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High resolution remotely sensed data and spatial data infrastructure development**

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HIGH RESOLUTION REMOTELY SENSED DATA AND SPATIAL DATA INFRASTRUCTURE DEVELOPMENT

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ABSTRACT

High resolution data from satellite platforms is now widely available and is used for many applications. These range from mapping at large scales for urban planning, where accurate geospatial information is required, to damage assessment after disasters where speed of delivery is critical. In all applications it is essential that the data can be delivered to the users in a suitable format and within an appropriate time scale: a good spatial data infrastructure is necessary for this to happen. This paper examines the current range of sensors and technology available to collect and distribute the data, and the organisational structures which ensure that suitable data is acquired in the required timescale and provided to the end user. The paper also presents some case studies showing the importance of spatial data infrastructures.

Introduction

A Spatial Data Infrastructure is "..the means to assemble geographic information that describes the arrangement and attributes of features and phenomena on the Earth. The infrastructure includes the materials, technology, and people necessary to acquire, process, store, and distribute such information to meet a wide variety of needs" (CGER, 1993). In practical terms, in the context of imagery, this means providing imagery at low cost, broadband internet connection and the means to process large volumes of data by the receiver. It is also necessary for the effective extraction of information to meets the needs of society that the user is able to integrate different types of data.

For the purposes of this paper high resolution data is taken to be any image data acquired from space with a pixel size of 10m or less, and will include Radar.

Status of technology for data acquisition and distribution

Background

During recent years there have been a number of important technological developments which enable data to be collected more efficiently and delivered to where it is needed. These include the increase in computer power and the maintenance of costs which are affordable, the internet, and the development of Global Navigation Satellite Systems (GNSS), which provide instant positional information, and, when used with inertial navigation systems (INS) allow accurate georeferencing of image data. The use of GNSS and INS on satellite and airborne platforms with imaging sensors means that the georeferencing can be provided with a minimum number of ground control points, thus allowing the data to be merged with map data, ground positions and other image data in a very short time. In recent years some space missions have been designed to collect global or regional data: the Shuttle Radar Topography Mission (SRTM) is one example of this, and the SPOT HRS and ALOS PRISM missions are further examples.

Sensors

Current sensors are categorized as optical or microwave. Many medium and high resolution sensors are able to collect stereoscopic data which enables digital elevation models (DEMs) to be generated. This product is necessary to fully correct data so that it can be accurately merged with other data types. Table 1 shows examples of this type of sensor with the accuracy which can be obtained in elevation.

PLATFORM	SENSOR	LAUNCH DATE	TYPE	PIXEL SIZE	SWATH WIDTH
SPOT1-4	HRV	1986-	Cross Track Push broom	10m 20m	60km
IRS-1C/1D	Pan	1995	Cross Track Push broom	5.8m	70km
ASTER	TERRA	1999	Nadir/aft stereo	15m	60km
IKONOS		1999	Cross track, fore and aft pointing	1m	12km
Quickbird		2001	Cross track, fore and aft pointing	0.6m	17km
OrbImage 2		2003	Cross track, fore and aft pointing	1m	8km
SPOT 5	HRG	2002	Cross Track Push broom	5m⇒2.5m	60km
	HRS	2002	Along Track Push broom	10 x 5m	120km
ALOS	*PRISM*	*2005*	*3 line Along Track Push broom*	*2.5.m*	*35km*

Table 1. Optical sensors with stereo capability. *Systems in italic not yet launched*

Of particular note in table 1 are the high resolution systems IKONOS, Quickbird and Orbimage which have a pixel size of less than 1m, small swath width, and are operated by commercial companies and for which the price in generally high. Also of note are the SPOT 5 HRS and the ALOS PRISM sensors which are designed to collect DEMs at regional and global level.

Microwave or synthetic aperture radar (SAR) sensors are invaluable because of their ability to penetrate cloud. Furthermore the use of two SAR images enables interferometry to be used to generate very accurate DEMs, and 3 images, taken over a period of time, allow displacements to be measured with accuracy at the millimeter level. Table 2 shows some of the available sensors.

Satellite/ operator	**(Proposed) launch date**	**Sensors**	**Products**	**Spatial resolution**	**Swath**
ERS 1 and 2 (ESA)	1991 1995	C band	Images DEM	30m	100km
SRTM C-band (JPL)	2000	IfSAR C band	DEM Ortho Images	30m	225km
SRTM X-band (DLR)	2000	IfSAR X band	DEM Ortho images	3m	45km
RADARSAT 1 **(**Canada)	1995	C band SAR	Fine Standard	8m 30m	45km 100km
ENVISAT **(**ESA)	2002	ASAR C band	Image mode	12.5m	100km
RADARSAT 2 ***(****Canada)*	*2006*	*C band*	*Ultrafine Standard*	*3m 28m*	*20k 100km*
ALOS ***(****NASDA, Japan)*	*2005*	*PALSAR L band*	*Fine ScanSAR Polarimetric*	*7-44m 100m 24-89m*	
TerraSAR X *(Germany)*	*2006*	*X band*	*Spotlight Strip*	*1m 3m*	*10km 30km*

Table 2. Microwave sensors. *Systems in italic not yet launched*

The ERS 1 and 2 sensors have been used extensively to generate DEMs using interferometry, but of greater importance in this respect is the Shuttle Radar Topography Mission (SRTM) which obtained coverage of the whole of the landmass of Earth between 56°N and 60°S and which has been used to generate a DEM with 30m spacing which is available over the whole of the area covered with a spacing of 90m. The SAR image and the DEM are used to create orthoimages over the same areas.

Infrastructure

A very basic and essential requirement for tackling the problems is information on where the problem is located, what is there and how to get there. Existing mapping is frequently out of date, especially in less developed areas, but satellite images can provide up to date information. However to be able to collect data when it is required and in a form which can be used, frequent revisit cycles are necessary, and the imagery must be geolocated, and preferably orthocorrected with a DEM in order that it can be easily related to other data and to features on the ground.

As an example SRTM data can be freely downloaded from an ftp site at JPL. The data is geolocated and orthocorrected. Image data is available from a large number of sites at a range of prices, depending on the source of the data and on who is operating the site. The data The issue of pricing Earth observation data is a complex one and has been discussed in a number of publications (Harris 1997).

In order to ensure that the data can be used by the largest possible number of people, standards are necessary to allow interoperability on different software systems. Such standards are being set by the Open Geospatial Consortium (OGC) which has the aim of development of standards for geospatial and location based services. OGC works with government, private industry, and academia to create open and extensible software application programming interfaces for geographic information systems (GIS) and other mainstream technologies. The Working Group on Information Systems and Services (WGISS) of CEOS aims to stimulate, coordinate, and monitor the development of the systems and services which manage and supply the data and information. WGISS aims to assist CEOS participating agencies, as data providers, to maintain efficient support to diverse users worldwide for easy access and application of that data. Thus, WGISS aims to address the needs of data providers by improving their efficiency of operation and maximizing the usefulness and benefit of the EO data which they gather. WGISS also addresses the needs of data and information users by aiding the development of simpler and wider access to the resources they require.

WGISS places great emphasis on the use of demonstration projects involving user groups to solve the critical interoperability issues associated with the achievement of global services. WGISS has developed a number of tools, standards, and services to assist access to and use of Earth observation data resources available online. Refer to the WGISS Web site for more details.

An example of the application of OGC standards is the ESA ICEDS (Integrated CEOS European Data Server) which has wider objectives and aims to:

1. use (OGC) technologies for map and data serving;

2. serve datasets for Europe and Africa, particularly Landsat TM and Shuttle Radar Topography Mission (SRTM) digital elevation model (DEM) data;

3. provide a website giving access to the served data;

4. provide software scripts, etc., and a document reporting the data processing and software set-up methods developed during the project.

The Group on Earth Observations (GEO), discussed below, also recognizes the importance of the spatial data infra structure in the application of EO data.

In developed countries up to date data might exist and national mapping organisations can provide this. In United Kingdom, for example, the Ordnance Survey has a 24 hour emergency response capability to government requests for data. Disasters can give an impetus to technology; again drawing an example from UK, the foot and mouth crisis in 2001 Demonstrated to government how useful GIS can be and the uptake of this in government departments has greatly increased since that crisis. The Indian Ocean tsunami has demonstrated how EO data can be useful and has prompted further co-ordination and efforts to set up a tsunami early warning system.

The provision of weather information is also critical in predicting hurricane and floods for example and we are now all familiar with satellite images of hurricanes determinedly heading for SE USA or the western pacific seaboard.

International and regional structures for data distribution and application

In order to respond to disasters a co-ordinated system is needed. Two examples of this are the Charter for Disasters and the Disaster Monitoring Constellation.

Charter for Disasters

There are a number of initiatives in place to provide data, such as International Charter on Space and Major Disasters, under which the space agencies provide data to the disaster management authorities. This has been invoked on 54 occasions during the past 3 years and proved to be very effective in areas such as flooding, earthquakes and hurricanes. This service is co-ordinated by the UN Office for Outer Space Affairs (OOSA) (unosat.web.con.ch/unosat).

Disaster Monitoring Constellation

The Disaster Monitoring Constellation (DMC) is the first earth observation constellation of 5-7 low cost small satellites providing daily images for applications including global disaster monitoring. The consortium comprises Algeria, Nigeria, UK and China as partners and Turkey and Thailand as Associate Partners. Each partner owns an independent small satellite mission that services national needs and the consortium provides daily revisit capability, a wide swath width of over 600km, multispectral data at 32m resolution and in some cases panchromatic data at higher resolution.

Future structures for the benefit of Society

The importance of a spatial data infrastructure to the application of high resolution data is best illustrated by examples. It has been recognized by the group on Earth Observation (GEO) that future development of Earth observation should be linked to societal benefits.

Nobody doubts that there are serious threats to the population of planet Earth, many from physical phenomena brought about by changes to the environment caused by human activities. These threats have not escaped the notice of governments, and although there is discussion over who is responsible and what should be done, many governments have policies to tackle these problems. Of major interest to the remote sensing community is the intergovernmental Group on Earth Observations (GEO) established by the third Earth Observation Summit in February 2005 and which arose from the first EO Summit which declared the need for "timely, quality, long-term, global information as a basis for sound decision making". The second Earth Observation Summit in April 2004 agreed to a Framework which established the basic principles for preparing an Implementation Plan for a Global Earth Observation System of Systems (GEOSS). In the Implementation Plan from the World Summit on Sustainable Development (WSSD) in Johannesburg specific mention is made of Earth Observation and GIS to "Promote the development and wider use of earth observation technologies, including satellite remote sensing, global mapping and geographical information systems, to collect quality data on environmental impacts, land use and land-use changes, ….". The plan also calls for support to countries, particularly developing countries, in their national efforts to collect data, use satellite and remote-sensing technologies for data collection and to access, explore and use geographic information. All of these intergovernmental initiatives come on top of the on-going activities of the United Nations, CEOS and IGOS, (The Integrated Global Observing Strategy) and ICSU and the efforts of international societies such as ISPRS, ICA, FIG.

The GEOSS 10 Year Implementation Plan recognizes nine areas of Societal Benefit from Earth Observation. These are listed in table 3.

Societal benefit area	Issues and observations covered	Advantages of a planned approach and use of SDI
Disasters: Reducing loss of life and property from natural and human induced disasters	Wildland fires, volcanoes, earthquakes, landslides, subsidence, floods, coastal hazards, tsunamis, ice hazards, extreme weather, pollution events	Coordinated systems for monitoring, predicting, mitigating, and responding to hazards are operating at local, national, regional and global levels. Earth observations are enhanced and better integrated, blending *in situ* measurements with airborne and satellite remote sensing, and with diverse socio-economic data and maps. Gaps are filled in organization, technology and capacity. Disaster information is disseminated more timely and accurately.
Health: Understanding environmental factors affecting human health and well being	Nutrition, water quality, air quality, UV-B, hot and cold weather, disease vectors, health statistics	Satellite and *in situ* data are integrated with health census data, and models are developed. Availability of appropriate environmental data to the health community is improved, creating a focus on prevention.
Energy: Improving management of energy resources	Weather-related variations in energy demand and supply; risks to energy infrastructure; renewable resources; pollution and greenhouse gas emissions	Through coordinated observations, inventories of greenhouse gases, pollutants, and renewable energy potential are improved.
Climate: Understanding, predicting, mitigating and adapting to climate variability and change	Climate system variables (e.g. temperature, moisture, winds, gas composition etc) in atmosphere and oceans, on land and ice	Access to information of past and current climate conditions, variability and extremes is facilitated. Essential systems are maintained and key geographical gaps are filled. Implementation of new observing systems is promoted. Integrated climate products are generated, using data assimilation.
Water: Improving water resource management through better understanding of the water cycle	Precipitation, soil moisture, stream flow, lake and reservoir levels, snow cover, glaciers and ice, evapotranspiration, groundwater, water use	Integrated water management is supported by bringing together observations, prediction and decision support systems. A joint framework for water planning and a capacity building plan for developing countries are in place.
Weather: Improving weather information, forecasting and warning	41 weather variables observed *in situ* and from space, needed for accurate and timely short and medium term forecasts	Capacity in developing countries to deliver essential observations and use forecast products is improved. Needs are better communicated across a wide range of users and observing systems.
Ecosystems: Improving the management and protection of terrestrial, coastal and marine resources	Extent of major ecosystems, functional attributes (greenness, NPP etc), disturbance regimes, ecosystem change drivers	Ecosystem observations are better harmonized and shared. In situ data are better integrated with satellite observations. Data assimilation models for ecosystems and a framework for validating satellite observations are developed. Spatial and topical gaps are filled. Continuity is ensured for observing carbon, nitrogen, canopy properties, ocean color and temperature.

Societal benefit area	Issues and observations covered	Advantages of a planned approach and use of SDI
Agriculture: Supporting sustainable agriculture and combating desertification	Crop production, livestock and fishery statistics, food security and drought projections, agricultural area, degradation indices, nutrient balances, farming systems, land cover change	A truly global mapping and information service for poverty and food monitoring enables sustainable development and international planning. National and international capacities to use earth observation data in agriculture and fisheries and a seamless system for delivering observations to users are developed. Spatially explicit socio-economic data is integrated with agricultural, forest and fishery data. More comprehensive, validated, and harmonized land cover, land use and degradation products are made available.
Biodiversity: Understanding, monitoring and conserving biodiversity	Area and condition of ecosystems, distribution and status of species, genetic diversity in key populations	A platform is created to integrate biodiversity data with other types of information. Interoperability standards for biodiversity datasets are promoted.
Common Supporting Information	Maps such as topography, infrastructure, land cover; and socio-economic data such as population, GDP, well-being indicators	Access to best-quality supporting information is facilitated. Interpretive data is integrated with observational data.

Table 3. GEOSS topics for implementation. (GEO 2004)

Not all of these areas need high resolution data, those which clearly do need it are Disasters, Water, Eco systems. Agriculture, Biodiversity and the common supporting information.

GEO recognised the importance of SDI and in the 10-Year Implementation Plan reference Document (GEO 2005). the importance of SDI is clearly set out:

> "In common with Spatial Data Infrastructures and services-oriented information architectures, GEOSS system components are to be interfaced with each other through interoperability specifications based on open, international standards. Access to data and information resources of GEOSS will be accomplished through various service interfaces to be contained within the data exchange and dissemination component. The actual mechanisms will include many varieties of communications modes, with a primary emphasis on the Internet wherever appropriate, but ranging from very low technology approaches to highly specialized technologies. A key consideration is that GEOSS catalogues data and services with sufficient metadata information so that users can find what they need and gain access as appropriate. The Internet is a primary medium for the mechanism to allow users to access the catalogue of available data and products, with hardcopy media to also be available as appropriate. Users searching GEOSS catalogues will find descriptions of GEO Members and Participating Organizations and the components they support, leading directly to whatever information is needed to access the specific data or service in a harmonized way, independent of the specific provider. In this sense, the interoperable GEOSS catalogues form the foundation of a more general 'clearinghouse'."

Furthermore GEO recognized the relevance of many different types of data:

> "This provides a powerful synergy as GEOSS addresses types of data and information that are not always geospatial, while SDI's address types of data and information that are not always Earth observation.

Examples of SDI data and information types include transportation, population, political boundaries, land ownership, socio-economic data, cultural heritage, and minerals, among many others. GSDI ‘encompasses the policies, organizational remits, data, technologies, standards, delivery mechanisms, and financial and human resources necessary to ensure that those working at the global and regional scale are not impeded in meeting their objectives’.”

Case studies

Disaster management

The use of geospatial information for managing disasters is a key area in which earth observation already plays an important role, and in which we can also see the use of many different types of geospatial data. Table 4 is taken from the IGOS Geohazards report and show how different types of data are used to monitor and manage ground instability events. A good spatial data infrastructure is essential for this activity.

Required observations	**Background monitoring/assessment**	**Crisis response**
Characterise deformation with high accuracy and frequency (horizontal and vertical	Continuous GPS Satellite, airborne and ground-based SAR interferometry Other surveys e g leveling, laser scanning (terrestrial and airborne), aerial photography and high-resolution stereo satellite data, borehole inclinometers	Additional GPS stations More frequent satellite tasking More frequent occupation of all ground-based instrumentation
Map landslides, geomorphology, land-use, land cover, geology, structures, drainage network	Map existing features using high spatial resolution satellite and airborne imagery, aerial photography and geological and geophysical ground surveys	Over-flights to check extent and distribution of landslides
Topography/Elevation (incl slope angle, slope length, slope position)	High quality DEM from LiDAR, IfSAR, photogrammetry or high-resolution satellites	Rapid local update needed on how the landscape has changed
Soil strength parameters and physical properties (incl pore water pressures)	Geotechnical field logging and sampling, in-situ and laboratory test	More frequent observations
Climate Trigger: precipitation (rainfall, snow, magnitude, intensity, duration), temperature	Meteorological data field measurements Meteorological satellites data	Continuous recording
Seismic trigger: magnitude, intensity, duration, peak acceleration Decay of shaking level with source distance (source, propagation shaking and site effects)	Accelerometer network monitoring	Continuous recording

Table 4. Ground instability hazard observations most required and the best available observational systems. (From ESA 2004).

Another area of disaster management is flooding. Environmental protection agencies and insurance companies are collecting and using high resolution DEMs for this purpose. Airborne interferometric SAR (IfSAR) is particularly suitable for this purpose, giving an economic data source to cover large areas, and is often complemented by airborne LiDAR data to give more detail in critical areas. To take again an example from the UK, Intermap have covered the Britain with an IfSAR DEM with 1m vertical accuracy and the Environment Agency have collected LiDAR data over large areas which complements the IfSAR. Satellite data is widely used for monitoring flooding after it has taken place and can also be used to predict flooding by providing data to input to hydrological models.

Health

This is a relatively new area for Earth Observation data. Telemedicine and epidemiology is a fast developing early warning applications (Brachet et al, 2002). Environmental monitoring through EO from space and other non-EO space-based systems and services can dramatically help to develop and improve these applications. Increasing risks of epidemics, pandemics and diseases re-emergence (Malaria, Trypanosomiosis, Meningitis, Cholera, Tuberculosis or Hemorrhagic Fevers such as Dengue, Rift Valley Fever), increasing world population and its globally migration are many leading factors that have contributed to the development of specific health programme. The influence of several environment factors has been extensively studied. In co-operation with different partners from Europe and Africa, CNES set up a consortium and a programme of studies, validations and demonstrations of new satellite-based services, within education and medicine domains. In this context a Telemedicine programme was developed, aiming to set up a regional network for epidemics monitoring and allowing *real-time* recording and data exchange. Several countries in South America, West Africa and Asia are involved in this project.

Indian Village Resource Centres

An innovative and wide ranging initiative in India is the establishment of Village Resource Centres (VRC) in Tamil Nadu, established jointly by ISRO and the M S Swaminathan Research Foundation. VRC is a totally interactive VSAT (Very Small Aperture Terminal) based network to provide space enabled information and a variety of services like tele-education, telemedicine, online decision support, interactive farmers' advisory services, tele-fishery, e-governance services, weather services and water management. VRCs will also provide connectivity to speciality hospitals thus bringing the services of expert doctors closer to the villages. This of course goes far beyond the use of high resolution remote sensing data but demonstrates what can be done with a good spatial data infrastructure.

Conclusions

It is clear from the above that Earth Observation data will play an important role in meeting the needs of Society in the coming years. It is also clear that the data itself will not be effectively used if the means of distributing it, exchanging it, and integrating it with other data are not available. An efficient spatial data infrastructure is therefore essential. The plans of GEO, building on systems already initiated or planned with provide Society with access to the images data it needs through an efficient spatial data infrastructure.

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