FACTORS THAT INFLUENCE LOCAL AREA ACCESS AND PROCESSING OF SATELLITE REMOTE SENSING DATA

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ABSTRACT

There is a pressing need for timely and efficient flows of environmental information to support operational decision making in resource management at local and national scales. Remote sensing data can provide important environmentalinformation for more effective decision making. Greater flexibility in data access is necessary to improve the supply side. Direct acquisition by local area ground stations with prompt delivery of data will promote the development of appropriate applications for local demands and support the growing demands of national information networks. This will enable timely information production and better informed decision-making in support of operational resource management. In recent years, small, transportable ground receiving stations (GRS) have become available. Key technical factors introduced by these new GRS will have an important influence on timely information delivery. The Real-time Acquisition and Processing Integrated Data System (RAPIDS) ground station is a cost-effective, PC-based solution for direct, local area capture of data from high resolution satellites such as SPOT and ERS (especially SAR, which can penetrate cloud cover). Special regard is given to the local context so that the time lag between the acquisition and delivery of data is reduced and information arrives where it is required in support of the day-to-day activities of institutions, line agencies, ministries, NGOs, private sector enterprise, etc. Requirements for an end-to-end architecture and interfacing between the reception and (pre-) processing chain to the value adding and information distribution components are discussed. The RAPIDS system has been demonstrated successfully in Europe and the Far East. Results to date are presented with examples of the RAPIDS approach. Current research includes the development of SAR based information products related to flood monitoring in Bangladesh.

INTRODUCTION: THE NEED FOR TIMELY INFORMATION

Decision makers need up to date environmental information in order to manage natural resources more effectively. Remote sensing data, integrated with GIS, can provide useful environmental information on agricultural crops, forest status, the coastal zone, natural hazards (e.g. flood monitoring) and urban growth. However, to generate that information, users need effective and timely access to the data supply. The single most important comparative advantage of Earth Observation (EO) is that it provides up-to-the-minute observations of an area of interest. Therefore, the data need to arrive directly where they are required so that they can be analysed promptly in GIS or other management information systems to yield useful information (Williams and Rosenberg 1993). This can then begin to be integrated operationally into the day-to-day activities of local institutions, line agencies, ministries, NGOs, private sector enterprise, etc., to support the development of more effective national information networks for decision support (Figure 1).

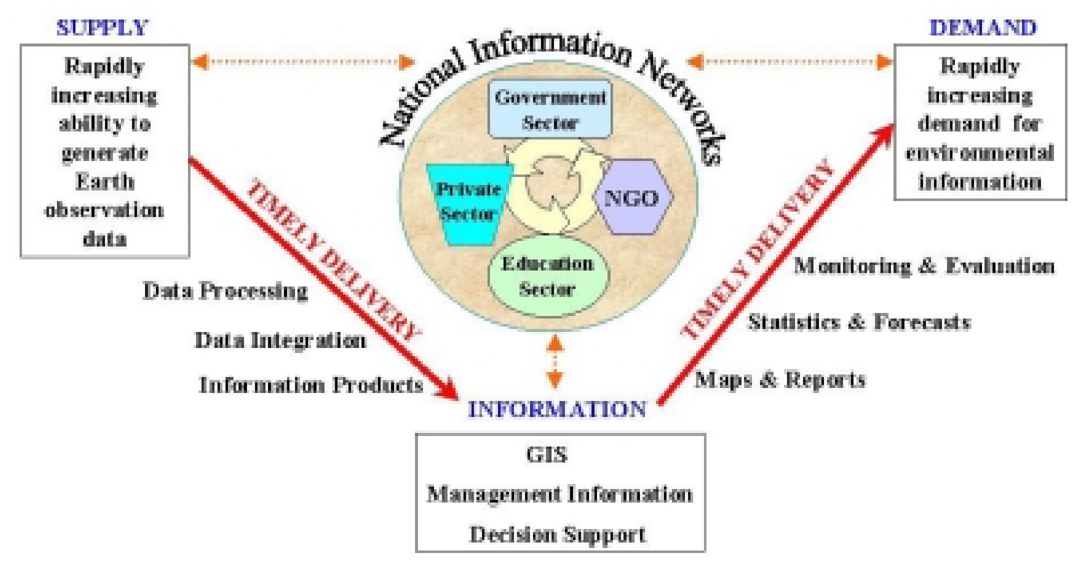


Figure 1. The importance of timely information flows for decision support

Previous studies have identified constraints on access to EO data especially, but not limited, to developing countries (EOS *et al* 1996, Westinga *et al* 1993, Swedish Space Corporation 1993). The ground segment is generally underfunded so the data distribution side is underdeveloped, making contact between users difficult and, in general, often rendering the EO supply side ineffective. This inhibits user uptake, applications development and market growth. The reliance of EO satellite operators on a system of large, regional ground stations presents significant obstacles to meeting the needs of potential EO users who are only interested in local areas and may only want small amounts of data. Affordable, local reception capabilities (such as RAPIDS) will reduce the time lag between the acquisition of data and delivery of data, enabling more timely production of spatial information, improving monitoring and supporting prompt decision-making.

Growth in the demand for information, the variety of satellite data available and increases in the number of applications mean that greater flexibility in data access is necessary to improve the supply side. In an era of increasing (EO) data abundance, however, flexible access need not mean maximising data input. It is critically important that information supply matches the intervention capability of the end user. Addressing these issues is a necessary and vital step towards realising the true potential of (public and private) remote sensing investments to date. Nonetheless, to facilitate optimum exploitation of benefits of EO based environmental information, increased consideration of direct broadcast and more relaxed controls on data distribution are required (Harris 1997).

This paper is focused on the supply side issues represented in the left hand side of Figure 1, the conversion from EO data supply into information for decision making. Much work is required to remove the technical and institutional barriers so that efficient flows of data can support effective information extraction and applications development. The primary technical factors that influence timely information delivery using conventional and small, mobile GRS are addressed further below and are illustrated with examples from past and current projects.

COMPARISON OF CENTRAL VERSUS LOCAL AREA /MOBILE GROUND RECEIVING STATIONS

Technical Factors

Resource managers and other end users require relevant information for their decision making processes and are less interested in where the information comes from, as long as it is timely, reliable and in the right format. Satellite remote sensing is one of the sources to provide such information. Conventionally, these EO data can be retrieved from the international network of large central ground stations, which is operated in partnership with satellite operators. In recent years, small mobile ground receiving stations (GRS) have become available. The authors consider that three critical technical factors play a role in the utility of these stations:

1. mobility of the ground station (and what this brings to the application)
2. direct access to data (autonomy plus the consideration of performance trade-offs)
3. the (near) real time character of the application information requirement

Mobility

A mobile ground station introduces a number of interesting options for remote sensing data acquisition. A degree of autonomy of operation is available, and the important capacity for rapid deployment or response is implicit. In addition, mobile GRS offer the capacity to provide short term campaign or seasonally based ('gap filling') missions in areas beyond established groundstation coverage, or in areas where for political or administrative reasons, data access is constrained. This could apply to natural disaster monitoring, surveillance operations, and humanitarian relief for example. Mobile GRS also offer comprehensive coverage for smaller territories (which may not be able to afford a GRS otherwise, provide a minimum configuration backup for larger territories or GRS units in case of technical failure and offer a wider data uptake path via local or niche service providers. Mobile GRS can also be moved to protected areas during severe weather events (e.g. tropical cyclone) or in hostile environments (e.g. during civil unrest).

Direct access

This is perhaps the most tangible benefit to users of a small mobile or transportable GRS, especially those users charged with making important resource management or civil defence decisions. Again a degree of autonomy is offered as well as the removal of constraints such as poor or inefficient telecommunications and other infrastructure. Direct access enables better customisation of the application with local context and consequently introduces shorter lead times for information product generation. This, in combination with locally available expert knowledge on environmental and/or social conditions is an immensely valuable advantage of mobile GRS operations in support of real time operations. Full control over the entire processing inherently provides traceability / reproduceability of data at all levels and allows customisation of processing for better interfacing with the application specific processing / information extraction.

Near real time

The concept of 'real time' can be confused with the idea of providing immediate, virtually instantaneous access to information. It is more appropriate to consider real time requirements as the definition of an end-to-end solution, which ensures that information supply matches the intervention capability of the end user. Applications with a strong (near) real time requirement are often characterised as having good communications an infrastructure links, well defined products (probably low in data volume) and a responsibility to provide overall monitoring combined with delivering information about anomalies onwards for decision making or planning interventions.

Figure 2 presents the key characteristic issues for each of these three technical factors. The applicability of one or more characteristics to one or more of the factors can vary between applications. For flood monitoring applications in Bangladesh (described below) the issues of gap fill, autonomy and poor communications links were relevant. For military applications, autonomy is again important but also a near real time decision/reaction requirement and (under certain circumstances) poor infrastructure / communications links are important considerations.

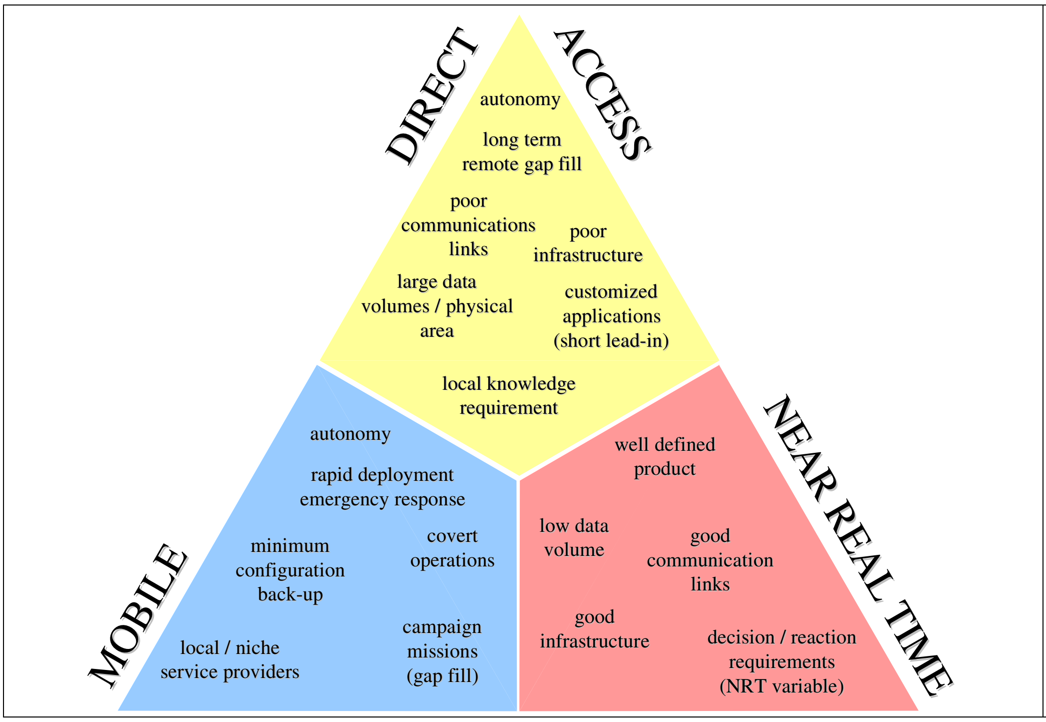


Figure 2. Characteristic GRS issues related to the three critical factors for the justification of local/mobile GRS

GENERIC PROCESSING OF EO DATA FOR INFORMATION EXTRACTION

This is basically independent of the application but there are two key questions that influence the pre-processing of remote sensing data for use as an input for information extraction:

1. where is it?
2. what are we looking at?

In order to answer both questions, the EO data downlinked from the satellite needs to fed through a transformation process, which includes both processing and interpretation. For many applications, one can only tell what is being looked at by means of multi-temporal data. This requires spatial co-registration of different datasets and hence the need to provide a solution for the first question. Both stages need to go hand-in-hand nonetheless. Figure 3 provides a simplified overview of such a process and indicates the logical steps in the processing chain.

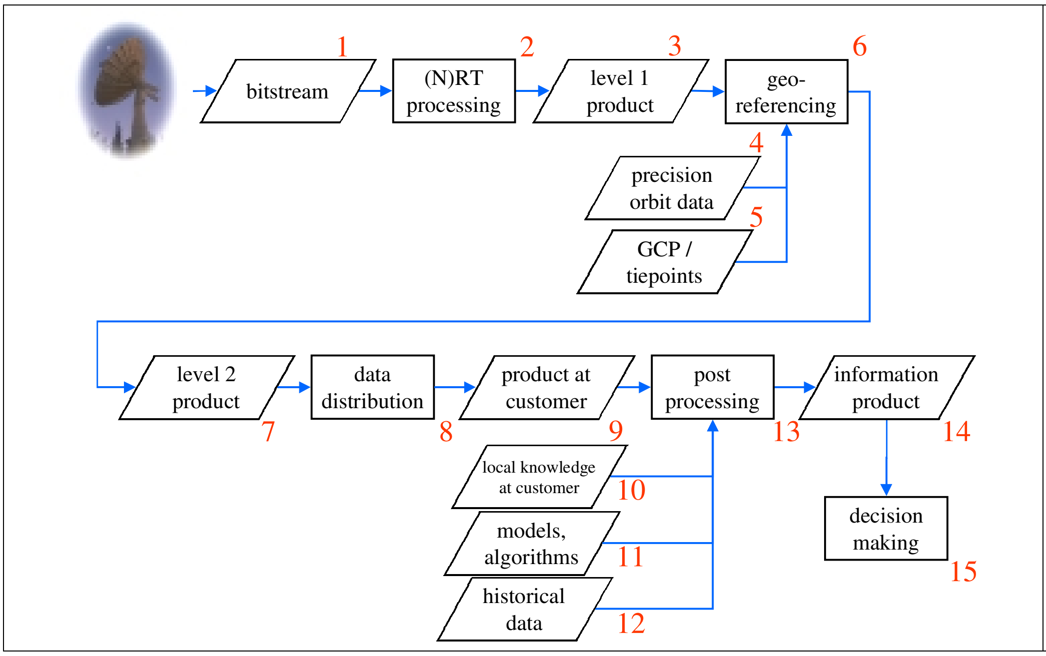


Figure 3. Steps in the conventional chain from data reception to generation of an information product

The EO data received by a large central ground station can be processed into a level 1 product almost instantly or "on the fly". The output is an image that gives a first clue to question number 2 above. In order to locate the image on the globe and to compare it with other images and/or data from other sources, it needs to be geo-referenced: the "where is it?" part. Ephemeris data on the satellite position is received at the same time as the image data. This can be processed to generate an approximate Earth location. However, depending on the required accuracy and/or available information, one needs precision orbit data or ground control points (GCP) as well to locate the image accurately. The precision orbit data is not available in near-real-time and generally can only be obtained from satellite operators usually after a couple of days. This time delay is caused by the need to process (e.g. laser altimeter) ephemeris data into precision orbit data. After these data are made available, the actual georeferencing is simply a matter of mathematics and calculation power.

The use of GCPs to georeference the level 1 product to a level 2 data product directly is a very time consuming process. Consequently it is an activity that an operational end user does not want to waste time with. The consequent level 2 product needs to be sent to the customer either by (express-) mail, which may take some days, or by a fast network connection, if available at both the ground station <u>and</u> the customer end. Adding all up, it can take at least some (2 to 3) days before the customer can start his/her application specific post processing. For areas where infrastructure is not tailored to facilitate timely data supply, it can take weeks or longer to obtain appropriate image products.

In the mode described above it is the data which are physically distributed to the customer. In some respects therefore is not so relevant whether it is level 0, 1 or 2 standard products. The important point is that it is high volume data, not smaller volume information, that is distributed. The subsequent information extraction is application specific and equipment, models, algorithms and reports need to be configured and optimised to the local context. Local user knowledge is therefore essential in reducing the high volume data into useful low volume information for decision making.

Alternatively, on-site/local GRS can be used for local area data reception. The mobile, small RAPIDS system is an example of such a system. Coverage is smaller than for the more centralised stations, but given the local context of the information need this is an advantage rather than a constraint. The flow of data in this case is given below (Figure 4).

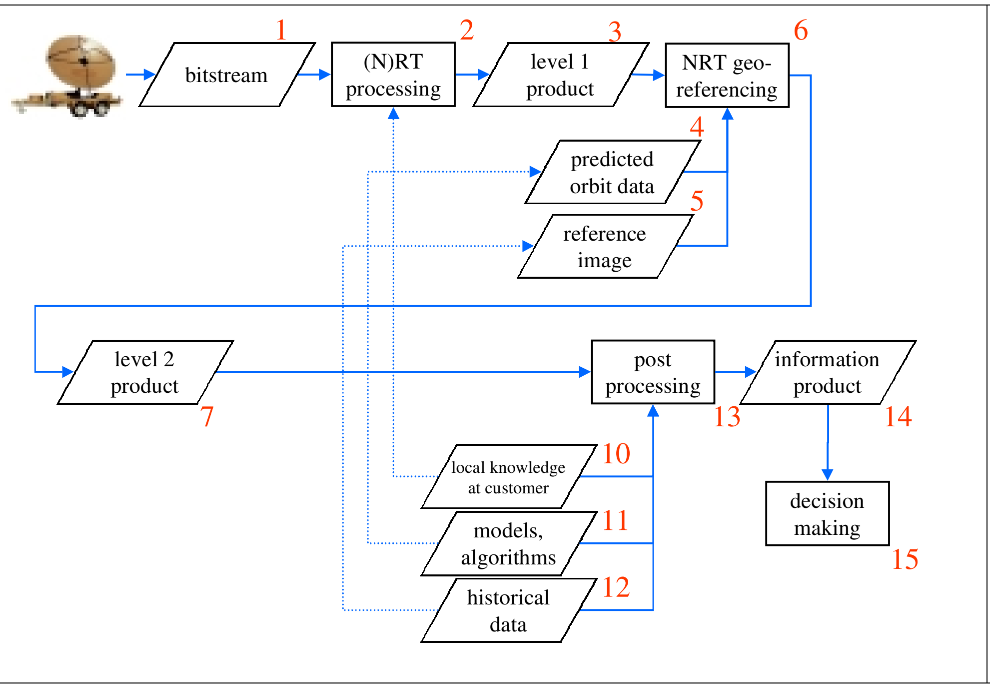


Figure 4. Logical steps in the RAPIDS near-real-time chain from data reception to generation of an information product

This process differs in three essential points from the conventional process using central stations:

1. There is less need for data distribution (steps 8, 9). The absence of an explicit need for data distribution enables greater efficiency in data processing and transmission and a greater focus on delivering lower volume information products due to the on-site / local presence of the ground station.

2. The required technical inputs are different (steps 4, 5). For example, one can use calculated high precision orbit data and/or a reference image instead of derived precision orbit data and/or GCPs,. Using advanced orbit models that are continuously fed with historic orbit data, one can achieve an accuracy (available at the time of data reception) sufficient to georeference the level 1 product. If such a model is not available to the user, or the model can not be fed with historic data, one can use a reference image to georeference the level 1 product. This reference image is a (manually or automatically) georeferenced, one-off, image of the area of interest prepared beforehand and acquired by the same sensor as the new image. By image-to-image mapping, the new image can georeferenced indirectly, in near-real-time.
3. It has recently been demonstrated (Sowter *et al* 2000) for ERS-SAR using RAPIDS that such mapping can be performed automatically. Current research is being done on image-to-image mapping for optical EO data as well. Overall accuracy depends on the quality of georeferencing of the reference image and the accuracy of image-to-image mapping. The latter is in principle accurate to within one pixel.
4. Local knowledge is brought into the processing chain earlier. Consequently, knowledge and data commonly used in post-processing only can now be is used in data selection (area of interest) and pre-processing (steps 10, 11, 12) to support efficient information extraction.

Bearing these distinctions in mind, the two different approaches can be further compared with respect to the three technical factors described earlier.

Mobility

Mobility of a ground station provides autonomy, 'gap filling' capabilities and simplifies campaign based acquisition programs due to small size and ease of transportation (e.g. rapid deployment). Next to these advantages, it supports direct access and near real time processing for users which have requirements that can not be met by central stations. There are also (niche) markets where mobility of a ground station is a must.

Mobile GRS usually have smaller antenna dish diameter than central stations have, resulting in a smaller coverage or a higher bit error rate at low elevations, due to the distance between the satellite and the GRS. Nevertheless, smaller coverage still means an area over 1000 km diameter which, given the local context of the information need, reduces the importance of low elevation performance.

Direct access

With local reception the end user has direct access to the EO data. As discussed below, this is a prerequisite for operation in near real time for some applications. Direct access not only provides real time availability of the raw data, it gives full control over the end-to-end chain to the end-user as well. This is a very valuable aspect since one wants the so-called 'standard' products to be processed in a repeatable and traceable way to ensure smooth, problem free information extraction process. Past experience has shown that 'standard' products vary from ground station to ground station, not all stations commit to the ESA CEOS format (see Gråbak *et al*) and the used SAR processors differ. Where these variations stem from is not always known, let alone that these can be corrected for afterwards. This may seriously hamper, delay or even obstruct proper post processing.

Having full control over the end-to-end chain, it becomes possible to optimise the pre-processing, given the availability of the raw data <u>and</u> the local knowledge and information. It is exactly this that makes the migration from the Figure 3 mode to that of Figure 4. Thereby, for example, enabling near-real-time automated georeferencing.

Near real time

The third critical factor is near real time availability of information. In Figure 3 and Figure 4 different approaches to achieve an information product available for decision making are presented. In Figure 5 below a timeline is presented for each of those chains. It shows a significant shorter throughput time for RAPIDS/local reception chain compared to a conventional chain using a central station. The question is, however, what extra efficiency or added value does this bring? The answer is not straightforward, multiple factors need to be taken into consideration. These factors are discussed below.

TIME FACTORS

Is near-real-time required?

To address this question, it is important to define what is meant by the term near-real-time. The authors take the opinion that, this depends on four key time factors:

1. timescale of the process (and/or its impact) that is monitored;
2. throughput time for data processing, distribution and information extraction;
3. data update rate / acquisition frequency
4. time period required for decision / intervention

Timescale of process

The timescale of the process involved can vary from (a) some hours for sea-ice monitoring, oil spill detection and intelligence type of operations, to (b) some days for disaster relief and flood monitoring operations, and up to (c) some weeks for crop monitoring. Near-real-time information supply should be balanced against these timescales, and hence, near-real-time is an application dependent definition.

End-to-end throughput time

This comprises the total time required for data processing, distribution and information extraction. This is the process as described in the section above and in Figure 5. The processing to availability of a level 2 product at the user varies between hours and weeks or even longer. Information extraction time depends on the complexity of the application and the level of automation of the extraction.

Data update rate

The data update rate is set by the revisit time of a (constellation of) applicable satellite(s). This varies with latitude and type of sensor (SAR radar / optical). For a combination of Radarsat-1 and ERS-2 satellites, the revisit time at the 50 degrees latitude is less than 4 days (4 days for Radarsat-1 (medium-low resolution) and 18 days for ERS-2). When Envisat ASAR is operational, it will have a revisit time of about 5 days at 50 degrees latitude (medium-low resolution). This means a combined ERS / Radarsat ascending / descending SAR update rate of once every 2 to 3 days. The number of platforms with medium resolution optical sensors (SPOT, Landsat, IRS) is much higher than for SAR sensors, resulting in an average revisit time of less than a day.

Decision time

Decision time concerns the time needed to decide if and what action to take once the information has become available. Depending on the complexity of the application and the degree of autonomy that a given decision making body has, this can vary from minutes (go/no) to hours and even much longer.

Ideally, the timescales related to the four factors mentioned should be in balance or of the same order of magnitude. The information supply chain is as fast as the slowest of the segments. Figure 5 shows the respective information supply chain for conventional GRS operations and small/mobile GRS operations.

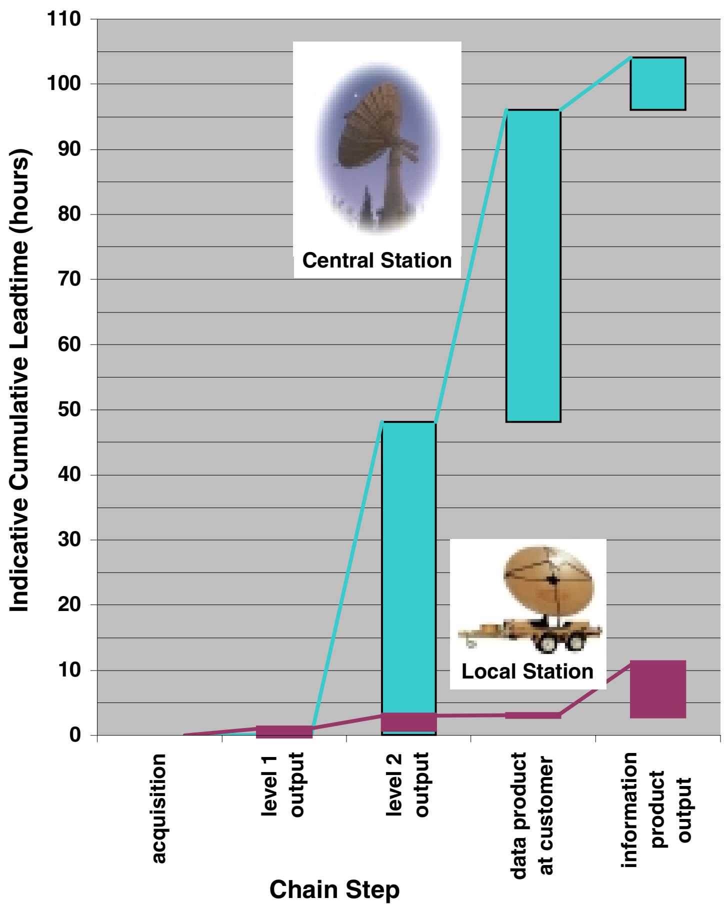


Figure 5. Indicative leadtime comparison between the conventional and the RAPIDS end-to-end chain (chain step numbers refer to figures 3 and 4).

Applications which have timescales of hours to days exist (time factor 1). Amongst these applications, some use medium resolution data and the near-real-time requirement is limited by a data update rate of between one and a few days. Given the rapid developments in space infrastructure, this time will most likely decrease significantly in the near future and will be applicable for higher resolutions as well. This means that, depending on the application, the space infrastructure is already there or will be there soon (time factor 2). Timely availability of EO data in the traditional way can not always be provided. The main technical limitation currently is not in the space segment, but in the ground segment which is traditionally underfunded. The approach described in Figure 4 using local groundstations can contribute to resolving this problem using local reception, local processing and using a different approach to georeferencing (time factor 3). Decision time (time factor 4) is related to political and institutional factors and is outside the scope of this paper.

RAPIDS LOCAL / MOBILE GRS

The design philosophy of the RAPIDS PC-based ground station is to meet national and/or local needs for timely environmental data. With RAPIDS, the ground segment has been scaled down to support operations within only a local area footprint. This means the station can be inexpensive, easy to transport, install and maintain (Figure 6). The RAPIDS system is one of several mobile GRS currently available. It has been described in various papers elsewhere (Downey *et al* (1997), Stephenson *et al* (1997), http://www.nri.org/RAPIDS and http://www.neonet.nl/RAPIDS) so only a brief technical description is given.

The principal design requirement is a system to capture moderate amounts of data regularly for local areas. This requires the system to maximise control during overhead passes where the rate of change in satellite position is highest. A cone of acquisition of ± 45° enables capture of (relatively) small unit volumes of data, which meet the needs of users within a diameter of about 1,000 km. The system also has to minimise the effect of wind forces during tracking, and to be simple to maintain and operate. Standard PCs are used for management, tracking, capturing and processing of data (Figure 7). Their performance to cost advantage and widespread availability and use in developing countries encourages local maintenance and cost-effective integration with existing capacity.

Figure 6. RAPIDS mobile GRS at NLR

The ground station comprises four major subsystems:

- Orbit Planning
- Satellite Tracking
- Data Capture (ERS SAR, ERS LBR, SPOT HRV)
- Data Processing (ERS SAR, SPOT XS, SPOT Panchromatic)

All the PCs are connected to each other by fast Ethernet or RS232 links. Current capability includes ERS and SPOT. Other satellites can potentially be accessed (i.e. Envisat, Indian, Japanese, Landsat, EOS etc.). Current plans include implementation of Envisat capabilities and researching capabilities for Radarsat and others. Because satellite data rates vary, the total amount of data captured is different for different satellites. Up to 650 Mbytes of ERS data (equivalent to one minute of transmission) and up to 900 Mbytes of SPOT data (three minutes) can be acquired, using a single capture PC. Disk striping or multiple capture PCs can be used to increase these figures.

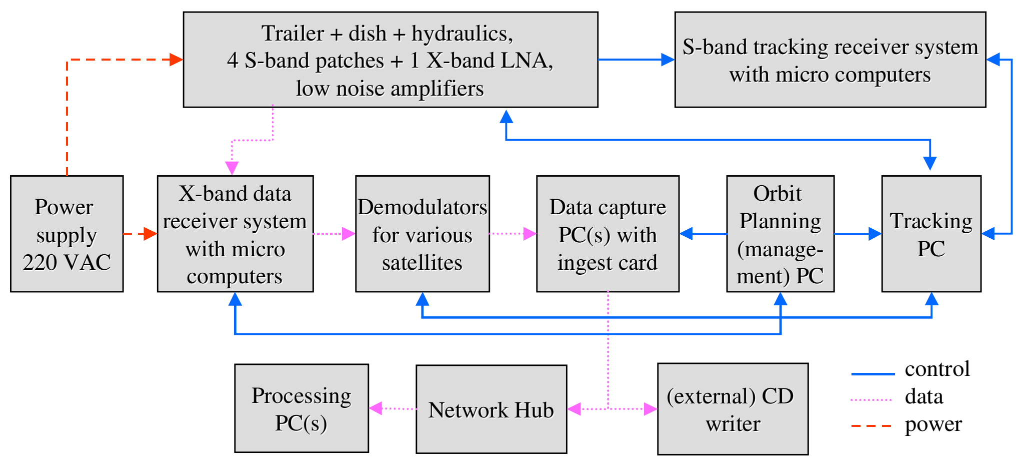


Figure 7. Schematic RAPIDS system configuration

APPLICATIONS DEVELOPMENT IN THE LOCAL CONTEXT

A great many applications using high resolution optical and SAR data have already been developed to support environmental monitoring and decision making around the world. Easier access to less expensive high resolution EO data would lead to massive growth in its utilisation by developing countries, especially if the flow of data was streamlined to generate information that fits the local context and information needs.

Development of the RAPIDS programme to date has included a number of technical and applications demonstrations in the UK, the Netherlands and Southeast Asia. Data from the ERS and SPOT satellites have been successfully acquired, and processed into useful images as a routine operation in these regions. Whilst, these have been important demonstrations of capability it is important to ensure that the applications supported in this way are useful and reliable for local information needs. The information flows can then, in turn, be integrated with operational local data capture for optimum effectiveness in local decision making processes. Increasingly, therefore the program is linking to real world information demands focused on developing streamlined information flows to support local environmental decision making. Past and current RAPIDS related projects include system evaluation in Indonesia, the development of flood mapping and monitoring tools for Bangladesh using ERS SAR data, volcano monitoring on Montserrat and development of a mobile GRS for military applications.

National Ground Station in the Netherlands

A RAPIDS system has been installed at NLR in the Netherlands, since November 1997. This has operated as the Netherlands national (ERS) ground station since end of 1998. The system has been demonstrated to a wide range of interested organisations. At the same time the system has been used routinely in support of specific operations. Day-to-day experience indicates that a minimum of manual intervention is required. In general, 1 to 2 two hours are required to plan, acquire, process and archive optical data and between 2 and 3 hours for SAR data. Approximately 85% of this is processing time. Development of speed-optimised software and faster computing hardware will further reduce processing time significantly.

System evaluation in Indonesia

A RAPIDS station was installed, demonstrated and operated at the Pekayon facilities of Lembaga Penerbangan dan Antariksa Nasional (LAPAN), near Jakarta, Indonesia (Downey *et al* 1998). LAPAN is the Indonesian National Institute of Aeronautics and Space, responsible for the acquisition, processing and distribution of satellite data in Indonesia. The objectives of the demonstration were: to show the capabilities of RAPIDS in tropical conditions and to promote greater awareness and appreciation of the practicality and usefulness of near real time data delivery for local decision support systems. The potential to provide up to date environmental information on forestry, rice production monitoring and coastal zone studies was investigated.

Data acquisitions were operating successfully within two days of installation. Local users were trained to operate the station reliably and with confidence in a matter of days. Routine data acquisitions were made and the ERS and SPOT data captured were archived on CD-R media..

Flood mapping in Bangladesh

During the last decade several initiatives (such as Flood Action Plans - FAP) have been set up by the United States in order to monitor the flood process in Bangladesh by using geographical information. The FAP-19 activities have led to a geographical knowledge centre (EGIS) in Dhaka with local Bangladesh experts trained abroad or in house through special courses. Recently, the Netherlands government has taken over the funding of a programme in which the knowledge transfer must lead not only to education of local people, but also to establishing an independent and self-supporting centre to support development of geographical solutions for problems concerning flooding, fisheries, agriculture and other land and marine application.

Previous studies with SAR systems showed that the use of space-borne SAR observations could provide indications of flood extent and flooding directions. SAR images are not hampered by cloud coverage or night time operations and can provide a guaranteed image supply as opposed to optical systems. Results from these studies were promising, but problems associated with scheduling data acquisition, time-consuming SAR processing, shipping, and customs clearance restricted the use of radar data in an operational context. The immediate handling of images is essential for fast response measures by local authorities and validation in the field.

Within this context a project was established under the ESA Data-User Programme (DUP) to utilise the RAPIDS PC-based ERS Ground Receiving Station as part of a Flood Monitoring Service Demonstration/Operation in Bangladesh during the 1999 monsoon season. The DUP flood monitoring demonstration/operation service was focused on timely interpretation of ERS images with easy-to-use PC based software in an operational flood monitoring environment developed by Synoptics BV under ERDAS and Arc-View shell. The DUP project had two main objectives:

1. Demonstration/operation of a 'low cost', up-to-date and easy-to-handle flood monitoring service in the floodplains of Bangladesh.
2. Consolidation of the flood monitoring service with the EGIS centre in Bangladesh as end-user and (set up of archive for) additional applications.

SAR data acquisition is unaffected by cloud cover and local area capture enables quick and frequent data captures that cover the entire Ganges and Brahmaputra-Jamuna floodplain (figures 8 and 9). Combinations of ascending and descending orbits permits more frequent data availability than the normal ERS 35 days cycle. Used in this way, RAPIDS can yield large amounts of local area image data at relatively low cost, in near real-time and directly at (or very close to) the decision maker. Consequently, SAR data can be more easily interpreted for assessing flood hazard and supporting direct action in times of flood alert or damage. The eventual creation of longer period multi-temporal SAR archives will also enable the study of other processes, such as river morphology dynamics, coastal erosion and a number of land applications (e.g. rice monitoring, settlement mapping).

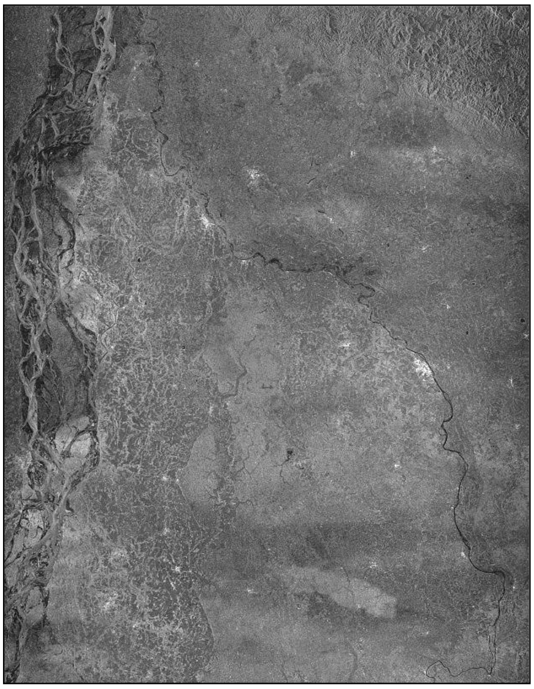
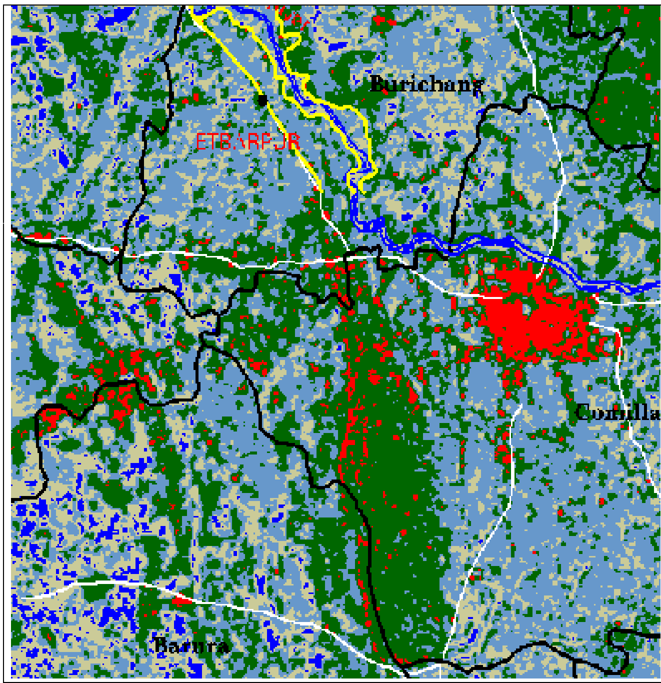


Figure 8. ERS-2 SAR image of the Brahmaputra-Jamuna floodplain in Bangladesh, acquired by RAPIDS in Dhaka, 18/4/99 (© ESA 1999)

The DUP project was implemented by Synoptics BV and NLR (supported by NRI and BURS) as a parallel, reinforcing, activity linked to an existing long term Netherlands government programme of support in Dhaka. The ultimate objective of EGIS is to provide useful environmental information operationally, and on an independent basis. The EGIS centre has a well equipped infrastructure with qualified employees. A RAPIDS ground station was installed at the SPARRSO facilities in Dhaka, Bangladesh from April to November 1999. The station provided information to EGIS to perform flood monitoring and mapping during the 1999 monsoon season. Counterparts were trained to operate the system and to generate outputs from FLOMON software developed by Synoptics.



Open flood, calm water
Open flood, wavy water
Crop: early or ripe, mixed with open water
High canopy crops, vegetation with / without water underneath
Corner reflectors (mostly infrastructure

Figure 9. A NRT flood map: Classified ERS-2 image acquired on 13th July, 1999 showing flooding caused by breach in embankment at Etbarpur

Dedicated QSAR processors were developed to determine the extent of flooding, particularly in rice growing areas. FloodSAR (a collaborative development between Synoptics, NLR and EGIS) generated output products that include: maps of flooded areas and time series change analysis of flood location and extent. The demonstration was developed for monitoring floods and not to predict hazardous peaks and natural disasters at this stage.

There is definite in-country user demand, a well developed application need and a strong requirement for low-cost direct reception as the only mechanism to enable successful implementation of this application and encourage wider ERS uptake in Bangladesh.

Other, technical experience from the project includes a definite need for further automation of the pre-processing, especially georeferencing. This would free up valuable time that can be spent on information extraction. The data update rate using ERS-2 only is about 18 days, but satellite passes, and hence the repeat cycle for the process described in Figure 4, are approximately every 3 days. The current level of automation makes pre-processing the dominating activity in floodmonitoring. The need for freeing-up time for post-processing is taken seriously and resulted in a number of projects to implement this. One of these projects is the EUCLID project described below.

EUCLID RTP9.8 satellite surveillance technology

Recent developments in both the commercial space infrastructure (e.g. availability of high resolution EO data) and in the ground segment (affordable mobile GRS and ever improving processing algorithms) have stimulated a European military development project focused on on-board and on-ground processing and handling of satellite data. Requirements for this type of applications differs significantly from the ones mentioned above; robustness and a short throughput time from the moment of reception till information generation is even more important.

The project is carried out by an European consortium with participants from Norway, Germany, Italy and The Netherlands. The project is funded by the local defence departments. The Dutch contribution to the project focuses aims at demonstration of the full chain as described in Figure 4. The demonstration uses the current RAPIDS system as a basis for upgrades, which include Envisat ASAR capability, high resolution optical capability, near real time georeferencing for both SAR and optical images, automated feature / information extraction and automated reporting functions. Key is the minimal user interaction required, especially in the generation of 'standard' image products.

The test and integration phase will start early 2001 and will result in a series of demonstrations in 2001 and 2002.

Volcano monitoring on Montserrat

The Soufriere Hills volcano on Montserrat has been erupting since 1995 and may continue to do so for several years. The UK Defence Evaluation and Research Agency (DERA) is managing the MONSAR Project to look at the use of ERS radar data to support volcano monitoring in Montserrat. The project is partially funded through the BNSC Earth Observation LINK Programme and is being implemented in collaboration with partners at the University of Reading Environmental Systems Science Centre (ESSC) and Phoenix Systems Ltd. Day-to-day advice on crisis management of the eruption since 1995 has been in the hands of the Montserrat Volcano Observatory (MVO). ESSC has been involved in helping MVO provide the best advice to government on mitigating the effects of the eruption through forecasting possible events and converting them into effective warnings. This has been done as part of a national project of the UK International Decade for Natural Disaster Reduction (IDNDR).

The MONSAR project is split into two phases. Phase 1 (1999) involved obtaining SAR data from the ERS and Radarsat satellites over the Soufriere Hills Volcano, Montserrat to create DEMs of the changing topography and to measure ground deformation using radar interferometry. Because of the challenging environment the Project is seeking ways to improve the quality of the phase information of interferograms of the volcano (Wadge et al 1999). Phase 2 will involve the deployment of a RAPIDS mobile ground receiving station at the Montserrat Volcano Observatory during 2000. This will test the ability to receive, process and validate SAR data under operational conditions at a volcano observatory. ESSC are be responsible for the processing in Phases 1 and 2, the analysis and integration of the data. The DERA INSAR processing chain is being used for processing (http://www.space.dera.gov.uk/monsar/monsar.html)

DISCUSSION

There is a clear environmental and commercial need to stimulate high resolution data markets and product uptake in both the developed and developing world. An EU funded study (EOS *et al* 1996) on the constraints and opportunities of Earth Observation in developing countries identified the lack of more direct access to satellite data as a major global restriction on resource management needs in these countries.

The authors believe that reduced ground station operational costs, lower data (capital and running) costs, together with an improved, timely service to customers, especially in developing countries, will remove this obstacle and will be highly advantageous for applications development and market growth. So much so, that access to remote sensing data will become increasingly open to many potential users that would otherwise not be aware of, or inclined to utilise EO products and information in GIS for decision support or management information systems.

However, institutional issues need very careful consideration. Remote sensing applications that improve already on-going activities are more likely to start well, and be sustained, than applications in totally new domains. Once potential users or customers become accustomed to having such products available on a regular basis, ideas and interests will develop to diversify the use of the data for other purposes. This may well require integration with (existing or evolving) GIS capacity in the process. All of this, of course, has to start with the real decision making needs of the many potential users and customers.

Focusing remote sensing on operational activities and needs helps to avoid institutional inertia that may arise with (for example) a self-serving, highly centralised remote sensing centre. It is also important that the host institution prepares for the associated, and necessary, changes in working practice and attitude towards information use and service provision. Once started, sustained operation of a satellite receiver and associated data processing routines requires a commitment to (minimal) running costs as an essential prerequisite (Williams and Rosenberg 1993). The example of RAPIDS shows that operational remote sensing for resource management in the local context can be made sustainable if applications, benefits and costs are carefully matched with appropriate technology.

Decentralised operation of a ground receiving station and local processing of the EO data offers significant advantages in terms of autonomy, improved controllability and significantly reduced throughput time of the end-to-end chain. These advantages, in combination with current space infrastructure, enable sensible operational use of EO data for managing processes with time scales down to a day. Such applications include floodmonitoring, sea-ice monitoring, disaster relief operations. Given the planned EO missions, the list of applications that can benefit from local ground receiving stations and local processing will grow in the near future.

CONCLUSIONS

The conditions that govern access, distribution and pricing of EO data are vital to the exploitation of this important environmental information resource (Harris 1997). RAPIDS is a relatively inexpensive, PC based X-band receiver system capable of capturing data signals from the ERS and SPOT (and potentially other) satellites. Direct, local access to EO data enables faster delivery of products to the user, allows customisation of the processing to the application, gives full control over the entire flow and provides a high level of autonomy.

RAPIDS systems have been installed, operated and demonstrated successfully in recent overseas trials in Indonesia and Bangladesh. ERS and SPOT data were successfully acquired, processed and archived on a routine basis. The data can be visually assessed and processed into information within a short time of being captured.

Research and applications development work is ongoing to refine useful information products from the data in support of real information needs on the ground. Specific examples are flood monitoring (Bangladesh), volcano monitoring (Montserrat) and the EUCLID military development project.

Special attention is given to further automation of the pre-processing steps for EO data, providing on one hand more time for post-processing and on the other hand increasing the number of applications that can benefit from local ground receiving station and local processing as provided by means of RAPIDS.

These results demonstrate that local direct reception of EO data has a number of tangible benefits for natural resource managers and decision makers and that the capabilities of low cost, PC based data reception and processing can be realised in tropical conditions. This will enable a growing number of institutes and organisations in developing countries (and elsewhere) to access and utilise this technology for improved understanding and management of their natural resources.

This potential offers significant advantages for the reception, analysis and distribution of information from the predicted expansion in satellite and sensor availability. Such developments have profound implications for future EO system design, operation, market development and data policy.

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