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The expanded space-based component of the Global Observing System and the role of the coordination group for Meteorological Satellites

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सार – भूमंडलीय प्रेक्षण तंत्र और उसके प्रतिरूप के अंतरिक्ष से प्राप्त घटक, विश्व मौसम निगरानी के भूमंडलीय प्रेक्षण तंत्र तैयार करते है। विश्व मौसम संगठन विश्व मौसम निगरानी के गठन के दौरान ही भूमंडलीय प्रेक्षण तंत्र सीापित हुआ है। विश्व मौसम निगरानी के गठन के लगभग चपर दशकों से, कम से कम ध्रुवीय कक्षा के चक्कर काट रहे उपग्रहों और कम से कम पाँच तुल्यकाली पर्यावरणीय प्रेक्षण उपग्रहों वाले दो तारामंडलों से एक अथवा अधिक ध्रुवीय चक्कर काट रहे मौसम वैज्ञानिक उपग्रहों के तारामंडलों से अंतरिक्ष से प्राप्त भूमंडलीय प्रेक्षण तंत्र के घटक विकसित किए गए है। हाल ही में सही अनुसंधान और विकास उपग्रहों से एक तीसरा तारामंडल इसमें सम्मिलित हुआ है। इस शोधपत्र में भूमंडल प्रेक्षण तंत्र (जी.ओ.एस.) के अंतरिक्ष से प्राप्त संरूपण और मौसम विज्ञान संबंधी आँकड़ों के समन्वयन समूह की उसवके कार्यान्वियन में उसकी भूमिका का ऐतिहासिक वर्णन किया गया है।

विश्व मौसम संगठन के उपयोगकर्ताओं की आवश्यकताएँ अंतरिक्ष से प्राप्त संरूपणों का मूल आधर है। विश्व मौसम निगरानी के लिए प्रमुख उत्तरदायित्व के साथ विश्व मौसम संगठन का तकनीकी कमीशन आधारभूत तंत्र का कमीशन (सी.बी.एस.) है। सी.बी.एस. ने प्रेक्षण तंत्र की संभावित क्षमताओं के साथ विश्व मौसम संगठन के कार्यक्रमों और विश्व मौसम संगठन द्वारा पोषित कार्यक्रमों के लिए उपयोगकर्ताओं की आवश्यकताओं की तुलना की समीक्षा प्रक्रिया को विकसित किया है। उपयोगकर्ताओं की आवश्यकताओं में हुए विकास के परिणामस्वरूप अंतरिक्ष से प्राप्त भूमंडलीय प्रेक्षण तंत्र के वर्तमानसंरूपण की समीक्ष की आवश्यकता अनुभव हुई है। सी.बी.एस. ने वर्तमान संरूपण के विकास के उद्देश्य से उपयोगकर्ता की आवश्यकताओं और संभावित क्षमताओं के मुल्यांकन के लिए समीक्षा प्रक्रिया का उपयोग करनते का निर्णय लिया है। इस शोध पत्र में विश्व मौसम संगठन के सदस्यों की यथोचित एवं बढ़ती हुई मागों का पूरा करने में सक्षमता लाने हेतु आगामी दशकों में जी.ओ.एस. प्रदान करने के संयुक्त प्रयास के रूप में समीक्षा प्रक्रिया और हाल ही के विश्व मौसम संगठन के निर्णयों का वर्णन भी किया गया ह।

ABSTRACT. The space-based component of the Global Observing System and its *in situ* counterpart form the World Weather Watch's Global Observing System. The Global Observing System (GOS) was established during the formation of the World Meteorological Organization (WMO) World Weather Watch (WWW). During the nearly four decades since the formation of the WWW, the space based component of the GOS evolved from a constellation of one or more polar-orbiting meteorological satellites to two constellations comprised of at least two near-polar-orbiting satellites and at least five geostationary environmental observation satellites. Recently, a third constellation of appropriate Research and Development satellites has been added. This paper provides an historical description of the space-based configuration of the GOS and the role that the Coordination Group for Meteorological Satellites (CGMS) has had in its implementation.

Fundamental to the space-based configuration has been WMO user requirements. The WMO technical commission with the lead responsibility for the World Weather Watch is the Commission for Basic Systems (CBS). CBS has developed a review process to compare user requirements for WMO programmes and WMO supported programmes with expected observing system capabilities. The evolution of user requirements has resulted in the need for a review of the present configuration of the space-based global observing system. CBS has decided to use its review process to evaluate user requirements and anticipated capabilities in order to propose an evolution of the present configuration. This paper also describes the review process and recent WMO decisions that are part of a concerted effort to provide a GOS for the following decades capable of meeting the stringent and increasing demands of WMO members.

Key words – Global Observing System, Environmental satellites, Satellite observations, World weather watch, World Meteorological Organization Commission for basic systems, Remote sensing.

1. Historical review of the global observing system

The space-based GOS has had a profound impact on WMO Members since the inception of the WWW. Its present observational capabilities permeate almost all products and forecasts provided by the National Meteorological and Hydrological Services (NMHSs) in meeting their national mandates. Indeed observations are fundamental to the NMHSs and without them almost all other services would not be possible. These facts alone would justify the high value placed on the GOS by WMO members. However, the space-based GOS was also the genesis of the WWW. While it is possible that a WWW may have evolved, it was the new and exciting possibilities for observations from space that acted as the catalyst to bring together some of the world's leading experts and allowed them to provide a blueprint, the WWW, for international cooperation that is unparalleled within the meteorological communities. The vision and genius of such a small select group have produced reverberations across the world and through several decades. Thus, it is worthy that we briefly review the history of the development of the space-based component of the GOS.

WMO was formally established on 23 March 1950 with the thirtieth accession to its convention. At that time, its Commission for Synoptic Meteorology was responsible for the establishment of a system for the standardization of meteorological observations. Although the Commission continued the excellent work of its predecessor, the International Meteorological Organization's (IMO) Commission for Synoptic Weather Information, there were still large areas of the Earth's surface without an adequate observational network. All this was soon to change in an almost explosive fashion.

The then USSR launched the first Earth-orbiting satellite, Sputnik-1, on 4 October 1957. The USA launched its first satellite, Explorer I, on 2 January 1958. A little over 40 years ago, the "shot heard around the meteorological world" occurred with the launch of TIROS-1 on 1 April 1960. TIROS-1 was a polar-orbiting satellite with a television that provided for the first time pictures of the distribution and complexity of clouds previously undreamed of. The potential for such a new observing system was not only obvious to meteorologists but also to the rest of the world. Indeed first responses started a chain reaction that would have a major impact on the meteorological community for years to come and the chain reaction progressed at near lightning speed.

The United Nations General Assembly (UNGA) unanimously passed on 20 December 1961 its Resolution 1721 (XVI) on the "International Co-operation in the Peaceful Uses of Outer Space". The UNGA noted with gratification the marked progress for meteorological science and technology opened up by the advances in outer space and was convinced of the world-wide benefits to be derived from international cooperation in weather research and analysis. It recommended to all United Nations Member States and to WMO and other appropriate specialized agencies the early and comprehensive study, in the light of developments in outer space, of measures: to advance the state of atmospheric science and technology so as to provide greater knowledge of basic physical forces affecting climate and the possibility of large-scale weather modification; to develop existing weather forecasting capabilities and to help UN Member States make effective use of such capabilities through regional meteorological centres.

The resolution further requested WMO, in consultation, as appropriate, with the United Nations Educational, Scientific and Cultural Organization (UNESCO) and other specialized agencies, governmental and non-governmental organizations, such as the International Council of Scientific Unions (ICSU), to submit a report to WMO Members and to the United Nations (UN). It was the report that would become the bellwether for WMO. And the UNGA wanted the report six months later for its earliest consideration by June 1962.

WMO quickly agreed upon a course of action to meet such a demanding deadline. Two world recognized leaders in the young science of satellite meteorology, Dr H. Wexler, the principal expert in the USA on meteorological satellites, and Academician V.A. Bugaev from the then USSR worked together in Geneva, Switzerland to prepare the First Report of the WMO on the Advancement of Atmospheric Sciences and Their Application in the Light of Developments in Outer Space.

Wexler and Bugaev vividly highlighted potential benefits resulting from satellite data to both operational and research communities. Having laid the foundation, Wexler and Buqaev then proposed a new structure, the WWW. Thus, the WWW was established in response to the emergence of the meteorological satellite and based on an observing system comprised of meteorological satellites and conventional observations. Wexler and Bugaev went further to describe, in general terms, the space-based component of the GOS although it was not yet called such. One of the new observing system's main requirements was the continuous existence of one or more satellites. Thus, at the time of the First Report, only polar-orbiting satellites existed and the space-based GOS needed only one or more such satellites.

The First Report was a colossus. It should be noted that a formally defined set of WMO user requirements did not exist when the First Report was written. A process to identify user requirements would not start in earnest until the 1980s and it would be into the 1990s before such requirements would be used to "redesign" the GOS although the need for an observing system to be responsive to the user needs was recognized from the onset. At least initially, the space-based GOS was the result of technology push. Remote sensing and satellite meteorology were the genesis of the WWW.

In the course of the evolution of the space-based GOS, there would be a slow and steady increase in its scope. However, it would be sixteen years, in 1977, when WMO would receive again profound insight by two more visionaries. But first, let us continue to follow the evolution of the space-based GOS's three pillars: space agency plans; technology; and user requirements. We shall find that the space-based GOS has been greatly influenced by these three primary forces, providers, technology and user requirements. We shall see that the space-based GOS would be guided by user requirements, compelled by technology and made possible by the few space-faring nations and organizations in the world.

The Fourth Report of the WMO on the Advancement of Atmospheric Sciences and Their Application in the Light of Developments in Outer Space, WWW – Phase I, August 1965 contained detailed reference to user requirements for the WWW. It also used for the first time the now well-recognized abbreviation WWW for the World Weather Watch. It took WMO as long to codify the WWW abbreviation as it did to form it. With regard to user requirements, the Fourth Report noted that :

"The purpose of an observational system is to meet the requirements of the user for meteorological data. Thus, the design of a global system must depend essentially upon the data requirements to be placed upon it. However, the problem of stating the global data requirements appropriate to WWW is a very difficult one. There are thus great difficulties in assessing the detailed requirements of the observational system and an objective assessment of requirements (wholly or partially), taking into account the needs of the whole system of the WWW cannot be made before a number of detailed studies have been conducted."

Thus the last pillar, user requirements, emerged - in concept but not in content – in 1965 to accompany technology and the satellite providers as the foundation's triad of the GOS. In 1966, the Fifth Report of the WMO on the Advancement of Atmospheric Sciences and Their Application in the Light of Developments in Outer Space, WWW – Phase II, August 1966 formally refers to the GOS for the first time

"It follows that the essential elements of the WWW are:

The observational networks and other observational facilities, hereafter called the Global Observing System;"

The year 1971 was a watershed for satellite meteorology and the space-based GOS because of a recent and dramatic development in satellite meteorology. In 1966, a technology demonstration communications satellite, ATS-1, flew in geostationary orbit with a meteorological payload. Guided by the acknowledged father of satellite meteorology, Dr V. Suomi (winner of father of satellite meteorology, Dr V. Suomi (winner of the WMO IMO award in 1993 for his leadership), the geostationary satellite had emerged as a vital and necessary component of the now established GOS. The WMO, WWW, The Plan and Implementation Programme, 1972 – 1975, July 1971 contained a new and more formal description of the space-based GOS as follows:

Meteorological satellites can be divided into two groups, those in polar or near-polar orbits and those in geostationary orbit. With the former it is possible to choose the orbit altitude within a wide range, while with the latter it must be approximately 37,000 km. A satellite in near-polar orbit at an altitude of, say 1,000 km, has a big advantage over a geostationary satellite as regards the resolution that can be obtained with a particular optical system. The near-polar orbiting satellite has the further advantage of being able to observe the whole globe whereas a geostationary satellite can only provide useful cloud cover information in an area within a range of about 60-65 degrees from the sub-satellite point; to provide reasonably complete coverage in the tropics for wind determination from cloud displacement measurements, four geostationary satellite are necessary. These satellites should be capable of taking cloud observations between about 50° N and 50° S at short-time intervals both by day and by night.

According to the latest information available, there will be two or three near-polar orbiting meteorological satellites in continuous operation during the period 1972-1975. This number should be adequate to meet the needs of the GOS.

The final WWW Planning Report also recorded the observational requirements for the First GARP Global Experiment (FGGE) for a global network suitable for providing input to numerical models dealing with atmospheric motions on a large or planetary scale. The FGGE requirements were set out separately for the middle/high latitudes and for the tropics. For both areas, requirements were defined only for temperature, relative humidity and wind profiles and for sea surface temperature.

The WMO, WWW, Third Status Report on Implementation, July 1970 mentioned the project of the European Space Research Organization (ESRO) for launching a geostationary satellite in 1977 over approximately the 0° longitude, and also the Japanese plan to set up a geostationary meteorological satellite (GMS) at 120°E as part of its contribution to WWW and the Tropical Cyclone Project. Two new providers were about to join the exclusive club of satellite operator. The provider pillar was now stronger and solid.

The WMO, WWW, Sixth Status Report on Implementation, July 1973 noted that the USA was developing a Geostationary Operational Environmental Satellite (GOES) service to be inaugurated late in 1973. The first satellite in this system (SMS-A) would be located provisionally near 100° W. The Sixth Status Report also recorded that the USSR had announced its plans for setting up a geostationary meteorological satellite at approximately 70°E longitude. This pronouncement brought to full strength the plans of the satellite providers to implement the GOS constellation of five geostationary satellites. However, it would be well into the 1990s before the plans would be realized for full global geostationary coverage. The Sixth Status Report also recognized that meetings of representatives of the countries and agencies concerned in geostationary meteorological satellite programmes were held since 1972 to ensure coordination of these activities. Thus, WMO announced to its Members the formation of the Co-ordination of Geostationary Meteorological Satellites (CGMS). CGMS would play an ever-increasing role in meeting the needs and requirements of WMO and eventually expand its mandate to cover both polar-orbiting and geostationary satellites. CGMS became the Co-ordination Group for Meteorological Satellites (CGMS) in 1992 without the need to change its acronym.

By 1977, the space-based GOS was well established in terms of plans and implementation. However, the pace of development and implementation had not kept abreast of the rapid advances being made in technology. The introductory chapter for the WMO, WWW, Planning Report No. 36, The Role of Satellites in WMO Programmes in the 1980s, 1977 by D.S. Johnson and I.P. Vetlov heralds an impending change of major significance.

"Until quite recently this early planning for WWW served as a useful guide for the development of a global satellite observing system. However, satellites will soon play a far greater role than was originally anticipated in 1961. Satellites will play an increasingly important role not only in obtaining observational data, but also in providing a capacity for the collection and distribution of information in support of various WMO programmes."

The defining phrase "in support of various WMO programmes" greatly extended the scope of responsibility for the space-based GOS. Not only the WWW but almost all WMO programmes would be served. This expansion would require a review of the then definition of the space-based GOS. Johnson and Vetlov would propose a possible constellation of satellites to be a system consisting of three to four satellites in quasi-polar orbits and four to five geostationary satellites in equatorial orbits. From a system point of view, the polar-orbiting satellites would have a primary role in providing global sounding data and high-resolution surface observations, especially those required for specialized applications programmes. The spacecraft in geostationary orbit would be used primarily for continuous monitoring of clouds for short-period and mesoscale forecasting and storm warnings, and to obtain winds at two or three levels in the troposphere.

Johnson and Vetlov further alerted the meteorological community to the expanding explosion of new data sets. The authors outlined a list of expected parameters for the atmosphere, clouds, ocean surface and land surface. Thus, the technology pillar was again urging user requirements to be responsive to new capabilities. This urging would culminate in a concerted effort during the 1980s by each of the WMO Technical Commission to define its user requirements.

The latest and formal description of the space-based GOS can be found in the 1993 edition of the Manual for the GOS which notes the need for a system of atleast two near-polar-orbiting satellites and atleast five geostationary environmental observation satellites. Here an environmental observation satellite was defined as "An artificial Earth satellite providing data on the Earth system which are of benefit to WMO Programmes. These data support a variety of disciplines including, but not limited to, meteorology, hydrology, climatology, oceanography, climate and global change related disciplines." With this new definition, Johnson and Vetlov's vision could become a reality.

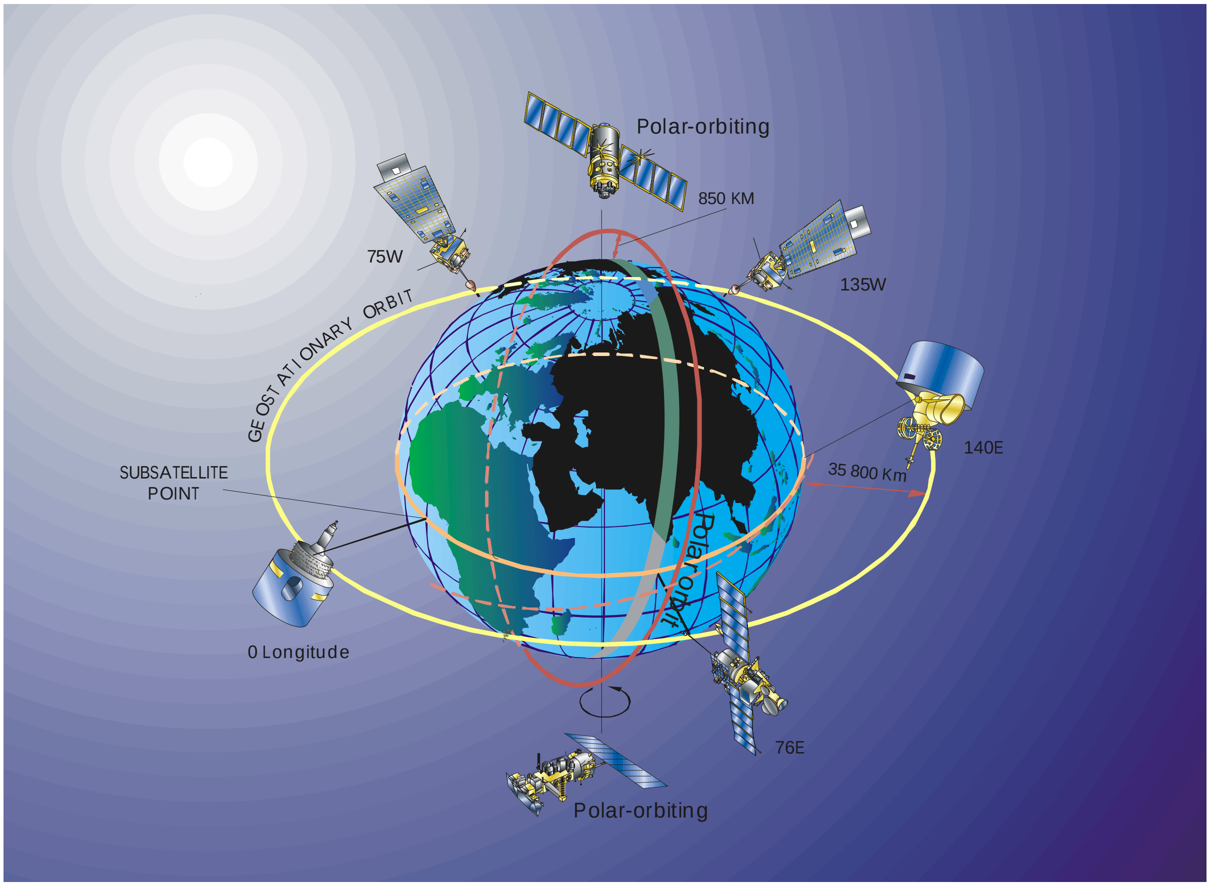

Fig. 1. Two component space-based system for global meteorological observations

2. Co-ordination of Geostationary Meteorological Satellites (CGMS) [Co-ordination Group for Meteorological Satellites]

As noted above, in 1972 a group of satellite operators formed the Co-ordination of Geostationary Meteorological Satellites (CGMS) that would be expanded in the early 1990s to include polar-orbiting satellites and changed its name - but not its abbreviation - to the Co-ordination Group for Meteorological Satellites. The Co-ordination Group for Meteorological Satellites (CGMS) provides a forum for the exchange of technical information on geostationary and polar orbiting meteorological satellite systems, such as reporting on current meteorological satellite status and future plans, telecommunication matters, operations, inter-calibration of sensor, processing algorithms, products and their validation, data transmission formats and future data transmission standards.

A global network of satellites evolved during the 1960s and 1970s following the successful demonstration of the large benefits shown by the USA's TIROS Operational System (TOS) and Applications Technology Satellites (ATS-1 and ATS-3) for meteorological applications.

There are two major components in the current meteorological satellite network. One element consists of the various geostationary meteorological satellites operated by Europe, China, India, Japan, the United States of America and the Russian Federation. These satellites operate on the equatorial belt and provide a continuous view of the weather from approximately 70 degrees North to 70 degrees South. The launch of the first GOES satellite in 1974 by the USA was followed in 1977 with the launches of GMS by Japan and METEOSAT by the European Space Agency (responsibility for this satellite now rests with the European Organisation for the Exploitation of Meteorological Satellites (EUMETSAT). The network was augmented in 1983 with the launch of the first INSAT, in 1994 with the launch of the Russian Federation's GOMS and in 1997 with the launch of FY-2 by China.

The second major element comprises the polar-orbiting satellites operated by the Russian Federation, China and the United States of America. A diagram of the two component space-based system can be seen in Fig. 1.

Since 1972, the Co-ordination Group for Meteorological Satellites (CGMS) has provided a forum in which the satellite operators have studied jointly with the WMO technical operational aspects of the global network, so as to ensure maximum efficiency and usefulness through proper coordination in the design of the satellites and in the procedures for data acquisition and dissemination. The specific design of each of the satellites is based on national and regional requirements for data and services and therefore some differences in design and mission are inevitable. However, the regular meetings of the group have permitted a gathering and exchange of results during the course of the development of each system and a considerable measure of coordination has been achieved.

CGMS came into being on 19 September 1972, when representatives of the European Space Research Organisation (since 1975 called the European Space Agency), Japan, the United States of America and observers from the World Meteorological Organization (WMO) and the Joint Planning Staff for the Global Atmospheric Research Programme met in Washington to discuss questions of compatibility among geostationary meteorological satellites. The meeting identified several areas, in particular for the collection of data from moving platforms and for WEFAX image dissemination, where both technical and operational coordination would be needed.

It was decided at the original CGMS meeting in Washington to establish two working groups, one under the designation "System Engineering Working Group" to study the engineering aspects, and the other entitled "User Considerations Working Group" to look after the interests of future users.

CGMS-I, furthermore, concluded that a meeting of Senior Officials of the participating agencies should be held each time immediately following the meetings of the technical working groups to finalize the report of the meeting and to approve decisions, recommendations and actions.

In the course of CGMS activities, it appeared that some items were related simultaneously to both of the above-mentioned working groups. In the beginning of CGMS such items were resolved by exchanging temporarily individual experts between the two working groups. CGMS-V however, introduced the idea of "joint sessions". In subsequent meetings this resulted in the establishment of an autonomous "Joint Working Group", acting on its own agenda and generating, by CGMS-VII, a separate report to the Senior Officials.

The then USSR, having expressed its intention to develop and operate a geostationary meteorological satellite, GOMS, joined the small group of satellite operators in January 1973. At that time WMO became a full member of CGMS and the then USSR cooperated in developing the technical elements and operational principles for the system of geostationary satellites.

Since 1983, India has operated a series of geostationary telecommunications satellites (INSAT) with an imaging radiometer on board. India joined CGMS in 1979.

EUMETSAT, operator of the Meteosat series, joined CGMS in 1987. It currently serves as CGMS Secretariat.

The People's Republic of China, in considering the development of both polar orbiting and geostationary satellites, joined CGMS in 1989.

On 31 January 1992, the members of the Co-ordination for Geostationary Meteorological Satellites formally adopted the final draft of a new charter for the Co-ordination Group for Meteorological Satellites. In so doing, the charter extended the area of responsibilities for CGMS to include both geostationary and polar-orbiting meteorological satellites.

2.1. *Membership of CGMS*

The table of members shows the lead agency in each case. Delegates are often supported by other agencies, for example, ESA (with EUMETSAT), NASDA (with Japan) and NASA (with NOAA).

The current membership of CGMS is :

EUMETSAT	-	joined 1987 currently CGMS Secretariat
India Meteorological Department	-	joined 1979
Japan Meteorological Agency	-	founder member, 1972
China Meteorological Administration	-	joined 1989
NOAA/NESDIS	-	founder member, 1972

Hydromet Service of the Russian Federation - joined 1973

WMO - joined 1973

The World Meteorological Organization, a specialized agency of the United Nations, has a membership of 185 states and territories (as of June 2000). Amongst the many programmes and activities of the organization, there are three areas which are particularly pertinent to the activities of CGMS:

(*i*) To facilitate world-wide cooperation in the establishment of networks for making meteorological, as well as hydrological and other geophysical observations and centres to provide meteorological services;

(*ii*) To promote the establishment and maintenance of systems for the rapid exchange of meteorological and related information;

(*iii*) To promote the standardization of meteorological observations and ensure the uniform publication of observations and statistics.

The main purpose of the WMO Satellite Activities Programme is to coordinate environmental satellite matters and activities throughout all the WMO Programmes and to give guidance to WMO and other multi-sponsored programmes on the potential of remote-sensing techniques in meteorology, hydrology, related disciplines and their applications.

Satellites have become a fundamental tool for WMO to carry out its basic goals. WMO needs to play a role in the coordination of the global network of meteorological satellites because of the data and services provided to the large number of countries who are neither satellite operators nor members of a consortium operating such satellites. This is also very pertinent for the large parts of the globe outside national jurisdiction, especially the large open ocean areas.

WMO, in its endeavours to promote the development of a global meteorological observing system, participated in the activities of CGMS from its first meeting. There are several areas where joint consultations between the satellite operators and WMO are needed. The provision of data to meteorological centres in different parts of the globe is achieved by means of the Global Telecommunication System (GTS) in near-real-time. This automatically involves assistance by WMO in developing appropriate code forms and provision of a certain amount of administrative communications between the satellite operators.

The active involvement of WMO has allowed the development and implementation of the operational ASDAR system as a continuing part of the Global Observing System (GOS). Furthermore, the implementation of the IDCS system was promoted by WMO and acted jointly with the satellite operators as the admitting authority in the registration procedure for IDCPs.

The global network of meteorological satellites, whose technical and operational coordination is the objective of CGMS, constitutes a major portion of the space-based component in the Global Observing System (GOS) of the World Weather Watch (WWW). This network design evolved during the period from 1965 to 1978 as a portion of the Global Atmosphere Research Programme (GARP). The GARP and WWW are responses of WMO and the International Council of Scientific Unions (ICSU) to three resolutions of the General Assembly of the United Nations, calling for international programmes in Meteorology for the benefit of mankind. WWW is a continuing programme of WMO to assist meteorological services in all parts of the world in operational and research functions by making available basic meteorological and other relevant data. The GOS provides the input data for numerical weather prediction models. GARP was a research effort, sponsored jointly by WMO and ICSU, to gain a better understanding of the laws and the behaviour of the earth's atmosphere. This is important both for improving operational forecasting and for a better determination of the influence of human activities on the atmosphere. The World Climate Programme is a follow-on to the GARP activities.

CGMS members contributed to the implementation of the first GARP Global Experiment (FGGE) by developing the network of the 5 geostationary satellites. FGGE was started in September 1978 with a build-up phase, followed by a 12 month operational phase starting 1 December 1978. The latter included two special observing periods of one month's duration (15 January to 15 February 1979 for the first and 15 May to 15 June 1979 for the second), where all components of the GARP Global Observing System were simultaneously in operation.

Since approximately 70 per cent of the Earth's surface is water and even the land areas have many regions which are sparsely inhabited, the polar-orbiting satellite system provides the data needed to fill-in the gaps of surface and atmospheric temperature profiles over the areas not adequately covered by conventional observing systems particularly in the Southern Hemisphere and in high latitudes both in the Arctic and Antarctic. Flying in a near-polar orbit, these spacecraft are able to acquire data from all parts of the globe in the course of a series of successive revolutions. With a relatively low altitude their sensors can acquire higher-resolution data, both spatially and spectrally, than can the high-altitude geostationary satellites. For these reasons the polar-orbiting satellites are principally used to obtain specific sets of observations of three main types: (*i*) daily global cloud cover; (*ii*) reasonably accurate quantitative measurements of surface temperature; and (*iii*) most important, the vertical variation of temperature and water vapour in the atmosphere.

The importance of operational continuity and reliability for the global coverage from satellites was discussed at the CGMS-XIII and XIV sessions. In particular, all satellite operators were asked at CGMS-XIV to re-examine the opportunities and constraints for redeployment of satellites in the event of failure of one or more geostationary meteorological satellite in the network. WMO at CGMS-XV presented a comparison of several different strategies for achieving reliability and coverage on a global scale. This comparison strongly indicated that a strategy based on the redeployment of operating satellites has limited utility due to the inability to rationalise the needs for geographical coverage by different users and due to the presence of different types of spacecraft. EUMETSAT, also at CGMS-XV, proposed that a strategy based on deployment of spare satellites. CGMS-XV also considered the strategy of overlapping satellite coverage with a resultant "fail-soft" global network which was one of the alternative strategies analyzed by WMO. CGMS members endorsed the idea of increased direct participation in geostationary meteorological satellite operations.

2.2. *Geostationary satellite systems and their missions*

The nine geostationary meteorological satellite systems currently in operation are provided by:

EUMETSAT	(two METEOSAT spacecraft)
Russian Federation	(one GOMS spacecraft)
Japan	(one GMS spacecraft)
USA	(two GOES spacecraft)
India	(two INSAT spacecraft)
China	(one FY-2 spacecraft)

All these satellite systems have been designed to fulfil the following mission objectives:

(*i*) High-resolution imaging of the Earth's surface and of its cloud coverage, in the visible and thermal infrared spectra, and extraction of meteorological information such as cloud motion wind vectors, sea surface temperatures, cloudiness and cloud top heights from the image data;

(*ii*) Dissemination of cloud cover images and other meteorological information to user Stations;

(*iii*) Collection and relay of environmental data from fixed or mobile data collection platforms, located either on the Earth's surface or in the atmosphere.

The design characteristics of all the geostationary meteorological satellite systems differ from one to another, but they bear a general similarity in their mission performance:

(*i*) They all carry scan imagers to provide high-resolution full disc images in the visible and in the infrared. The useful coverage of these images, in particular for acceptable wind vector extraction, extends up to 50 or 55 degrees around the sub-satellite points. They employ comparable imaging techniques; *i.e.*, a maximum of 48 full earth images per day can be generated by each satellite system.

(*ii*) They all include data relay capabilities for the dissemination of images and data collection. Furthermore, since these two missions affect a wide community of users operating APT stations, Data User Stations and Data Collection Platforms, the transmission characteristics and the operational procedures have been standardised. The coverage of the data relay capability extends up to about 75 degrees around each sub-satellite point.

2.3. *Polar-orbiting satellite systems and their missions*

The seven polar-orbiting meteorological satellite systems are currently operational and provided by:

Russian Federation	(two METEOR spacecraft)
USA	(two NOAA and two DMSP spacecraft)
China	(one FY-1 spacecraft)

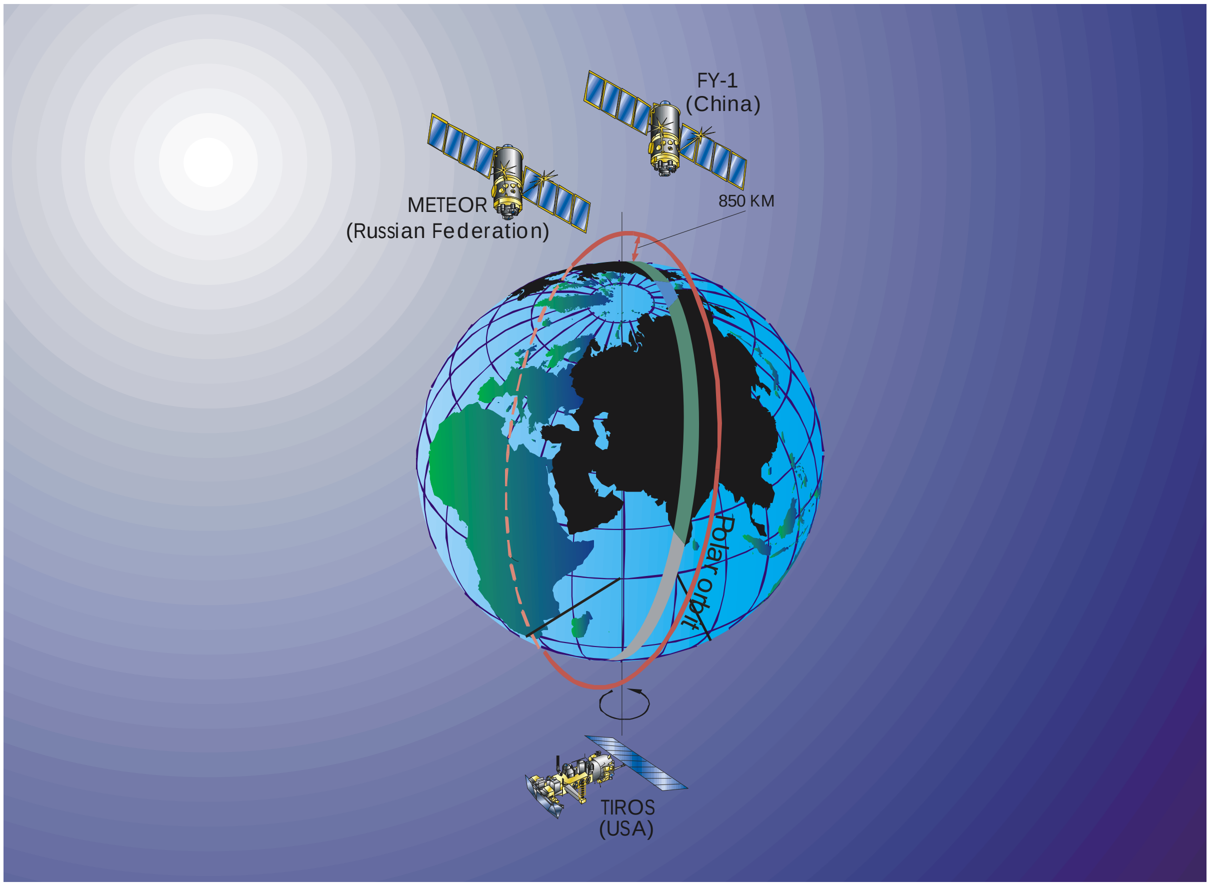

Fig. 2. Polar orbiting satellite systems for meteorological observations

These satellites circle the earth each 100 minutes passing nearly over the North and South Poles. Each satellite sees the entire planet twice per 24 hours. Fig. 2 shows polar-orbiting satellites systems.

2.4. *Satellite system contingency plans*

The operational continuity and reliability of global coverage is an important requirement of the space-based global observing system. There have, consequently, been regular discussions on contingency planning by the satellite operators at CGMS meetings. Distinction has been made between :

– Regional contingency plans: what is planned by the satellite operator to maintain operational continuity;

– Inter-regional contingency plans: what is foreseen by neighbouring satellite operators to remedy a failure of one of their satellites;

– Global contingency plans: what is agreed by all satellite operators to remedy the failure of any one of the existing operational satellites.

2.5. *Inter-regional contingency arrangements*

So far, there have been two examples of inter-regional contingency arrangements between the USA and Europe. From 1985 to 1988, NOAA repositioned its GOES-4 spacecraft to fill a gap over Europe created by the loss in DCS service from Meteosat-2. In the beginning of 1991 EUMETSAT repositioned its Meteosat-3 to back-up the ageing GOES-7 in providing Atlantic Ocean image coverage. This latter arrangement was referred to as the Atlantic Data Coverage (ADC), which eventually became Extended Atlantic Data Coverage (XADC), from January 1993 to May 1995, when ESA/EUMETSAT moved Meteosat-3 westward from 50° West to 75° West, using upgraded facilities at the NOAA Wallops Island ground station.

Following the success of these contingency operations, NOAA and EUMETSAT have since concluded a long-term agreement on back-up of operational geostationary meteorological satellite systems.

Another example of inter-regional contingency satellite operations occurred in the Pacific region in the autumn of 1992, using temporary DCS support capacity provided by the Japanese GMS-4 for data collection of regional DCP which would normally use the GOES DCS - International Channel 1-16.

2.6. *Global contingency plans*

In 1991, the forty-fourth Executive Council of WMO recommended the development of contingency plans by the satellite operators to increase the reliability of the space-based global observation system. WMO considered that space segment contingency planning was the core of the statement of WMO requirements for system continuity. It was anticipated that CGMS would continue its role of coordination and standardization such that ground receiving equipment would be able to receive and process services from any contingency satellite provided by another operator, *e.g*., by using standardized down-link broadcasts and data formats. In 1992, the statement of WMO requirements for continuity was subsequently endorsed by the satellite operators, who subsequently established a CGMS Working Group on Global Contingency Planning.

However, at the first meeting of this Working Group in October 1992, CGMS concluded that no single satellite operator could be expected to guarantee satellite availability in all circumstances and that the establishment of joint contingency plans was essential in order to achieve a reliable global system at a realistic cost. A proposal for a contingency concept, which could meet global needs, was thus established. This concept was based upon a philosophy of assisting neighbouring satellite operators by using data transfer techniques similar to that already developed for the Europe-USA Extended Atlantic Data Coverage scheme mentioned above.

In 1994, the CGMS Working Group on Global Contingency Planning agreed a technical strategy based upon the "help your neighbour" concept. This strategy assumes that each satellite operator tries, with its best efforts, to maintain its nominal configuration, in accordance with its own constraints. Any CGMS satellite operator faced with a contingency situation, whereby priority satellite based services cannot be supported, should immediately discuss the situation with other satellite operators who, in good faith, should try to find a solution.

In 1997, CGMS considered that it would be beneficial for the user community to develop similar arrangements to cover unexpected contingencies affecting services provided by the satellite operators.

In 1998, Japan and China looked into possible contingency arrangements to support each other's services. The GMS and FY-2 satellite systems have a high level of compatibility with regard to the area of the globe covered and transmission characteristics. However, it was decided that long-term contingency arrangements could only be considered if respective launch schedules allowed sufficient in-orbit redundancy. A constraint to the provision of a back-up of MTSAT or FY-2 was the limited overlap in the fields of view of GMS/MTSAT and FY-2.

Bearing this in mind, the Working Group on Global Contingency planning considered that in the event of a major system failure, back-up in areas such as product generation might be an appropriate solution. As a consequence, the satellite operators are currently actively studying such possibilities for support to product generation using data from neighbouring satellite systems.

Additionally, in 1998, discussions were initiated between EUMETSAT and the Russian Federation with a view to investigating possibilities for the use of Meteosat -5 at 63 °E to relay Russian Federation DCP messages and provide a temporary WEFAX image dissemination service in the region.

Also in 1998, India agreed to transmit to its higher authorities the need for regional contingency planning as stipulated in the CGMS Contingency Strategy. To this end, EUMETSAT has concluded an Agreement with ISRO for the possible relay of some INSAT imagery and products *via* the Meteosat system. In return, India will have access to imagery provided by Meteosat-5 located at 63°E.

In 2002, the governments of Japan and the United States of America exchanged diplomatic notes for the implementation of a procedure to backup GMS-5 with GOES-9, if required, starting in the second quarter of 2003. JMA has provided all WMO Members in the service area for GMS-5 with more detailed information concerning the back up. Concurrently, NOAA/NESDIS and JMA intended to begin discussions on a long-term contingency back up agreement. Such a long-term agreement would take effect once both agencies had established their planned baseline configuration. This baseline configuration, planned to be in place sometime in the next decade would provide for a robust national programme and would also have some capability to back up the other agency's programme in an emergency situation. Additionally, the China Meteorological Administration (CMA) has indicated that it intends to launch FY-2C by the end of 2003. CMA's intentions were to launch a geostationary satellite every three years but would have the capability to launch a satellite, if required, with only one year's notice. CMA noted that it planned to maintain a nominal two satellite configuration, one at 86 and one at 105 degrees East longitude with the contingency to use an "on-demand launch" if required. Finally, ROSHYDROMET noted that it intended to maintain its nominal one geostationary satellite configuration at 76 degrees East longitude. ROSHYDROMET indicated that GOMS N2 was an approved programme with a planned launch date in 2005. The imager, MSU-GS, on GOMS N2 would be similar in capabilities to SEVIRI on the MSG series of EUMETSAT satellites.

2.7. *Polar orbiting contingency planning*

With regard to polar orbiting contingency planning, CGMS first discussed the principles for such plans in 2002. CGMS noted that the basic WMO requirement for the polar orbit was for two satellites - one in the AM and one in the PM orbit. CGMS has agreed that in order to meet WMO's requirement for contingency planning a constellation of four polar-orbiting satellites would be required, two in the AM orbit capable of serving as backup to the other and two in the PM orbit also capable of serving as backup to the other.

3. WMO's rolling review of requirements process

WMO has had a long history in defining its observational data requirements. It presently follows a process that results in a hierarchical set of requirements. At the highest level, WMO is guided by its Long-term Planning Process. The Fifth Long-term Plan is the current plan and spans the time frame 2000 to 2009. The Plan provides a vision for the twenty-first century and contains overall guidance, objectives, opportunities and challenges for the organization including those for economic development, political developments, demographic dynamics, urban environment, human health, energy production and consumption, fresh water, land use, food security and combating desertification, protection of climate and atmosphere, natural and human-caused disasters. Within each major WMO Programme, *i.e.*, World Weather Watch Programme, World Climate Programme, Atmospheric Research and Environment Programme, Applications of Meteorology Programme, Hydrology and Water Resources Programme, Education and Training Programme and the Technical Cooperation Programme, there are similar but focused high-level requirements with guidance, objectives, opportunities and challenges.

The current procedure for setting, reviewing and updating observational data requirements for the various Technical Commissions is now well founded in a process called the Rolling Review of Requirements (RRR). All WMO Programmes and supported programmes have ascribed to the RRR process. It has become an effective tool to assess current capabilities of a global observing system and provide guidance for future enhancements. There are periodic comparisons, normally on an annual basis, made between the requirements and expected observing system performances. Between these comparisons, the observational requirements and expected performances are reviewed and updated. The database allows a static view of the observational requirements while the process allows dynamic review and update, as appropriate.

Rolling Requirements Review (RRR)

The RRR procedure consists of four stages:

(*i*) A review of users' requirements for observations, within areas of applications covered by WMO programmes;

(*ii*) A review of the observing capabilities of existing and planned satellite and *in situ* systems;

(*iii*) A "Critical Review" of the extent to which the capabilities (*ii*) meet the requirements (*i*); and,

(*iv*) A "Statement of Guidance" based on (*iii*).

Requirements for observations are stated quantitatively in terms of a set of relevant parameters, of which the most important are horizontal and vertical resolution, frequency (observing cycle), timeliness (delay of availability), and accuracy. For each application, there is usually no abrupt transition in the utility of an observation as its quality changes; improved observations (in terms of resolution, frequency, accuracy, etc.) are usually more useful while degraded observations, although less useful, are usually not useless. Moreover, the range of utility varies from one application to another. The requirements for each parameter are expressed in terms of two values, an upper boundary or "maximum" and a lower boundary or "minimum" requirement. The "maximum" requirement is the value, if exceeded, does not yield significant improvements in performance for the application in question. The "minimum" requirement is the value below which the observation does not yield any significant benefit for the application in question.

However, as a system that meets only minimum requirements is unlikely to be cost-effective, it should not be used as a minimum target level (for an acceptable system).

Critical Review (CR)

The CR process compares user requirements with the satellite system capabilities and records the results, in terms of the extent to which the capabilities of present, planned and proposed systems meet the stated requirements.

Statement Of Guidance (SOG)

The role of the SOG is to provide an interpretation of the output of the CR, to draw conclusions, and to identify priorities for action. The process of preparing the SOG is necessarily more subjective than that of the CR. Moreover, whilst the CR attempts to provide a comprehensive summary, the SOG is more selective, drawing out key issues. It is at this stage that judgements are required concerning, for example, the relative importance of observations of different variables.

4. Expanded space-based component of the Global Observing System

The fifty-third session of the WMO Executive Council made a landmark decision in June 2001 when it agreed that the space-based component should be expanded to include appropriate Research and Development satellite missions. In so doing, the WMO Executive Council also approved a set of guidelines, Guidelines for requirements for observational data from operational and R&D satellite missions, to be agreed upon by perspective R&D space agencies when committing their satellite systems to participate in the space-based component of the GOS. Those guidelines have been sent to R&D agencies with satellite missions having the potential to measure geophysical parameters stated in the list of WMO observational data requirements. To date, four R&D space agencies have responded positively. In particular, the National Aeronautics and Space Administration (NASA) of the USA confirmed its commitment to WMO and to the world community to make observations available without restriction. It further indicated that this policy would apply to all relevant missions. Therefore, since data from NASA's Earth observation missions were readily available, its satellites can be considered *de facto* as part of the space-based component of the Global Observing System (GOS). The European Space Agency (ESA) confirmed that it was establishing a dialogue towards the development of information for WMO Members concerning the availability of specific data and products from ESA's EO satellite missions, and in particular from the ENVISAT mission launched in March 2002. ESA further indicated that it would propose to its Programme Board for Earth Observation (PB-EO), to jointly organize a dedicated, specific Announcement of Opportunity (AO) to foster the use of ESA Earth Observation data by the WMO community. The National Space Development Agency of Japan (NASDA) indicated that its future satellite missions including ADEOS II and the GCOM series were candidate systems to contribute to the new R&D constellation for the space-based component of the GOS. Finally, the Russian Aviation and Space Agency (Rosaviakosmos) confirmed that experimental and R&D instruments on board its operational METEOR 3M N1 satellite as well as on its future Ocean series and other missions could be considered as a potential contribution to the space-based component of the GOS.