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WORLD METEOROLOGICAL ORGANIZATION

WMO SATELLITE REPORTS

SATELLITE CAPABILITIES TO 1995 FOR METEOROLOGY AND OPERATIONAL HYDROLOGY

by

DAVID S. JOHNSON

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National Oceanic and Atmospheric Administration
TIROS Satellites and Satellite Meteorology

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ABBREVIATIONS USED

ALT	ALTimeter, microwave (Japan, MOS-2 and 3)
AMI	Active Microwave Instrument (ESA, ERS-1)
AMSU	Advanced Microwave Sounding Unit (UK, USA-NOAA Satellites)
APT	Automatic Picture Transmission (METEOR, NOAA Satellites)
ARGOS	Name of French DCPLS (Used on USA NOAA Satellites)
ATSR-M	Along-Track Scanning Radiometer-Microwave (ESA, ERS-1)
AVHRR	Advanced Very High Resolution Radiometer (USA, NOAA Satellites)
CGMS	Co-ordination of Geostationary Meteorological Satellites
CZCS	Coastal Zone Colour Scanner (Japan, MOS-3; USA, Nimbus 7)
DCP	Data Collection Platform
DCPLS	Data Collection and Platform-Location System (France, on USA NOAA Satellites)
DCS	Data Collection System
DSB	Direct Sounding Broadcast (USA, NOAA Satellites)
ERS	ESA Remote-sensing Satellite
ERS	Earth Resource Satellite (Japan)
ESA	European Space Agency
EUMETSAT	European consortium to finance and manage operational METEOSATS
FGGE	First GARP Global Experiment
Fragment-2	Name given an 8-channel multispectral (80m resolution) scanning system (USSR, METEOR-Priroda)
GARP	Global Atmospheric Research Programme
GDPS	Global Data Processing System
GEOS	Geostationary Earth Observation Satellite (Japan)
GMS	Geostationary Meteorological Satellite (Japan)
GOES	Geostationary Operational Environmental Satellite (USA)
GOMS	Geostationary Operational Meteorological Satellite (USSR)
GTS	Global Telecommunication System
HIRS	High-resolution Infra-Red Sounder (USA, NOAA Satellites)
HR-FAX	High-Resolution Facsimile (Japan, GMS)
HRPT	High-Resolution Picture Transmission (USA, NOAA Satellites)
HRV	High-Resolution Visible scanner (France, SPOT)
INPE	Instituto de Pesquisas Espacias (Institute for Space Research) (Brazil)
INSAT	Indian National SATellite (geostationary, multipurpose)
IR	Infrared
LR-FAX	Low-Resolution Facsimile (Japan, GMS)
MDD	Meteorological Data Distribution system (EUMETSAT, METEOSAT)
MDUS	Medium-scale Data Utilization Stations for HR-FAX (Japan, GMS)
MESSR	Multi-spectral Electronic Self-Scanning Radiometer (Japan, MOS)
METEOR	Operational meteorological (polar) satellite system of USSR, now series 2
METEOR-Priroda	METEOR-Nature; USSR experimental (polar) satellite series
METEOSAT	European Geostationary meteorological satellite (ESA and EUMETSAT)
MOS	Marine Observation Satellite (Japan)
MRTVK	Multispectral television system includes MSU-M and MSU-S (USSR, METEOR-Priroda)

MSR	Microwave Scanning Radiometer (Japan, MOS)
MSS	Multi-Spectral Scanner (USA, Landsat)
MSU	Microwave Sounding Unit (USA, NOAA Satellites)
MSU-M	Optical-mechanical low-resolution scanning equipment (USSR, METEOR-Priroda)
MSU-S	Optical-mechanical medium-resolution scanning equipment (USSR, METEOR-Priroda)
MSU-SA	Optical-mechanical (170m resolution) scanning equipment (USSR, METEOR-Priroda)
MSU-VA	Electronic scanning equipment of high (30m) resolution (USSR, METEOR-Priroda)
NASDA	National Space Development Agency (Japan)
Nimbus	Name of experimental polar meteorological satellite (USA)
NOAA	Name of polar operational environmental satellite (USA, National Oceanic and Atmospheric Administration)
N-ROSS	Navy-Remote Ocean Satellite System (USA)
PRARE	Precise Range And Range-rate Experiment (ESA, ERS-1)
SAR	Synthetic Aperture Radar
SBUV	Solar Backscatter Ultra-Violet spectrometer (USA, NOAA Satellites)
SCAT	SCATterometer, microwave (Japan, MOS)
SEM	Space Environment Monitor (Japan, GMS; USA, GOES and NOAA Satellites)
SPOT	Système Probatoire de la Terre (French land satellite)
SST	Sea Surface Temperature
SSU	Stratospheric Sounding Unit (UK, on USA NOAA Satellites)
TDRSS	Tracking and Data Relay Satellite System (USA)
TIR	Thermal Infra-Red radiometer (Japan, GEOS)
TIROS	Television and Infra-Red Observation Satellite (USA)
TM	Thematic Mapper (USA, Landsat)
TOPEX	TOPography (of the ocean) EXperiment (USA Satellite)
TOVS	TIROS Operational Vertical Sounder (USA, NOAA Satellites)
TV	Television
UHF	Ultra High Frequency (radio band)
USA	United States of America
USSR	Union of Soviet Socialist Republics
VAS	VISSR Atmospheric Sounder (USA, GOES)
VHF	Very High Frequency (radio band)
VIS	Visible
VISSR	Visible and Infrared Spin Scan Radiometer (Japan, GMS; USA GOES)
VNIR	Visible-Near Infra-red Radiometer (Japan, ERS, GEOS)
VNTIR	Visible-Near and Thermal Infra-red Radiometer (Japan, ERS)
VTIR	Visible and Thermal Infra-red Radiometer (Japan, MOS)
WCP	World Climate Programme
WEFAX	WEather FA(X)csimile broadcast from geostationary meteorological satellites
WMO	World Meteorological Organization
WOCE	World Ocean Circulation Experiment
WWW	World Weather Watch

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Satellite Capabilities to 1995 for Meteorology and Operational Hydrology

(By David S. Johnson*)

1. INTRODUCTION

The period since the launch of the first dedicated weather satellite in 1960 has seen the rapid development and application of space technology in meteorology, hydrology and related fields. This technology played a vital role in the Global Weather Experiment, and the World Weather Watch (WWW) already is dependent on satellites for certain important global observations and telecommunication. However, it is recognized that there are many benefits yet to be derived from new or improved space technology and its application. Indeed, it is generally believed that the successful achievement of many, if not most of the long-term goals of the World Meteorological Organization (WMO) programmes is dependent on realizing the benefits potentially available from space technology.

It is relatively easy to predict the satellite systems and data which will be available in support of meteorology and operational hydrology through at least 1992. This results from the fact that the time between government planning for and the operational implementation of a specific satellite configuration usually is eight to ten years. Beyond 1992, it is easy to conjecture what useful technology might be made available, but this is of little value to WMO planning. Also, it usually is not possible for government representatives to indicate what their governments may do operationally ten or so years in advance because of the sensitivity of disclosing such views prior to a decision being taken by the governments concerned. Nevertheless it is felt that some assessment of the most probable ensemble of satellites which may be in operation during the last half of the next decade would be very useful in developing long-term plans for programmes of the WMO and its Members.

Because the following represents the views and judgements of the author only, without the review and endorsement of either the governments concerned or the WMO itself, it should not be considered an offical document of the Organization. Rather, it is an informal paper for which the author assumes full responsibility.

In describing the satellite systems that it is believed will influence meteorology and operational hydrology circa 1995, primary attention is given to a basic or "core" operational constellation of satellites and related services. Only limited attention will be given to the large variety of specialized observations which may be available, at least temporarily through experimental programmes. In other words, emphasis is placed on probable continuing operational systems and services which can be expected to support

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* Consultant to the World Meteorological Organization (WMO)

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priority needs on a routine basis. However, the discussion is not limited to meteorological satellites; other environmental satellites are considered, and telecommunication functions also are included as they relate to meteorology and operational hydrology. In this report, the status and outlook is presented in three categories: meteorological satellites, other environmental satellites, and communication satellites.

It is hoped that this form of presentation will be helpful to the WMO and its Members as they consider long-term plans to utilize space technology effectively and in developing statements of service needs.

2. CURRENT SATELLITE PROGRAMMES

WMO publication No. 411, Information on Meteorological Satellite Programmes Operated by Members and Organizations (1), provides some information on current programmes. However, at this time it does not include other environmental and communication satellite programmes which can or do contribute to WMO programmes. Two important examples are land observing satellites, of special interest to hydrology and water resources, and to the World Climate Programme; and various types of common-carrier and specialized communication satellites, of particular importance to the World Weather Watch. Publication No. 411 now is being revised to include other environmental satellites reported by Members which are applicable to WMO Programmes.

Meteorological Satellites

During the past 25 years, meteorological satellites have become an indispensable part of the Global Observing System and, as such, their data have become an integral part of the international meteorological data base freely exchanged among nations for the benefit of all. Much broader application of their data also has evolved than just "synoptic meteorology". Meteorological satellites now play an important communication role, both in collecting in situ data and in dissemination of data and products. Both the communication and remote sensing functions support hydrology, oceanography, agriculture, climate monitoring and other fields, as well as meteorology. This broader role which has evolved needs to be kept in mind when the label "meteorological satellites" is used.

The parameters of meteorological satellites in routine use today are summarized briefly in Appendix I; additional details are contained in (1). Two basic classes of spacecraft are used: Those at low altitude (less than 1000km) in nearly a polar orbit provide complete global coverage (twice a day for each satellite) and customarily are used for precise radiance measurements needed for temperature and water vapour soundings, sea surface temperature and radiation fluxes. Those in geostationary orbit (36,000 km above the equator) provide a continuous view of a large portion of the earth (except the polar areas). The latter are used primarily for a "continuous weather watch", to produce wind estimates by measuring the motion of clouds viewed over a period of one to two hours, and for communication functions.

Both types of satellites are used in complimentary ways. Although the polar satellite data usually have higher resolution and precision, the geostationary satellite data often are used to filter out the effect of clouds

which in some areas may obscure surface features, such as the sea surface for temperature determination. By processing a series of images acquired over a period of several hours, moving clouds in partly cloudy regions can be eliminated by digital filtering in a computer. The output is a single, average image field of the surface without cloud interference.

The present operational meteorological satellites in polar orbit are the METEOR-2 series of the Union of Soviet Socialist Republics (USSR) and the NOAA series of the United States of America (USA). The operational geostationary satellites at present include the Geostationary Meteorological Satellite (GMS) series of Japan at 140°E, the Geostationary Operational Environmental Satellites (GOES) of the USA at 75 and 135°W, the Indian National Satellite (INSAT) at 74°E, and the METEOSAT series at 0° of Europe.

The quantitative data derived by the operators from the satellite observations are exchanged internationally via the WWW Global Telecommunication System (GTS). Included are soundings, upper air winds and sea surface temperatures. Some of the cloud images or analyses thereof receive limited distribution via the GTS. However, they are disseminated primarily by broadcast from the satellites, e.g. Automatic Picture Transmission (APT), WEather FACSimile broadcast (WEFAX), and High Resolution Picture Transmission (HRPT). Many analyses are derived from the satellite data for specialized uses which are transmitted in a variety of ways depending on the application. Examples are maps of ice and snow coverage and sea surface temperature gradients; clear land surface images analysed in terms of vegetative index; cloud analyses; and weekly, monthly, seasonal and annual averages of different parameters. As an example of the array of routine observational satellite products produced, see Appendix II.

Other Environmental Satellites

No land or specialized ocean observation satellites are in routine operation today (defined as daily, scheduled operation with a series of spacecraft to assure continuity over a period of years). However, a large amount of high resolution, multispectral imaging-type data are available. The METEOR-Priroda series of experimental satellites frequently provides high resolution images of land surfaces and ice. So far as is known, spacecraft in this series will continue to be launched for experimental purposes. Landsat 5, the last satellite of that series which is now planned, still is operating. The performance characteristics of these satellites are summarized in Appendix III. The data from these satellites have been useful in hydrology (2) and studies of a variety of land-surface processes (3), such as desertification (4), vegetative index (5) and surface albedo (6). There is a very long period between observations (several days) with these satellites because of their limited fields of view. Therefore, increasingly these high resolution data are used in conjunction with the more frequent image data from meteorological satellites (e.g. the Advanced Very High Resolution Radiometer (AVHRR) 1 km resolution image data from the NOAA series) to provide for time continuity, for example, in vegetation monitoring (7).

Communication Satellites

Communication satellites used in WMO programmes are of two types. Most widely used are those operated in common-carrier service for point-to-point communication, such as the Intelsats. There is a growing number of regional and national communication satellites as well in this

category. Growing use is being made of these satellites in the Global Telecommunication System (GTS), resulting in both increased reliability and rapidity of data exchange. The second class of satellites is those which provide specialized communication services, most notable of which is Inmarsat for communication to and from ships at sea. It is expected that the use of Inmarsat will improve significantly the collection of surface observations from merchant ships in terms of quality, timeliness and improved global coverage.

Meteorological satellites also provide specialized communication functions by collecting observations (from automatic stations on buoys and ships, ASDAR on aircraft, and suitably equipped land stations) and broadcasting these data, as well as remotely sensed data acquired by the satellite to local receiving stations within radio range of the satellite. The GOES system also is used to broadcast to the Western Hemisphere analyses and prognostic charts produced by WMC-Washington. Finally, the NOAA series of spacecraft in polar orbit also includes the ARGOS system for locating moving platforms (e.g. buoys) equipped with automatic observing equipment.

3. NEAR-TERM OPERATIONAL SATELLITE DEVELOPMENTS

Because of the long lead time for financing, designing and constructing complex satellites, the characteristics of the satellites to be launched during the next six to eight years are reasonably well defined. In most cases, the developers and operators of these satellites disseminate information to the world community. Such information is the basis of this section of the report. There may be some surprises in cases where nations defer any external discussion until after successful launch of a new spacecraft type. Also, there are some land and ocean satellite observing programmes which may be approved in the next year or two which could lead to launches in the 1989-1994 time period.

Meteorological Satellites

(Europe)

A new European consortium, EUMETSAT, is being established to carry the METEOSAT programme into the operational phase. EUMETSAT is contracting with the European Space Agency (ESA) for spacecraft construction, launchings and at least some of the required ground operations. Three satellites are planned initially for launch in 1987, 1988 and 1990; they are expected to give operational coverage up to at least 1995. An existing prototype METEOSAT is scheduled to be refurbished and launched in June 1986 to assure continuity in the early part of the programme. The new satellites will be very similar to the present METEOSAT with the following changes:

- All three imaging channels (visible, water vapour and thermal infrared window) will operate simultaneously;

- A Meteorological Data Distribution (MDD) capability (12 channels, 2400 bits/sec each) will be added, primarily to supplement the GTS in Africa;

o The Data Collection Platform (DCP) interrogation capability will be deleted, but the basic Data Collection System (DCS) will be continued.

(India)

India plans to launch INSAT-IC (the same functional design as the present spacecraft) in mid-1986. The follow-on programme in India is under study and no information is available regarding the options being considered or the time schedule for decision and implementation.

(Japan)

The GMS-3 spacecraft of Japan was launched in August 1984 and is the current operational spacecraft at 140°E; it is functionally identical to GMS-1 and 2. Japan is studying the design approach to GMS-4 and subsequent spacecraft. They are considering the possibility of adding a water vapour channel to the imager (12). The space plan of Japan includes continued operation of a geostationary meteorological satellite at 140°E.

(USSR)

The USSR (9) in 1982, envisioned trends in the future development of the METEOR-2 spacecraft up to 1985 to include an increase in the altitude to provide continuous imaging coverage at the equator, provision of orbit adjustment "to synchronize (phase the orbits of) the three vehicle system to increase the system efficiency", and the introduction of an improved, higher resolution infrared sensor with local direct broadcast (in addition to the present daylight APT). It also is envisaged that microwave equipment will be introduced to provide all-weather observations of ice and snow cover and to determine cloud water content. An eight-channel infrared radiometer for temperature soundings has been flying experimentally on the METEOR-2 series. It seems reasonable to suppose that an operational sounding programme will be introduced in the not too distant future.

The USSR also is developing a series of Geostationary Operational Meteorological Satellites (GOMS), the first of which may be launched before 1988 (9, 13). It will be located at 70°E. Indications are that this will be a continuing series. The spacecraft will be three-axis stabilized and include a two-channel imager, visible and 8-11um, with resolutions of 1-2 and 5-8km respectively. The characteristics of its data collection and dissemination subsystems will be in conformity with the CGMS standards. Increased emphasis is being placed on the dissemination function; there will be two facsimile (WEFAX) channels and two channels for broadcasting digital data. The spacecraft is designed to carry varying experimental equipment in addition to the operational equipment.

(USA)

The decision has been taken by the USA to continue its operational meteorological satellite programme as a governmental function. In another effort to reduce the cost of the programme, the President has proposed reducing the number of polar orbiting (NOAA) spacecraft in operation from two

to one. However, so far the Congress has rejected this proposal and instead has indicated its desire to see increased co-operation with other countries in support of the operational system (France and the U.K. now are contributing subsystems). Discussions held so far give cause for optimism that greater collaboration may be feasible (12). Therefore, it is predicted that the basic two-satellite NOAA series in polar orbit can be continued indefinitely. There has been no discussion in respect of a reduction of the two-GOES geostationary satellite system.

There is a strong possibility of some interruption in GOES service during the period 1984-1986 because of recent premature spacecraft failures. No more GOES spacecraft will be available for launch until two now being built are delivered beginning in late 1985 or in 1986. No similar problem exists in the NOAA series as average lifetimes exceeded expectations and adequate spacecraft are available for launch when necessary.

The current GOES series of spacecraft is expected to terminate about 1990 at which time it will be replaced by "GOES-NEXT" now in the procurement process. The current projection is that the first GOES-NEXT will be launched in 1989. The NOAA spacecraft now on order should be exhausted in the 1990-1993 time period, requiring additional spacecraft at that time. Funding approval is expected in 1985 for three additional NOAA spacecraft (K, L and M).

The changes in GOES-NEXT and NOAA K, L and M are covered in Section 4, since they most likely will provide the basic operational system of the USA during the 1995-1997 time period. GOES-NEXT will provide simultaneous imaging, soundings, WEFAX and data collection, instead of the time-sharing arrangement of the present GOES. The earth location and gridding process will be accelerated and increased in accuracy, and the number of channels and quality of both the imaging and sounding systems will be improved. The principal change on NOAA from the present system will be the introduction of the Advanced Microwave Sounding Unit (AMSU) for all-weather soundings of improved quality.

Other Environmental Satellites

Most of the other environmental satellites, primarily oriented to land or ocean observation, which are planned for this time period cannot be considered as part of a routine operational series expected to continue indefinitely without interruption, as has been the case with most "operational" meteorological satellites. Perhaps the only exceptions to some degree so far are the French SPOT (Système Probatoire d'Observation de la Terre) and USSR METEOR-Priroda series. Three SPOT spacecraft are under construction; they are designed to provide high resolution multispectral (20m resolution) and panchromatic (10m) images primarily of land features. Five METEOR-Priroda spacecraft were launched in the 1974-1980 time period. Three new multispectral imaging sensors with resolutions of 170, 80 and 30m were used on the 1980 launch. These sensors are described as "prototype equipment to be mounted on a vehicle of the continuously operating quick-look subsystem for earth resources research "(9). While both of these series may provide frequent coverage during the next eight years or so, primarily of land areas, the image data are not available quickly or for all land areas on a daily basis. In the case of SPOT, the image data must be purchased at a significant cost (as is the case now with Landsat), and the operator gives preference for the limited coverage to those paying for it. The arrangements and availability of image data from the METEOR-Priroda series are not known.

The other approved spacecraft programmes are, initially at least, for one or two launches of each type for development, test and primarily experimental use. Nevertheless, their data may be of considerable value to research and climate activities of the WMO programmes. The following spacecraft, as well as SPOT and METEOR-Priroda, are described briefly in Appendix III.

- Brazil: Remote sensing satellite, launch 1991 and 1992;
- European Space Agency: ESA Remote-sensing Satellite, ERS-1, ocean emphasis, launch 1987;
- India: Indian Remote Sensing (IRS) Satellite, land emphasis, tentatively planned for launch in 1986;
- Japan: Marine Observation Satellite, MOS-1, ocean emphasis, 1986; Earth Resource Satellite, ERS-1, land emphasis, 1990.

The United States now is in the process of establishing a commercial land remote sensing satellite programme in private industry. The United States is planning a single spacecraft mission called "Navy-Remote Ocean Satellite System" (N-ROSS). If it is approved in the fiscal year 1985 budget, it is expected that the spacecraft will be launched in 1988 or 1989. The orbit will be sun synchronous at an altitude of about 800km, providing global coverage about every 40 hours. The payload, which is expected to operate for at least one year, will include an altimeter, microwave imager, scatterometer and a single-channel radiometer. The USA expects to have an operational land remote sensing system in place before the end of this decade. It is expected that the land system will be operated as a commercial venture, the details of which are not available at the time of writing.

It is expected that flights of relatively short duration of experimental land and ocean sensors on "platforms of opportunity" (e.g., space stations and shuttle) will continue. Examples are metric cameras and synthetic aperture radars (SAR). In some instances, it may be possible to program the operation of the sensors to support specific geophysical experiments to which they may make a significant contribution.

Special note should be taken of the requirement in the World Climate Research Programme for satellite observations of ocean currents (by precision altimetry and orbit tracking) and surface winds or stress (by scatterometer) (10). Such data will be particularly important for the World Ocean Circulation Experiment (WOCE) being proposed for the latter part of this decade and the first half of the next. The European ERS-1 planned for 1987 includes the necessary sensors to achieve this. The United States and France are considering the flight of TOPEX (ocean topography experiment), a spacecraft specifically configured to meet the requirements of WOCE; approval of this programme may come in 1985. TOPEX will be equipped with a precision altimeter and orbit determination equipment to detect departures of the sea surface from the mean geoid of 10 cm or less. As with ERS-1, these data can be used to determine the slope of the sea surface which is related to the magnitude and direction of the ocean currents. Both the USSR and Japan also are considering the flight of altimeters and scatterometers, as well as synthetic aperture radars, on their METEOR-Priroda and MOS satellites respectively. However, no information is at hand that governmental approval has been granted for the follow-on spacecraft containing these sensors.
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Taking into account the totality of land and ocean satellite sensors approved or planned for flight in the time frame 1986-1994, it seems reasonable to expect good coverage during much of this period, even though routine, continuous coverage with data products rapidly processed for forecast and warning use may not be available.

Communication Satellites

Growth and diversification of communication satellites and services can be expected to continue. Both national and regional satellites (for a consortium of nations, e.g. Arabsat) will contribute to improved communications, particularly within the developing nations, which should contribute to the improvement of the GTS.

The use of satellites for specialized communications also will grow, both within meteorological satellite programmes and in specialized service programmes, such as marine and aeronautical communications. Another example is Brazil's environmental data collection satellite programme (11) in which spacecraft are expected to be launched in 1989 and 1990 to collect meteorological and hydrological data from about 500 remote ground stations for relay to a central location.

The development of direct broadcast (radio and television) satellites to be introduced during the last half of this decade is noteworthy on two counts. First, they should increase the opportunity for national meteorological and operational hydrological services to provide wide and rapid dissemination of forecasts and warnings. Second, the technology being developed will hasten the wide-spread introduction of data transmission to small, inexpensive ground receiving terminals. Again this could be of potential value to the WWW for dissemination of data and products, if the tariff structure which evolves is reasonable.

The cost of communication services is of major concern to Members in implementing an effective WWW. It seems likely that the next ten years will see both an increase in the diversity and global coverage of communication techniques, and a reduction in cost of services. This will result from both the expansion of communication satellite services, and the wide-spread introduction of fibre-optics communication circuits in areas having high demand for point-to-point communication. In such areas, this technique is much less expensive than satellites. Also, there is no practical limit to the number of circuits which can be used simultaneously as there is with communication satellites. The spread of satellite and fibre-optics systems throughout the world should lead to a significant lowering of communication costs, except perhaps within those nations where the governments wish to maintain high rates to offset the cost of other governmental services which are provided at a loss.

4. EXPECTED DEVELOPMENTS CIRCA 1995-1997

With few exceptions, there is little firm information regarding the programmes which will exist after about 1995. There are many technological ideas and preliminary plans, but little information regarding what programmes are likely to be approved and funded. Thus, Parts 4, 5 and 7 reflect the judgement and degree of optimism or conservatism of the author.

There are several factors which will influence significantly the level of space activity which may contribute to meteorology and operational hydrology during this time period:

- Several new countries are developing their own space technology programmes (e.g., Brazil, China and India). The number certainly can be expected to grow by 1995, and some of this new activity will be directed toward atmospheric, oceanic and land observations.

- There is growing interest and activity in the development of reusable launch vehicles and in large space stations. By 1995, this may lead to opportunities to add new observational capabilities at lower relative cost than today.

- The growth in world-wide dependence on satellites for communication and earth observation will result in increased stability of support for operational satellite systems, a vital factor for most WMO programmes.

- The economic status in those nations contributing to the space programmes has a significant influence on these programmes because of their very high cost. This has been evident during the recent recession. In favourable economic times, one can expect to see a growth in the number and diversity of national programmes. In adverse times there is a reduction in space programmes which don't have direct economic or social benefit, and there is a trend toward more joint ventures.

The uncertainty with which one can forecast these factors 10 or more years in advance contributes significantly to the uncertainty of forecasting the space programmes which indeed will be available about 1995. Taking into account the recent state of the economy and all of the other trends listed above, it appears that there is reason for optimism regarding a limited but steady growth in the application of space technology to earth observation and communication.

In the remainder of this section and in Part 7 the information available and judgement on the probable programmes of the various nations and organizations already launching satellites will be summarized. Part 5 will describe the core operational satellite systems which the author believes will provide the primary continuing operational support to meteorology and operational hydrology during the last half of the next decade.

Meteorological Satellites

In this section, emphasis is placed on those announced development activities prior to 1995 which it is believed are most likely to influence the character of operational systems beginning about 1995 and extending through most of the remainder of the decade. There are many other developments and tests contemplated, such as those involving the use of space-borne lasers, which it is felt will not come into routine operational use in that time frame.

In the descriptions that follow, it should be kept in mind that most are proposed programmes at this time. Clearly, not all of them will be approved at the proposed levels of activity. On the other hand, one can expect programmes to develop which have not been announced publicly in 1984.

(Europe)

The approved series of operational METEOSAT geostationary spacecraft should provide continuity until about 1995. No decision has been taken regarding continuation of the programme after that time. The European Space Agency and its interested Members are beginning to consider the technical alternatives for the development of an advanced METEOSAT which might be a possible prototype of a second generation operational satellite for Europe with a launch about 1994. Thus, there are two important decisions ahead for the interested nations in Europe. Will the operational programme be continued beyond 1995? What will be the configuration of the satellites and resulting services? The author believes that the answer to the first question will be yes. The answer to the second question is much less clear; it is probable that there will be a modest increase in resolution, particularly over Europe and adjacent oceans, and at least some limited form of atmospheric sounding capability will be added.

(India)

No information is available regarding the future plans of India. It seems reasonable to expect that they will want geostationary satellite coverage of the Indian subcontinent and ocean available to them.

(Japan)

A recent paper (14) outlined plans for satellite developments up to the year 2000 prepared by the Space Development Commission of Japan which are now being studied by the Remote Sensing Technology Center. Included are two developmental Geostationary Earth Observation Satellites (GEOS). GEOS-1 is proposed for launch in the first half of the 1990s and GEOS-2 in the last half. The preliminary outlines for each spacecraft follow:

GEOS-1

- Visible, Near Infrared (VNIR) radiometer, 4 channels, 1km resolution
- Thermal Infrared (TIR) radiometer, 4 channels, 5km resolution
- Microwave Scanning Radiometer (MSR), 3 channels: 18, 24, 31 GHz
- Data Collection System (DCS)
- Real time data system

GEOS-2:

- VNIR, no change
- TIR, increase resolution to 3km

- Synthetic Aperture Radar (SAR), X band, 25m resolution
- MSR, 5, 10, 20, 30 GHz
- DCS, no change
- Data relay system
- Real time data system

The microwave instruments in geostationary orbit included above are indicative of very ambitious plans. Because of their 36,000 km altitude and today's technology, it is very difficult to contemplate flying such systems on geostationary satellites with useful resolution, sensitivity and precision. A SAR with 25m resolution would require very large spacecraft weight, volume and power. However, the inclusion of GEOS in Japan's remote sensing planning indicates a strong interest in continuing a geostationary satellite programme, providing improved capabilities, and increasing the emphasis on ocean observations. These plans do not appear to have been developed in detail nor have they received approval by the government.

It is reasonable to expect the GMS programme to be continued. One publication (15) indicates that plans of Japan's Space Council and National Space Development Agency (NASDA) include the launching of GMS-4, 5 and 6 in Fiscal years 1989, 1994 and 1999, and an experimental satellite in 1997. As far as technology improvements in the operational programme circa 1995-2000 are concerned, the addition of infrared channels for atmospheric sounding seems more plausible than microwave channels. However, such an addition most likely will be dependent on government decisions on the development and use of this technology in Japan.

(USSR)

No information is available regarding the plans of the USSR for meteorological satellites in the 1990s. It is expected that emphasis will be placed on improved soundings, as well as the extensive use of microwave sensors for "all-weather" capability and more effective coverage of high latitude areas in winter. There should be continued improvement in the spatial and spectral resolution, sensitivity and precision of sensors.

The USSR also should be interested in continuing GOMS geostationary satellite coverage of the Indian Ocean-central Asia area. However, the USSR may not be motivated to add sounding capability because of the high latitude of most Soviet territory. For the latter reason, the USSR (9) is investigating "the problem of launching similar satellites into orbits with polar inclination and 24-hour revolution periods to observe the regions situated northward and southward of 50° north and south latitudes respectively that cannot be observed from geostationary satellites". If such spacecraft are introduced, it may be more useful to the USSR to incorporate sounding capability in them rather than GOMS.

(USA)

New GOES and NOAA spacecraft procurements are planned to meet the observational needs of the decade of the 1990s. Three "GOES-NEXT" spacecraft (GOES I, J and K) are being procured with the first launch planned for 1989-1990. It is expected that the NOAA-K, L and M procurement will begin in 1985-1986, with the first launch when needed some time between 1990 and 1993. It is considered likely that these spacecraft configurations will be used throughout most of the decade of the 1990s. There could be some sensor changes later in the decade provided they can be accommodated within the basic power, weight, volume, control and communications capability of the spacecraft. Thus, the capabilities of these two spacecraft likely will prevail with few changes in the 1995-1997 time frame.

The performance specifications for GOES-I, J and K (16) represent a major departure from the current GOES series:

- Simultaneous full-time (except during eclipse) imaging, sounding, data collection and WEFAX broadcast functions, each independently controlled;

- Five-channel imager similar to the present Advanced Very High Resolution Radiometer (AVHRR) on NOAA spacecraft; resolution 1km in visible channel, 4km in 3 thermal infrared window bands, 8km in 6.7-7.0 um H_2O band. Image area between 60°N and S latitude obtained in 25 minutes or less. Calibration and earth location data available within 3 minutes of sensing. Accuracy of location data at the satellite sub-point, 2km or better. Registration of data for simultaneous channels or images adjacent in time, 1km at the sub-point;

- Improved 14-channel infrared sounder designed to produce soundings comparable to the High-resolution Infra-Red Sounder (HIRS) on the current NOAA polar orbit satellites. Field of view about 8km at the satellite sub-point, with coverage over an area of 60° great circle arc radius from the satellite subpoint. A 3000x3000 km area will be covered within 40 min. Earth location data will be available within 3 minutes of sensing with an accuracy of 4 km or better at the sub-point. Registration of soundings acquired in the same sounding interval will be better than 1km at the sub-point, and 4km for soundings acquired in two consecutive sounding intervals.

Most notable is the very large improvement in the quality and amount of imaging and sounding data, and the speed and accuracy with which earth location data will be provided to the user. The characteristics of the WEFAX channel will not be changed, but the provisions for full time transmission will enhance data dissemination in the Western Hemisphere. There will be no functional change in the Space Environment Monitor (SEM) or the Data Collection System (DCS) from the current systems.

Few changes in the functional design of NOAA-K, L and M are contemplated. The primary change is in the sounding system. It is planned to replace the Microwave Sounding Unit (MSU) and Stratospheric Sounding Unit (SSU) with the Advanced Microwave Sounding Unit (AMSU). The AMSU includes two parts. AMSU-A is a 15 channel instrument primarily for temperature sounding.

It has a horizontal resolution of about 60 km at the satellite sub-point. AMSU-B, to be provided by the U.K., contains five channels for water vapour profiles; it will have a horizontal resolution of about 20 km. The main advantages of AMSU are the elimination of cloud interference in both temperature and humidity determinations and somewhat improved vertical resolution compared to the present soundings. It also will provide information on ice beneath clouds and global rain patterns.

Since the AMSU will be a new instrument, and it is uncertain how well it will perform in the lowest layers of the atmosphere over land, the High-resolution Infra-Red Sounder (HIRS) will continue to be flown, at least on the first few launches. After successful demonstration of AMSU, if HIRS is found to add little or no information to the soundings derived from the AMSU data, it may be possible to discontinue HIRS on later spacecraft. No significant changes in the functional specifications of HIRS are planned. The visible channel spectral response will be broadened to improve the accuracy of earth radiation budget determinations.

The AVHRR will be changed slightly from the current model. The spectral interval of channel 2 will be changed from 0.725-1.10 um to 0.82-0.87 um. A sixth channel will be added, 1.57-1.78 um, which can be switched by ground command to replace the band 3.55-3.93 um. It is expected that the new band will be used in daylight and the old one during the night. The new channel will permit improved discrimination between snow and cloud during daylight.

No functional changes are planned for the Solar Backscatter Ultra-Violet (SBUV) instrument to determine ozone profiles and total amount; the Data Collection and Platform-Location System (DCPLS) now provided by France; the Space Environment Monitor (SEM); or the Automatic Picture Transmission (APT) and High Resolution Picture Transmission (HRPT) formats, transmission characteristics and quality. Because of the change in the sounder, the Direct Sounding Broadcast (DSB) format must be changed, affecting that portion of the HRPT and beacon transmission. Also, it is necessary to shift the beacon frequencies from the Very High Frequency (VHF) band because of a change in radio frequency allocations. It is proposed to shift to 1694.1 and 1694.9 MHz for the beacon (and DSB).

Other Environmental Satellites

It seems clear that there will be a few land observation satellite programmes in at least semi-continuous operation, based on the current programmes and plans. Routine operational programmes, such as SPOT and the proposed USA commercial systems will be increasingly dependent for survival on economic return for services rendered. This means that users needing high resolution imaging data must anticipate paying for these data, which probably will limit their use to those environmental applications of major economic or social importance. If the economic return from land remote sensing does not reach the levels some proponents predict, one can expect joint efforts to emerge among some of the satellite operating entities which would assure the financial viability of land remote sensing from space.

(SECGEN 917)
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Imaging will still be the predominant function of land remote sensing. Resolution probably will remain about 10 meters maximum, but with more spectral channels at high spectral and spatial resolution. The resolution in the thermal infrared should increase significantly in 10 years. To provide more frequent coverage, there should be a trend to increased altitude coupled with wider swath width of sensor coverage. Also, the use of high resolution (10-30m) synthetic aperture radar (SAR) which is not affected by clouds should become routine by 1995. The SAR also will be important for ocean observations, particularly of the extent and character of sea ice. In this time frame, one may also see a significant reduction in the cost and time required for the processing of SAR data. This is essential if these data are to be used routinely in global operational programmes.

Ocean observations from space should see significant growth during the 10-year period. It may be premature to expect routine operational ocean observing systems by 1995. However, it certainly seems likely within a few years thereafter, perhaps through a multinational consortium or closely co-ordinated programme. There are few technological uncertainties. And the growing interest in the oceans and their importance, especially the contiguous economic zones, should result in strong support for improved ocean observations on a routine basis.

Even today, sea surface temperatures and the extent of sea ice are provided routinely using data from meteorological or environmental satellites. However, more microwave observations are needed for "all-weather" capability and to provide information on ocean currents, surface winds and ocean waves. Space tests already have demonstrated the feasibility of such observations. Plans for experimental programmes during the next several years indicate that some operational capability is very likely by 1995.

Communication Satellites

The communication trends discussed in Part 3 should continue into 1995 and beyond. Higher power, smaller antenna beam widths, more sophisticated modulation and transmission schemes, and greater efficiency will result in both a dramatic increase in communication capacity world-wide compared to today and the ability to use very small ground terminals in less populated areas for the kind of bandwidths needed for the GTS. One would hope that the dramatic increase in both space and terrestrial communication capabilities and specialized services will result in increased deregulation and a significant decrease in charges for these services so that the Members of WMO can fully implement the planned GTS.

5. PREDICTION OF BASIC OPERATIONAL SYSTEMS, 1995 - 2000

Again, the reader is cautioned about the risks associated with forecasting the scope of operational satellite systems which can contribute to meteorology and operational hydrology in the time period 1995-2000. The factors and judgemental aspects discussed in the introduction to Part 4 apply equally well to Part 5. Also, in this Part, the author is injecting some recommendations to increase the utility of the satellites. The time period 1995-2000 is chosen since the GOES-NEXT and NOAA spacecraft likely will cover this period; the other next generation spacecraft likely to be introduced in the same period are now under study in both Europe and Japan, and probably in other countries as well.

Primary emphasis is placed here on a basic or core constellation of satellites which it is believed must exist to provide routine operational services. Of course most meteorological and operational hydrology programmes also will be supported by the same systems; additional satellite possibilities relevant to some of these programmes also will be mentioned here and in Part 7.

It must be recognized that advanced satellite systems are not enough. If they are to benefit users, much more should be done to provide a wide variety of highly reliable, high quality data reception, processing and analysis schemes and facilities for use at meteorological centres and local levels. It is believed essential that such schemes and facilities be designed for a wide range of national capabilities and needs.

Geostationary Meteorological Satellites

It is expected that the four geostationary meteorological satellites of Europe, Japan and the USA will continue in operation and that they will use improved designs compared to today. There should be at least one geostationary satellite in routine operation over the central Asian-Indian Ocean area; more likely there will be at least two, which may provide for improved continuity.

(Imaging)

All satellites will have at least three spectral channels (visible, water vapour and infrared window). Three or four will have five channels (adding the 3.7 um band and split water vapour window for improved regional sea surface temperature determinations). It seems reasonable to expect 1km visible and 4 km infrared resolution.

All geostationary satellites contributing to meteorology and operational hydrology should be capable of essentially instantaneous direct broadcast of the images; the power and bandwidth should be compatible with rather modest receiving facilities using a 3-4m diameter antenna. This will arise from the continued improvement in transmitter and solar cell efficiencies, and receiver sensitivity. It may be necessary to limit the resolution (e.g., 2 km) and/or number of channels of the data transmitted in order to have a suitable signal for reception at a local user terminal. This could become the primary source of image data for those forecast and warning offices within the field of view of a geostationary satellite, replacing image reception by APT or WEFAX.

(Atmospheric Soundings)

The GOES satellites and perhaps one other will have infrared sounding capability. In the former case, it will be a 14-channel instrument with a maximum resolution of about 8 km at the satellite sub-point. It will produce soundings in clear to partly cloudy areas equivalent to those produced by the TIROS Operational Vertical Sounder (TOVS) on the current NOAA satellite series. However, it will be capable of repeatedly covering an area 3000x3000 km every 40 min. It is likely that the satellite operator will use the sounder for frequent coverage of areas of bad weather of primary concern to national interests rather than for full coverage of the earth's disk; the latter can be obtained about every six hours from the two-spacecraft polar orbiting system.

On a limited regional basis then, one should expect improvements in short period severe weather forecasts and warnings as a result of both improved imaging from geostationary satellites and the advent of high quality soundings coupled with interactive processing.

(Winds)

Not much improvement is foreseen in the provision of winds from geostationary satellites. There should be a modest improvement in cloud tracking accuracy as a result of more accurate navigation on the next generation of spacecraft. Those spacecraft equipped with sounders may be able to increase the accuracy of upper-level winds by improved altitude estimates through vertical "temperature slicing" of the high resolution images by means of the lower resolution temperature channels of the sounder. This improvement will be limited because of the relatively low vertical resolution of the sounder channels. The use of stereo viewing by adjacent satellites is not expected to come into widespread use, nor will microwave sensors be added to the operational geostationary satellites in this time frame.

(Data Collection)

Data collection systems (DCS) will be similar to those now in use. National and international agreement should be sought for multi-national use of DCS on all of the geostationary satellites by WMO Members. Highest priority should be placed on this use for the collection of data from automatic meteorological and hydrological stations as well as regular stations where standard communications continue to be inadequate.

To take full advantage of satellite communication, it should be possible, even with today's technology, to produce highly reliable, low cost data collection platforms (DCP's) and receivers. A major effort is needed to develop reliable and low cost sensors to work with the DCP's. The receivers should be about the same cost and complexity as present APT receivers, but more reliable (no tracking antenna or photo recorder). If DCP's are used along with receivers at the national or regional level, it may be possible to meet the basic observational data needs within data-sparse and less developed areas of the world while at the same time the data are being relayed on the GTS.

(Data Dissemination)

While data dissemination by direct broadcast from geostationary satellites (e.g. WEFAX) to small receiving stations will continue, changes can and should be introduced to make it much more useful to WMO Members. Expansion should be sought to two simultaneous channels (perhaps two sub-carriers) on each satellite and the transmission changed from the present analog format to digital for both alphanumeric and pictorial data. At the same time, the power flux density of the received signal should remain high. By the above steps, the dissemination capacity can be increased several fold, and the reliability and quality of the received data increased significantly with only a modest increase in the cost of the receiving units. In this regard, major effort should be directed to the development of low cost, high reliability ground terminals using solid state, "plug-in" modules, microprocessors and "firm ware" (non-destruct software).

This approach could provide a basic minimum service for the relay of broad-scale alphanumeric data, analyses and prognoses from the GDPS to all nations. It will require arrangements for data and product generation and transmission via the respective satellite operators to meet the basic regional needs. Agreement of the satellite operators should be sought regarding the transmission characteristics and scheduling. However, if the planning and co-ordination were implemented now, it should be feasible to initiate the improved dissemination by 1995. Ample lead time will be required for the development, procurement and institution of the necessary ground receiving equipment.

Polar Orbiting Meteorological Satellites

It is expected that some form of polar-orbiting satellites will continue to provide data and services for meteorology and operational hydrology. The most critical elements of the polar orbiting spacecraft are the APT service, data collection and platform location system (DCPLS), and atmospheric soundings. The latter two are essential for global forecasting while the former provides basic minimum support at the national level for short period storm warning. However, by 1995, it is hoped that many Members in the tropics and mid-latitudes will have switched to the use of the more frequent geostationary satellite images for short period forecasts and warnings.

At least two nearly identical, high quality sounding and DCPLS instruments must be available in orbit to assure continuity of these vital services. It is preferable, although not essential, that the two orbits be time phased such that each point on the equator is covered approximately once every six hours. This will require close collaboration among those flying pairs of these sensors, if it should not be the same organization. This is an important matter requiring early attention if the continuity of the highest quality soundings and platform location service are to be assured in the 1995-2000 period.

The preceding should not be interpreted as the only necessary or likely functions to be performed by polar satellites in the 1995 time period. Rather, they are an indication of the highest priority functions needed for the basic mission of global weather forecasts and warnings, and where planning and co-ordination are particularly critical at the present time. The following paragraphs briefly summarize the observations and services that likely will be available from polar orbiting satellites during the last half of the next decade.

(Imaging)

Instruments comparable to the present AVHRR (5 or 6 channels, 1km resolution, high precision) can be expected on all polar orbiting satellites.

In addition to cloud data, the imagers will be used to derive many products. Global sea surface temperatures will be available with an accuracy of 0.5 - 1°K and resolution of at least 50 km. Even in cloudy areas a resolution of about 100 km will be feasible with the Advanced Microwave Sounding Unit. Maps of ice and snow cover and vegetative index will continue to be produced. However, they would be of higher quality if produced regionally or nationally from direct broadcast (HRPT) data. The satellite

operators are in the best position to produce lower resolution global products for climate monitoring. The multispectral image data will continue to be used to monitor the backscattered solar and emitted thermal radiation for climate purposes. (It is not likely that the results of the Earth Radiation Budget Experiment will be available in time to influence the sensors to be flown operationally circa 1995.)

It is probable that a few of the polar orbiting satellites will include a microwave imager for surface observations in cloudy regions. This will be particularly important for ice mapping. Steps should be taken to assure that ice analyses will be distributed promptly on the GTS.

(Atmospheric Soundings)

The basic sounder will be the Advanced Microwave Sounding Unit (AMSU) for both temperature and water vapour, with only minor improvements based on the experience with the AMSU's to be flown early in the next decade. This experience also is needed to determine the extent to which infrared channels must be retained on the same spacecraft. It is likely that those channels, (e.g., of HIRS) which detect radiation from the surface and lower troposphere will need to be retained because of the variability of the surface emissivity over land in the wavelengths used for microwave sounding.

It is not considered likely that a limb scanner* to obtain the temperature of the tropopause and stratosphere will come into operational use. The only (remote) possibility of a limb scanning instrument being added to the operational system would result from a major increase in the urgency to monitor minor constituents in the stratosphere. However, it is expected that profiles and total amount of ozone will continue to be monitored on a nearly continuous basis.

(Data Collection and Platform Location)

Capability equivalent to the present ARGOS system for data collection and platform location can be expected on at least two satellites to assure continuity. If the present operators (France and USA) are unable to maintain this commitment, participation in this programme by other nations should be explored as a matter of urgency. The system has demonstrated satisfactory accuracy and has ample capacity for anticipated needs. It is most important for tracking drifting buoys and collecting their data, and also collecting data from remote areas not accessible by the geostationary satellite data collection system.

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* A limb scanner views above the Earth's horizon tangentially, that is, views the limb of the Earth. By scanning up and down a few degrees, the sensor measures the thermal radiation emitted by, or the solar radiation transmitted through the upper atmosphere above the clouds. Such an instrument provides greater vertical resolution than the downward-viewing sounding instruments in general use today.

(Other Ocean Observations)

Sea surface temperature, ice extent and the addition of microwave imaging already have been mentioned. From the information in Sections 3 and 4 it is clear that there will be a growing number of new ocean observations on at least a part-time experimental basis. However, it is difficult to predict what other sensors will be in routine, daily operational use in 1995-2000. Considered the most likely candidates are a microwave imager as mentioned earlier, and the measurement of the surface wind field or wind stress over the oceans by means of a radar scatterometer. Somewhat less likely is the addition of a multi-spectral precision scanning radiometer operating in the visible portion of the spectrum to measure the "ocean colour". This would be similar to the Coastal Zone Colour Scanner (CZCS) flown on the Nimbus-7 experimental meteorological satellite to determine concentrations of chlorophyll, sediment and "gelbstoff" in the top few meters of the ocean. Other new oceanic sensors are not expected to be introduced routinely until after the year 2000.

(Direct Broadcast of Satellite Data)

It is expected that direct broadcast of visible and infrared images via APT and HRPT, and all quantitative data via HRPT and beacon will continue indefinitely. WMO should seriously consider requesting the polar satellite operators to convert the APT broadcast from an analog to a digital transmission. As discussed earlier under Geostationary Satellites - Data Dissemination, the use of a digital signal will increase the reliability and quality of the received image products. The development of new reliable receiving units for APT could and should be done together with the WEFAX digital ground station development. As at the present time, APT and WEFAX users would benefit from common data formats.

The layout of the digital data in the beacon and HRPT frames will have to be changed to accommodate the changes expected in the satellite sensors. Satellite operators should be urged to make this information known to WMO at the earliest possible time so that Members will have ample time to modify their receiving and processing facilities before launch of the new satellites.

6. CONTINUITY OF THE SPACE COMPONENTS

The most probable constellation and configuration of operational satellites expected in 1995-2000 has been outlined in the previous section. The continuity of satellite data and services will become even more critical in 1995 than it is today. Both numerical prediction, and storm monitoring and warning will require a high degree of reliability of the space component of the WWW. In many cases, there will be no practical and economical alternative to the communication services provided by the meteorological-environmental satellites. Thus, it is essential for the WMO to assure with high reliability the continuity of the basic satellite components upon which its Members and programmes are becoming ever more dependent.

This concern has been magnified recently by the proposal in one Member nation to reduce its polar orbiting meteorological satellite system from two spacecraft in orbit to one. In the present configuration, when one spacecraft fails the remaining one can provide minimum coverage and services until a

second one is launched. With a change to only one spacecraft in orbit, all data and services would be terminated when it fails and could not be restored for at least five months and probably much longer until a replacement satellite could be launched and placed into operation. Clearly, an in-orbit spare spacecraft is needed for each satellite system if continuity is to be meaningful.

A second aspect in any satellite system is assuring the availability of an adequate number of spare satellites for launch when needed to replace those which fail in orbit. To be able to recover from a launch failure, it is necessary to have two of each type available for launch. A difficult problem exists today in respect of all of the geostationary satellites; none of the satellite operators have any spares on the ground available for launch. ESA is refurbishing a prototype METEOSAT for launch in 1986; the next GOES satellite will not be delivered until late 1985 at the earliest; India plans its next launch in 1986; and Japan does not plan to launch a replacement for GMS-3 until 1989-90. Only one GOES satellite in orbit still has a fully operational imager so it has been moved to a location south of the contiguous United States, leaving a gap in coverage in the central part of both the Pacific and North Atlantic Oceans. There is concern that the one remaining GOES spacecraft also will fail before a replacement can be launched.

From these examples, it should be clear that steps are urgently needed by the world community to increase the probability of continuous availability of basic data and services from both the geostationary and polar orbiting satellites. While there may be considerable debate as to which data and services should be considered "basic", the following is proposed. In all cases, continuity means available every day, with a maximum interruption of 24 hours only under highly unusual and infrequent circumstances.

Polar orbiter - Minimum of one operational

- Soundings of the highest quality (e.g., AMSU); global coverage once a day
- Data-collection/platform location system (DCPLS)
- APT for local storm warnings; back up to geostationary satellite imaging

Geostationary - Constellation of five operational

- Images for wind extraction twice a day
- Data collection and dissemination to assure a minimum data base for WWW
- Direct broadcast of images for storm warning; polar orbiter APT can be used as backup

Geostationary satellite winds are given a somewhat lower priority than polar satellite soundings based on the results from the First GARP Global Experiment (FGGE) which show considerably less impact of the geostationary satellite winds than of the satellite temperature soundings on the numerical

predictions. This could change with further development of analysis and prediction models. Thus, from the point of view of global, large scale numerical weather prediction, some failures within the geostationary satellite constellation can be tolerated more readily than in the polar component, if the remaining geostationary satellites are distributed well enough to provide continued communication coverage. If any one should fail, this condition could be met, perhaps with only small adjustment in the position of the two adjacent spacecraft. Also, experience has shown that the imaging sensor is more likely to fail than the communications subsystems. Today, there are ample geostationary satellites in space which can still perform the communication functions.

While not very desirable, the APT on the polar orbiting satellites can provide back-up to the geostationary satellite images for storm monitoring. It is obvious that the geostationary images are superior to those from the polar orbiter because of their high frequency, but the polar orbiter does provide global coverage and back-up capability which can be used if all else fails.

The polar orbiter DCPLS is needed to monitor the satellite performance through ocean surface observations, and by 1995 could be the primary means of obtaining surface observations from many ocean areas devoid of commercial shipping.

Following are some possibilities for improving the probability of continuity for each class of system. Some of the suggestions may not be realistic. However, they may stimulate wider discussion of the problem and lead to action in the near future.

Geostationary Meteorological Satellite Continuity

The Co-ordination of Geostationary Meteorological Satellites (CGMS) group has been examining this question from a technical point of view. CGMS already has achieved common frequencies and formats for the data collection and WEFAX (low resolution image transmission) systems. However, there is no standardization for other data transmission formats. Increased flexibility could be achieved if each satellite operator could receive and process the data from adjacent satellites as well as his own. Should this be feasible, a series of bilateral agreements could be developed between operators of adjacent satellites for sharing on-orbit back-up capability in case of a failure. Some shifting of the positions of the remaining operational spacecraft also may be feasible, although national and regional high priority requirements may preclude very large shifts (e.g., more than 10 degrees longitude).

The ideal solution would be the use of common command systems as well as data formats, so that the same back-up spacecraft could be used by all satellite operators, with its cost shared by all. Even more ideal would be for all satellite operators to pool their spacecraft needs and have a common procurement. Both of these approaches are considered to be improbable today because of strong national interests in developing and sustaining indigenous technological capabilities and independence. An alternate approach might be the mutual exchange of those subsystems upon which the configuration of ground systems is dependent.

Polar Meteorological Satellite Alternatives

APT subsystems now have adequate redundancy, since they are carried on all polar orbiting meteorological satellites. It would be highly desirable to reach agreement with the satellite operators on common specifications for the output format, and on changing to a digital transmission system.

Continuity, then, must still be assured for an AMSU-type sounder and DCPLS. Functionally identical subsystems of each type must be flown on at least two satellites in orbit at the same time with adequate back-up units on the ground available for launch following an in-orbit failure of either subsystem. The ideal arrangement is that which has prevailed in the past with the NOAA series of satellites. Certainly, the best solution technically would be to assure its continuation. Perhaps this can be assured by increasing the level of international participation through additional countries providing subsystems or services. France already is providing the ARGOS DCPLS subsystem and data processing. The United Kingdom has been providing the Stratospheric Sounding Unit and plans to provide the water vapour portion of the AMSU.

A less desirable alternative than the preceding would be to fly back-up sounding and DCPLS units either individually or as an ensemble on non-meteorological satellites in suitable orbits. High inclination orbits are required but they don't have to be sun-synchronous. It may be that one or more nations or international satellite organizations could be interested in such a role.

7. OTHER SOURCES OF SATELLITE SERVICES

The trends in respect of other environmental satellites as well as communication satellite services discussed in Part 4 are expected to continue through the last part of this century. The technical capabilities to meet the telecommunication and very high resolution image requirements of WMO programmes will exist. The cost of telecommunication services should decrease from today's level, but image data with resolutions better than 100m are expected to become more expensive. In both cases, the variety and quality of services should increase significantly over the next ten years (see Part 4).

Both operational and research satellites will contribute extensively to climate programmes. There is a concern about the continuity of data sources and their intercomparability for use in long-term climate monitoring. A greater effort probably is needed to assure intercomparison, monitoring and evaluation over decades of those sensors and data systems whose outputs are essential for climate monitoring, research and applications.

Data archiving services are important for all meteorology and operational hydrology programmes. This is particularly critical for satellite data because of the very large volumes involved. Unfortunately, there have been few cases where the user communities have been able to agree on methods of averaging and formatting the satellite data before permanent archiving. Yet the user subsequently cannot afford the cost to retrieve and process the original full resolution data. There is some hope that new laser-based storage and retrieval systems and expanding computer capabilities will

ameliorate this storage and retrieval problem. However, there may be difficulty in each satellite operator installing the kind of flexible data systems that are desired by the world community. Perhaps more attention should be given by the satellite operators and the WMO to what may be feasible in the 1995 time period.

8. CONSIDERATIONS FOR IMPROVED SATELLITE DATA AND SERVICES

A number of broad programme considerations of concern to meteorology and operational hydrology already have been raised. While some of these may be considered to be the purview of those nations providing and operating the satellites, their importance to the entire community of nations is so great that the WMO should, as a minimum, represent the global interests and needs to the community of satellite operators. The items are summarized below in three broad categories. It should be recognized that an item in one category may be closely related to an item in another category. For example, the suggestion to convert the WEFAX and APT transmissions from analog to digital format and to increase the capacity of WEFAX summarized under "Space Components" must be considered in consort with the necessary receiving stations mentioned under "Specific Ground Facilities", as well as data and product generation to meet regional and national needs included under "Data Handling, Product Generation and Distribution". The numbers in paretheses at the end of each item indicate the pages in this report where the topic has been discussed.

Space Components

(1) Steps urgently need to be taken by the world community to increase the probability of the continuous availability of the basic data and services from both the geostationary and polar orbiting satellites which are essential for meteorology and operational hydrology (17, 18, 19-22).

(2) Expansion should be sought of the dissemination of data by geostationary satellite (e.g. WEFAX) to two simultaneous channels and conversion to digital transmission for both alphanumeric and pictorial data (16).

(3) The WMO should seriously consider requesting the polar satellite operators to convert the APT broadcast from an analog to digital transmission in order to increase the reliability and quality of the received image products (19).

(4) Satellite operators should be encouraged to develop coordinated digital formats for WEFAX and APT which are as nearly identical as possible in order to simplify the required ground equipment (19).

(5) Those operators of geostationary satellites supporting meteorology and operational hydrology should be urged to provide for essentially instantaneous direct broadcast of the satellite images (15).

(6) National and international agreement should be sought as necessary for multi-national use by WMO Members of Data Collection Systems (DCS) on all of the geostationary satellites. Highest priority should be placed on the

collection of data from automatic meteorological and hydrological stations as well as regular stations where standard communications continue to be inadequate (16).

(7) There is a growing need for long-term intercomparability of certain satellite data to be used in climate programmes. A greater effort is needed to assure intercomparison, monitoring and evaluation over decades of those sensors and data systems whose outputs are essential for climate monitoring, research and applications (22).

(8) The growing ability of geostationary satellite sensors to view a relatively small area with high frequency raises the issue of how each satellite operator will deploy this sensing capability to meet national requirements without ignoring international needs (15).

(9) Satellite operators again should be reminded to inform the WMO at the earliest possible time of any changes contemplated in direct broadcast frequencies, modulation or formats so that Members can have adequate time to modify their receiving and processing facilities before launch of the new satellites (19).

Specific Ground Facilities

(1) Develop highly reliable, low cost Data Collection system Platforms (DCPs) and associated sensors to facilitate the expansion of the surface observation network. Also, develop highly reliable DCP data receivers for regional and national use (16).

(2) Develop highly reliable, low cost receiver-terminals for the reception of proposed digital transmissions of alphanumeric and pictorial data (e.g., via WEFAX) from geostationary satellites (16).

(3) Develop highly reliable, low-cost receivers for the proposed digital APT transmissions (19).

(4) Develop the equipment components to meet the regional, national and local needs for reliable and high quality data handling, product generation and distribution (see below).

Data Handling, Product Generation and Distribution

(1) With the proposed improved data dissemination by geostationary satellite, arrangements should be made for data and product generation and transmission via the satellite operators to meet basic regional needs. Agreement of the satellite operators should be sought regarding transmission characteristics and scheduling (17).

(2) Steps should be taken to assure that ice analyses based on satellite data will be distributed promptly on the GTS (18).

(3) More attention should be given by the satellite operators and the WMO to the satellite data storage and retrieval systems that will be needed and feasible in the 1995 time period.

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(4) Members in the tropics and mid-latitudes should be encouraged to switch from APT to the use of the more frequent geostationary satellite images, where they are available, to provide improved short range forecasts and warnings (15, 17).

(5) Priority must be placed on the availability of facilities and techniques within regional and national meteorological and hydrological services to adequately assimilate, analyse and disseminate to those who need it, the information derived from satellites and other data sources.

(6) Consideration should be given to production at the regional and national levels of high resolution satellite products, such as atmospheric and sea surface temperatures, ice and snow cover, and vegetative index, by utilizing HRPT reception (17).

(7) As a near-term task, user specialists and satellite data experts should evaluate the needs of WMO programmes and expected satellite capabilities to determine those areas of high priority which should be pursued in terms of application development. For each area identified, the necessary planning and development should be initiated to assure that adequate knowledge and methodology will be available for application at the regional and national levels.

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Summary of Operational Meteorological Satellites-1984

Satellites in Polar Orbit

METEOR-2 Operational Series (USSR)

Orbit: Near polar (inclination 81°), altitude 900 km, period 102 minutes.

Spacecraft operating in orbit at the same time: two-three.

Sensors:

- Scanning telephotometer for APT, one channel (0.5-0.7um), resolution 2km, swath width 2100km.
- TV-type scanner, one channel (0.5-0.7um), resolution 1km, swath width 2400km.
- Infrared scanning radiometer, one channel (8-12um), resolution 8km, swath width 2600km.
- Infrared scanning sounder radiometer (on some satellites), eight channels (11.1, 13.33, 13.70, 14.24, 14.43, 14.75, 15.02, 18.70um), resolution (angular) 2°, swath width 1000km.

Direct boradcast data

APT, one channel: visible (2km) or infrared (8km), standard transmission and format.

NOAA series (USA)

Orbit: Sun-synchronous, near polar (inclination 98.9°), altitude 833 or 870km, period 101 minutes.

Spacecraft operating in orbit at the same time: one or two of the Advanced TIROS-N design.

Sensors:

- Advanced Very High Resolution Radiometer (AVHRR), four or five channels: NOAA-8 (0.55-0.90, 0.72-1.10, 3.55-3.93, 10.3-11.3um) NOAA-9 (0.58-0.68, 0.72-1.10, 3.55-3.93, 10.3-11.3, 11.5-12.5um), resolution 1km, swath width 2600 km. APT, HRPT and Global Area Coverage derived from AVHRR output.
- TIROS Operational Vertical Sounder (TOVS), with three sub-systems:
  - o High-resolution Infra-Red Sounder (HIRS), 20 channels, resolution 20 km, swath width 2250 km.
  - o Stratospheric Sounding Unit (SSU), provided by the UK, 3 channels in 15um CO_2 band, resolution 147 km, swath width 1500 km.

o Microwave Sounding Unit (MSU), 4 channels (50.3, 53.7, 55.0, 58.0 GHz), resolution 110km, swath width 2250km.

- ARGOS Data Collection and Platform Location System (DCPLS), provided by France, locates and collects data from platforms (e.g., drifting buoys) and relays the data to central processing facility. Up to 4000 platforms can be handled per day. Location accuracy is about 1 km.

- Solar Backscatter Ultra-Violet (SBUV) Radiometer for determination of total amount and vertical distribution of ozone in the stratosphere (beginning with NOAA-9). Fixed nadir-viewing spectrometer measures radiation at several wavelengths from 160 to 400 nm.

Direct broadcast data

- APT, two channels: visible and infrared (4km), standard transmission and format.

- HRPT, same channels, resolution and coverage as AVHRR. S-band transmission also includes all other digital sensor data (TOVS, ARGOS, SBUV, etc.).

- Direct Sounder Broadcast (DSB), TOVS digital data are broadcast on the VHF beacon frequency.

Satellites in Geostationary Orbit

METEOSAT (Europe)

Number of spacecraft in operation and location: One at 0° longitude

Sensors:

- High resolution radiometer, 3 channels: 0.4-1.1um at 2.5km resolution, and 5.7-7.1 and 10.5-12.5um at 5km. Full earth disk coverage possible every 30 min.

- Data Collection System (DCS), 62 channels of 3 KHz bandwidth, CGMS standard format and transmission characteristics, to relay data from Data Collection Platforms (DCPs).

Direct boradcast data

- WEFAX (weather facsimile) dissemination full time in APT format according to CGMS standards for reception by Secondary Data User Stations (SDUS). Between WEFAX transmissions, DCP data are transmitted to modified SDUS ground receivers.

- High-resolution image dissemination to Primary Data User Stations (PDUS); format and transmission specifications are unique to METEOSAT.

INSAT (India)

Number of spacecraft in operation and location: One at 74°E.

Sensor:

- Very High Resolution Radiometer (VHRR), 2 channels: 0.55-0.75um at 2.75km resolution, and 10.5-12.5um at 11.0km. Coverage over India and adjoining land and sea area possible every 30 min.

- Data Collection System (DCS), capable of collecting meteorological data from up to 400 Data Collection Platforms (DCPs) with pseudo-random, burst mode reporting.

Direct broadcast data

- All images and data transmitted to Meteorological Data Utilization Centre (MDUC), New Delhi for processing and analysis, and distribution of processed data to India forecasting offices using point-to-point communications. Synoptic inferences and cloud motion vectors are transmitted on the GTS twice and once a day, respectively.

GMS (Japan)

Number of spacecraft in operation and location: One at 140°E

Sensors:

- Visible and Infra-red Spin Scan Radiometer (VISSR), 2 channels: 0.5-0.75um at 1.25km resolution and 10.5-12.5um at 5km. Full earth disk coverage possible every 30 minutes.

- Data Collection System (DCS) in accordance with CGMS standard format and transmission characteristics to relay data from Data Collection Platforms (DCPs).

Direct broadcast data

- Low-Resolution Facsimile (LR-FAX) (WEFAX) dissemination part time in APT format according to CGMS standards for reception by Secondary Data Utilization Stations (SDUS).

- High-Resolution Facsimile (HR-FAX) dissemination to Medium-scale Data Utilization Stations (MDUS); format and transmission specifications are unique to GMS.

GOMS (U.S.S.R.) - Not yet operational; following is provisional

Number of spacecraft planned and location: One at 70°E

Sensors:

- Imaging, 2 channels: visible at 1-2km resolution and 8-12um infrared at 5-8km.

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- Data Collection System (DCS), in accordance with CGMS standard format and transmission characteristics to relay data from Data Collection Platforms (DCPs).

Direct broadcast data

- Two full-time weather facsimile (WEFAX) dissemination channels in APT format according to CGMS standards.

- Two digital (alphanumeric) data broadcast channels.

- High-resolution image dissemination; characteristics and international availability unknown.

GOES (USA)

Number of spacecraft operational and locations: Two at 75° and 135°W; one at 107°W with WEFAX direct broadcast only.

Sensors:

- VISSR (Visible and Infrared Spin Scan Radiometer) Atmospheric Sounder (VAS), two imaging channels: 0.55-0.75um at 1km resolution and 10.5-12.6um at 7km. Four-channel multispectral imaging mode: above two channels plus any two of the sounding channels at 14km resolution. Both modes can cover the full earth disk every 30 minutes, smaller areas more frequently. Sounding mode: 12 channels at 14km resolution (3.94, 4.44, 4.52, 6.72, 7.2, 11.24, 12.66, 13.3, 14.0, 14.2, 14.4 and 14.7um); all channels except 3.94, 4.44, 4.52, 14.4 and 14.7um also can be used with a resolution of 7km. Time to acquire soundings for a zone 20° latitude wide (N-S) is about 1 hour. Only one operating mode of VAS can be used at a time.

- Data Collection System (DCS), 160 channels of 3KHz bandwith, CGMS standard format and transmission characteristics, to relay data from Data Collection Platforms (DCPs).

Direct broadcast data:

- WEFAX dissemination part time in APT format according to CGMS standards. (Full time transmission from GOES at 107°W.)

- High-resolution image dissemination to Primary Data User Stations; format and transmission characteristics are unique to GOES.

- DCP dissemination on a single DCP channel can be received directly by a user equipped with a receiver whose cost is in the range of US$50,000-100,000.

Note: Most of the above information was obtained from WMO Publication No. 411 (1) to which the reader is referred for additional details. Resolutions specified are at the satellite subpoint.

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PRODUCT AND SERVICES SUMMARY - 1979
NOAA National Environmental Satellite Service*

Product description	Accuracy	Spatial Resolution	Map Scale	Geographic coverage	Output format	Schedule
I. IMAGE PRODUCTS						
A. GEOSTATIONARY SATELLITES						
1. Full-disk (VIS and IR): East GOES	--	4 km VIS, 8 km IR	--	Pole to Pole, 15 W to 135 W	Photographic display and archive tape	At hour and half hour
West GOES	--	4 km VIS, 8 km IR	--	Pole to Pole, 75 W to 165 E	"	At 15 and 45 minutes after the hour
IR-enhanced	--	8 km	--	E & W GOES	"	E & W GOES
Sectors (VIS & IR):	--	1, 2, and 4 km	--	Specific areas:	"	E & W GOES
2. Movie loops (VIS/ IR(IR-enhanced)	--	1, 2, 4, 8 km	--	"	80 or more joined in stop, flow or alternated stop loop	in-hourse/daily, others on request
TV filmstrips	--	2 km	--	Continental United States	Commercial TV films	Daily
3. U.S. cloud cover	--	"	--	"	Photographic display, surface analysis chart and weather summary	Daily
4. Daily Weather Picture	--	"	--	"	Photographic display and weather summary	3/day
B. POLAR-ORBITING SATELLITES						
1. Stretched, Gridded, Pass-by-Pass Imagery (VIS and IR)	Nominal ± 10km grid placement	4km	--	Global	Stretched, Gridded photographic strips, archive tape	Daily
2. Hemispheric polar-stereographic mosaics (VIS and IR)	--	14.8km equator 29.6km - poles	1:480 M	Northern and Southern Hemispheres	Mapped photographic displays and archive tape	Daily
3. Polar-stereographic quadrant mosaics (VIS and IR)	--	"	1:40 M	"	Mapped photographic displays	Daily
4. Mercator mosaics (VIS and IR)	--	9.8km - equator 7.5km - 40°N	1:180 M	Northern and Southern Hemispheres to 40°N or S	Mapped photographic displays	Daily
5. Local Area Coverage images (VIS and IR)	--	1.1km	--	Selectable orbit segments	Photographic displays and digital tape archive	Daily selectable orbit segments
6. Seven-day minimum brightness composite (VIS and IR)	--	1:75 M	1:120 M	Northern Hemisphere from 20°N to Pole Southern Hemisphere from 50°S to Pole	Photographic displays and and digital tape archive	Daily

* From reference (8)
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APPENDIX II

Product description	Accuracy	Spatial Resolution	Map Scale	Geographic coverage	Output format	Schedule
II. IMAGE SERVICES						
A. GEOSTATIONARY SATELLITES						
1. GOES facsimile displays (VIS and IR)	--	VIS: 4 x 4 km IR: 4 x 8 km		Continental United States - 55-120 W long and 15-60 N lat.; Eastern U.S and Atlantic - 20-90 N long and 15-60 N lat.; Southern South America 25-80 W long and 10-50 S lat; U.S. West Coast and Pacific - 115-180 W long and 15-60 N Lat; Western U.S. and Pacific - 105-180 W long and 15-60 N. lat.	Facsimile display	24-hour schedule
2-3GOES WEFAX link: GOES and NOAA polar-orbiter data in VIS and IR	--	Same as photographic imagery	1:80 M	Specified areas (see latest NESS WEFAX list)	Facsimile - satellite relayed broadcast	24-hour schedule
4. GOES - Direct readout	--	Same as full-disk and sector displays	--	Same as full-disk and sector displays	Photographic imagery	Same as full-disk and sector displays
5. GOES - Tap VISSR data		"		"	"	"
B. POLAR-ORBITING SATELLITES						
1. Polar-orbiting satellite facsimile displays (VIS and IR)	--	1:120 M - mercator 1:30 M - polar stereographic	1:20 M	Specified areas	Facsimile display	Daily, selected passes
2. Polar-orbiting satellite - direct readout	--		--	Area of view at time of readout	Photographic digital imagery and alphanumerical data	Daily passes
III. METEOROLOGICAL PRODUCTS						
A. Satellite winds (from GOES): low-, middle-, high-level cloud motion vector field messages	See text	--	--	Global ocean areas	Raw numeric data, chart form and archive cloud motion vectors-archive tape	00Z and 12Z daily for distribution at 03Z and 15Z
B. Atmospheric soundings (from Polar orbiter):		Nominal 250km near sub-satellite track	--	Global	Computer disk - 24 hour rotating files, archive tapes	Continuous-orbit-by orbit
Layer-mean temperatures (^{o}K)						
SFC-850 mb 300-200	SFC-850 mb					
mb 30-10 mb	±2.5 K					
850-700 mb 200-100	850-tropopause					
mb 10-05 mb	±2.25°K					
700-500 mb 100-70						
mb 05-02 mb						
500-400 mb 70-50	trop.-2.0 mb					
mb 02-01 mb	±3° K					
400-300 mb 50-30						
mb 01-0.4 mb	2.0 - 0.4 mb ±3.5° K					

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Product description	Accuracy	Spatial Resolution	Map Scale	Geographic coverage	Output format	Schedule
III. METEOROLOGICAL PRODUCTS						
B. Atmospheric soundings (from Polar orbiter):						
Layer precipitable water (mm) Surface-700mb 700-500 mb above 500 mb	30%	"	--	"	"	"
Equivalent blackbody temperature (^{o}K) for 20 HIRS/2 stratospheric channels. 4 MSU channels, 3 SSU channels	$\pm 2^{o}$ K	Nominal 250 km near sub-satellite track	--	Global	Computer disk-24 hour rotating files, archive tape	Continuous orbit-by-orbit
Thickness (m) and layer-mean temperatures (^{o}K) between selected standard pressure levels	In areas of single layer cloud cover $\angle$50%, $\pm 2^{o}$K (and equivalent Δz)		--	"	"	"
Precipitable water (mm) between selected standard pressure levels	$\pm$30%	"	--	"	"	"
Clear Radiances mW/(m^2-sr-cm^{-1})	$\pm$2%	"	--	"	"	"
Earth-located, calibrated radiances from SSU plus selected HIRS/2 and MSU channels	Instrument specifications	"	--	"	"	"
C. Global Heat Budget: 1) Daytime Longwave flux 2) Nighttime Longwave flux 3) Reflected Energy or Equivalent (albedo, absorbed) 4) Available Solar Energy (calculated field)	7 watts/m^2 reflected and outgoing energy	Observations - 100 km	--	Global	Digital Tape - a) gridded earth-located arrays b) 2.5^{o} x 2.5^{o} mercator map array c) 125° x 125° polar map array Quality Control photographic image	Twice/day IR flux, once/day reflected, energy monthly (time averaged)
D. WATER SUMMARIES AND BULLETINS						
1. Satellite Interpretation Message	$\pm$6 n. Mi. (8.4 km)	--	--	Continental United States	Teletypewriter	Satellite Field Services Stations at Washington, D.C., 8/day, Kansas City, 8/day, Miami, 1/day, Honolulu, 2/day, Anchorage, 2/day
2. Satellite Weather Bulletins	--	--	--	Atlantic, Pacific, Indian Oceans	Teletypewriter	As needed

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Product description	Accuracy	Spatial Resolution	Map Scale	Geographic coverage	Output format	Schedule
3. Satellite Weather Summary and TV movie overlay	--	--	--	Continental United States	Teletypewriter message and acetate overlay	Daily
4. Cloud Top and Tropopause message	±3000 ft	1° lat/long	1:20 M	GOES East and West Area	Teletypewriter	4/day
5. Tropical Disturbance Summary	±30 N. mi. (42 km)	--	--	Atlantic and East Pacific (to 180 W), West and South Pacific, Indian Ocean	Teletypewriter	2/day/area
IV. OCEANOGRAPHIC PRODUCTS						
A. SEA SURFACE TEMPERATURE PRODUCTS						
1. Sea Surface Temperature Observations	±1.5°C Absolute ±1.5°C Relative	Nominal 50 km	--	Global	Computer Disk and Digital Archive Tape	Daily (disk) Weekly (tape)
2. Global Sea Surface Temperature monthly Observation mean	"	2.5° lat/long. 250 km grid	--	Global	Computer Disk Digital Archive Tape Contour Analysis Chart	Monthly (disk) Yearly (tape) Monthly (chart)
3. Sea Surface Temperature Regional Scale Analysis	"	0.5° lat/long. 50 km grid	1:22 M	1) 5°N-53°N, 52°W-100°W 2) 15°N-63°N, 97°W-145°W 3) 15°N-63°N, 142°W-170°E	Computer Disk Digital Archive Tape Contour Analysis Chart Photographic quality control image	Weekly (disk) Monthly (tape) Weekly (chart) Weekly (photo)
4. Sea Surface Temperature Global Scale Analysis	±1.5°C Absolute ±1.5°C Relative	1.0° lat/long. 100 km grid	1:45 M	Global Charts - 50°x50° lat/long	Computer Disk, Digital Archive Tape, Computer Terminal Display, Contour Analysis Chart Photographic quality control Image	Daily (disk) Semi-Monthly (tape) On-demand (terminal) Weekly (chart) Daily (photo)
Sea Surface Temperature Climate Scale Analysis	±1.5°C Absolute ±1.5°C Relative	5.0° lat/long. 500 km grid	--	Global	Computer Disk Digital Archive Tape Photographic quality control Image	Daily (disk) Monthly (tape) Daily (photo)
5. Great Lakes and Coastal Surface Water Temperature Analyses	1.5°C Absolute 0.5°C Relative	1 km Great Lakes 5 km Coastal Zones	Varies with type of transmission	Great Lakes and US Coastal Regions	Gridded Analysis	Weekly
B. ICE CHARTS						
1. Great Lakes Ice Chart	±5 km	1 km	Varies with type of transmission	Great Lakes	Gridded analysis	Weekly

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Product description	Accuracy	Spatial Resolution	Map Scale	Geographic coverage	Output format	Schedule
2. Polar Regional Ice Charts	±5 km	1 km	Alaskan - 1:5 M Arctic - 1:10 M Antarctic- 1:10 M	Polar Ocean Ice Regions	Gridded Chart	Daily and Weekly
C. OCEAN CURRENT ANALYSIS						
1. Gulf Stream Wall Bulletin and Analysis	±5 km	1 km	Varies with type of trans-mission	US Coastal waters of the Gulf of Mexico and and east coast	Teletypewriter message Gridded Analysis	3/week (bulletin) weekly (analysis)
2. West Coast Thermal Front Analysis	±5 km	1 km	--	US West Coast out to 4° longitude	Gridded Analysis	2/week
V. HYDROLOGICAL PRODUCTS						
A. River Basin Snow Cover Observations	±5%	1 km	--	Selected basins	Percent covered analysis	Daily and weekly depending on basin
B. Regional Snow Cover Analysis	±5 km	1 km	1:7.5 M and 1:10 M	Great Lakes, North-western U.S., Himalayas	Gridded Analysis	2/week - Western Hemisphere 1/week - Eastern Hemisphere
C. Northern Hemisphere Snow and Ice Chart	±5 km	1 km	1:50 M	Northern Hemisphere	Gridded Analysis	Weekly (Analysis) Monthly (mean)

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Other Environmental Satellites, 1984 - 1995

(Reference numbers are in parentheses)

A - Now in Operation

(USSR) METEOR - Priroda (9)

- o Five launches 1974-1980 and continuing, leading to a "continuously operating quick-look subsystem for earth resources research" using the MSU-SA, MSU-VA and Fragment-2 sensors.

- o METEOR-Priroda launched 18 June 1980:

  - Orbit sun-synchronous, 98° inclination, 650 km altitude.

  - Standard sensors, MRTVK scanning radiometers.

    . low resolution, also called MSU-M (1x1.7 km), 4 channels (0.5-0.6, 0.6-0.7, 0.7-0.8, 0.8-1.1 um), swath width 1930 km.

    . medium resolution, also called MSU-S (240 m), 2 channels (0.5-0.7, 0.7-1.0 um), swath width 1380 km.

  - "Quick-look" subsystem sensors.

    . MSU-SA, multispectral mechanical scanning radiometer of medium resolution (170 m), 4 channels (0.5-0.6, 0.6-0.7, 0.7-0.8, 0.8-1.0 um), swath width 600 km.

    . MSU-VA, multispectral electronic scanning radiometer of high resolution (30 m), 3 channels (0.5-0.7, 0.7-0.8, 0.8-1.0 um), swath width 30 km.

    . Fragment-2, multispectral scanning system, resolution 80 m, 8 channels (0.4-0.8, 0.5-0.6, 0.6-0.7, 0.7-0.8, 0.7-1.1, 1.2-1.3, 1.5-1.8, 2.1-2.4), swath width 85 km.

  - Data transmission.

    . Analog direct broadcast to simplified self-contained receiving stations of one channel from standard MRTVK low resolution sensor.

    . Analog link in 460-470 MHz band to central receivers for all MRTVK output, and MSU-SA and MSU-VA.

. MSU-SA and MSU-VA also can be transmitted over a digital link.

. Digital link at 1000 MHz for transmission of data from Fragment-2.

o Sensing systems under development

- Optical-mechanical scanners of high and medium resolution;

. Medium resolution (150-250 m visible, 500-600m infrared), 4 channels (from 0.4 to 12.5 um), swath width 500-700 km, repeat observation coverage at equator 4-5 days.

. High resolution (50 m visible, 200 m infrared), 8 channels (from 0.4 to 12.5 um), swath width 180-200 km, repeat observation coverage at equator 14-17 days.

- Radar equipment (e.g., side-looking radars, scatterometers, altimeters).

- UHF scanning radiometric equipment.

- Data collection system.

o From Aviation Week and Space Technology, Vol. 120; No. 11 (March 12, 1984) pp. 111-113, excerpt on 1983 USSR satellite flights: "During 1983 there were 10 flights of film-return Earth resources spacecraft compared with seven per year in 1980-82. In addition ------- the Soviets launched another radio image transmission spacecraft into a Sun-synchronous orbit similar to that used by U.S. Landsat. ------- In addition, the Cosmos 1500 oceanographic spacecraft carrying a synthetic aperture radar was launched and returned ocean surface images and images of Arctic ice conditions ------".

<u>(USA) Landsat-5</u>

o Previously there have been 4 Landsat launches, beginning in 1972. Landsat-5 is the last spacecraft in the series.

o Landsat-5 was launched 1 March 1984, sun-synchronous orbit, inclination 98.2°, altitude 706 km, orbital period 98.9 min, local time of equator crossing 0945, 16-day repeat cycle of observation.

o Sensors:

- Multi-Spectral Scanner (MSS), resolution 80 m, 4 channels (0.5-0.6, 0.6-0.7, 0.7-0.8, 0.8-1.1 um), swath width 185 km.

- Thematic Mapper (TM), resolution 30 m (except 10.4-12.5 um is 120 m), 7 channels (0.45-0.52, 0.52-0.60, 0.63-0.69, 0.76-0.90, 1.55-1.75, 2.08-2.35, 10.4-12.5 um), swath width 185 km.

- o Data transmission: both direct broadcast of MSS and TM to local receiving stations and transmission to central facility via Tracking and Data Relay Satellite System (TDRSS).

B - Under Development

(Brazil) environmental data collection satellites (11)

- o Two experimental satellites planned for launch in 1989 and 1990. Spacecraft being constructed by the Instituto de Pesquisas Espacias (INPE).
- o Orbit, 20-25 deg inclination, 700 km altitude.
- o Collect and relay data from more than 500 meteorological and hydrological ground stations in remote areas of Brazil. Up-link Ultra High Frequency (UHF) band, down-link S-band.
- o Planning two remote-sensing satellites for launch in 1991 and 1992.
  - Orbit, sun-synchronous, 98° inclination, 650 km altitude, earth coverage repeat cycle at the equator of 35 days.
  - Sensor: charge-coupled device, 40 m resolution.

(ESA) ERS-1 (17,18)

- o One satellite planned for launch in 1989, primarily for ocean observations; design lifetime is two years. Follow-on spacecraft in the ESA Remote-sensing Satellite (ERS) series being considered, but none approved.
- o Orbit: Sun synchronous, 98.5° inclination, 780 km altitude, 1015 local time of equator crossing (descending), earth coverage repeat cycle at the equator of 3 days.
- o Sensors:
  - Active Microwave Instrument (AMI) will operate in one of three modes:
    - . Synthetic Aperture Radar (SAR), resolution 30 m, swath width 80 km.
    - . Wave (spectra) mode, 5 km by 5 km SAR image, 30 m resolution, every 100 km along the orbit track, can operate at the same time as
    - . Wind mode, 3-beam, C-band scatterometer for surface wind speed and direction, 50 km resolution with observations every 25 km and 500 km swath width.

- Radar Altimeter, nadir viewing, 10 cm precision. Significant wave height to be determined to an accuracy of 0.5 m or 10% over the range 1-20 m. Measurement of ice height contours to 40 cm precision.

- Along - Track Scanning Radiometer-Microwave (ATSR-M) contains two sub-components: scanning radiometer and microwave sounder.

  . Scanning infrared radiometer for sea surface temperature (SST), resolution 1 km (radiometric resolution 0.1 K), 3 channels (3.7, 11, 12 um), swath width 500 km, objective for SST accuracy is 0.5 K over an area 50x50 km.

  . Microwave sounder for total atmospheric precipitable water content, non-scanning nadir pointing 25 and 16 km fields of view for channels at 23.8 and 36.5 GHz respectively, predicted accuracy of 2 cm preciptable water.

- Precise Range and Range-Rate Experiment (PRARE) to measure the radial component of the satellite orbit to a precision of about 5-10 cm, for use with the altimeter in determing ocean currents, and for geodesy and geodynamic studies.

o Subsequent ERS missions being considered are a second ocean mission and a land-oriented derivative of ERS-1 with a synthetic aperature radar being a major part of its payload.

<u>(France) SPOT</u> (19)

o Three satellites are planned at present with the first launch scheduled for 1986. The objective is to provide for high resolution land observations for a period of 10 years.

o Orbit: Sun-synchronous, 98.7° inclination, 832 km altitude, 1030 local time of equator crossing (descending), earth coverage repeat cycle variable, about 5 days nominal.

o Sensor: High Resolution Visible (HRV) operates in either of two modes:

  - Panchromatic, 1 channel (0.51-0.73 um), resolution 10 m, swath width 60 km.

  - Multispectral, 3 channels (0.50-0.59, 0.61-0.68, 0.79-0.89 um), resolution 20 m, swath width 60 km.

o Sensor can view in nadir direction or up to 27° (475 km) to the right or left of the spacecraft track. Two HRVs are included, which can be operated simultaneously to give a swath width of 117 km. With pointing capability, stereo pairs can be obtained on adjacent days.

- o Data Transmission: Direct readout to selected ground stations in various countries. Frequency band 8025-8400 MHz, bandwidth 100 MHz, transmission rate $5x10^7$ bits/sec for two HRVs. Primary receiving station at Toulouse, France can receive image data recorded on board the spacecraft as well as direct readout.

(India) IRS (21)

- o Indian Remote Sensing (IRS) Satellite being developed by the Indian Space Research Organisation (ISRO); tentatively planned for launch in 1986.

- o Orbit: Sun synchronous, 99.03° inclination, 904.1 km altitude, earth coverage repeat cycle at the equator of 22 days.

- o Sensors: Two types of Linear Imagery Self Scan (LISS) units, both utilising solid state linear arrays operating in the "push-broom" scan mode. Each unit has 4 channels within the spectral band 0.45-0.9um.
  - LISS-1: resolution 73 m, swath width 148 km
  - LISS-2: resolution 40 m; two swaths, each 74 km wide for a combined width of 148 km.

- o Data Transmission: Direct data reception in X and S bands. Data rates are 5.2×10^6 bits per second for LISS-1, and 2 channels at 10.4×10^6 for LISS-2.

(Japan) MOS and ERS (14, 15, 20)

- o Marine Observation Satellite-1 (MOS-1) and Earth Resources Satellite-1 (ERS-1) are under development for planned launch dates of 1986 and 1990 or 1991 respectively. Additional, more advanced MOS and ERS satellites are being planned for launch during the 1990s, but none have been approved yet.

- o MOS-1

  - Orbit: Sun-synchronous, 99.1° inclination, 909km altitude, earth coverage repeat cycle 17 days at the equator.

  - Sensors:

    . Multispectral Electronic Self-Scanning Radiometer (MESSR), 4 channels (0.51-0.59, 0.61-0.69, 0.72-0.80, 0.80-1.1 um), resolution 50m, swath width 170 km.

    . Visible and Thermal Infrared Radiometer (VTIR), 4 channels, one (0.5-0.7 um) at 0.9 km resolution and three (6.0-7.0, 10.5-11.5, 11.5-12.5 um) at 2.7 km, swath width 1500 km, radiometric resolution 0.5 K, primarily for sea surface temperature.

. Microwave Scanning Radiometer (MSR), 2 channels: 23.8 GHz at 31 km resolution and 31.4 GHz at 21 km, swath width 320 km, thermal resolution 1 K, primarily for atmospheric total water vapour and cloud liquid water content.

. Data Collection System (DCS) for collecting data from and locating Data Collection Platforms (DCPs). Platform up-link frequency near 400 MHz.

- Data transmission: From spacecraft to central data acquisition facility (no direct broadcast).

o ERS-1

- Orbit: Sun-synchronous, 570 km altitude, earth coverage repeat cycle 42 days at the equator.

- Sensors:

. Synthetic Aperature Radar (SAR), resolution 25 m, swath width 75 km.

. Visible Near Infrared Radiometer (VNIR), 4 channels (0.45-0.52, 0.52-0.60, 0.63-0.69, 0.76-0.95 um), resolution 25 m, swath width 150 km.

o Follow-on MOS (in planning stage; not approved)

- As many as 6 more MOS spacecraft are under consideration for development and launch by the year 2000, perhaps moving to an operational system with the launch of MOS-4a and b about 1997.

- Two active microwave sensors now are being developed for flight on MOS-2 and MOS-3, if approved.

. Microwave Altimeter (ALT)

. Microwave Scatterometer (SCAT) with 6-beam antenna to remove ambiguity of wind direction determination; for surface wind speed and direction over the oceans.

- Sensors proposed for MOS-2 are MESSR, VTIR, MSR and DCS from MOS-1, plus ALT. Proposed launch date is 1991.

- Sensors proposed for MOS-3 are MSR, DCS, ALT, SCAT and a Coastal Zone Colour Scanner (CZCS), with launch proposed before 1995.

- MOS-4a, b, 5a, b would add SAR to MOS-3 payload, with launches of 4a, b proposed for 1997 and 5a, b about the year 2000.

o Follow-on ERS (in planning stage; not approved)

Conflicting information (both articles dated June 1984) probably is indicative of the early state of planning.

(SECGEN 947)
10.12.84

Reference (14):

- Two ERS described: ERS-2 a and b planned for launch in first half of 1990s, and ERS-3 a and b in last half in what is defined as operational stage.

- ERS-2a and b to include the SAR from ERS-1, a modified VNIR (6 channels at 15m resolution) and data relay system.

- ERS-3a and b would include the SAR and data relay system from ERS-2, a VNIR with 4 channels at 50m resolution, and a new Visible Near and Thermal Infrared Radiometer (VNTIR) with 3 visible and 3 near infrared channels at 15m resolution, and 3 thermal infrared channels at 150m resolution.

Reference (15) amends the above as follows:

- ERS-2a and b, planned for launch about 1995 would be Japan's first operational land satellites and will include a stereo VNIR, an improved VTIR, a MSR and a SAR.

- ERS-3a and b, would replace ERS-2a and b with a planned launch of 1998 and would add data relay via a proposed tracking and data relay satellite system.

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