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Characteristics, sources, and management of remotely-sensed data

J E ESTES AND T R LOVELAND

This chapter focuses upon the importance of remotely-sensed data as an input to GIS, and describes some of the ways in which they may be managed for operational use. The authors assume that many of the information managers reading this work will be GIS novices, practitioners, or experts who will have little knowledge of the field of remote sensing, and as such our discussion is intended to augment that of Barnsley (Chapter 32) and Dowman (Chapter 31) in a non-technical sense. Remote sensing is defined as the gathering of information about objects and phenomena by systems not in intimate contact with those objects and phenomena. Key characteristics and sources of remotely-sensed data commonly employed as input to GIS are described, as are the key minimum set of GIS facilities required to support the use and effective management of remote sensing data. A number of important concepts and policy-level issues related to the uses of remote sensing data within GIS for basic and applied research and resource management decision-support are also explored. In short, this chapter is designed to inform managers of the sources and potential of remotely-sensed data so that they can discharge their responsibilities for effective monitoring or operations with maximum effectiveness but minimum cost.

1 BACKGROUND

GIS and remote sensing are linked both historically and functionally. In an historic context, some of the early work leading to the development of GIS revolved around methods to provide better access to aerial photographic coverage of specific areas. GIS facilitate the storage of and access to many diverse data types. GIS, correctly employed, also permit the data held within a database to be readily updated. The synergy that exists between remote sensing and GIS technologies is built on the foundation that, for many applications, remote sensing can be employed effectively and efficiently to update GIS data layers; and that data layers in a GIS can, when appropriately employed, improve the interpretability and information extraction potential of remotely-sensed data (Star et al 1991).

GIS users routinely require timely input data in order to optimise their systems for analysis and decision-making (see, for instance, Shiffer, Chapter 52). In many instances, raster data are preferred. Typically in the past, only a single type of photography or imagery was acquired for a given application (see Dowman, Chapter 31). While this is still sometimes true, users are increasingly addressing more sophisticated applications which require multiple images from different regions of the electromagnetic spectrum and/or different dates, at scales ranging from local studies to global investigations. These more sophisticated investigations are employing data with a variety of spatial, spectral, and temporal resolutions. More importantly, applications have evolved that require the integration of both raster and vector data. Processing and analysis of these data are improved when an analyst has access to collateral information, often in vector format, for an area covered by the imagery being analysed. In addition, raster data from satellite sensors have inherent information content beyond their use as an image backdrop. Indeed, it is important to note that most operational base cartographic products produced by mapping organisations around the world are compiled using photogrammetric techniques to process remotely-sensed data. It is maps such as these that supply the base upon which GIS applications are accomplished.

While remotely-sensed data are used in making maps, they are also being employed to measure a variety of environmental parameters. Surface and cloud top reflectances, albedo, soil and snow water content, fraction of photosynthetically active radiation, areas and potential yield of given crop types, and the height and density of forest stands are but a few of the measurements that can be made with the aid of remotely-sensed data. Such data measured and/or mapped over time constitute the basis for monitoring. As we measure, map, and monitor environmental features and phenomena we can then employ the data generated as input to models. Remote sensing data are being employed today in a wide variety of modelling activities. Finally, environmental planners, resources managers and public policy decision-makers are employing remotely-sensed data within the context of GIS to improve the management of the resources for which they are responsible.

2 SOURCES OF REMOTE SENSING DATA

Remote sensing data are currently acquired by aerial camera systems and a variety of both active and passive sensor systems that operate at wavelengths throughout the electromagnetic spectrum (see Barnsley, Chapter 32). Data currently acquired by aerial, metric camera systems can be scanned, converted into digital form, and input to GIS. More typically, such data are interpreted and the interpreted information is then digitised for input to a GIS. The authors assume that most readers know sources of aerial photography. These sources typically include commercial photogrammetric engineering firms, local planning and transportation agencies, national mapping organisations, environmental and research agencies, and university collections. A full discussion of the sources of such data is beyond the scope of this chapter, but see Dowman (Chapter 31). Here we focus primarily on sources of satellite remotely-sensed data that are acquired in digital format.

Most satellite scanners are typically electro-mechanical scanners, linear array devices, or imaging spectrometers that operate in either a 'sweep' (e.g. LANDSAT) or 'pushbroom' (e.g. SPOT – see section 2.2) mode. These are passive systems which record solar radiation reflected from the Earth's surface. Data derived from multispectral scanners can provide information on (among other things) vegetation types, its distribution and condition; geomorphology; soils; surface waters; and river networks. Reflectance or short wavelength infrared (SWIR) sensors record emitted energy from surfaces and have been particularly useful for monitoring fires and for studying areas of volcanic and geothermal activity. Thermal or long wavelength infrared (LWIR) sensors have been popular for mapping ocean temperatures and study of the dynamics of coastal waters and currents. On land, plant water stress induces changes in canopy temperatures which are detectable. Thermal maps are also popular in monitoring urban areas, industrial sites, manufacturing centres, and agricultural scenes.

Active systems operating in the visible spectrum use laser technologies – light detection and ranging systems (LIDARS) – primarily for oceanographic (e.g. ERS-1 and RADARSAT) and forestry applications. Radar systems use active microwave energy for oceanographic, navigation, forestry, geology, and other similar studies. Regardless of the wavelengths they employ, active systems do not depend on reflected energy from the Sun for image formation. They are able to acquire data during the day or night. In addition, as longer wavelength microwave radiation is not distorted by the atmosphere to as great a degree as shorter wavelength energy, radar systems can collect data through cloud layers and some precipitating clouds.

Other remote sensing systems are employed to detect the Earth's magnetic and gravitational fields. These tools are used extensively in oil and mineral exploration. Analyses of such multispectral data can, if properly designed and carried out, increase both the quality and quantity of information for given applications.

Thus there is a wide variety of satellite-based sensors currently providing operational raster remotely-sensed data for GIS developers and users. Our emphasis here is upon information on the sources of those satellite remote sensed data being operationally acquired for use within GIS today. The spatial, spectral, and temporal characteristics of these systems vary according to specific design goals and engineering trade-offs. Here, we provide basic data characteristics (Table 1) and information for gaining access to data from the primary sensors being used. Again, here we make no attempt to be comprehensive as there are dozens of platforms and hundreds of sensors, either currently operational or planned. Some others are described in Barnsley (Chapter 32) and in Table 1, and readers interested in more exhaustive listings should consult *Earth Observing Platforms and Sensors*, a CD-ROM available from the American Society of Photogrammetry and Remote Sensing, or *Observations of the Earth and Its Environment: Survey of Missions and Sensors* published by Springer. Here we also provide details about the management of these common remote sensing data sources, as well as the organisational context to availability and access to data from them.

2.1 LANDSAT

The LANDSAT programme has provided coverage of the Earth for almost 25 years. LANDSAT is the result of the NASA (National Aeronautics and Space Administration) Earth Resources Survey Program and involves the cooperation and shared resources of several other US government agencies. Landsat was known as the Earth Resources Technology Satellite (ERTS) when the first satellite was launched in 1972. The original satellite was part of a proof-of-concept project to determine the feasibility and utility of monitoring the Earth's natural and cultural resources using data from orbiting satellites. Four additional satellites have been placed into orbit since 1972, providing continuous data for use in a wide range of environmental applications. The first three LANDSATs had a multispectral scanner (MSS) as the primary sensor, while the following two satellites added a higher resolution scanner called the Thematic Mapper (TM). The MSS has 80 m spatial resolution and images in the visible and near-infrared region while the TM has 30 m spatial resolution and images across a broader portion of the spectrum (visible through thermal infrared).

The LANDSAT programme was instrumental in establishing the operational viability of synoptic space-based remotely-sensed data. To provide ready access to LANDSAT data, the US Congress placed the ground segment responsibilities with the US Geological Survey's EROS Data Center in Sioux Falls and the Department of Commerce. The programme was privatised by Congress in 1985 and both the space and ground segments of LANDSAT were transferred to the EOSAT Corporation. In 1992, the responsibilities were returned to NASA (provider), Department of Commerce (operations), and USGS (United States Geological Survey: data archiving). The international network of LANDSAT ground stations provides regional access to LANDSAT data. Global coverage are available from the USGS EROS Data Center and from the Space Imaging EOSAT Corporation. Rhind (Chapter 56) describes the changing data pricing policies that have been applied to LANDSAT data.

2.2 Satellite Pour l'Observation de la Terre (SPOT)

SPOT is an operational, commercial remote sensing programme that operates on an international scale. An established global network of control centres, receiving stations, product generation centres, and data distribution outlets ensure access to SPOT data. SPOT satellites are owned and operated by the French space agency, the Centre National d'Etudes Spatiales (CNES). Several private companies, including SPOT Image in France, SPOT Image Corporation in the USA, SPOT Imaging Services in Australia, and SPOT Asia in Singapore, are the core of the SPOT data distribution system (see also Rhind, Chapter 56). The system is further augmented by distributors in over 70 countries. Three SPOT satellite have been placed into orbit since 1986, and two more are planned for launch during the next five years. This allows data continuity for environmental applications for an expected 15–20 year period.

The mission objectives for SPOT include providing remotely-sensed data suited for land cover, agriculture, forestry, geology, regional planning, and cartography applications. Data from the High Resolution Visible sensor (HRV) provide both multispectral coverage with 20 m spatial resolution and panchromatic imagery with 10 m resolution. The high resolution of SPOT's panchromatic data are particularly well suited to urban and cartographic applications. SPOT data are available from SPOT Image SA in France, SPOT Image Corporation in the USA, SPOT Imaging Systems in Australia, and SPOT Asia.

Table 1 Basic data characteristics of 'standard' imagery from some satellites launched to date.

Satellite	*Dates of operation*	*Sensor*	*Spatial resolution*	*Scene dimensions*	*Repeat interval*	*Spectral properties (micrometres)*
LANDSAT 1–3	1972–1983	Multispectral Scanner (MSS)	80 m	185 x 185 km	18 days	0.50–0.69, 0.60–0.70, 0.70–0.80, 0.80–1.10
LANDSAT 4–5	1982–1992	Multispectral Scanner (MSS)	80 m	185 x 185 km	16 days	0.50–0.69, 0.60–0.70, 0.70–0.80, 0.80–1.10
	1982–	Thematic Mapper (TM)	29/30 m	185 x 185 km	16 days	0.45–0.52, 0.52–0.60, 0.63–0.69, 0.76–0.90, 1.55–1.75, 2.08–2.35, 10.4–12.5
SPOT 1–3	1986–	High Resolution Visible Sensor – multispectral	20 m	60 x 60 km	26 days or 1–3 days in off-nadir mode	0.50–0.59, 0.61–0.68, 0.79–0.89
		High Resolution Visible Sensor – panchromatic	10 m	60 x 60 km	26 days or 1–3 days in off-nadir mode	0.51–0.73
TIROS–N, NOAA–6, 8, 10	1978–	Advanced Very High Resolution Radiometer	1.1 km	2600 km x orbital track	1 day	0.58–0.68, 0.725–1.10 3.55–3.93, 10.5–11.5, 10.5–11.5 (repeated)
NOAA–7, 9, 11, 12, 14	1981–	Advanced Very High Resolution Radiometer	1.1 km	2600 km x orbital track	1 day	0.58–0.68, 0.725–1.10 3.55–3.93, 10.3–11.3, 11.5–12.5
MOS–1, 1b	1987–1996	Multispectral Self-Scanning Radiometer (MESSR)	50 m	100 x 100 km or 185 x 185 km	17 days	0.51–0.59, 061–0.69, 0.72–0.80, 0.90–1.10
	1987–1996	Visible and Thermal Infrared Radiometer (VTIR)	900 m (visible), 2700 m (thermal)	1500 km	> 17 days	0.50–0.70, 6.0–7.0, 10.5–11.5, 11.5–12.5
	1987–1996	Microwave Scanning Radiometer (MSR)	32 km (23.8 GHz), 23 km (31.4 GHz)	317 km	17 days	23.8 GHz, 31.4 GHz
JERS–1	1992–	Synthetic Aperture Radar (SAR)	18 m	75 km	44 days	1.275 GHz (L-Band)
		Optical Sensor (OPS) – VNIR	18.3 x 24.2 m	75 km	44 days	0.52–0.60, 0.63–0.69, 0.76–0.86, 0.76–0.86
		Optical Sensor (OPS) – SWIR	18.3 x 24.2 m	75 km	44 days	1.60–1.71, 2.01–2.12, 2.13–2.15, 2.27–2.40
IRS–1	1988–	Linear Imaging Self-Scanning System (LISS)	23 m (LISS1) 36.25 m (LISS2)	148 km	22 days	0.45–0.52,0.52–0.59, 0.62–0.68, 0.77–0.86
	1995–	Linear Imaging Self-Scanning System (LISS)	23 m, 70 m for 1.55–1.70 μm channel (LISS3)	148 km	22 days	0.52–0.59, 0.62–0.68, 0.77–0.86, 1.55–1.70
ERS–1	1991–	Synthetic Aperture Radar	Nominal 30 m, 8–200 m range	80.4–99 km	16–35 days (latitude dependent)	5.3 GHz (C-Band)
RADARSAT	1995–	Synthetic Aperture Radar	6.25–500 m	45–500 km	1–24 days (latitude dependent)	5.3 GHz (C-Band)

2.3 Advanced Very High Resolution Radiometer (AVHRR)

The AVHRR sensor is carried onboard the United States National Oceanic and Atmospheric Administration's (NOAA) Polar Orbiting Environmental Satellites (POES). This operational satellite and Earth observation programme was primarily established to provide data for use in meteorological applications. However, the daily coverage provided by AVHRR and the spectral bands used have resulted in AVHRR data being used for many operational land mapping and monitoring programs.

The first of the series of AVHRR instruments was placed into orbit on the TIROS-N satellite in 1978. Because the POES programme is operational, new satellites are launched approximately every 18–24 months. The most recent satellite, NOAA–14, was placed into orbit in late 1994. AVHRR data are multispectral and the data have a resolution of 1.1 km at nadir, and the orbital swath is approximately 2600 km wide.

The AVHRR data stream can be tapped by any ground receiving station without restrictions or payment of subscription fees. As such, the potential sources of AVHRR data are anywhere there is a ground receiving station. Three sources for obtaining global AVHRR data are NOAA/SAA User Assistance, the USGS EROS Data Center, and the European Space Agency/ESRIN.

2.4 Marine Observation Satellite (MOS)

The Japan National Space Development Agency (NASDA) established their Earth observation satellite programme for the purpose of using domestic technologies for the collection of environmental data that could be used for national resource utilisation and environmental protection priorities. The first Japanese earth observation satellite, the Marine Observation Satellite 1 (MOS-1), was launched in 1987 and a second satellite was launched in 1990.

The MOS satellite series carry three sensors: a Multispectral Self-Scanning Radiometer (MESSR), a Visible and Thermal Infrared Radiometer (VTIR), and a Microwave Scanning Radiometer (MSR). The MESSR operates in the visible and near-infrared portions of the spectrum and was intended for land applications. It has two spectral channels in the visible region and two channels in the near-infrared region and has a ground resolution of 50 m. The VTIR instrument provides moderately coarse resolution (900 m–2700 m) observations that are intended for use in cloud and sea surface temperature investigations. The MSR is a passive microwave sensor that records long wave radiation emitted from the Earth's surface. The purpose of the MSR is to provide measurements on atmospheric water vapour and water content over the ocean, and information on sea ice and snow. MOS-1 and -1b products are available from the Remote Sensing Technology Centre of Japan.

2.5 Japanese Earth Resources Satellite (JERS)

JERS-1 was launched by NASDA in 1992. Its mission is to provide global data for agriculture, forestry, environmental protection, disaster assessment, coastal monitoring, and fisheries studies. JERS-1 includes two instruments: a synthetic aperture radar (SAR) and an optical sensor (OPS). The SAR is an active sensor which transmits L-band microwave energy and collects the returned backscattered signals. The active energy source provides all-weather capabilities. The OPS consists of a Visible and Near-Infrared Radiometer (VNIR) and SWIR. Each radiometer has four spectral channels, for a total of eight OPS bands. Band 4 of the VNIR provides stereo capabilities. The SWIR channels were designed to provide information for mineral exploration and other geological applications. As for MOS, data products are available from the Remote Sensing Technology Centre of Japan.

2.6 India Remote sensing Satellite (IRS)

The IRS programme includes a series of satellite systems dedicated to the collection and distribution of land remotely sensed data. IRS is operated by the National Remote Sensing Agency (NRSA) and the Indian Research and Scientific Organisation (ISRO). Three satellites (IRS-1a, -1b and -1c) have been launched since 1988 carrying the Linear Imaging Self-Scanning System (LISS). The LISS sensor provides multispectral coverage in four spectral regions. The spatial resolution of LISS data is 72.5 m for LISS-1, 36.25 m for LISS-2, and 23 m and 50 m for LISS-3.

The IRS mission objectives includes the provision of state-of-the-art satellite remotely-sensed data for use in India's National Natural Resources Management System. NRSA has also joined with other international satellite data providers to form a global network for access to IRS datasets. IRS data are available from a variety of international sources, including the Indian National Remote Sensing Agency Data Centre and the Space Imaging EOSAT Corporation.

2.7 European Resource Satellite (ERS)

The European Resource Satellite-1 (ERS-1) is a project of the European Space Agency. The initial ERS-1 was launched in 1991 for the purpose of providing global synthetic aperture radar coverage of the Earth's surface. The ERS-1 mission was designed to provide global measurements of sea wind and waves, ocean and ice monitoring, and coastal observations. ERS-1 objectives had limited focus on land studies but, with the launch of ERS-2, data acquisitions have a greater land observation focus; for instance, some digital elevation models have been computed by interferometric imaging. The ERS SAR instrument provides C-band active microwave measurements with a nominal ground resolution of 30 metres. ERS-1 and -2 data are available from EURIMAGE ERS Customer Services, RADARSAT International ERS Order Desk, and SPOT Image ERS Order Desk.

2.8 RADARSAT

RADARSAT provides one of the first space-based active microwave instruments designed for the collection of global synthetic aperture radar data. RADARSAT SAR data are intended for use in studies of ice conditions, geology, agriculture, and forestry. Special emphasis has been placed on the provision of real-time data for use in Arctic Ocean navigation and iceberg surveillance. Arctic regions are imaged daily, while equatorial regions are covered every 24 days. The SAR instrument provides C-band observations with a selectable pixel resolutions varying from 6.25 m to 500 m. Information concerning sources for acquiring RADARSAT data are available from the Canadian Space Agency RADARSAT Programme or the RADARSAT International ERS Order Desk.

2.9 High spatial resolution satellites

At the time of writing, the launch of a new class of civilian satellites is imminent. These are based on previously classified military technology and financed by major corporations. Operating in the visible and near-infrared wavebands and using optical sensors, they have a predicted resolution up to two orders of magnitude better than SPOT and new delivery mechanisms are being deployed to ensure the data are made available more quickly and more easily. The investments are very substantial: for instance, Space Imaging Inc. purchased EOSAT Corporation in 1997 to obtain its delivery capabilities and market contacts. The characteristics of these are summarised in Barnsley (Chapter 32 Table 2).

It is self-evident that the advent of these satellite systems represents a fundamental change in remote sensing: operating on a commercial and competitive basis and at levels of detail hitherto unknown, they are predicted to form stiff competition for the aerial survey industry around the world and may in themselves have a major influence on the GIS industry over the next few years. National security and sensitivity issues are also raised by the general availability of high resolution images. In practice, the US government controls the availability of imagery through licensing of the commercial firms involved, but this is only applicable for US-based data collecting organisations (and other governments may well be less than delighted that access to information about their territories is controlled by the USA; see Rhind, Chapter 56). But the proposed 1 to 3 m imagery still lags behind estimates of the technology currently being planned or operated by various military bodies, for example 0.3 m in the US, 1 m in Israel, and 1–2 m resolution (using Helios-1) in France. On the other hand, some military agencies are also proposing to procure imagery from the commercial dealers – a development which appears to confirm that civilian and military requirements are increasingly overlapping as budgets are reduced throughout the world (see Swann, Chapter 63, for a general discussion).

3 DATA ARCHIVING

The digital raster data received at ground stations come in a continuous stream so long as the satellite is within line-of-site of the receiver. These down-linked data are in binary form for satellite-to-ground transmission. The amount of data to be telemetered cannot exceed data transmission technology and the bandwidth over which the data are carried. Telemetry rates and carrier wave bandwidths have increased significantly in the past few decades from kilobytes per second (kbs) to megabytes per second (mbs). This means that 6-bit partitioning of the *y*-axis (64 levels of grey) in older systems can now be designed for 8-bit accuracy or higher (as in the new high-resolution satellites). Nevertheless, it is clear that higher Nyquist sampling rates and increased bit rates combine to create exponential growth rates in data transmission requirements. These data streams must also be processed and formatted (to remove random and systematic distortions and to calibrate radiometrically and rectify geometrically) by users or data suppliers before they are suitable for input into GIS.

Once acquired, these data are stored in data and information centres in a number of nations around the world. Both national (public sector) and commercial remotely-sensed data can typically be accessed and acquired through these data centres directly or with the aid of an intermediary such as a commercial vendor, a governmental agency, or an academic institution working in the area. They may be accessed in a variety of formats and in a variety of forms, ranging from full scene to quarter scene to specific area coverage. The data may also be acquired as 'raw' system-corrected data or in a variety of processed formats including geometrically and atmospherically corrected, and georeferenced data registered to a given geospatial coordinate system. Typical choices of data are those listed as 'levels of processing' for the NASA Earth Observing System (EOS). These processing levels are listed in Table 2. The choice of processing level is up to the data users and is both cost- and specific application-dependent. Science users may want data more toward the 'raw' end (level 0) of the processing spectrum while many applications-oriented users will opt for more processed forms of the data (typically level 1A or higher).

4 FACILITIES FOR INTEGRATING REMOTELY-SENSED DATA INTO GIS

A wide variety of photogrammetric, image processing, and statistical analyses are utilised to extract information from raster data. Systems to accomplish such processing range from the relatively simple PC-based desktop mapping, 'softcopy' photogrammetry, and combined image processing/GIS systems to complex analytical stereoplotters, orthophotoscopes, mainframe and super computer-based image processing/GIS systems. The choice of the hardware and software to be employed in any remote sensing/GIS application depends upon a wide range of factors (see Bernhardsen, Chapter 41). These include: cost; type of application (e.g. commercial operation or fundamental research); timeliness required in data production; level of understanding/training of the staff involved; and the appropriateness, accessibility, and availability of the input data, hardware, and software.

To accomplish the integration of remotely-sensed data into vector-based GIS requires the addition of relatively sophisticated image processing packages to

Table 2 Definitions of processing levels for Earth Observation System Data and Information System Data. *Source*: NASA 1995

Level 0	Processed, unprocessed instrument/payload data at full resolution; any and all communications artifacts, e.g. synchronisation frames, communications headers, and duplicate data removed
Level 1A	Reconstructed unprocessed instrument data at full resolution, time-referenced, and annotated with ancillary information, including radiometric and geometric calibration coefficients and georeferencing parameters, e.g. platform ephemeris, computed and appended but not applied to the Level-0 data
Level 1B	Level 1A data that have been processed to sensor units (not all EOS instruments will have a level 1B product or equivalent)
Level 2	Derived geophysical variables at the same resolution and location as the Level 1 source data
Level 3	Variables mapped on uniform space-time and grid scales usually with some completeness and consistency
Level 4	Model output or results from analyses of lower level data, e.g. variables derived from multiple measurements

these systems. For instance, ESRI's ARC/INFO, ArcView, and ARC GRID software accomplish much of this integration. Correspondingly, some raster-based image processing systems have considerable GIS functionality. ERDAS/Imagine, ER Mapper, EASI/PACE, and Intergraph's MGE Base Imager (MAI) version are examples of such systems that are commercially available today (Graham and Gallion 1996). An important consideration in linking any of these systems to a vector-based GIS is the grid interface between the two systems and the file structures of the systems. Care should be taken by the managers involved, and advice sought from users, prior to going forward with an attempt to link raster and vector systems for a particular applications area.

5 KEY MANAGEMENT ISSUES

Important management issues with respect to these data are their availability and accessibility and their use within the context of databases. More is said about these issues in Smith and Rhind (Chapter 47). Here, however, we will focus on the multinational management efforts to encourage the exchange of Earth observation data through the Committee on Earth Observation Systems (CEOS). CEOS understands the need for global coordination in achieving the goal of fullest potential use of international Earth observing systems. It has already initiated steps to coordinate the development of observing satellites in order to provide complementary data to users. To optimise the use of the data collected by these satellites, it will be necessary to achieve a corresponding degree of international coordination in the systems that disseminate and enable access to that data. The interconnectivity of available global networks and the interoperability of network services are key factors in achieving this objective. 'CEOS agencies are in the process of defining a strategy for the use of a global network infrastructure and standard network services. This activity is placing significant emphasis on the provision of user services and the encouragement of wider use of Earth observation data through expanded, easier access to metadata (data about data; see Guptill, Chapter 49) and data products on the 'information superhighway' (European Space Agency 1995).

CEOS has also recognised the need to provide users with a broad array of access to Earth observation data which is as simple and as comprehensive as possible. To accomplish this, CEOS working groups have undertaken a number of experiments on interoperability of on-line user services, such as catalogues and image browser systems. These experiments have been designed to develop methods which, when implemented generally, would enable quick and easy access to Earth observation satellite data resources held anywhere in the world. A number of prototype services are already in place (European Space Agency 1995).

With a view towards maximising the use of Earth observation data collected worldwide, CEOS agencies have also developed principles for the exchange of satellite remotely-sensed data. These guiding principles were developed by the participating agencies in support of 'key areas of global change research and operational environment use for public benefit' (European Space Agency 1995). As such, they expand upon the CEOS Terms of Reference which state that: 'Members must have a continuing activity in space-borne Earth observations, intended to operate and provide non-discriminatory and full access to data that will be made available to the international community' (European Space Agency 1995). The mechanisms behind these principles are already being tested in a variety of programmes, including an International Geosphere Biosphere Programme (IGBP) pilot project to exchange high-resolution image data between agencies.

6 CONCLUSIONS

Remotely-sensed data are being employed to provide users with:

- basic measurements of environmental parameters;
- maps of the spatial distributions of environmental features and phenomena;
- mechanisms for monitoring changes in the world around us;
- a means to incorporate all these types of data for use in modelling aspects of the Earth as a system.

These data can then hopefully be employed to improve the management of our planetary resource base at scales from local to global. We should not forget that, prior to the development of Earth-orbiting satellite remote sensing, we had no practical means for the timely gathering of globally consistent datasets whose accuracy could be verified in a meaningful fashion. While some might argue that the acquisition of such data is still not feasible, we believe that we are rapidly approaching a time when such data collection will become routine. Resource management at scales from local to global which is directed at economic growth within the context of sustainable development (Htun 1997) can only be achieved through the wise use of both remote sensing and GIS. Thus we are confident that the widespread use of remote sensing to update key GIS data layers and of GIS to maintain the base data layers, process the data, keep track of changes, and allow decision-makers to assess the consequences of alternative strategies prior to making decisions, and then to track the actual results after decision implementation, will become increasingly common management functions worldwide.

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