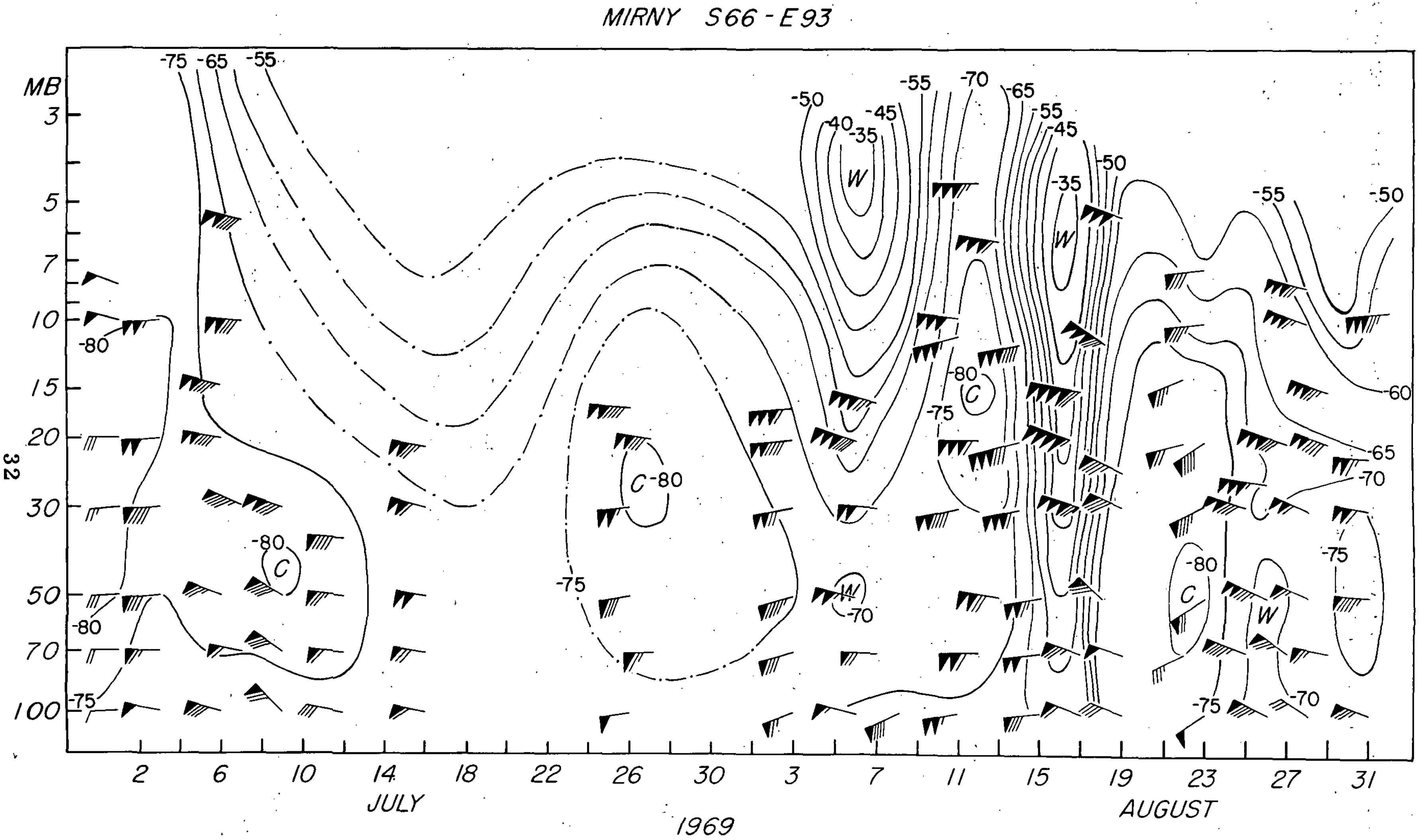

Figure 15.—Time-height section of radiosonde observations at Mirny, Antarctica (66°33'S, 93°01'E). Temperature units: °C. The broken portion of the analysis (- - -) reflects a period where data were sparse and resulted in a decreased confidence level in the analysis. Wind units: knots [Ref. 18].

It is recognized, however, that the major effects of a midwinter warming event in the Southern Hemisphere may occur at altitudes higher than those portrayed by the current radiosonde analyses. For example, it is noted that the results of several studies [Refs. 19, 20, 21] as well as recent satellite data from the Selective Chopper Radiometer (SCR) instrument on board Nimbus IV (private communication) support the concept of a mid-winter warming in the Southern Hemisphere that is principally confined to the upper stratosphere. A similar phenomenon has been observed in the Northern Hemisphere [e.g., Ref. 22].

Some hemispheric comparisons have also been accomplished for the lower latitudes. For example, the circulation at Chamical, Argentina (30°S) was compared with that of White Sands, New Mexico (32°N) [Ref. 20] utilizing the SCI (Stratospheric Circulation Index). The zonal wind components at the two stations were found to be similar. However, differences between the meridional components of the two stations were found. The reason for the observed differences remains to be determined.

The data available during the 1969 Southern Hemisphere winter, in conjunction with maps of the Northern Hemisphere summer, allowed a very general approximation of the world-wide circulation pattern, as was attempted with the earlier "Croatan" data. One important aspect of the pattern was the complex differences that may occur from year to year (Fig. 16) according to the phase of the so-called quasi-biennial cycle. As can be seen, the biennial cycle may influence the circulation pattern, even at middle latitudes and up to 50 km.

A special effort to obtain all possible Southern Hemisphere data, which involved the cooperation of EXAMETNET member states, allowed a series of synoptic charts to be drawn for a portion of the springtime stratospheric circulation change. Again, certain phases of this annual event appeared to take place in a different manner from the Northern Hemisphere [e.g., Ref. 19]. For example, the reversal of the temperature field at 30 mb appeared more orderly in the Southern Hemisphere. In addition, it is rather remarkable that the circulation at higher latitudes remained westerly several weeks after the temperature reversal had been fully completed. Rocket winds from Mar Chiquita indicate that even at higher levels the summertime circulation was not yet established by the middle of November, although the temperature reversal had been completed. This again points to the extreme intensity of the wintertime polar cyclone which, of course, is partially regulated by very cold Antarctic air below the stratosphere.

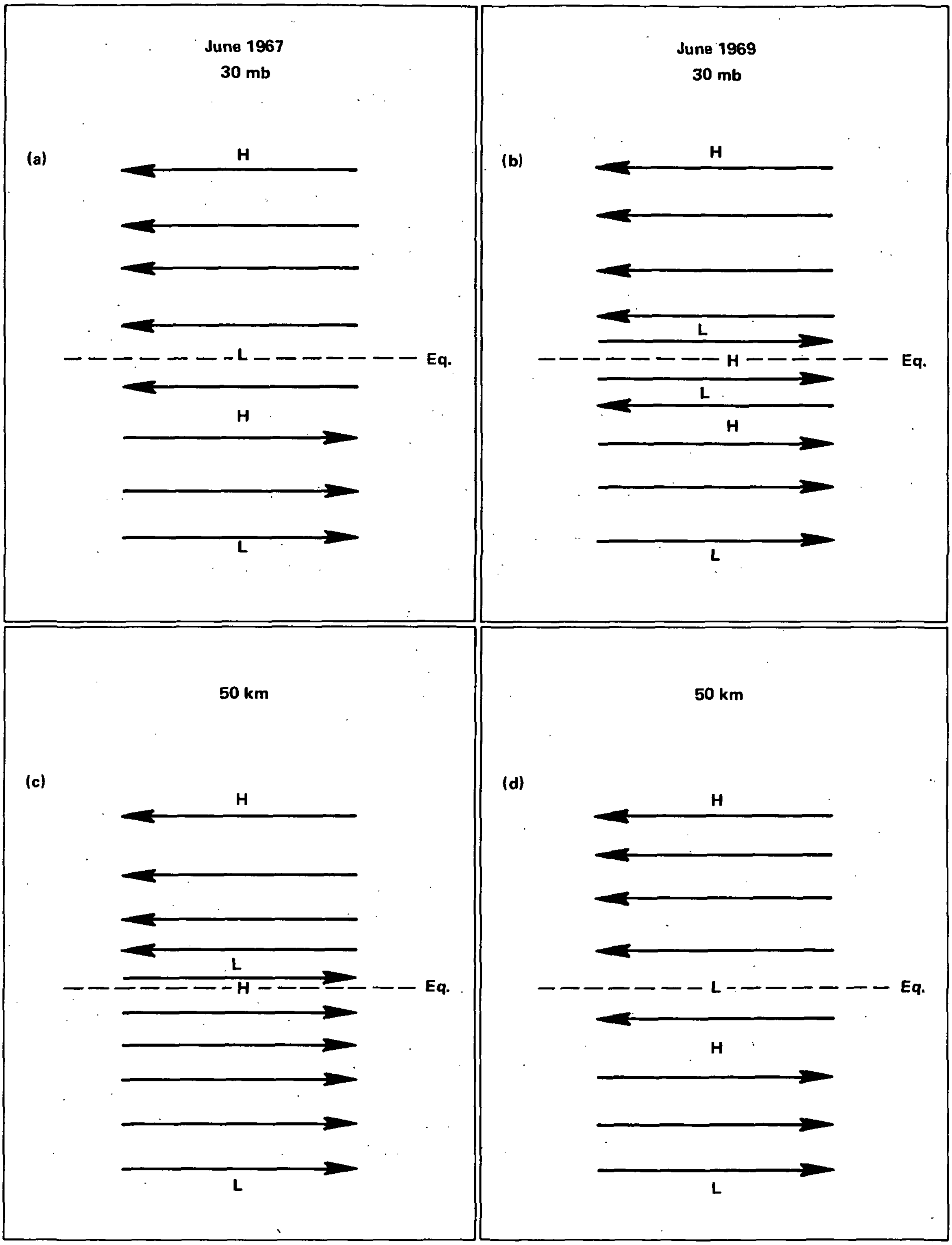

Figure 16.—Schematic diagram of general synoptic pattern at 30 mb (a,b) and 50 km (c,d) for June 1967 (left side) and June 1969 (right side). North Pole is at top and South Pole is at bottom in all diagrams [Ref. 18].

D. Tropical Circulations

As shown above, networks such as the EXAMETNET can provide valuable data for use in studying high-level hemispheric circulations and also to study differences between the patterns in each hemisphere. An additional basic function of the EXAMETNET is to increase our knowledge of the stratospheric behavior within the tropical regions, paying special attention to the possible relationships between phenomena of tropical and middle latitudes. Analysis of the tropical regions of both hemispheres is valuable, not only for solving purely meteorological problems, but also for providing information to those concerned with problems such as tracing radioactivity introduced into the atmosphere.

Major aspects of the low-latitude circulation are the quasi-biennial oscillation, known to be most pronounced in the middle stratosphere, and the semiannual variation, which peaks near the stratopause. With the aid of rocketsonde observations from stations near the equator (including information from the EXAMETNET station at Natal) together with data from other longitudes north and south of the equator, it was possible for the first time to establish that the semi-annual cycle occurs at low latitudes around the entire globe [Refs. 23, 24]. For example, the time sections of Ascension Island and Natal, Brazil (Figs. 17, 18) show quite comparable wind variations with time. The components of the quasi-biennial cycle may be subtracted, leaving variations that are probably a consequence of the double passage of the sun between latitudes 23.5N and 23.5S. Subsequent analyses [Refs. 25, 26, 27], have provided further information on the amplitude of the semiannual cycle as a function of latitude.

The results of the low latitude studies suggest a link between these circulations and the basic annual cycle of high latitudes. The full importance of the semi-annual variation, which is significantly stronger than the quasi-biennial oscillation, is not yet known. A possible influence of the semiannual cycle on semiannual variations encountered at higher altitudes, even to satellite orbiting levels, merits investigation. It may well be that these tropical variations have an important role in the triggering of stratospheric warmings.

Yet another use of EXAMETNET data has been directed toward the improvement of standard atmospheres. The Natal data, in particular, have been used by a working group of the Committee on Extension of the Standard Atmosphere, as a check on the adequacy of the existing "supplemental" atmosphere for the tropics. Significant departures from the CIRA 1965 model atmosphere have been found [Refs. 24, 28, 29, 30].

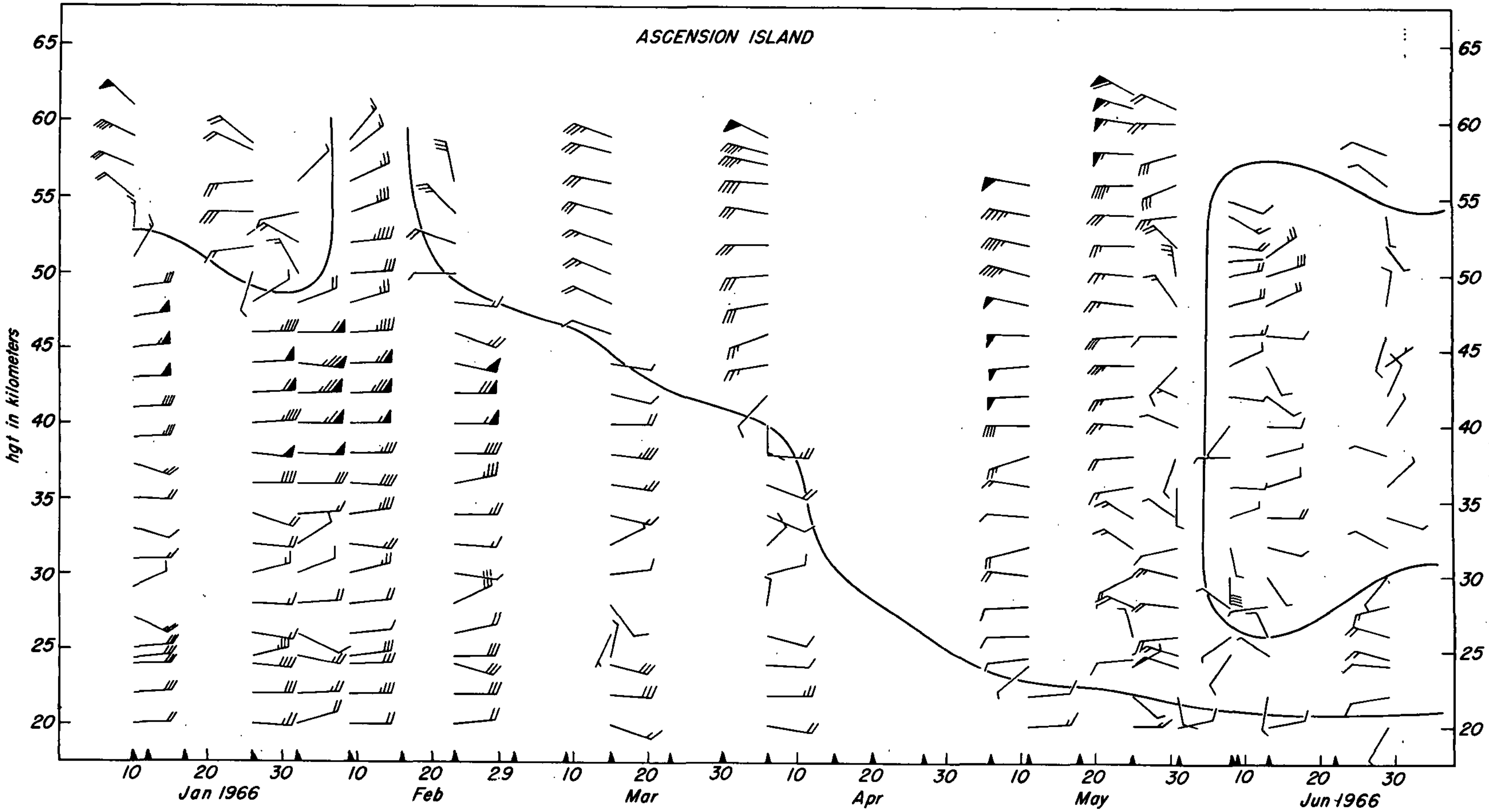

Figure 17a.—Time section of observed rocketsonde winds (m. sec. $^{-1}$) for Ascension Island: January - June 1966. The heavy black lines generally separate winds with easterly components from those with westerly components. Indentations from bottom scale indicate all days for which observational data were used. A full barb represents 10 m. sec. $^{-1}$; a pennant, 50 m. sec. $^{-1}$ [Ref. 23].

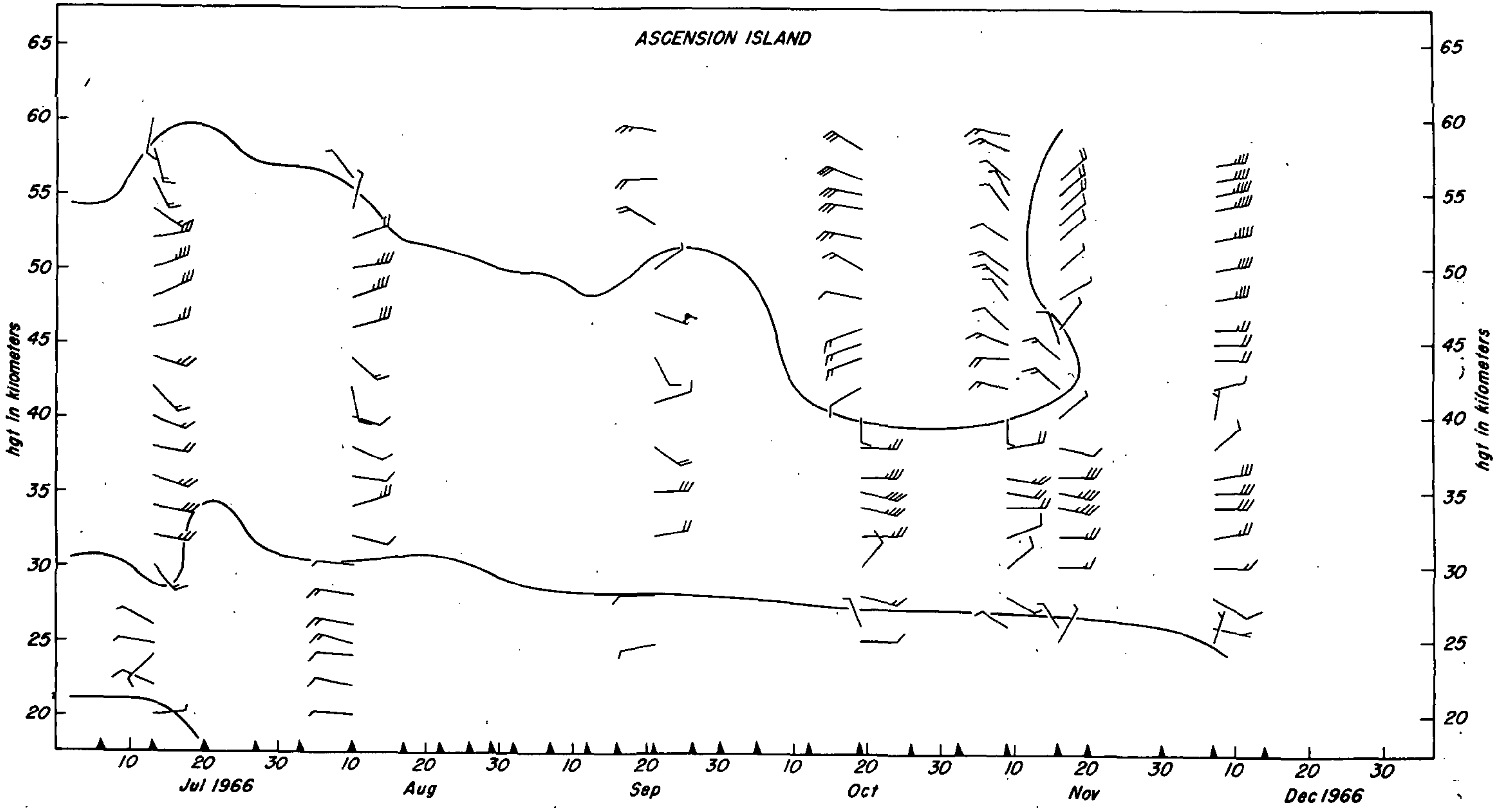

Figure 17b.—Time section of observed rocketsonde winds (m. sec.$^{-1}$) for Ascension Island: July - December 1966. The heavy black lines generally separate winds with easterly components from those with westerly components. Indentations from bottom scale indicate all days for which observational data were used. A full barb represents 10 m. sec.$^{-1}$; a pennant, 50 m. sec.$^{-1}$ [Ref. 23].

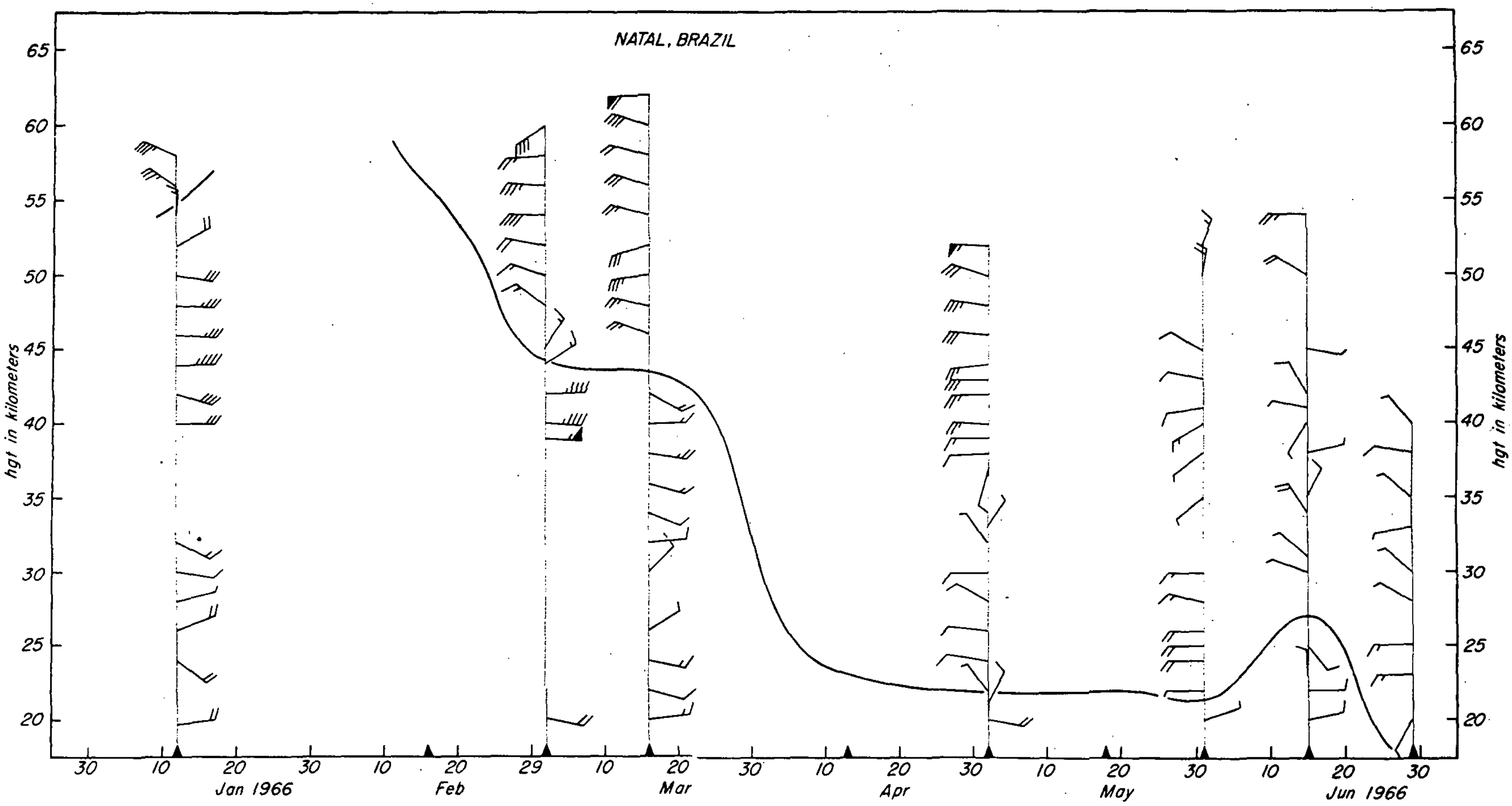

Figure 18a.—Time section of rocketsonde winds (m. sec.$^{-1}$) for Natal, Brazil: January - June 1966. The heavy black lines generally separate winds with easterly components from those with westerly components. Indentations from bottom scale indicate all days for which observational data were used. A full barb represents 10 m. sec.$^{-1}$; a pennant, 50 m. sec.$^{-1}$ [Ref. 23].

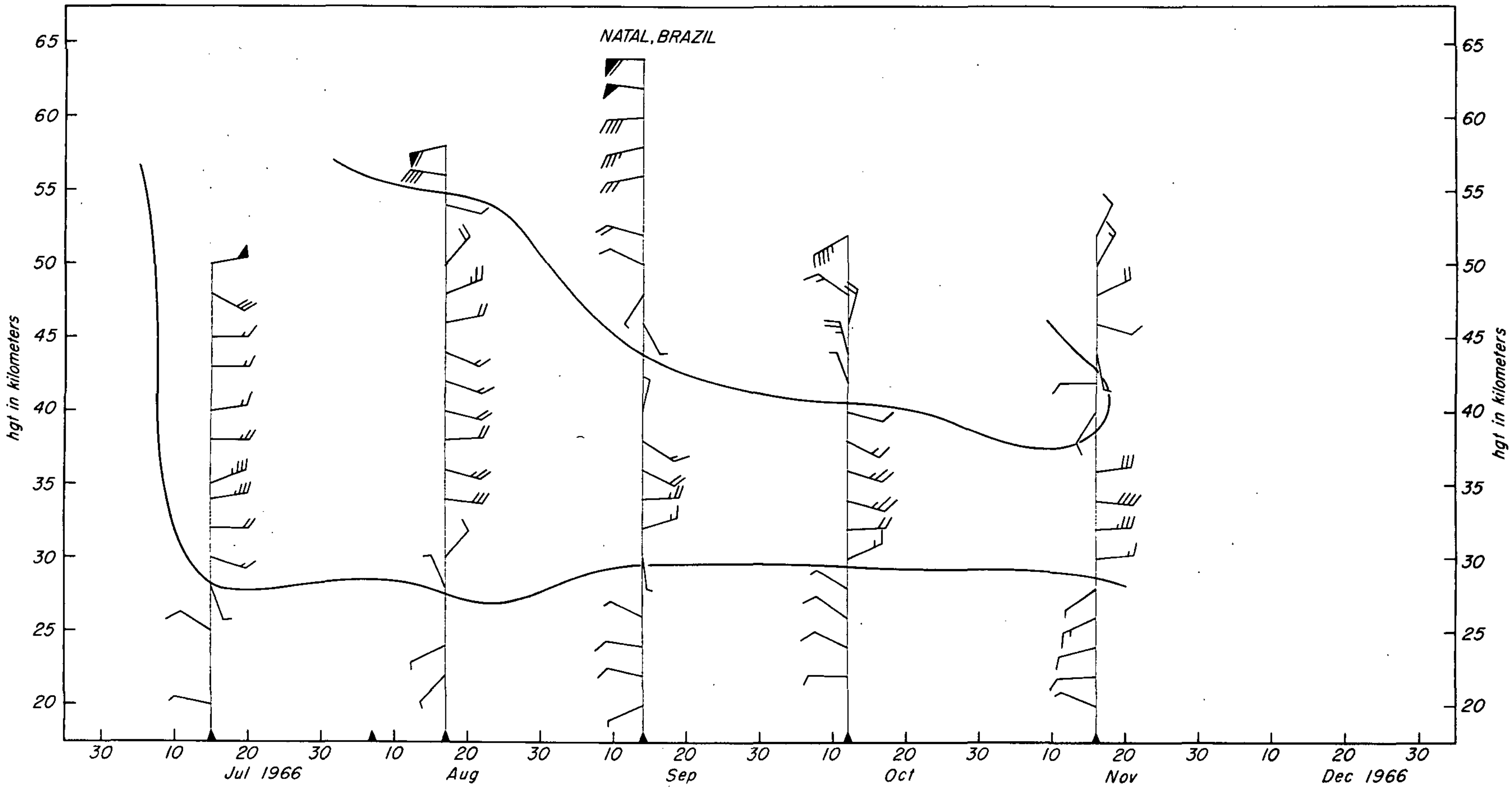

Figure 18b.—Time section of rocketsonde winds (m. sec.$^{-1}$) for Natal, Brazil: July - December 1966. The heavy black lines generally separate winds with easterly components from those with westerly components. Indentations from bottom scale indicate all days for which observational data were used. A full barb represents 10 m. sec.$^{-1}$; a pennant, 50 m. sec.$^{-1}$ [Ref. 23].

E. Stratospheric-Tropospheric Interactions

As described above, the essential purpose of the EXAMETNET as an observational network is to offer coordinated rocketsonde launchings that, when utilized with all other available data, allow the maximum information to be obtained concerning the structure and circulation of the Northern and Southern Hemisphere stratospheres. Delineation of the general synoptic patterns and depiction of the differences and similarities between the two hemispheres as described in the previous sections, however, inevitably raises the question of why the events occur as they do. For example, why is the Southern Hemisphere wintertime stratospheric circulation more symmetric about the pole than the Northern Hemisphere? Is this circulation difference related to the observed differences in the mid-winter warmings or even to the cause of the quasi-biennial oscillation?

While a complete report of the many studies that seek to answer these questions is beyond the scope of this brief review, a few words should be stated on one aspect of research that may prove to be fundamental to a host of aerological problems. It has long been recognized by theory [e.g., Ref. 31] and observation [e.g., Refs. 32, 33, 34, 35] that the troposphere is a major source of kinetic energy for the stratosphere by means of the mechanical coupling at the tropopause; that is, the troposphere does work at the stratospheric boundary, thereby providing kinetic energy to the stratospheric flow.

While computations of the energy flux have been made only in the lower stratosphere, it has been shown that this exchange can be directly related to the mid-winter warming events and the quasi-biennial oscillation [e.g., Refs. 35, 36]. In comparing an estimate of the energy flux [Ref. 35] with a 10-mb circulation index [Ref. 37], it was concluded that an increase in the vertical energy transfer precedes an observed effect in the circulation at 10 mb by 2-4 days and that the existence of the well-known Aleutian anticyclone is related to an energy flux at that scale-length. Unfortunately, at this time it is not possible to extend this type of correlation analysis to the upper stratosphere as the data are rather restricted both spatially and temporally. Vertical motion analyses for the upper stratosphere, however, have been constructed for limited geographical areas [Ref. 22]. It is hoped that these calculations can be extended in the near future to include the entire hemisphere, so that the energy flux computations can be accomplished for this region.

Furthermore, it is noted that because the atmospheric density decreases so rapidly with height, a relatively small transmission of the energy through the lower stratosphere can have a profound effect at higher levels. Indeed, several investigators are presently studying anomalous ionospheric situations that may be related to energy transfer.

F. Eclipse Studies

The EXAMETNET has cooperated in two experiments oriented toward determining structural and circulation changes during a solar eclipse. The first experiment took place at Tartagal, Argentina (23°S) on November 12, 1966. Observational data indicated a temperature drop exceeding 10°C near 50 km in the eclipse, and an increase of about 20°C at 60 km from before totality to an observation time in mid-afternoon. Clearly, these large changes required clarification. Since temperature errors in rocketsondes tend to increase with height there is a question as to whether these changes reflected those of the real atmosphere.

Fortunately, a total solar eclipse also occurred at Wallops Island during March 7, 1970. Preliminary results from meteorological rocketsonde observations taken during the period of this phenomenon [Ref. 38] also indicated significant temperature changes. However, there were some rather startling differences. For example, the analyzed Wallops data show the maximum changes (Fig. 19) occurring in the 40-55 km layer instead of higher as shown by the Tartagal data. It is noteworthy that the amplitude of temperature change decreases above about 55 km. This result suggests that instrumental error due to solar radiation was not a prime factor in this experiment, since the radiational error would be expected to increase with height.

The observed temperature variation at Wallops Island is more nearly in accord with the prediction from tidal theory, which suggests that maximum amplitude of the day-night variation, due to ozone heating and cooling, should occur below the stratopause. A more detailed investigation is being made of the March 7 eclipse temperature data and of the relationship between the wind and thermodynamic changes.

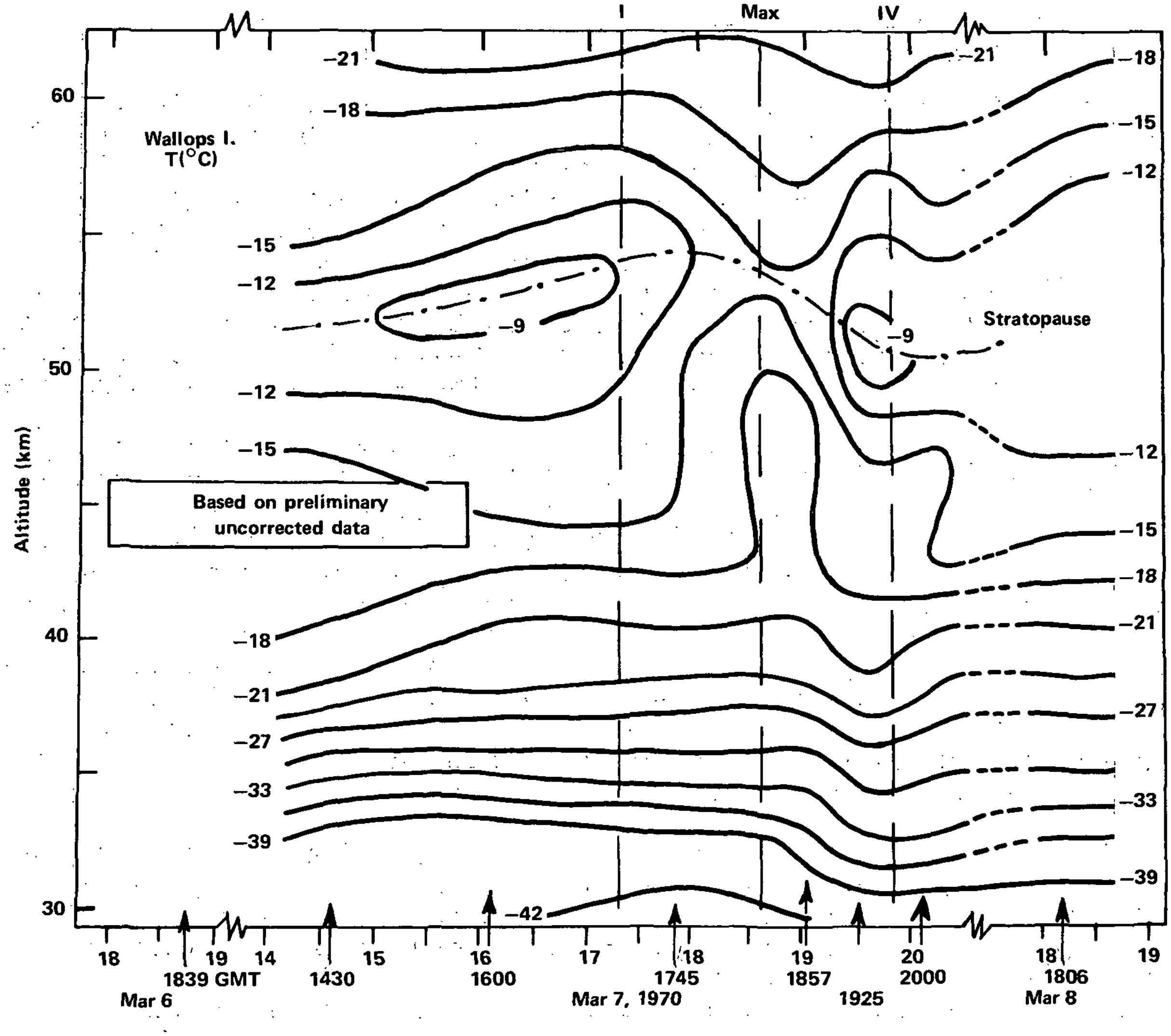

Figure 19.—Preliminary analysis of smoothed rocketsonde temperatures for Wallops Island, Virginia, for the solar eclipse of March 7, 1970, indicating a temperature decrease by as much as 7 degrees within the layer 40 to 60 km [Ref. 38].

SUMMARY

The Experimental Inter-American Meteorological Rocket Network (EXAMETNET) was established to fill a gap in the knowledge of the stratosphere, especially in the Southern Hemisphere.[3] The goal is the organization of an inter-hemispheric network of sounding rocket stations which would coordinate their operations and combine their resources and scientific capabilities to expand the knowledge of the structure and dynamics of the atmosphere to about 60 km. It is recognized that this endeavor requires a high degree of cooperation, as well as the utilization of other sources of atmospheric measurements such as from rawinsonde and satellite soundings.

In August 1965, personnel of the space agencies, representing Argentina, Brazil and the United States met at Wallops Island, Virginia to organize the network. The result is a basically meridional line of stations within the Americas, one in each country, and extending between 40°S and 40°N. It is hoped that the network can be expanded to a line from pole to pole and to as high an altitude as possible, although at present the altitude capability is about 60 km. The cooperative agreements among the participating countries involves training, loan of equipment, procurement of rocket systems and related hardware, ground-range facilities, station personnel, and so forth. In terms of the organizational structure created for conducting the network, the activity consists of an Executive Committee to guide and advise the operation and two Working Groups, scientific and technical. The Working Groups contain project managers, scientific coordinators, experimenters and other personnel necessary to the operations. Each country is represented on the Committee and Working Groups.

While the original membership of the network was confined to countries having sounding rocket facilities in the Americas, it was realized that the utility of the data would be enhanced if sounding rocket activities in other regions were coordinated with those of EXAMETNET. To do this an adjunct membership was established for those countries with launch sites outside the Americas. It is a procedure through which these countries can participate in the deliberations, plans and activities of EXAMETNET. Spain is the first country to become such a member.

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[3] The important contribution of rocket-grenade and falling sphere programs conducted in Australia is fully recognized. The EXAMETNET program, however, provided for the first coordinated inter-hemispheric rocket network.

Although EXAMETNET is an international regional network (i.e., in the region of the Americas), it soon became a recognized part of the international community. For example, the organization is represented in the WMO and COSPAR through the national representatives of the participating countries. Another aspect is coordinated launchings. India requested and received the coordination of EXAMETNET launches with launches in India. Furthermore, the USSR has proposed coordinated launchings from an Eastern and a Western Hemisphere meridional chain or network of stations to study various aspects of stratospheric circulation, and has further proposed that EXAMETNET form the basis of the Western Hemisphere chain.

Nationally the EXAMETNET program is related to activities within each participating country. In Argentina, the evaluation and scientific study of the sounding rocket data are performed by the National Meteorological Service, and the data are made available to universities and scientific organizations as well. In Brazil, there is cooperation between CNAE and the Ministry of Aeronautics to perform the EXAMETNET operations. Other agencies are informed of the EXAMETNET plans and make use of the data, such as the Ministry of Agriculture and the Meteorology Laboratory of the Aeronautics Technical Center. In the United States, close contact is maintained with the advisory groups which coordinate the efforts of the Meteorological Rocket Network of the United States. EXAMETNET is also represented in the committees and working groups of the Office of the Federal Coordinator for Meteorological Services and Research through the NASA members of this organization. The National Weather Service of the National Oceanic and Atmospheric Administration (NOAA) cooperates with NASA in fulfillment of the United States commitment for scientific research.

Improvement and standardization of operations are aspects important to the success of the network. In addition continued advances in technology are essential. To this end Argentina and Brazil have each developed sounding rocket systems which are to be used in the EXAMETNET observing program. The Argentine rocket system (named DIM) and the Brazilian rocket system (named SONDA-1) are expected to be available in 1971 and will be used for meteorological and aeronomic investigations. EXAMETNET has incorporated also in its operations the use of the Datasonde rocket system for wind and temperature measurements. Other technological improvements include modification of a 403 MHz telemetry recorder to yield high-resolution temperature data and improve the signal reception, the introduction of digital computer methods in the data reduction and radar modifications for improved tracking and location resolution.

Network stations conduct special tests on a continuing basis to determine the reliability of rocket systems, especially in terms of the repeatability and accuracy of their atmospheric measurements. These tests include the intercomparison of data from the various rocket systems. Allied to these tests is the project for comparing rocket and satellite soundings. Proof of compatibility will allow the use of satellite data along with regular radiosonde and rocketsonde information to greatly increase our upper atmosphere data sample.

At the inception of the network, it was recognized that uniform reduction procedures and publication formats were a prerequisite to the efficient exchange and scientific application of the data. The EXAMETNET participants, after a review of existing methods, developed improved reduction techniques and formats now described in a data preparation and procedures manual. This accomplishment permitted significant contributions to the development of a uniform international rocketsonde format for the exchange and publication of rocket data, which was adopted by WMO and COSPAR for international use and for archiving and data dissemination by WDC-A.

Research studies conducted by the EXAMETNET participants cover a wide range of interests. Basically, they might be summarized under several major subjects including, a) diurnal variations, b) data accuracy (including comparisons with other instruments and methods of observations such as satellites), c) circulation studies, and d) stratospheric-tropospheric interactions.

Although rocket observations provide extremely valuable data in the layer from about 30 to 60 km, the inherent design problems of some systems can result in errors of measured parameters, especially temperature. Error possibilities were clearly brought out by careful analysis of data gathered during experiments designed to determine the diurnal variation of wind and temperature. Recognition of the error problem and subsequent investigations led to the realization that the separation of errors from true variabilities is indeed a difficult task. Therefore, it has become mandatory to conduct instrumented intercomparison tests. Although one could not expect precise corrections to emerge from such tests, certainly they have resulted in meteorologists being able to use the data with higher confidence than before.

Closely related to the determination of instrumental error is the question of the reality of small-scale atmospheric motions and temperature variations, in contrast to apparent variation due to instrumental or tracking error. Conclusions from rocketsonde experiments clearly point to the existence of real perturbations of temperature at stratospheric levels, with characteristic time scales of several hours and a magnitude exceeding 5°C.

Wind variations are also noteworthy. Experiments performed during solar eclipses using rockets of all sizes tend to reinforce the concept of true small-scale perturbations at stratospheric levels.

One of the main uses of EXAMETNET data is in research directed toward determining the stratospheric circulations of both the Southern and Northern Hemispheres. To this end, as well as for other problems, the network data are used with all other available reports. The combined information indicates that the Southern Hemisphere stratosphere, at least during the past few years, has exhibited significant mid-winter warming trends, but these did not result in the chaotic circulation breakdowns known to occur in the Northern Hemisphere. Unfortunately most of the observations were restricted to the lower stratosphere and it is not clear if a similar statement can be made for the higher altitudes. Differences in the regular springtime circulation transitions have also been noted between the two hemispheres.

Stratospheric circulation features of the tropics historically have been treated separately from those of higher latitudes. However, it has become increasingly evident that some of the phenomena can be found at nearly all latitudes, although with varying degrees of intensity. One reason for separate treatment, of course, has been that the usual method of synoptic analysis is not readily applicable in very low latitudes, where the geostrophic approximation is no longer valid.

The basic meridional configuration of the EXAMETNET is highly conducive to research directed toward a determination of the possible linkages between the high and low latitudes of each hemisphere, as well as between the hemispheres themselves. Background for these studies is the information published on the quasi-biennial cycle, which is dominant in the tropical stratosphere up to about 30 km. Above about 30 km a semi-annual component becomes more important, with a peak amplitude at about 45 km. Significantly, the EXAMETNET data have helped to confirm the global extent of the latter mentioned phenomenon.

Because of the obvious impact of satellite-derived temperature-height profiles as a new data source, EXAMETNET recommended an experiment to compare these data with those obtained from rocketsonde and radiosonde observations. In response to this, NASA conducted such an experiment at Wallops Station. Comparison observations are now available in significant numbers and analysis is proceeding.

RECOMMENDATIONS

The recommendations that follow are oriented toward improvements in the scientific, technological and organizational areas of EXAMETNET:

1. Efforts should be continued by each participant to maintain the planned coordinated schedule of launches so as to provide the greatest scientific utility of the network data.

2. Efforts should be continued by the scientists in the analysis of both single station and network rocketsonde data and such other atmospheric measurements that will enhance the scientific utility of the upper atmosphere research.

3. Consideration should be given to the desirability (need) to add launch sites near the latitudes of 25°S, 50°S, 6°N and 50°N. A site at 25°S would provide continuity of measurements between Natal (6°S) and Mar Chiquita (38°S) while sites at 50°S and 50°N would help extend coverage into the higher latitudes. Data from a site at about 6°N, such as Kourou, French Guiana with those from Natal would provide greater information on the structure of the equatorial atmosphere and inter-hemispheric relations.

4. Consideration should be given to gaining cooperative launchings with other countries and agencies who have the capability of operating within the polar regions, such as the Japanese station at Showa and the USSR station at Molodeznaja in the Antarctic. Prime areas in Canada where very useful information could be obtained are Newfoundland and Resolute Bay.

5. Consideration should be given to an increased frequency of launchings. Assurances of at least two meteorological rocket observations per week increases the level of confidence by the scientists using the data. Where possible, a launch schedule which provides more than two launches per week is recommended so that synoptic features of the stratosphere may be followed and studied. Additionally, launch schedules should be provided which, within the capabilities of each participant, will allow phenomenological features to be studied, e.g., stratwarms, quasi-biennial and semi-annual oscillations.

6. Strong consideration should be given to a continuing effort to improve and develop reliable sensors as well as integrated ground, flight, and data systems, along with the particular procedures and techniques to meet the technical and scientific demands of EXAMETNET. These demands include higher accuracy, reliability, and altitude of the flight systems. Efforts should also be directed toward uniformity of standards, lower equipment costs, and improved utilization of manpower.

7. Consideration should be given to assisting the expansion of international meteorological sounding rocket activities. This could take many forms such as exchange of information on observational procedures and techniques, cooperative and coordinated launch campaigns, and representation on committees of international organizations and planning groups.

8. Consideration should be given to the participation in programs for the intercomparison of sounding rocket systems, such as that planned at Thumba, India, as well as to the broad dissemination of the results to the scientific and technical committees.

9. Efforts should be continued to obtain the comparison of satellite temperature sounder data with those from rocketsondes and radiosondes. These comparisons should use the "best" (that being derived by what is considered the best of perhaps several different methods) satellite derived temperatures, along with radiosonde and satellite information gathered at the time of satellite passage over the particular station. In addition, development of the optimum method for merging the satellite data with the *in situ* observations in an appropriate synoptic analysis technique should be initiated.

10. Consideration should be given to the full utilization of present (Nimbus III and IV) and future data from satellite temperature sounder experiments combined with rocketsonde data in the construction of global stratospheric analysis.

11. Consideration should be given to the utilization of measurements in the fields of Atmospheric Chemistry and Electricity. Preliminary research should, therefore, be oriented toward determining possible phenomenological interactions using data from EXAMETNET and other meteorological rocketsonde observations and parameters associated with chemistry and electricity, such as minor constituents.

    Plans should also be formulated for extension of EXAMETNET soundings to include such parameters if the preliminary studies yield optimistic results.

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