REGIONAL AND GLOBAL LAND COVER MAPPING AND ENVIRONMENTAL MONITORING BY REMOTE SENSING

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ABSTRACT

Recent advances in geomatics technologies of satellite remote sensing, geographic information systems and global positioning systems, accompanied by development of international standards for remote sensing data and derived products, modernization of remote sensing data archives and establishment of international remote sensing data networks, have created new opportunities for land cover mapping and environmental monitoring at regional and global levels. These new developments are also bringing the remote sensing methodologies for land cover mapping and environmental monitoring closer together. It is proposed that both should be sharing the same comprehensive land information databases. Selected ongoing and planned regional and global land cover and environmental monitoring programs at the regional and global levels are briefly described. The paper concludes by emphasizing the need for better international coordination of regional and global land cover mapping and environmental monitoring programs.

RÉSUMÉ

Les développements technologiques récents en géomatique (télédétection satellitaire, systèmes à référence spatiale et systèmes de positionnement globaux) combinés à l'élaboration de normes internationales pour les produits, archives et réseaux de télédétection ont créé de nouvelles opportunités en cartographie de l'utilisation des sols et en suivi environnemental, aux niveaux régionaux et planétaire. Ces nouveaux développements ont aussi pour effet de rapprocher les domaines de la cartographie des sols au moyen de la télédétection et le suivi environnemental car ils partagent désormais des banques de données communes. Cet article traite de l'utilisation de la télédétection satellitaire à des fins de cartographie de l'utilisation des sols et de suivis environnementaux à l'échelle régionale et planétaire, en s'appuyant sur des cas précis. En guise de conclusion, nous soulignerons la nécessité d'une meilleure collaboration internationale au niveau des programmes de cartographie des sols et du suivi environnemental.

KURZFASSUNG

Neuentwicklungen in der Informationstechnologie im Bereich der Satelliten-Fernerkundung, der Geographischen Informationssysteme und der Globalen Positionssysteme haben neue Perspektiven für die regionale und globale Landnutzungskartierung und Umweltüberwachung eröffnet. Dazu haben insbesondere die Entwicklungen in Bezug auf die internationale Standardisierung von Fernerkundungsdaten und -produkten, die Modernisierung von Datenarchiven und das Errichten von Datennetzwerken in der Fernerkundung entscheidend beigetragen. Diese Neuentwicklungen im Bereich der Landnutzunskartierung und der Umweltüberwachung haben die Fernerkundungsmethoden in diesen beiden Gebieten einander näher gebracht, da in beiden Anwendungsbereichen auf die gleichen Landinformationsdatenbanken zurückgegriffen werden. Ausgewählte regionale und globale Landnutzungs- und Umweltüberwachunsprogramme werden kurz vorgestellt. Zum Schluss wird die Bedeutung für eine verbesserte internationale Koordination der regionalen und globalen Kartierungs- und Umweltüberwachungsprogramme hervorgehoben.

1. INTRODUCTION

The United Nations Conference on Environment and Development (UNCED), better known as the "Earth Summit", which took place in Rio de Janeiro in 1992, has focused the world's attention on the alarming state of environmental degradation caused by growing population pressures and short-sighted development strategies which have not taken into account protection of the natural environment. One of the main UNCED documents, the Agenda 21, identifies the main causes of environmental degradation and recommends a set of specific activities essential for the achievement of sustainable development and management of natural resources.

High on the priority list of Agenda 21 is the availability of reliable, geographically-specific information on natural resources and the environment. Such information is required by decision-makers for rational planning of development strategies and their implementation. The existing geospatial information, although readily available in industrialized countries, is often either incomplete or outdated and thus not compatible with modern management requirements in developing countries. Consequently, the decision makers in developing countries, who need such information most, have the least chance of obtaining it. (ECA, 1994; Liebig, 1995). Furthermore, most developing countries have neither the capacities nor the resources to undertake the extensive mapping and monitoring programs required to fill the geospatial information gaps. Yet, no country should be left out of the effort to achieve one of the most noble of our goals: to preserve the heritage of the earth's natural resources and its healthy environment for future generations. (Kalensky, 1995).

Since 1972, when the first civilian earth resources technology satellite (ERTS, later renamed Landsat) was launched by the National Aeronautics and Space Administration (NASA) of the United States, satellite remote sensing (RS) data have been increasingly used for land cover mapping, natural resources assessment and environmental monitoring worldwide. Growing networks of earth observation (EO) satellites and ground receiving stations provide unprecedented opportunities for the use of RS in the mapping and monitoring programs at the regional and global levels. Acquisition of RS data is not hindered by the remoteness of the area nor by its difficult accessibility, which is of particular importance for developing countries. (Cihlar et al., 1989; Estes et al., 1992; Ryerson & Lo, 1995).

While natural resources assessment is typically conducted at the national level, there is a growing demand for land cover mapping and environmental monitoring at regional and global levels (Townshend et al., 1991). Effective measures for environmental protection, which is an essential requirement of sustainable development, can be best implemented at international levels. Eight selected regional and global programs, ongoing and planned, are briefly described in Section 4. Term "regional" in the context of this paper follows the United Nations terminology and is approximately synonymous with the term "continental".

There is a considerable confusion in the scientific literature over the use of terms "land cover" and "land use". The land cover characteristics interpreted from RS data represent a complex mixture of natural and anthropogenic ground classes (mapping units). They reflect not only the variations in natural vegetation, topography, soils, soil moisture and surface water bodies, but also the type and intensity of land use and land degradation. While each area on the earth's surface can be identified by a unique land cover class, only areas used by humans can also be identified by land use classes. Although there is a link between the land cover and land use, not all land use types can be identified from RS data alone. Supplementary information, such as socio-economic, agronomic, climatic, etc., is required for the mapping of land use. In 1994, the United Nations Environment Programme (UNEP) and the Food and Agriculture Organization of the United Nations (FAO) started a joint project, the "Initiative on Standardisation of Land Use and Land Cover Classification Systems", in order to clarify and settle this issue.

The term "geomatics" is used in Canada, and increasingly by other countries, as an overall, encompassing term for disciplines concerned with surveying and mapping of the earth's surface. It includes the land surveying, topographic mapping, photogrammetry, remote sensing, cartography, global positioning systems and geographic information systems. Its use underlines stronger links between such disciplines, because of the increasing integration and processing of their data by geographic information systems, which requires harmonization of standards for quality and formats of data and derived products, as well as compatibility of their databases.

2. ADVANCED GEOMATICS TOOLS FOR REGIONAL AND GLOBAL MAPPING AND MONITORING

Land cover mapping and environmental monitoring at regional and global levels have only recently become possible because of significant technological advances in geomatics. These advances include the growing operational uses of EO satellites with optical and microwave RS payloads, global positioning systems, geographic information systems, modernization of RS data archives, and establishment of electronic information networks, accompanied by development of international standards for RS data formats. Such significant developments have significantly broadened the scope and effectiveness of RS applications and, in particular, further enhanced the RS mapping and monitoring capacities. (Howard et al., 1985; Kalensky, 1994; Konecny, 1995; Watkins, 1994).

2.1 EO Satellites with Imaging Radar Systems

Clouds prevent recording of good quality images of the earth's surface by the optical RS systems used in most EO satellites. In some tropical areas, for example in Indonesia and in the Amazon region of Brazil or Peru, it can take several years to obtain an image with less than ten percent cloud cover by the medium-resolution, optical RS system, such as those used by Landsat or SPOT satellites. Long delays in data acquisition, caused by clouds, have reduced the usefulness of satellite optical RS systems in applications where a quick response is required. Yet, timely assessment of the extent and impact of natural disasters usually requires data on short notice, regardless of weather conditions. This limitation of optical RS systems has now been overcome by the increasing availability of satellite imaging radar systems for civilian applications.

The recent advent of EO satellites with imaging radar systems, such as the Canadian RADARSAT, the European and Japanese ERS series of satellites and the Russian Almaz, has significantly advanced the production of timely RS data. This new generation of EO satellites is using a synthetic aperture radar (SAR) for recording image data of the earth's surface and its features. Satellite SAR systems emit microwave radiation to the ground scene and record the backscattered part, which is then used to reconstruct an image of the original scene. Since the SAR systems are using their own source of microwave radiation, rather than depending upon reflected solar radiation, they can record images day-and-night. Furthermore, due to the properties of microwave radiation, the SAR systems produce clear images of ground surface under most weather conditions, even through heavy clouds, rain, falling snow and fog. For example, the first RADARSAT image, recorded over Cape Breton Island, Canada, on 28 November 1995, was acquired under conditions of darkness, rain and strong winds. Yet, the image is clear, without any deterioration of its quality.

RADARSAT 1, launched 4 November 1995, is the first EO satellite with the SAR payload designed for global, operational applications. In addition to the growing worldwide network of ground stations for its SAR data, the RADARSAT has onboard data recorders which enable data acquisition even from areas outside the range of ground stations. It is expected that eight ground stations will be receiving the RADARSAT SAR data at the end of 1997. The RADARSAT SAR system works at 5.3 GHz frequency (C-band), corresponding to 5.6 cm wavelength, with horizontal polarization (HH). Its unique feature is the wide choice of imaging modes. There are 25 possible choices, depending on the selection of incidence angle (SAR beam position), ground resolution (SAR beam operational mode) and size of RADARSAT SAR scene. The choice of incidence angles, at which the ground scene can be viewed by the RADARSAT's SAR steerable antenna, ranges from 10 to 59 degrees. This enables frequent coverage of selected areas, which is important for monitoring the impacts of natural disasters, such as floods. RADARSAT SAR image data can be recorded at 6 different ground resolutions, ranging from 10m to 100m. Its actual ground resolution is better than the specified nominal values. For example, the first tests indicate that the actual fine resolution is between 8m and 8.5m, rather than 10m (see below). The size of RADARSAT SAR scenes ranges from 50km x 50km (recorded with 10m ground resolution) to 500km x 500km (recorded with 100m ground resolution). This provides an adequate flexibility to select the imaging mode best suited to a particular application. (Engel et al., 1995; Nazarenko et al., 1996).

Analysis of first RADARSAT images has already yielded better than expected results. For example, a complex pattern of forest clearcuts, which is usually difficult to delineate on SAR images, was clearly delineated on RADARSAT SAR image recorded at a shallow incidence angle (43-46 degrees) with actual ground resolution between 8m and 8.5m. (Ahern & Banner, 1996).

The strongest benefits of satellite SAR image data are expected in monitoring applications, when data have to be often recorded under adverse weather conditions, unsuitable for optical RS systems. For example, monitoring of extensive floods, oil spills or icebergs is needed day and night, during all weather conditions. Furthermore, the combination of image data from the SAR and optical RS systems will usually increase the interpretability of land cover classes and thus result in higher information contents and accuracies of natural resources assessments and land cover maps.

The interpretation of SAR images requires different expertise and skills than the interpretation of images from optical sensors. In order to overcome this problem, the Canada Centre for Remote Sensing (CCRS), with funding support from the Canadian Space Agency (CSA) and International Development Research Centre (IDRC), has initiated an innovative GlobeSAR program for training prospective users of RADARSAT SAR images in developing countries. The GlobeSAR training, which is implemented by CCRS jointly with private sector companies, is based on pilot projects and focused on the effective application of SAR images to tasks defined by participants. (Campbell, 1993, 1994 & 1995; St.-Pierre, 1995).

2.2 NOAA/TIROS Series of EO Satellites

The NOAA/TIROS series of polar orbiting meteorological satellites operated by the U.S. National Oceanic and Atmospheric Administration (NOAA) is of particular interest to global environmental monitoring programs, because of its Advanced Very High Resolution Radiometer (AVHRR). Actually, the ground resolution of AVHRR data is only 1.1 km at best, which is rather coarse for land applications, but these are very high resolution data for meteorological applications. AVHRR image data are recorded at 4-5 spectral bands (red, near-IR, mid-IR and 1-2 thermal IR). The size of AVHRR image scenes is about 2500 km x 2500 km. Twice daily global coverage by NOAA/TIROS satellites, coupled with about 1 km ground resolution yielding a manageable size of regional and global datasets, and with relatively low-cost access to data, have contributed to their popularity in global and regional vegetation cover monitoring programs. Processing of AVHRR data into normalized difference vegetation index products (NDVI), further enhanced their usefulness for vegetation monitoring. The NDVI products, sometimes combined with the AVHRR thermal imagery, have been successfully used for the regional and global monitoring of forest cover, forest and grassland fires, assessment of agricultural drought risk, monitoring of desert locust recession areas, etc. (Cihlar et al., 1996 a & b; Gutman, 1991; Gutman & Ignatov, 1994; Townshend, 1994; Tucker et al, 1985).

2.3 Landsat Program

The Landsat program of EO satellites started in 1972, as a civilian spin-off from the military satellite reconnaissance technology. While the meteorological applications of satellite RS started about a decade earlier, it was the success of Landsat program which provided the basis for mapping and monitoring of the Earth's surface from space platforms. The main sensor system of the first 3 satellites was a Multispectral Scanner (MSS), with 4 spectral bands (green, red, and 2 near-IR) and about 80m ground resolution. Although the MSS has been retained in the RS payload of Landsats 4 & 5 in order to provide a continuity of MSS coverage, the more advanced Thematic Mapper (TM) has become their main sensor system. It has 7 spectral bands (blue, green, red, near-IR, 2 mid-IR and thermal-IR), with ground resolution of 120m for the thermal-IR band and 30m for the remaining 6 bands. The size of MSS and TM scenes is 185km x 185km, covering about 34000 sq.km of the Earth's surface. Such a large area of Landsat scenes covered with 30m ground resolution in 6 optical spectral bands, and the availability of long-term Landsat database, are the main comparative advantages of Landsat program. Its weakness is the uncertainty about its future in the near term (before the launch of Landsat 7, and long term (the follow-on to Landsat 7). Landsat 6 failed to reach its operational orbit. Landsat 7 is scheduled for launch in 1998 as part of the EOS program (Section 3.3).

2.4 SPOT Program

The first of three SPOT satellites was launched by the French Space Agency (CNES) in 1986. SPOT satellites have two identical RS sensor systems onboard, the High Resolution Visible (HRV). They can operate in either panchromatic mode, producing a single-band image with 10m ground resolution, or in multispectral mode, in which 3 spectral bands are recorded (green, red and near-IR) with 20m ground resolution. The size of a SPOT scene is 60km x 60km, covering 3600 sq.km of the Earth's surface. SPOT has introduced a steerable sensor system, which enables recording of ground scenes located up to 450km on each side of SPOT ground track. This unique side-looking capacity of SPOT is important for monitoring applications requiring high frequency of coverage, such as natural disasters. Furthermore, it enables production of SPOT stereo-images, by recording the same ground scene from two different satellite locations. They are increasingly used for production of digital elevation models (DEM) and for 3-dimensional viewing of the object scene. SPOT 4 is scheduled for launch in 1997 (Section 3.4).

2.5 Other Ongoing Satellite Programs

Significant civilian EO satellite programs are operated by the space agencies of India, Japan and Russia, as well as by the European Space Agency (ESA). However, RS data from these programs are not as widely available for operational applications at regional and global levels as the data from the programs described above. This is partially due to the experimental nature of some of these programs, difficult access to their data and gaps in their global coverage because of an incomplete network of ground receiving stations and lack of onboard data recorders. This situation is quickly changing, helped by international agreements for data reception, marketing and distribution. It is expected that the future contributions by some of these programs to regional and global mapping and monitoring activities will grow significantly.

2.6 Global Positioning Systems

The potential of satellite remote sensing for mapping and monitoring at regional and global levels has been further enhanced by the growing operational use of the space-based Global Positioning System (GPS). Developed by the United States for military applications in the mid-1970s, a constellation of 21 geostationary GPS satellites, with 3 spares in orbit, enables near instantaneous determination of positions anywhere on the earth's surface. GPS continuity is assured because the first satellites of the next-generation GPS are ready for launch. Russia is deploying a similar satellite positioning system called the Global Navigation Satellite System (GLONASS).

Portable and relatively inexpensive GPS receivers are increasingly used for quick completion of mapping control, preparation of base maps, and for the precise geometric rectification and positioning of image data recorded by satellites. (Clavet et al., 1993). This is of particular importance in developing countries where the existing mapping control is often incomplete or unreliable. Hence, the GPS have become essential and effective tools for verification and, when necessary, completion of existing mapping control. Their use will assure that the compilation of base maps is done with uniform geometric accuracy for the whole region.

2.7 Geographic Information Systems

Other important developments, effecting the implementation of large mapping and monitoring programs, have been the expanding capacity and user-friendliness of Geographic Information Systems (GIS), accompanied by their decreasing price. EO satellites provide a source of RS data, while GIS provide the capacity for integration of geo-referenced data from different sources, their joint analysis and generation of cartographic, statistical and modeling products from integrated and harmonized databases.

Integration of remote sensing data with other relevant geographically referenced data, such as topographic, soils, climatic, demographic, etc. in GIS, increases the quantity as well as the quality of the derived information. Some GIS software packages also provide a mathematical modeling capacity for the analysis of trends, environmental impact assessment, agricultural drought forecasting, etc. Thus, GIS facilitate the transformation of geospatial data into information, knowledge, and, ultimately, decisions. However, it should be remembered that the usefulness and impact of GIS depend on the quality of the input data. Even the most sophisticated GIS are useless if no reliable input data are available. Furthermore, there is a need for the development of innovative procedures for interpretation and analysis of integrated multi-source RS data, in particular for combined analysis of optical and SAR RS data, resulting in their more effective and efficient applications.

2.8 RS Data Archives and Information Networks

Effective dissemination of information on RS data, and user-friendly access to data archives worldwide have become priority requirements by decision-makers responsible for land cover mapping, natural resources assessment and environmental monitoring programs. The impact of these programs, and thus their success, will depend on the extent to which their products will be used. In order to speed up and facilitate this process, the following approach should be followed:

(a) establishing user-friendly data archives and effective information networks;
(b) establishing a clear copyright policy;
(c) establishing a reasonable pricing structure;
(b) training of prospective users of new products.

The number of countries which have established information networks for RS data and derived products is steadily increasing. Furthermore, those networks are being linked to provide access to foreign data archives. Examples of such state-of-the art RS information networks were selected from Canada and the United States.

Since 1990, the Canada Centre for Remote Sensing (CCRS) has been operating a dedicated RS information network, the GCNet. It serves as one-stop-shop for information on RS data, products, services and publications. It also provides a link to the International Directory Network (IDN) operated by the Committee on Earth Observation Satellites (CEOS). The IDN is a global network with three regional coordinating nodes located at NASA (USA), ESA-ESRIN (Italy) and NASDA (Japan). Since 1995, the GCNet has been accessible on World Wide Web. The capacity of GCNet will be significantly upgraded and broadened when its follow-on system, the Canadian Earth Observation Network (CEONet) becomes operational in 1998. It will provide a state-of-the art, fast interface between the geospatial data archives and their users in Canada and abroad. (Cihlar et al., 1994; Fisher et al., 1995; Kalensky, 1996).

One of the most important components of the Earth Observing System (EOS), planned by the United States National Aeronautics and Space Administration (NASA), will be the EOS Data and Information System (EOSDIS). The EOSDIS will provide a two-way link between the EOS and its users. It will assure timely processing of RS and collateral data, generation of standardized EOS products, serve as an interactive source of information on EOS data, products and programs, and provide links with the national and international EOS Centers. Although the total EOS' budget, at present about US $ 7 billion, is still being discussed, EOSDIS is expected to cost about one third of this total. Such a significant funding is indicative of the importance that NASA assigns to effective management and dissemination of EOS data, derived products and information.

In order to further increase the effectivness of management of geospatial information, Canada and the United States have initiated the establishment of spatial data infrastructures, the Canadian Spatial Data Infrastructure (CSDI) and National Spatial Data Infrastructure (NSDI), respectively. Their objective is to enhance and promote the interoperability between the geospatial data archives. Their successful implementation requires an effective network of geospatial data archives; adherance to standards for spatial data formats, quality and electronic transfers (section 2.9); development of appropriate regulatory and institutional policies; as well as promotional activities. It is expected that these developments will eventually lead to the establishment of Global Spatial Data Infrastructure (GSDI).

2.9 Standards for Geospatial Data and Products

The increasing number of countries operating EO satellites and thus generating a wide range of RS data and derived products, as well as fast growing electronic transfers of such data, make necessary the adoption of international standards. The international standards are particularly important for regional and global projects, when large geospatial datasets, including RS data and derived products, originating in many countries, have to be transformed to a common database, integrated and processed in GIS, and the results transmitted back to participating countries. These tasks are best achieved under a broader framework of developing standards for all geospatial data formats, to assure their compatibility.

Recognizing the growing need for the development of standards for geospatial data and derived products, the International Organization for Standardization (ISO) established a Technical Committee for Geographic Information / Geomatics, the ISO/TC-211, in 1994. At present, there are 23 member countries and 13 countries in an observing capacity, participating in the work of the ISO/TC-211. All the countries operating EO satellites are among the member countries. It is expected that the existing national and international standards for geospatial data formats, most notably the NATO Digital Geographic Exchange Standard (DIGEST) for geographic digital data in vector formats and DIGEST-Image for data in raster formats, will be gradually harmonized with and incorporated into the standards to be developed by the ISO/TC-211. (Ostensen, 1995).

Another important series of international standards, which is relevant to geospatial data and products, is the ISO 9000 series of standards on quality assurance. Strict compliance with these standards by the regional and global mapping and monitoring programs will guarantee their quality, and thus facilitate the international acceptability of their products.

3. NEXT GENERATION OF EO SATELLITES FOR REGIONAL AND GLOBAL MAPPING AND MONITORING

3.1 Earth Observing System (EOS)

Remote sensing capacities for continuous environmental monitoring and land cover mapping at regional and global levels will be significantly strengthened when the NASA - led international program, the Earth Observing System (EOS), starts the deployment of a new generation of EO satellites in 1998. The EOS is the centerpiece of NASA's program "Mission to Planet Earth", which aims at gaining a broad understanding of the Earth as a system. It is based on systematic, long-term Earth observations from space platforms, complemented by ground observations in selected sites. The overall objective of EOS is to support the Mission to Planet Earth with RS data from EO satellites, relevant to worldwide assessments and forecasts of impacts of global change. EOS is the most important and comprehensive attempt to close the wide gaps in geospatial information about the Earth natural resources. The timely availability of such information, to be generated by EOS, is a prerequisite to sustainable development.

The EOS space segment will consist of up to 17 EO satellites. Its final configuration, sensor payloads, and the extent of international participation are still being discussed. Landsat-7, to be launched in 1998, will be part of EOS. (Section 3.3) It is expected that EOS, when fully deployed, will generate over 2 terabytes of data daily. In order to be able to process, archive and disseminate such a huge volume of data to scientists around the world, NASA initiated development of EOS Data Information System (EOSDIS). (Section 2.8).

One of the key RS sensor systems for environmental monitoring, developed for EOS, is the Moderate Resolution Imaging Spectroradiometer (MODIS). It will record images of the Earth's surface in 32 spectral bands, with ground resolution of 250 m for 2 bands (red and near-IR), 500 m for 5 bands (visible and near-IR) and 1 km for 25 bands (ranging from the blue part of spectrum to thermal-IR). MODIS is of particular interest to the regional and global environmental monitoring and land cover mapping programs because it will provide a complete global coverage with 250m - 1km ground resolution, and 32 spectral bands every 2 days. Its spectral bands were selected to enable better spectral discrimination of land cover classes, compared to the NOAA/AVHRR system. Furthermore, MODIS data will have significantly improved geometric rectification and radiometric calibration. The size of MODIS scenes will be 2000km x 2000km. MODIS will be included in the RS payload of several EOS satellites, starting with AM-1, which is scheduled for launch in 1998. (Asrar & Dozier, 1994; Justice et al., 1994; NASA/GSFC, 1996; Townshend et al., 1991).

3.2 NOAA/TIROS Follow-on

A follow-on to the NOAA/TIROS successful series of polar-orbiting meteorological satellites with the AVHRR RS sensor system will be the National Polar Orbiting Environmental Satellite System, operated jointly by NOAA and the U.S. Department of Defence. It will consist of three spacecrafts, orbiting in conjunction. Currently, NOAA and the U.S.

Department of Defence operate separate but similar polar orbiting meteorological satellite systems, each with two spacecrafts. Deployment of the new, integrated system will start around the year 2005. Configuration of its RS payload is still being designed. It is hoped that in addition to 1km and 4km AVHRR data of the present system, the new system will have improved data calibration and also record multispectral data with ground resolution in the 200m - 500m range.

3.3 Landsat 7

Although Landsat 7 is part of EOS (Section 3.1), it is described separately because of its importance for continuity of the Landsat series of Earth observations, started in July 1972. Landsat 7 is scheduled for launch in 1998. It will have an upgraded RS system, the Enhanced Thematic Mapper Plus (ETM+). RS data will be recorded in 8 spectral bands. Their ground resolution will range from 15m to 60m: panchromatic band - 15m, 6 multispectral optical bands (blue, green, red, near-IR and 2 mid-IR) - 30m, and the thermal-IR band - 60m. Global coverage by Landsat 7 RS data will be assured by the existing dense network of ground receiving stations, supplemented by onboard data recorders.

3.4 SPOT 4 and 5-a & b

SPOT 4 is scheduled for launch in 1997, and SPOT 5-a in 1999. Starting with SPOT 4, their RS payload will include the Vegetation sensor system. It is of particular interest to global monitoring, because it will have similar parameters to the NOAA/AVHRR system: about 1 km ground resolution and 4 spectral bands: blue (experimental), red, near-IR and mid-IR. Hence, it will be possible to process image data from the SPOT Vegetation system into 1km NDVI products, important for global and regional monitoring of vegetation cover. The main RS sensor system of SPOT 4 will be the High Resolution Visible and Infrared (HRVIR). It will have 4 spectral bands (green, red, nea-IR, and mid-IR). Its other parameters will be identical to the HRV sensor system on-board of SPOTs 1-3. (Section 2.4). The multispectral system onboard SPOT 5a & b satellites will have the same spectral bands as the HRVIR system, but the ground resolution of its data will be 10m in multispectral mode and 5m in panchromatic mode.

3.5 RADARSAT 2 and 3

Continuity of RADARSAT SAR data is assured, with RADARSAT 2 fully funded and scheduled for launch by the year 2000. Inclusion of a global positioning system in its payload is being considered. RADARSAT 3 has received funding for its development. A dual-frequency and dual polarization SAR system, as well as a combination of SAR and multispectral optical RS system are some of the options being considered for RADARSAT 3 payload. Its launch is scheduled by the year 2005.

3.6 Other Planned EO Satellite Systems

The European Space Agency (ESA) and Japan are developing advanced EO satellite systems. To what extent RS data from these systems will be used by the regional and global mapping and monitoring programs will depend on their operational availability related to such large-area applications, and on the continuity of coverage by these systems.

The European Space Agency (ESA) is developing the Envisat EO satellite. Its RS systems are being designed for monitoring of the atmosphere, oceans, ice cover and land natural resources. They will include an advanced SAR (C-band, with dual polarization, HH&VV) and optical multispectral systems. Envisat is primarily a research-oriented program. It is scheduled for launch in 1999. Furthermore, ESA and the European Organization for the Exploitation of Meteorological Satellites (Eumetsat) are also discussing the possibility of developing a series of 3 polar-orbiting meteorological satellites. This latter program is called METOP.

The National Space Development Agency (NASDA) of Japan also plans to launch two EO satellite series for environmental monitoring, natural hazards forecasting and land cover mapping: the Advanced Earth Observing Satellites (ADEOS), starting in 1999, and the Advanced Land Observing Satellites (ALOS), starting in 2002. ADEOS sensors are designed for monitoring the concentration of greenhouse gasses, depletion of ozone layer, weather conditions, as well as for the mapping and monitoring of land and oceans. ADEOS-2 will have a RS payload designed for land cover mapping. Like Envisat, the ADEOS-2 and ALOS will have SAR and optical systems in their RS payload. These planned advanced EO systems will complement EOS. (CEOS, 1995; Osawa, 1995).

4. COORDINATION BETWEEN THE LAND COVER MAPPING AND ENVIRONMENTAL MONITORING PROGRAMS AT REGIONAL AND GLOBAL LEVELS

4.1 Worldwide Selection and Integration of RS data for Both Types of Programs

Global availability of RS data has been steadily increasing as a result of growing number of EO satellites, RS sensor systems, ground receiving stations and improved performance by on-board RS data recorders. However, selection of the most appropriate combination of RS data for land cover mapping and environmental monitoring should be preceded by a thorough study of users' information requirements and by rigorous cost - benefit analysis. The regional and global programs will typically require RS data with medium and coarse ground resolution, ranging from 10m to 4km, depending on particular applications and users information requirements. Accordingly, the project implementation may be based on a complete, "wall-to-wall" coverage of the area or on a sampling design. (Section 5). Alternatively, a two-phase approach may be adopted for RS coverage, when the complete, multi-temporal coverage is obtained with coarse RS data, such as the NOAA/AVHRR data, while the medium resolution data, such as Landsat, SPOT and/or RADARSAT data, would be used only in sampling units. Geometric correction of multi-source RS data and products, their transformation into uniform cartographic projection and integration with relevant vector datasets, is a prerequisite for the effective use of RS data in mapping and monitoring applications. These tasks have been successfully accomplished (Toutin, 1994).

As it was stated earlier (Section 2.1), a combined analysis of RS data recorded by optical and SAR systems will yield higher information content and accuracy of land cover maps and environmental monitoring products. While the SAR imagery is superior for delineation of geomorphological features and surface water bodies of the ground scene, the imagery from optical multispectral RS systems, when available, is superior for discrimination of vegetation classes. For some areas in humid tropics, outside the range of ground receiving stations, it may take years before a good quality image is acquired by an optical RS system. Regarding the environmental monitoring applications, the SAR systems are prefered when monitoring at frequent or fixed intervals is required, because of their all-weather, day-and-night image recording capacity. They are particularly suitable for monitoring the extent and assessing the impact of natural and man-made disasters. Both systems are complementary and the availability of RS data from both, the optical as well as SAR systems is an essential requirement for operational land cover mapping and environmental monitoring applications.

One of the most important criteria for judgement of the usefulness of land cover maps and environmental monitoring products is the extent to which their information content reflects the current situation. While the topographic databases and maps have a relatively stable information content and serve for as long as 10 - 20 years without the need for major revision, the land cover maps have to be updated more frequently. Their actual update intervals depend on the rate of land cover change and this may differ from one map sheet to another. For example, in areas subject to high rate of development activities, deforestation, land degradation, etc., updating of land cover information at annual intervals may be necessary. Forecasting and assessment of impacts of natural disasters, such as floods, forest and grassland fires, requires monitoring at frequent intervals. The EO satellites with SAR and optical RS systems, linked with GPS and GIS, international geospatial information networks, and electronic data transfers, provide the technical and economical means for practically continuous monitoring of changes in land cover all over the world.

International standards for RS data and the derived products (Section 2.9) used by the regional and global land cover mapping and environmental monitoring programs will have an increasingly important role in contributing to their closer coordination and effective implementation. Such international programs will typically require RS data from several EO satellites, recorded and processed in different countries. Furthermore, RS data will have to be integrated with other geospatial data, such as topographic, as well as with ground verification data supplied by participating countries. In order to fulfill this role, the relevant standards for different types of geospatial data and products, as well as for electronic data transfers, will have to be harmonized and closely followed during all the design and implementation phases of regional and global mapping and monitoring programs. There is a worldwide convergence of opinions on these issues and significant progress has already been made. It has been helped by relatively coarse scales used by the regional and global mapping and monitoring programs:

1 : 100 000 to 1 : 250 000 for regional applications;
1 : 1 million to 1 : 5 million for global applications.

Geospatial information at these scales is usually available without restriction for use by the regional and global programs.

4.2 Standardization of Land Information Databases

There are many common features between the ongoing and planned regional and global land cover mapping and monitoring programs. (Section 5). All these programs and, more importantly, the end users of their products and services, would benefit from their closer coordination and, when appropriate, cooperation. While such coordination is an obvious requirement for the programs belonging to each of these two types of applications, the land cover mapping and environmental monitoring respectively, it should be extended across the application barrier and include both types of programs. It would increase the efficiency of their implementation and improve their results. The land cover mapping programs would have a possibility of bringing up-to-date their databases with results from environmental monitoring programs, while these would benefit from access to more accurate, reference, land cover mapping database.

Recent advances in geomatics technologies of satellite remote sensing, global positioning systems and geographic information systems are bringing the remote sensing methodologies for land cover mapping and environmental monitoring closer together. Sharing the same geospatial data, when appropriate, will reduce the cost of their acquisition and processing. It is therefore recommended that all the regional and global land cover mapping and environmental monitoring programs establish effective linkages between their respective land information databases (LIDs). This requires development of a comprehensive LID, compatible with both, the land cover mapping and environmental monitoring applications. Another requirement is to link the LIDs with dedicated information networks, as well as with the public access Internet. It would open their access not only to other regional and global programs, but also to geospatial databases of several major RS data producing countries and international organizations. Furthermore, it would facilitate wider dissemination of timely information on geospatial data and derived products generated by the regional and global land cover mapping and environmental monitoring programs and would lead to their increased impacts and cost-benefits. It would also be easier to reference the monitoring of changes in vegetation cover, bare land, surface water bodies and land use to a corresponding land cover map. Consequently, it would be possible to broaden the number of mapping and monitoring products generated from such comprehensive LIDs. These products would be available in the form of land cover line maps; image maps; change maps; and statistics. Another group of products, needed for the assessment and forecasting activities, would result from mathematical modeling. Examples of the former include the assessment of deforestation or land degradation rates; land suitability for cultivation of specific crops, irrigation or aquaculture; etc. Examples of the latter include the forecasting of agricultural crop production; agricultural drought; floods; etc A system flowchart for the above concept is in Fig. 1. It is based on the central, integrating role of GIS feeding and, when new data are available, refreshing the comprehensive LID.

Hence, each comprehensive LID would be kept up-to-date through monitoring activities, and thus reflect continuous environmental changes caused by increasing population pressures, climate vagaries and natural disasters. Close links between the regional and global land cover mapping and

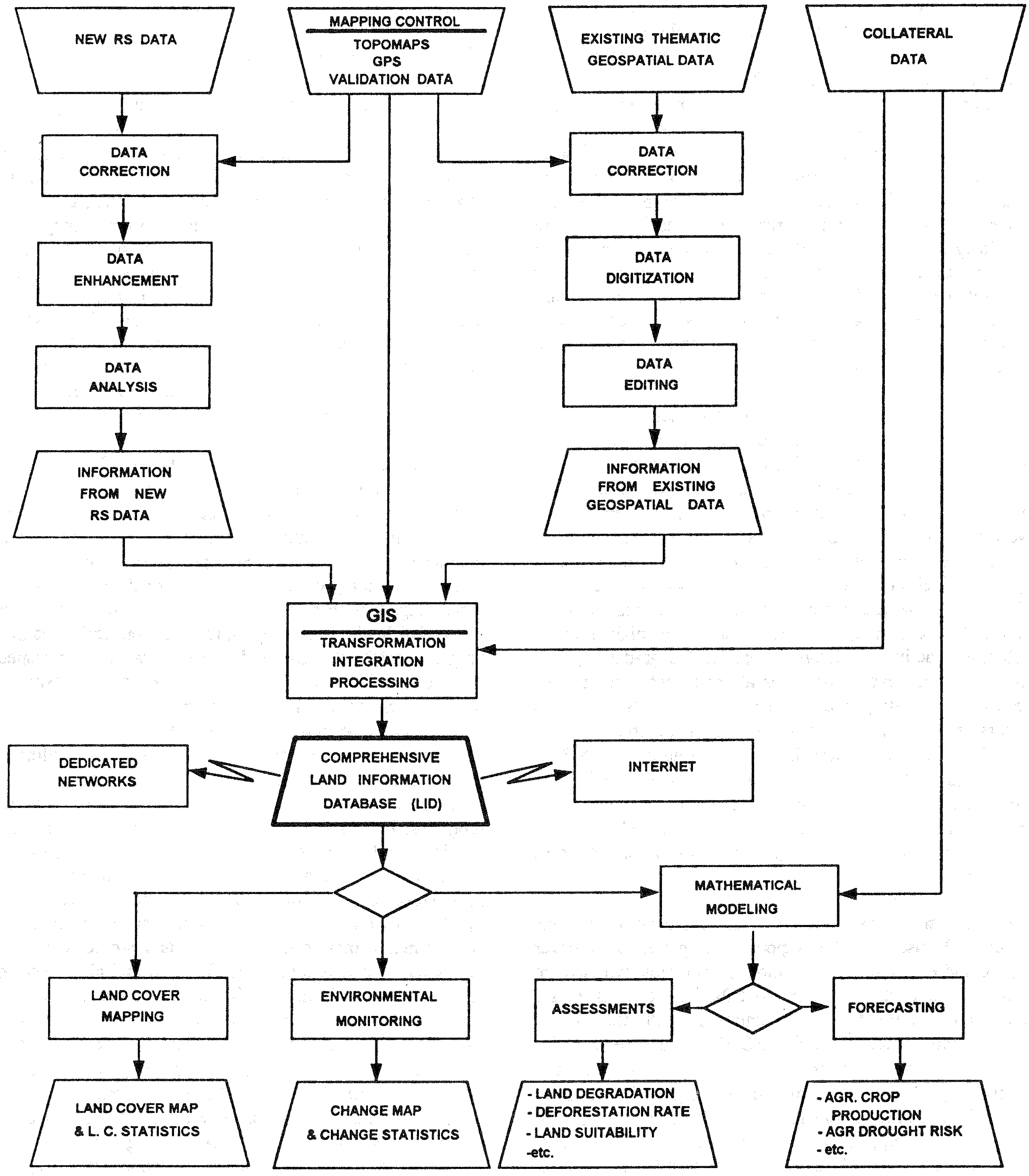

Figure 1: System Flowchart for Coordinated Land Cover Mapping and Environmental Monitoring from RS Data

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environmental monitoring programs would facilitate an early detection, location and monitoring of problem areas, the environmental "hot spots". Their early identification is important to the effectiveness of early warning systems, forecasting the risk of natural disasters and environmental degradation. Hence, the comprehensive LID would have two functions: it would serve as a reliable reference for monitoring and, in some cases, forecasting of environmental changes, including the natural disasters, while its hard copy products would provide a "snapshot" record of the land cover situation as it existed at a given time.

Obviously, each regional and global program should remain responsible for managing its own comprehensive LID, because their respective information databases are specific to objectives of each program. Nevertheless, it should be possible to design a standardized architecture for the comprehensive LID which would satisfy requirements of all the regional and global land cover mapping and environmental monitoring programs. Currently, there is no such standardization of databases of the programs listed in Section 5, and hardly any harmonization between them. Yet, these programs are complementary, some partially overlapping, and all would benefit from closer coordination.

When any international coordination is proposed, the question always arises which country is going to be responsible for it. It is a sensitive issue and, not surprisingly, a fair number of good proposals has faltered on it. However, in this case the situation is simpler because of the existence of the United Nations Environment Program (UNEP), and its Global Resource Information Database (GRID). The proposed coordinating task, involving environmental monitoring at the regional and global levels, is clearly within the GRID's mandate. Furthermore, GRID has recently started two important initiatives relevant to this task:

(a) developing the UNEPnet, which will become the global environmental Internet, with the objective to enhance access to environmental information products from UNEP and other sources;

(b) developing a dedicated satellite network, Mercure, for effective global environment-related communication.

5. EXAMPLES OF REGIONAL AND GLOBAL LAND COVER MAPPING AND ENVIRONMENTAL MONITORING PROGRAMS

Several examples of major on-going, planned or proposed regional and global programs related to land cover mapping and environmental monitoring by remote sensing are briefly described. These programs are addressing the growing need for reliable, consistent and timely information about changes in vegetation cover, surface waters, land degradation, settlements, and other land cover features of the earth's surface. Such information is essential for the sustainable management of natural resources and environmental protection. Implementation of all these programs is based on the use of RS data from EO satellites. However, it is important to note that RS data are complemented by other geospatial data, such as the existing maps, GPS location data, validation data and in some cases by field surveys in sampling areas.

5.1 Land Cover Mapping

5.1.1 Land Cover Database and Map of Africa (AFRICOVER)

Status: ongoing, regional - Africa.

Organization: Food and Agriculture Organization (FAO) of the United Nations.

The AFRICOVER project will produce a digital land cover database and associated hard copy land cover map for the whole African continent. The overall project objective is to provide reliable land cover information required for the sustainable management of natural resources, environmental protection and international development projects. An equally important objective is to strengthen the capacities of participating African regional and national organizations for maintaining the AFRICOVER database, monitoring of land cover changes, and initiating national land cover mapping projects at larger scales. The mapping scales are 1 : 200 000 or 1 : 250 000 (depending on the scales of topographic base maps in respective countries) and 1 : 1 million. Land cover classification system, map legends and formats, structure of digital database, mapping methodology and standards for geometric and thematic accuracies have been developed with the involvement of experts from industrialized as well as African developing countries. The United Nations Economic Commission for Africa (UNECA), and the selected African regional and national mapping organizations, will participate in project implementation. Although it is a regional project, its implementation was divided into sub-regional and national modules in order to accommodate the priorities of funding organizations. However, it should be emphasized that the mapping methodology and standards are the same for all project modules. One of the first tasks, which is currently being undertaken, is development of a uniform, hierarchical land cover classification system for Africa. The map legend for scales 1 : 200 000 and 1 : 250 000, based on such a uniform land cover classification system, may differ between different map sheets, depending on the type of ecosystems which they cover. But its overall consistency will be retained. The first phase of the AFRICOVER program, funded by Italy, is being implemented in East Africa. It is the largest module, comprising 12 countries with a total area of 9.6 million sq. km. The Africover is a truly pioneering project for land cover mapping at scales 1 : 200 000 to 1 : 250 000 and 1 : 1 million of the whole continent.

5.1.2 Coordination of Information on the Environment (CORINE) - Land Cover project

Status: ongoing, regional - the European Union countries and several Central/Eastern European and North African countries.

Organization: European Environment Agency (EEA) of the European Commission.

The objective of the CORINE Land Cover project is to produce a computerized inventory of Europe's land cover. The inventory is conducted by each participating country under EEA coordination and according to CORINE standards for land cover classification, accuracy assessment and types and formats of CORINE products. The CORINE land cover classification system consists of three levels, with 44 classes in the third level. The inventory results are compiled at a mapping scale 1 : 100 000. The area of the smallest mapping unit is 25 hectars. Landsat-TM and SPOT digital and hard copy images are the primary source of RS data. Ancillary data inputs include the existing topographic maps, thematic maps related to land cover, aerial photographs and statistical information. Some countries are also producing land cover inventories at 1 : 50 000 scale, based on SPOT imagery. All land cover inventory data are digitized, georeferenced, transformed to a common cartographic projection and integrated with GIS-based comprehensive CORINE database. The Lambert Azimuthal Equal Area Projection was selected as the standard cartographic projection system for CORINE. In order to facilitate timely dissemination of land cover and other environmental information stored in the CORINE database, the EEA is establishing the European Information and Observation Network (EIONET), linked with Internet.

5.1.3 Global Map

Status: implementation starting in 1996 - global.

Organization: Geographical Survey Institute (GSI), Japan.

The Global Map concept has been initiated by Japan in response to recommendations by the Earth Summit (Section 1). Its plan of action, the Agenda 21, identified a lack of reliable geographic information as one of the most serious impediments to sustainable development. The Global Map's objective is to establish a comprehensive digital geographic database, containing topographic and land cover information at 1km level, and to produce a hard copy global map at 1 : 1 million scale by the year 2000. Its main data source will be satellite RS data recorded by the NOAA-AVHRR system with approximately 1km ground resolution (Section 2.2), complemented by the medium resolution satellite RS data (Sections 2.3 & 2.4). In addition, the Globe Map database will incorporate existing geographic databases, relevant to global mapping at 1 : 1 million scale. Examples of such databases are the Digital Chart of the World (DCW) at 1 : 1 million scale (Danko, 1992) and the Global Land 1km Baseline Elevation (GLOBE) database, both produced by the United States; the international Global Land Cover Characteristics Database, based on 1km RS data from the NOAA-AVHRR system; as well as selected geographic databases compiled at the regional and national levels. (GSI, 1995; Kondo, 1994). The International Steering Committee for Global Map was established during the Second International Workshop on Global Mapping, held in Tsukuba, Japan, in February 1996.

5.1.4 EARTHMAP

Status: proposal - global.

Organizations: US Department of State
US Agency for International Development
The World Bank
Earth Council
Environmental Systems Research Institute.

The Earthmap proposal is a joint initiative by the U.S. public and private sector, the World Bank and the Earth Council. Its overall objective is to promote and facilitate wider application of geospatial data and tools in sustainable development projects. In order to achieve this objective, the EARTHMAP would participate in building a Global Geospatial Framework. It would involve development of an multiscalar digital world map framework, within which different types of existing and new geospatial data would be inventoried, organized, processed, integrated and distributed in user-friendly, standardized formats. Other proposed activities include improvement of linkages among the existing geospatial data archives; increasing the users' awarness and strengthening their institutional capacities in the use of geospatial data and tools; and establishment of Internet-based information network on geospatial applications. The EARTHMAP proposal also includes updating the Digital Chart of the World at 1:1 million scale with new satellite imagery, and exploring the development of the next generation global base map. Implementation of the EARTHMAP would be coordinated by a consortium of public, private and international organizations. (Wood et al., 1995).

5.2 Environmental Monitoring

5.2.1 Africa Real Time Environmental Monitoring and Information System (ARTEMIS)

Status: ongoing, regional - Africa.

Organization: Food and Agriculture Organization (FAO) of the United Nations.

FAO has been operationally monitoring precipitation and vegetation in Africa by its dedicated Africa Real Time Environmental Monitoring and Information System (ARTEMIS) since August 1988. The main purpose is to provide timely RS inputs for early identification of agricultural drought and desert locust risk areas. Development of the ARTEMIS system had benefited from the FAO experience with the application of RS data from the meteorological polar-orbiting and geostationary satellites to environmental monitoring in Africa. FAO started to experiment with the use of such RS data for environmental assessments in Africa at the end of 1970s. (Hielkema, 1980; Kalensky et al., 1985). The reason was an urgent need for timely and regular environmental assessments in Africa by the FAO Food Security Early Warning System, and by the Regional Desert Locust Control operations in Africa and Middle East. In 1988, the ARTEMIS, which was developed by the National Aerospace Laboratory of the Netherlands, became the first system for operational applications of meteorological satellite RS data to environmental assessments. Two types of RS data are used by ARTEMIS: thermal imagery recorded by the European geostationary satellite Meteosat, and the visible and near-infrared imagery from the Advanced Very High Resolution Radiometer (AVHRR) on-board of the U.S. NOAA series of polar orbiting satellites . The Meteosat imagery is recorded by the FAO receiving station at 30 minutes intervals. The NOAA-AVHRR imagery, recorded daily, is transmitted to FAO from the NASA Goddard Space Flight Center. It is processed into the Normalized Difference Vegetation Index (NDVI) products. All ARTEMIS precipitation-related and NDVI products are produced in digital and hard-copy formats with 7.6 km ground resolution at 10-day and monthly intervals. Based on the ARTEMIS experience, FAO prepared a proposal for an operational environmental monitoring system for Asia and the Pacific region. (Hielkema, 1990 & 1992; Kalensky, 1992; Snijders, 1996).

5.2.2 Monitoring Agriculture with Remote Sensing (MARS)

Status: ongoing, regional - the European Union countries and several Central/Eastern European counties.

Organization: Institute for Remote Sensing Applications of the European Union Joint Research Centre.

MARS started in 1988 as a 10-year pilot project for the improvement of agricultural statistics in Europe through the use of remote sensing. This required development of new methodologies appropriate for the European agricultural land use conditions. MARS implementation strategy consists of the following four main components:

(a) regional inventories of acreages of agricultural crops;
(b) assessment and monitoring of vegetation conditions;
(c) forecasting average yield of selected crops;
(d) forecasting of crop production for selected crops.

Over 100 public and private sector institutions from about 20 European countries are participating in the implementation of the MARS project. The main remote sensing inputs consist of medium resolution Landsat and SPOT imagery, and low resolution (1 km) NOAA-AVHRR optical and thermal imagery. The applicability of radar imagery to agricultural statistics in Europe is being explored. While the medium resolution imagery is only obtained for coverage of sampling units, total covearge is provided by low resolution imagery. During the crop growing season, the NOAA-AVHRR imagery is daily processed into two regional mosaics: the normalized difference vegetation index and the surface temperature differences. MARS priority is now shifting from developing new methodologies to providing technical support for their operational applications. (Bernard & Meyer-Roux, 1994).

5.2.3 Forest Resources Assessment - 1990 (FRA-90)

Status: ongoing - global

Organization: Food and Agriculture Organization (FAO) of the United Nations.

FAO, as part of its mandate, is conducting periodic assessments of global forest resources. The latest one, completed in 1995, was the Survey of Tropical Forest Cover and Study of Change Processes (FAO, 1996). Its main objectives were to provide reliable and globally consistent information on the state of the tropical forest cover and the rates of its change during the 1980s. Sampling design was based on two-stage stratification with 10% sampling intensity (117 sampling units out of the total of 1203). The area of sampling units (SU) for the assessment of the state of forest cover corresponded to one Landsat scene (34000 sq.km). The SU for change assessment were smaller because they corresponded to overlapping areas of two multidate (around 1980 and 1990) Landsat images. In the humid tropics, the overlap area was often further reduced by clouds. If the cloud-free overlapping area was smaller than 10000 sq.km, the SU was rejected. It happened in two SU, one in Colombia and one in Papua New Guinea. Landsat hard copy images at scale 1 : 250 000 were interpreted at the regional and national institutes familiar with forest resources in the SU areas. Results were compiled in the form of global, regional and sub-regional statistics and three types of maps: current and historical state of forest cover, and change maps. The "state of forest" maps have 10 land cover classes, the "forest change" maps 15 change classes. The area of the smallest mapping unit is 50 hectars. Future plans include testing the usefulness of satellite SAR imagery for global forest assessment, expanding the network of participating countries, transforming of FRA-90 into a program for continuous assessment of global forests, and strengthening the existing linkages with a complementary project "Tropical Ecosystem Environment Observation by Satellite" (TREES) of the European Commission Joint Research Centre - Institute for Remote Sensing Applications. TREES is developing a methodology for forest mapping in humid tropics, based on the NOAA-AVHRR 1 km imagery. (Drigo, 1996; D'Souza et al., 1995; FAO, 1993; Lanly, 1992; Malingreau et al., 1994; Singh, 1992).

5.2.4. Global Terrestrial Observing System (GTOS)

Status: ongoing - global.

Organizations: Food and Agriculture Organization (FAO) of the United Nations;
United Nations Environment Programme (UNEP);
World Meteorological Organization (WMO);
United Nations Educational, Scientific and Cultural Organization (UNESCO);
International Council of Scientific Unions (ICSU).

The Global Terrestrial Observing System (GTOS) is one of three major global monitoring systems established in mid-1990s as a follow-up to the Earth Summit. The other two systems, complementary to GTOS, are the Global Ocean Observing System (GOOS) and Global Climate Observing System (GCOS). All three systems are interlinked. Close coordination of their implementation is an essential requirement for the achievement of their objectives. GTOS was established in response to a growing need for a systematic, long term monitoring of changes in the natural and managed ecosystems at a global level. Its Scientific Secretariat is hosted by FAO. GTOS plan of operation is based on a global network of some 100 field sites and transects, covering all the major terrestrial ecosystems. Its hierarchy of observational levels includes EO satellites, aerial platforms and surfase-based systems. Remote sensing will play a vital role in the following three areas:

(a) monitoring changes in land cover and land use over large areas;
(b) extrapolating local observations from GTOS field sites to larger areas;
(c) ensuring a consistent set of measurements worldwide.

Data management will be implemented at three levels: (i) the field sites (national level); (ii) the regional and thematic centres; and (iii) the global coordinating centre, managing the GTOS meta-database. An important characteristic of

GTOS concept is its 2-way information flow: from the national field sites to regional and global databases, as well as the feedback to national sites in order to provide a wider context for analysis of local measurements. Global harmonization of GTOS measurements and data management at all three levels is a high priority requirement. (Heal et al., eds., 1993; Tsai-Koester, 1994)

6. CONCLUSION

In spite of the spectacular advancement of the geomatics information technologies of remote sensing, GIS and GPS, and their growing integration in recent years, the opportunities to fill the gaps in land cover information, and to establish a systematic environmental monitoring system at regional and global levels will not be realized by default. Their fulfillment requires more effective international coordination in the following four broad areas:

- planning the relevant earth observation satellite missions;
- standardization of satellite data formats and derived products;
- establishment of effective and user-friendly RS data archives and networks;
- planning and implementation of regional and global land cover mapping and environmental monitoring programs.

While the first three areas are looked after by the international Committee on Earth Observation Satellites (CEOS), the international coordination of land cover mapping and environmental monitoring programs at the regional and global levels has not been satisfactory. There should have been more effort to achieve complementarity between such programs and thus to reinforce their impacts through effective coordination and, when appropriate, cooperation.

The coordination should start with an international agreement on harmonization of the central component of the regional and global land cover mapping and environmental monitoring programs, their comprehensive land information databases (LIDs), in which all data resulting from these programs are stored. (Section 4.2, Fig. 1). Their structures should allow linkages, effective communication and exchange of data between all regional and global land cover mapping and environmental monitoring programs. Once this task has been accomplished, a solid foundation for international coordination between such programs is in place. It is proposed that the UNEP-GRID takes up this challenge.

Referring to the land cover mapping programs, there is an urgent need for international harmonization of the land cover classification systems designed for the global and regional programs; the scales, legends and formats of land cover maps; accuracy standards; and dissemination of information. Similarly, there should be harmonization of methodologies for environmental monitoring at the regional and global levels. It should include, in particular, the indicators to be monitored, at which levels and with what accuracies; reporting intervals; formats of data and derived products; and communication systems. Last, but not least, the international harmonization, in the context of regional and global land cover mapping and environmental monitoring programs, should also include the supporting field activities for collection of coherent ground data sets. Such datasets are essential for the validation of RS products; as a source of information which cannot be obtained from RS data alone; and for derivation of field inputs to mathematical models for assessments and forecasting.

CEOS has finally recognized the need for coordination of the growing number of global EO programs and started discussions on the development of Integrated Global Observing Strategy (IGOS) at its first IGOS Workshop in Seattle, USA, in March 1996. A good example of such international coordination is the successful collaboration in global meteorological observations by an international network of geostationary satellites. The Workshop ended with a consensus in support of the development of IGOS. The next CEOS meeting on this subject will take place in Fall, 1996. (CEOS, 1996; Embleton, 1996; Guertin, 1996).

The United Nations estimates an increase of population from the current about 6 billion to about 9 billion by the year 2030. Such an unprecedented increase of number of people during the next 35 years demands mobilization of all our resources to be able to assure adequate food supplies while preserving the Earth's environment for future generations. We have the technological means to achieve this goal. Up to now, the overall food production has always kept pace with the population increase. But mankind has never faced a population increase of 50% in such a short time and in such large numbers. Assuring the availability of reliable, timely and affordable information on changes in land cover, land use and land degradation at a global level, is part of the solution. Only by joining our forces and mobilizing our efforts shall we succeed in reversing environmental degradation and establishing sustainable development and management of the earth's natural resources. There is no other alternative.

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