SATELLITE REMOTE SENSING AND GIS APPLICATIONS IN AGRICULTURAL METEOROLOGY AND WMO SATELLITE ACTIVITIES

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Abstract : Agricultural planning and use of agricultural technologies need applications of agricultural meteorology. Satellite remote sensing technology is increasingly gaining recognition as an important source of agrometeorological data as it can complement well the traditional methods agrometeorological data collection. Agrometeorologists all over the world are now able to take advantage of a wealth of observational data, product and services flowing from specially equipped and highly sophisticated environmental observation satellites. In addition, Geographic Information Systems (GIS) technology is becoming an essential tool for combining various map and satellite information sources in models that simulate the interactions of complex natural systems. The Commission for Agricultural Meteorology of WMO has been active in the area of remote sensing and GIS applications in agrometeorology. The paper provides a brief overview of the satellite remote sensing and GIS Applications in agricultural meteorology along with a description of the WMO Satellite Activities Programme. The promotion of new specialised software should make the applications of the various devices easier, bearing in mind the possible combination of several types of inputs such as data coming from standard networks, radar and satellites, meteorological and climatological models, digital cartography and crop models based on the scientific acquisition of the last twenty years.

INTRODUCTION

Agricultural planning and use of agricultural technologies need application of agricultural meteorology. Agricultural weather and climate data systems are necessary to expedite generation of products, analyses and forecasts that affect

Satellite Remote Sensing and GIS Applications in Agricultural Meteorology
pp. 1-21

agricultural cropping and management decisions, irrigation scheduling, commodity trading and markets, fire weather management and other preparedness for calamities, and ecosystem conservation and management.

Agrometeorological station networks are designed to observe the data of meteorological and biological phenomena together with supplementary data as disasters and crop damages occur. The method of observation can be categorized into two major classes, manually observed and automatic weather stations (AWS). A third source for agrometeorological data that is gaining recognition for its complementary nature to the traditional methods is satellite remote sensing technology.

Remotely sensed data and AWS systems provide in many ways an enhanced and very feasible alternative to manual observation with a very short time delay between data collection and transmission. In certain countries where only few stations are in operation as in Northern Turkmenistan (Seitnazarov, 1999), remotely sensed data can improve information on crop conditions for an early warning system. Due to the availability of new tools, such as Geographic Information Systems (GIS), management of an incredible quantity of data such as traditional digital maps, database, models etc., is now possible. The advantages are manifold and highly important, especially for the fast cross-sector interactions and the production of synthetic and lucid information for decision-makers. Remote sensing provides the most important informative contribution to GIS, which furnishes basic informative layers in optimal time and space resolutions.

In this paper, a brief overview of the satellite remote sensing and GIS applications in agricultural meteorology is presented along with a description of the WMO Satellite Activities Programme. Details of the various applications alluded to briefly in this paper, can be found in the informative papers prepared by various experts who will be presenting them in the course of this workshop.

The Commission for Agricultural Meteorology (CAgM) of WMO, Remote Sensing and GIS

Agricultural meteorology had always been an important component of the National Meteorological Services since their inception. A formal Commission for Agricultural Meteorology (CAgM) which was appointed in 1913 by the International Meteorological Organization (IMO), became the foundation of the CAgM under WMO in 1951.

The WMO Agricultural Meteorology Programme is coordinated by CAgM. The Commission is responsible for matters relating to applications of meteorology to agricultural cropping systems, forestry, and agricultural land use and livestock management, taking into account meteorological and agricultural developments both in the scientific and practical fields and the development of agricultural meteorological services of Members by transfer of knowledge and methodology and by providing advice.

CAgM recognized the potential of remote sensing applications in agricultural meteorology early in the 70s and at its sixth session in Washington in 1974 the Commission agreed that its programme should include studies on the application of remote sensing techniques to agrometeorological problems and decided to appoint a rapporteur to study the existing state of the knowledge of remote sensing techniques and to review its application to agrometeorological research and services. At its seventh session in Sofia, Bulgaria in 1979, the Commission reviewed the report submitted by Dr A.D. Kleschenko (USSR) and Dr J.C. Harlan Jr (USA) and noted that there was a promising future for the use in agrometeorology of data from spacecraft and aircraft and that rapid progress in this field required exchange of information on achievements in methodology and data collection and interpretation. The Commission at that time noted that there was a demand in almost all countries for a capability to use satellite imagery in practical problems of agrometeorology. The Commission continued to pay much attention to both remote sensing and GIS applications in agrometeorology in all its subsequent sessions up to the 13th session held in Ljubljana, Slovenia in 2002. Several useful publications including Technical Notes and CAgM Reports were published covering the use of remote sensing for obtaining agrometeorological information (Kleschenko, 1983), operational remote sensing systems in agriculture (Kanemasu and Filcroft, 1992), satellite applications to agrometeorology and technological developments for the period 1985-89 (Seguin, 1992), statements of guidance regarding how well satellite capabilities meet WMO user requirements in agrometeorology (WMO, 1998, 2000) etc. At the session in Slovenia in 2002, the Commission convened an Expert Team on Techniques (including Technologies such as GIS and Remote Sensing) for Agroclimatic Characterization and Sustainable Land Management.

The Commission also recognized that training of technical personnel to acquire, process and interpret the satellite imagery was a major task. It was felt that acquisition of satellite data was usually much easier than the interpretation of data for specific applications that were critical for the assessment and management of natural resources. In this regard, the Commission pointed out that long-term planning and training of technical personnel was a key ingredient in ensuring full success in the use of current and future remote sensing technologies that could increase and sustain agricultural production, especially in the developing countries. In this connection, WMO already organized a Training Seminar on GIS and Agroecological Zoning in Kuala Lumpur, Malaysia in May 2000 in which six participants from Malaysia and 12 from other Asian and the South-West Pacific countries participated. The programme for the seminar dealt with meteorological and geographical databases, statistical analyses, spatialization, agro-ecological classification, overlapping of agroecological zoning with boundary layers, data extraction, monitoring system organization and bulletins.

The training workshop currently being organized in Dehradun is in response to the recommendations of the Commission session in Slovenia in 2002 and it should help the participants from the Asian countries in learning new skills and updating their current skills in satellite remote sensing and GIS applications in agricultural meteorology.

GIS APPLICATIONS IN AGROMETEOROLOGY

A GIS generally refers to a description of the characteristics and tools used in the organization and management of geographical data. The term GIS is currently applied to computerised storage, processing and retrieval systems that have hardware and software specially designed to cope with geographically referenced spatial data and corresponding informative attribute. Spatial data are commonly in the form of layers that may depict topography or environmental elements. Nowadays, GIS technology is becoming an essential tool for combining various map and satellite information sources in models that simulate the interactions of complex natural systems. A GIS can be used to produce images, not just maps, but drawings, animations, and other cartographic products.

The increasing world population, coupled with the growing pressure on the land resources, necessitates the application of technologies such as GIS to help maintain a sustainable water and food supply according to the environmental potential. The “sustainable rural development” concept envisages an integrated management of landscape, where the exploitation of natural resources, including climate, plays a central role. In this context, agrometeorology can help reduce inputs, while in the framework of global change, it helps quantify the contribution of ecosystems and agriculture to carbon budget (Maracchi, 1991). Agroclimatological analysis can improve the knowledge of existing problems allowing land planning and optimization of resource management. One of the most important agroclimatological applications is the climatic risk evaluation corresponding to the possibility that certain meteorological events could happen, damaging crops or infrastructure.

At the national and local level, possible GIS applications are endless. For example, agricultural planners might use geographical data to decide on the best zones for a cash crop, combining data on soils, topography, and rainfall to determine the size and location of biologically suitable areas. The final output could include overlays with land ownership, transport, infrastructure, labour availability, and distance to market centres.

The ultimate use of GIS lies in its modelling capability, using real world data to represent natural behaviour and to simulate the effect of specific processes. Modelling is a powerful tool for analyzing trends and identifying factors that affect them, or for displaying the possible consequences of human activities that affect the resource availability.

In agrometeorology, to describe a specific situation, we use all the information available on the territory: water availability, soil types, forest and grasslands, climatic data, geology, population, land-use, administrative boundaries and infrastructure (highways, railroads, electricity or communication systems). Within a GIS, each informative layer provides to the operator the possibility to consider its influence to the final result. However more than the overlap of the different themes, the relationship of the numerous layers is reproduced with simple formulas or with complex models. The final information is extracted using graphical representation or precise descriptive indexes.

In addition to classical applications of agrometeorology, such as crop yield forecasting, uses such as those of the environmental and human security are becoming more and more important. For instance, effective forest fire prevention needs a series of very detailed information on an enormous scale. The analysis of data, such as the vegetation coverage with different levels of inflammability, the presence of urban agglomeration, the presence of roads and many other aspects, allows the mapping of the areas where risk is greater. The use of other informative layers, such as the position of the control points and resource availability (staff, cars, helicopters, aeroplanes, fire fighting equipment, etc.), can help the decision-makers in the management of the ecosystems. Monitoring the resources and the meteorological conditions therefore allows, the consideration of the dynamics of the system, with more adherence to reality. For instance, Figure 1 shows the informative layers used for the evaluation of fire risk in Tuscany (Italy). The final map is the result of the integration of satellite data with territorial data, through the use of implemented GIS technologies (Romanelli *et al.,* 1998).

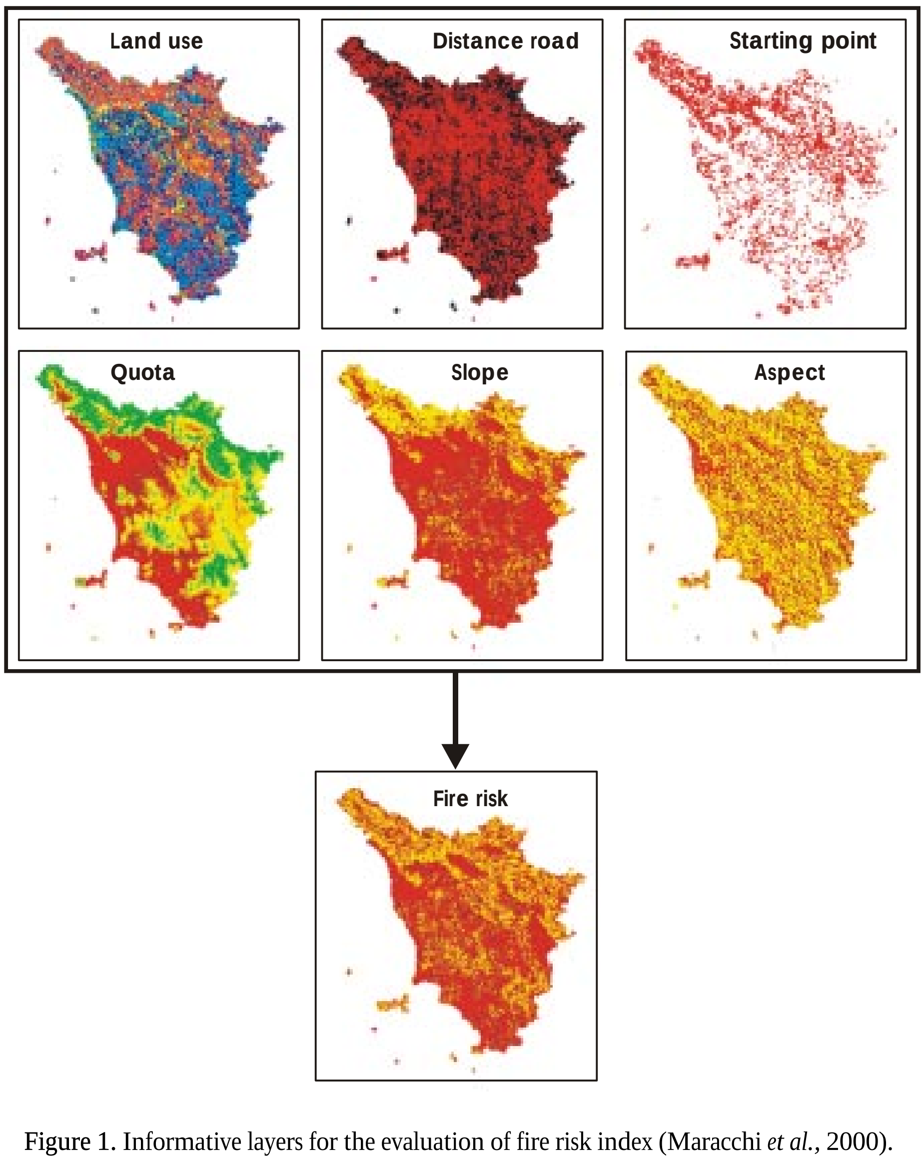

Figure 1. Informative layers for the evaluation of fire risk index (Maracchi *et al.,* 2000).

These maps of fire risk, constitute a valid tool for foresters and for organisation of the public services. At the same time, this new informative layer may be used as the base for other evaluations and simulations. Using meteorological data and satellite real-time information, it is possible to diversify the single situations, advising the competent authorities when the situation moves to hazard risks. Modelling the ground wind profile and taking into account the meteorological conditions, it is possible to advise the operators of the change in the conditions that can directly influence the fire, allowing the modification of the intervention strategies.

An example of preliminary information system to country scale is given by the SISP (Integrated information system for monitoring cropping season by meteorological and satellite data), developed to allow the monitoring of the cropping season and to provide an early warning system with useful information about evolution of crop conditions (Di Chiara and Maracchi, 1994). The SISP uses:

- Statistical analysis procedures on historical series of rainfall data to produce agroclimatic classification;
- A crop (millet) simulation model to estimate millet sowing date and to evaluate the effect of the rainfall distribution on crop growth and yield;
- NOAA-NDVI image analysis procedures in order to monitor vegetation condition;
- Analysis procedures of Meteosat images of estimated rainfall for early prediction of sowing date and risk areas.

The results of SISP application shown for Niger (Fig. 2) are charts and maps, which give indications to the expert of the millet conditions during the season in Niger, with the possibility to estimate the moment of the harvest and final production. SISP is based on the simulation of the millet growth and it gives an index of annual productivity by administrative units. These values, multiplied to a yield statistical factor, allow estimation of absolute production.

By means of such systems based on modelling and remote sensing, it is possible to extract indices relative to the main characteristics of the agricultural season and conditions of natural systems. This system is less expensive, easily transferable and requires minor informative layers, adapting it to the specific requirements of the users.

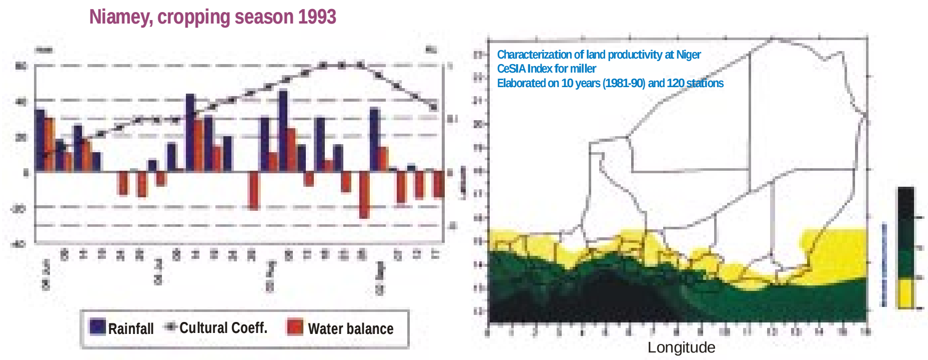

Figure 2. Examples of outputs of SISP (Maracchi *et al.*, 2000).

SATELLITE REMOTE SENSING

Remote sensing provides spatial coverage by measurement of reflected and emitted electromagnetic radiation, across a wide range of wavebands, from the earth's surface and surrounding atmosphere. The improvement in technical tools of meteorological observation, during the last twenty years, has created a favourable *substratum* for research and monitoring in many applications of sciences of great economic relevance, such as agriculture and forestry. Each waveband provides different information about the atmosphere and land surface: surface temperature, clouds, solar radiation, processes of photosynthesis and evaporation, which can affect the reflected and emitted radiation, detected by satellites. The challenge for research therefore is to develop new systems extracting this information from remotely sensed data, giving to the final users, near-real-time information.

Over the last two decades, the development of space technology has led to a substantial increase in satellite earth observation systems. Simultaneously, the Information and Communication Technology (ICT) revolution has rendered increasingly effective the processing of data for specific uses and their instantaneous distribution on the World Wide Web (WWW).

The meteorological community and associated environmental disciplines such as climatology including global change, hydrology and oceanography all over the world are now able to take advantage of a wealth of observational data, products and services flowing from specially equipped and highly sophisticated environmental observation satellites. An environmental observation satellite is an artificial Earth satellite providing data on the Earth system and a Meteorological satellite is a type of environmental satellite providing meteorological observations. Several factors make environmental satellite data unique compared with data from other sources, and it is worthy to note a few of the most important:

- Because of its high vantage point and broad field of view, an environmental satellite can provide a regular supply of data from those areas of the globe yielding very few conventional observations;

- The atmosphere is broadly scanned from satellite altitude and enables large-scale environmental features to be seen in a single view;

- The ability of certain satellites to view a major portion of the atmosphere continually from space makes them particularly well suited for the monitoring and warning of short-lived meteorological phenomena; and

- The advanced communication systems developed as an integral part of the satellite technology permit the rapid transmission of data from the satellite, or their relay from automatic stations on earth and in the atmosphere, to operational users.

These factors are incorporated in the design of meteorological satellites to provide data, products and services through three major functions:

- Remote sensing of spectral radiation which can be converted into meteorological measurements such as cloud cover, cloud motion vectors, surface temperature, vertical profiles of atmospheric temperature, humidity and atmospheric constituents such as ozone, snow and ice cover, ozone and various radiation measurements;

- Collection of data from *in situ* sensors on remote fixed or mobile platforms located on the earth's surface or in the atmosphere; and

- Direct broadcast to provide cloud-cover images and other meteorological information to users through a user-operated direct readout station.

The first views of earth from space were not obtained from satellites but from converted military rockets in the early 1950s. It was not until 1 April 1960 that the first operational meteorological satellite, TIROS-I, was launched by the USA and began to transmit basic, but very useful, cloud imagery. This satellite was such an effective proof of concept that by 1966 the USA had launched a long line of operational polar satellites and its first geostationary meteorological satellite. In 1969 the USSR launched the first of a series of polar satellites. In 1977 geostationary meteorological satellites were also launched and operated by Japan and by the European Space Agency (ESA). Thus, within 18 years of the first practical demonstration by TIROS-I, a fully operational meteorological satellite system (Fig. 3) was in place, giving routine data coverage of most of the planet. This rapid evolution of a very expensive new system was unprecedented and indicates the enormous value of these satellites to meteorology and society. Some four decades after the first earth images, new systems are still being designed and implemented, illustrating the continued and dynamic interest in this unique source of environmental data.

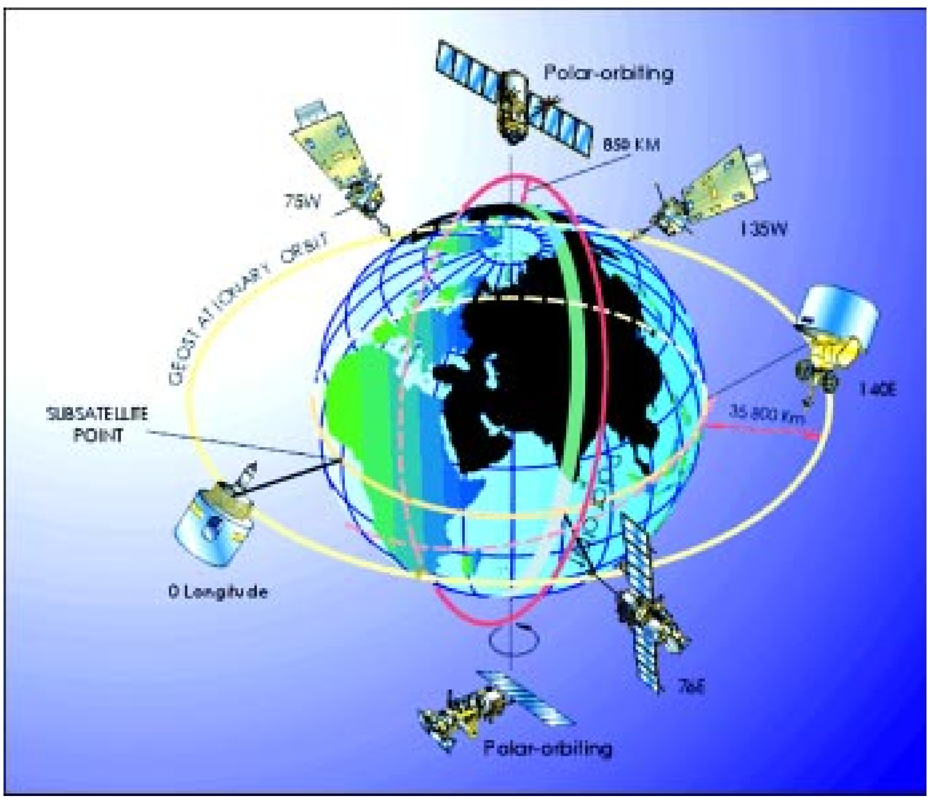

Figure 3: Nominal configuration of the space-based sub-system of the Global Observing System in 1978.

By the year 2000, WMO Members contributing to the space-based sub-system of the Global Observing System had grown. There were two major constellations in the space-based Global Observing System (GOS) (Fig. 4). One constellation was the various geostationary satellites, which operated in an equatorial belt and provided a continuous view of the weather from roughly 70°N to 70°S. The second constellation in the current space-based GOS comprised the polar-orbiting satellites operated by the Russian Federation, the USA and the People's Republic of China. The METEOR-3 series has been operated by the Russian Federation since 1991.

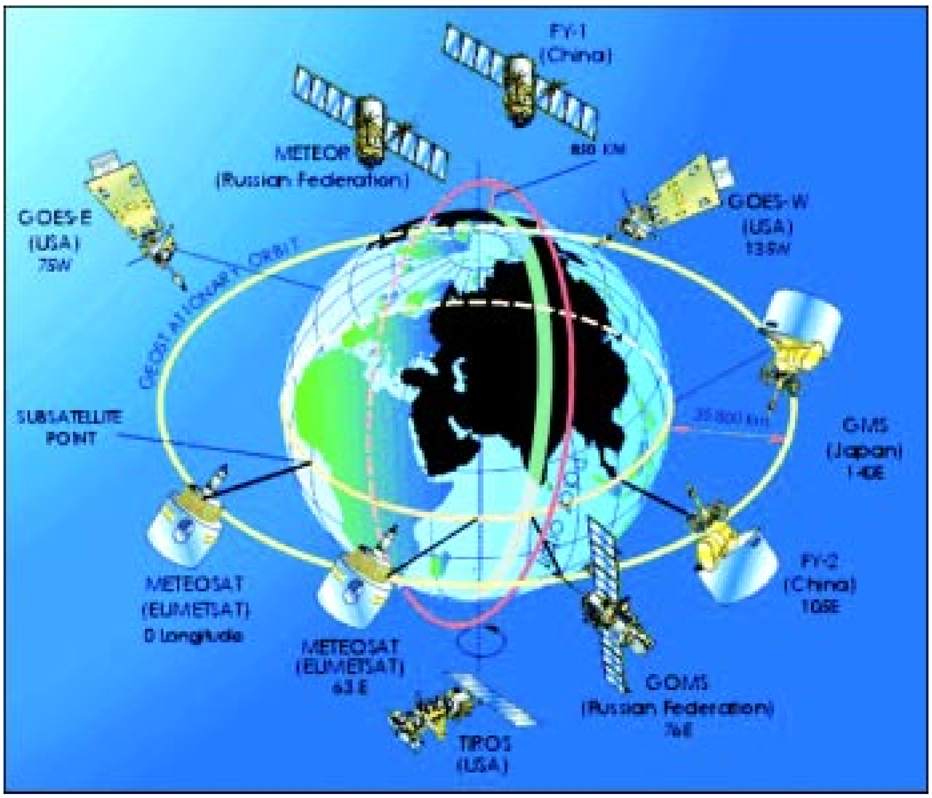

Figure 4: Nominal configuration of the space-based sub-system of the Global Observing System in 2000.

The ability of geostationary satellites to provide a continuous view of weather systems make them invaluable in following the motion, development, and decay of such phenomena. Even such short-term events such as severe thunderstorms, with a life-time of only a few hours, can be successfully recognized in their early stages and appropriate warnings of the time and area of their maximum impact can be expeditiously provided to the general public. For this reason, its warning capability has been the primary justification for the geostationary spacecraft. Since 71 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 compensate the deficiencies in conventional observing networks. Flying in a near-polar orbit, the spacecraft is able to acquire data from all parts of the globe in the course of a series of successive revolutions. For these reasons the polar-orbiting satellites are principally used to obtain: (a) daily global cloud cover; and (b) accurate quantitative measurements of surface temperature and of the vertical variation of temperature and water vapour in the atmosphere. There is a distinct advantage in receiving global data acquired by a single set of observing sensors. Together, the polar-orbiting and geostationary satellites constitute a truly global meteorological satellite network.

Satellite data provide better coverage in time and in area extent than any alternative. Most polar satellite instruments observe the entire planet once or twice in a 24-hour period. Each geostationary satellite's instruments cover about ¼ of the planet almost continuously and there are now six geostationary satellites providing a combined coverage of almost 75%. Satellites cover the world's oceans (about 70% of the planet), its deserts, forests, polar regions, and other sparsely inhabited places. Surface winds over the oceans from satellites are comparable to ship observations; ocean heights can be determined to a few centimetres; and temperatures in any part of the atmosphere anywhere in the world are suitable for computer models. It is important to make maximum use of this information to monitor our environment. Access to these satellite data and products is only the beginning. In addition, the ability to interpret, combine, and make maximum use of this information must be an integral element of national management in developed and developing countries.

The thrust of the current generation of environmental satellites is aimed primarily at characterizing the kinematics and dynamics of the atmospheric circulation. The existing network of environmental satellites, forming part of the GOS of the World Weather Watch produces real-time weather information on a regular basis. This is acquired several times a day through direct broadcast from the meteorological satellites by more than 1,300 stations located in 125 countries.

The ground segment of the space-based component of the GOS should provide for the reception of signals and DCP data from operational satellites and/or the processing, formatting and display of meaningful environmental observation information, with a view to further distributing it in a convenient form to local users, or over the GTS, as required. This capability is normally accomplished through receiving and processing stations of varying complexity, sophistication and cost.

In addition to their current satellite programmes in polar and geostationary orbits, satellite operators in the USA (NOAA) and Europe (EUMETSAT) have agreed to launch a series of joint polar-orbiting satellites (METOP) in 2005. These satellites will complement the existing global array of geostationary satellites that form part of the Global Observing System of the World Meteorological Organization. This Initial Joint Polar System (IJPS) represents a major cooperation programme between the USA and Europe in the field of space activities. Europe has invested 2 billion Euros in a low earth orbit satellite system, which will be available operationally from 2006 to 2020.

The data provided by these satellites will enable development of operational services in improved temperature and moisture sounding for numerical weather prediction (NWP), tropospheric/stratospheric interactions, imagery of clouds and land/ocean surfaces, air-sea interactions, ozone and other trace gases mapping and monitoring, and direct broadcast support to nowcasting. Advanced weather prediction models are needed to assimilate satellite information at the highest possible spatial and spectral resolutions. It imposes new requirements on the precision and spectral resolution of soundings in order to improve the quality of weather forecasts. Satellite information is already used by fishery-fleets on an operational basis. Wind and the resulting surface stress is the major force for oceanic motions. Ocean circulation forecasts require the knowledge of an accurate wind field. Wind measurements from space play an increasing role in monitoring of climate change and variability. The chemical composition of the troposphere is changing on all spatial scales. Increases in trace gases with long atmospheric residence times can affect the climate and chemical equilibrium of the Earth/ Atmosphere system. Among these trace gases are methane, nitrogen dioxide, and ozone. The chemical and dynamic state of the stratosphere influence the troposphere by exchange processes through the tropopause. Continuous monitoring of ozone and of (the main) trace gases in the troposphere and the stratosphere is an essential input to the understanding of the related atmospheric chemistry processes.

WMO SPACE PROGRAMME

The World Meteorological Organization, a specialized agency of the United Nations, has a membership of 187 states and territories (as of June 2003). Amongst the many programmes and activities of the organization, there are three areas which are particularly pertinent to the satellite activities:

- 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;
- To promote the establishment and maintenance of systems for the rapid exchange of meteorological and related information;
- To promote the standardization of meteorological observations and ensure the uniform publication of observations and statistics.

The Fourteenth WMO Congress, held in May 2003, initiated a new Major Programme, the WMO Space Programme, as a cross-cutting programme to increase the effectiveness and contributions from satellite systems to WMO Programmes. Congress recognized the critical importance for data, products and services provided by the World Weather Watch's (WWW) expanded space-based component of the Global Observing System (GOS) to WMO Programmes and supported Programmes. During the past four years, the use by WMO Members of satellite data, products and services has experienced tremendous growth to the benefit of almost all WMO Programmes and supported Programmes. The decision by the fifty-third Executive Council to expand the space-based component of the Global Observing System to include appropriate R&D environmental satellite missions was a landmark decision in the history of WWW. Congress agreed that the Commission for Basic Systems (CBS) should continue the lead role in full consultation with the other technical commissions for the new WMO Space Programme. Congress also decided to establish WMO Consultative Meetings on High-level Policy on Satellite Matters. The Consultative Meetings will provide advice and guidance on policy-related matters and maintain a high level overview of the WMO Space Programme. The expected benefits from the new WMO Space Programme include an increasing contribution to the development of the WWW's GOS, as well as to the other WMO-supported programmes and associated observing systems through the provision of continuously improved data, products and services, from both operational and R&D satellites, and to facilitate and promote their wider availability and meaningful utilization around the globe.

The main thrust of the WMO Space Programme Long-term Strategy is:

"To make an increasing contribution to the development of the WWW's GOS, as well as to the other WMO-supported Programmes and associated observing systems (such as AREP's GAW, GCOS, WCRP, HWR's WHYCOS and JCOMM's implementation of GOS) through the provision of continuously improved data, products and services, from both operational and R&D satellites, and to facilitate and promote their wider availability and meaningful utilization around the globe".

The main elements of the WMO Space Programme Long-term Strategy are as follows:

(a) Increased involvement of space agencies contributing, or with the potential to contribute to, the space-based component of the GOS;

(b) Promotion of a wider awareness of the availability and utilization of data, products - and their importance at levels 1, 2, 3 or 4 - and services, including those from R&D satellites;

(c) Considerably more attention to be paid to the crucial problems connected with the assimilation of R&D and new operational data streams in nowcasting, numerical weather prediction systems, reanalysis projects, monitoring climate change, chemical composition of the atmosphere, as well as the dominance of satellite data in some cases;

(d) Closer and more effective cooperation with relevant international bodies;

(e) Additional and continuing emphasis on education and training;

(f) Facilitation of the transition from research to operational systems;

(g) Improved integration of the space component of the various observing systems throughout WMO Programmes and WMO-supported Programmes;

(h) Increased cooperation amongst WMO Members to develop common basic tools for utilization of research, development and operational remote sensing systems.

Coordination Group for Meteorological Satellites (CGMS)

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 sensors, processing algorithms, products and their validation, data transmission formats and future data transmission standards.

Since 1972, the 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.

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
IOC of UNESCO	joined 2000
NASA	joined 2002
ESA	joined 2002
NASDA	joined 2002
Rosaviakosmos	joined 2002

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.

WMO's role within CGMS would be to state the observational and system requirements for WMO and supported programmes as they relate to the expanded space-based components of the GOS, GAW, GCOS and WHYCOS. CGMS satellite operators would make their voluntary commitments to meet the stated observational and system requirements. WMO would, through its Members, strive to provide CGMS satellite operators with operational and pre-operational evaluations of the benefit and impacts of their satellite systems. WMO would also act as a catalyst to foster direct user interactions with the CGMS satellite operators through available means such as conferences, symposia and workshops.

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. 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 expanded space-based component of the world weather watch's global observing system

Several initiatives since 2000 with regard to WMO satellite activities have culminated in an expansion of the space-based component of the Global

Observing System to include appropriate Research and Development (R&D) satellite missions. The recently established WMO Consultative Meetings on High-Level Policy on Satellite Matters have acted as a catalyst in each of these interwoven and important areas. First was the establishment of a new series of technical documents on the operational use of R&D satellite data. Second was a recognition of the importance of R&D satellite data in meeting WMO observational data requirements and the subsequent development of a set of *Guidelines for requirements for observational data from operational and R&D satellite missions.* Third have been the responses by the R&D space agencies in making commitments in support of the system design for the space-based component of the Global Observing System. And lastly has been WMO's recognition that it should have a more appropriate programme structure - a WMO Space Programme - to capitalize on the full potential of satellite data, products and services from both the operational and R&D satellites.

WMO Members' responses to the request for input for the report on the utility of R&D satellite data and products covered the full spectrum of WMO Regions as well as a good cross-section of developed and developing countries. Countries from both the Northern and Southern Hemispheres, tropical, mid- and high-latitude as well as those with coastlines and those landlocked had responded. Most disciplines and application areas including NWP, hydrology, climate, oceanography, agrometeorology, environmental monitoring and detection and monitoring of natural disasters were included.

A number of WMO Programmes and associated application areas supported by data and products from the R&D satellites. While not complete, the list included specific applications within the disciplines of agrometeorology, weather forecasting, hydrology, climate and oceanography including: monitoring of ecology, sea-ice, snow cover, urban heat island, crop yield, vegetation, flood, volcanic ash and other natural disasters; tropical cyclone forecasting; fire areas; oceanic chlorophyll content; NWP; sea height; and CO_2 exchange between the atmosphere and ocean.

WMO agreed that there was an increasing convergence between research and operational requirements for the space-based component of the Global Observing System and that WMO should seek to establish a continuum of requirements for observational data from R&D satellite missions to operational missions. WMO endorsed the *Guidelines for requirements for observational data from operational and R&D satellite missions* to provide operational users a measure of confidence in the availability of operational and R&D observational data, and data providers with an indication of its utility.

The inclusion of R&D satellite systems into the space-based component of GOS would more than double the need for external coordination mechanisms. Firstly, there will be unique coordination needs between WMO and R&D space agencies. Secondly, there will be coordination needs between operational and R&D space agencies in such areas as frequency coordination, orbit coordination including equator crossing-times, standardization of data formats, standardization of user stations. Figure 5 shows the present space-based sub-system of the Global Observing System with the new R&D constellation including NASA's Aqua, Terra, NPP, TRMM, QuikSCAT and GPM missions, ESA's ENVISAT, ERS-1 and ERS-2 missions, NASDA's ADEOS II and GCOM series, Rosaviakosmos's research instruments on board ROSHYDROMET's operational METEOR 3M Nl satellite, as well as on its future Ocean series and CNES's JASON-1 and SPOT-5.

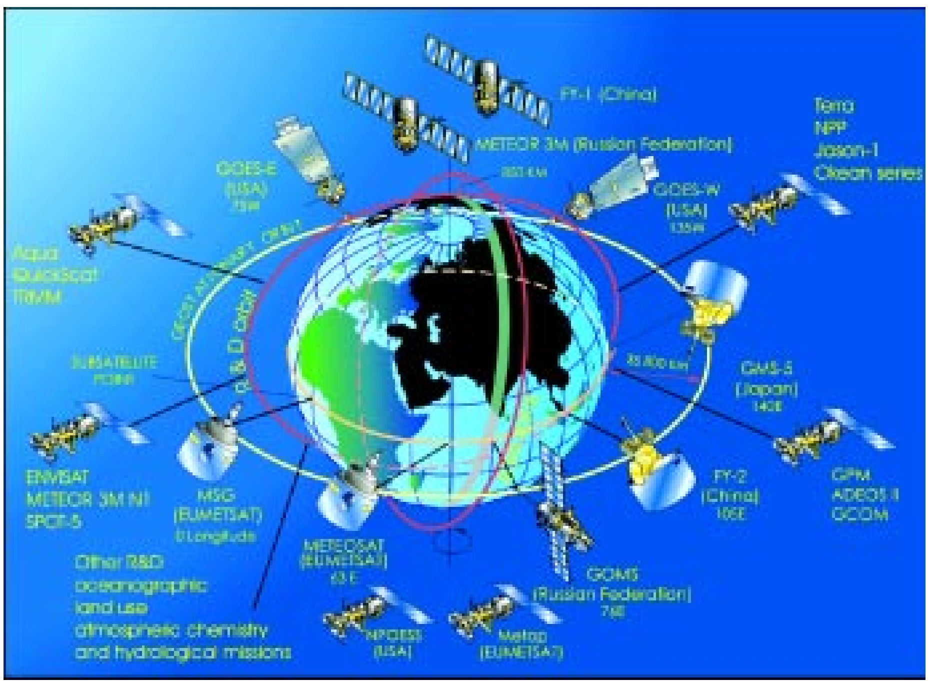

Figure 5: Space-based sub-system of the Global Observing System in 2003.

To better satisfy the needs of all WMO and supported programmes for satellite data, products and services from both operational and R&D satellites and in consideration of the increasing role of both types of satellites, WMO felt it appropriate to propose an expansion of the present mechanisms for coordination within the WMO structure and cooperation between WMO and the operators of operational meteorological satellites and R&D satellites. In doing so, WMO felt that an effective means to improve cooperation with both operational meteorological and R&D satellite operators would be through an expanded CGMS that would include those R&D space agencies contributing to the space-based component of the GOS.

WMO agreed that the WMO satellite activities had grown and that it was now appropriate to establish a WMO Space Programme as a matter of priority. The scope, goals and objectives of the new programme should respond to the tremendous growth in the utilization of environmental satellite data, products and services within the expanded space-based component of the GOS that now include appropriate Research and Development environmental satellite missions. The Consultative Meetings on High-Level Policy on Satellite Matters should be institutionalized in order to more formally establish the dialogue and participation of environmental satellite agencies in WMO matters. In considering the important contributions made by environmental satellite systems to WMO and its supported programmes as well as the large expenditures by the space agencies, WMO felt it appropriate that the overall responsibility for the new WMO Space Programme should be assigned to CBS and a new institutionalized Consultative Meetings on High-Level Policy on Satellite Matters.

CONCLUSIONS

Recent developments in remote sensing and GIS hold much promise to enhance integrated management of all available information and the extraction of desired information to promote sustainable agriculture and development. Active promotion of the use of remote sensing and GIS in the National Meteorological and Hydrological Services (NMHSs), could enhance improved agrometeorological applications. To this end it is important to reinforce training in these new fields. The promotion of new specialised software should make the applications of the various devices easier, bearing in mind the possible combination of several types of inputs such as data coming from standard networks, radar and satellites, meteorological and climatological models, digital cartography and crop models based on the scientific acquisition of the last twenty years. International cooperation is crucial to promote the much needed applications in the developing countries and the WMO Space Programme actively promotes such cooperation throughout all WMO Programmes and provides guidance to these and other multi-sponsored programmes on the potential of remote sensing techniques in meteorology, hydrology and related disciplines, as well as in their applications. The new WMO Space Programme will further enhance both external and internal coordination necessary to maximize the exploitation of the space-based component of the GOS to provide valuable satellite data, products and services to WMO Members towards meeting observational data requirements for WMO programmes more so than ever before in the history of the World Weather Watch.

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