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HOW RADARSAT CAN CONTRIBUTE TO TROPICAL FORESTLAND MANAGEMENT

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ABSTRACT

Canada's RADARSAT, to be launched early in 1995, will make important contributions toward the management of tropical forestland. To prepare for RADARSAT, we have been researching the use of C-Band SAR data in tropical forest environments since 1990. Experiments in Latin America using airborne SAR, ERS-1, and simulated RADARSAT data have identified some of the most promising applications to be:

* Deforestation and other pronounced changes in vegetation;

* Synoptic geological and geomorphological mapping;

* Coastal zone (shoreline and vegetation) monitoring;

* Monitoring flooding and its consequences.

Studies indicate that the market for these applications is potentially large. Now we must ensure that systems for data acquisition, image processing, and data manipulation are responsive to user needs, and that the user community has the knowledge and capability to put this new technology to best use.

1. INTRODUCTION

Having resisted human incursion for centuries, forested lands in the tropics have come under increasing pressure in the last few decades. In some areas timber extraction is the principal activity, while in others tropical forests are being converted to agricultural use. Mineral exploration and development, and inundation for hydroelectric power projects are additional causes of destruction of tropical forests. Experience is showing that tropical forests, both wet and dry, are less robust than temperate forests. They do not recover from mismanagement and abuse as readily as, for example, the forests of eastern North America have after conversion to agriculture by European settlers. Therefore it is imperative that attempts to manage the forests of the tropics be based on knowledge, rather than ignorance.

The technologies of remote sensing and geographic information systems represent important opportunities to bring more knowledge into the decision making process. One of the most important new technologies becoming available is spaceborne synthetic aperture radar (SAR). RADARSAT, in particular, has been designed from the outset to provide data to users around the world on a commercial, operational basis.

However, before RADARSAT can join the suite of operational remote sensing technologies, scientists and potential users must determine the kinds of resource management information it can provide, the best data modes to use for each type of information, suitable data processing methods, and appropriate information products.

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Some countries might be interested in indipendently managing the access to the satellites, for their own purposes, without necessarily having to pass through a Central C.M.C. This is possible, although certain precautions must be taken to ensure that the satellites integrity is not compromised. In fact, mission planning is the result of a complex optimization process considering the temporal evolution of the satellites' position w.r.t. both the ground 'target areas' and the relevant L.D.S., and of the time-evolving satellites' resources: solar array power, stored energy, propellant, equipments' performance and integrity. In principle, predetermined time slots may be preassigned to specific countries, for their own exclusive use, conditioned by a maximum utilization of the satellite resources on a per-slot basis.

By operating the National C.M.C. under supervision by the Central C.M.C., for constellation integrity verification, any country may send instructions to the satellites, directly from the N.C.M.C., about the on-board instruments' settings during the preassigned time slots which will approximately coincide with the satellites' overpasses of the concerned country.

This approach has several advantages specially considering emergencies and, in general, all those applications where a fast reaction between the occurrence of an event and commanding the satellites to take images of a 'target area' for immediate retransmission to the national L.D.S. is of utmost importance.

Though the proposed System stresses the importance of a fast reaction to data requests, frequent revisits of specified target areas and high ground resolutions, nevertheless it is also obviously capable of meeting the demand for high quality imagery in a context less sensitive to time factors, as in the case of getting routine data or performing extensive high resolution mapping, or acquiring scientific or statistically relevant data.

The key problem with the wealth of data provided by remote sensing satellites, is their translation in information accessible to non-specialists or to the general public. Solving this, will require appropriate technology investments in modeling, artificial intelligence, expert systems, data fusion, and specific application software to extract the wanted information from the satellite data.

One important aspect to be further addressed in the near-term, is how to further exploit the existing or planned country's telecommunication infrastructure to solve the information dissemination problem, inside the underdeveloped and developing countries, maximizing the costs-benefits ratio.

4.5 Programmatic aspects

The feasibility study showed that the total system cost for setting up a full constellation and the relevant ground infrastructure, will not be greater than that required to develop, build, launch and operate a single larger remote sensing satellite.

Nevertheless it is worth while recalling that a constellation of small satellites cannot be directly compared to any single, big, Earth Observation satellite, since they aim at essentially different and complementary remote sensing markets, serving different needs.

Alenia Spazio is proposing, along with Spain and Greece, the above constellation, with the name of COSMO (COnstellation of Small satellites for the Mediterranean Basin Observation), as an advanced remote sensing tool to foster the development of countries in and around the Mediterranean Basin.

COSMO might thus become, later, an available resource of a worldwide commercial remote sensing system, named GREENSENSE, that HOUWTEQ and Alenia Spazio have been promoting.

5. Conclusions

Existing and planned large remote sensing satellite systems do not cope well with several emerging needs characterized by unrestrained access to space assets, better ground resolution, more frequent revisits, all-weather and day-night observing capabilities, timely products delivery, user friendly information distribution. This means that unserved market niches do exist that could be filled by innovative systems.

Today's technology can produce small 'professional' dedicated satellites, in the half-ton launch mass range, capable of carrying high performance sensors at an affordable cost. Constellations of such small satellites can be set up to satisfy the new remote sensing needs in a fully decentralized system architecture, thus paving the way for innovative and commercially viable remote sensing services, for governmental and public use.

In our opinion, the next important step in Earth Observation will be the setting up of one or more constellations of small satellites in LEO, capable of copying with the emerging worldwide demand for frequent, timely, high resolution optical and SAR images, delivered on time and locally exploitable at affordable cost.

In order to get a head start on these problems, the Canada Centre for Remote Sensing (CCRS) has undertaken joint investigations with remote sensing and resource management agencies in several tropical countries, and with RADARSAT International Inc. (RSI), using airborne C-band SAR data obtained with the CCRS Convair 580 aircraft. The results of these collaborations are just becoming available, and are described in this paper.

2. FINDINGS

The first investigations were undertaken in the Americas. Countries which collaborated with CCRS included Brazil (through the Instituto Nacional de Pesquisas Espaciais), Venezuela (through the Ministerio del Ambiente y de los Recursos Naturales Renovables), Costa Rica (through the Instituto Geográfico Nacional), and Guyana. An airborne campaign, known as SAREX '92, was sponsored by the European Space Agency, the Canadian International Development Agency, and CCRS. Data acquisition occurred in April, 1992. Findings have been reported in numerous technical publications, notably the Proceedings of the SAREX Final Results Symposium, Paris, France, December 6-8, 1993, European Space Agency and Actas de Proyecto RADAR Costa Rica/Canada, Instituto Geográfico Nacional, San José, Costa Rica, and are summarized by Ahern *et al.*, 1993a). As a result of this experience, the most important applications have been identified and are discussed in the remainder of this section.

2.1 Deforestation and other pronounced changes in vegetation

Human clearing of tropical rainforests has become a worldwide environmental concern, under the term of "tropical deforestation." Although there is agreement that very large areas of moist tropical forests are being cleared every year, there is a great deal of uncertainty about the amount of area cleared, and of this, how much remains permanently deforested, how much is converted to plantation forests, how much regenerates naturally, and of the latter, how much has the potential to return to its pre-clearing state.

Experience in Brazil (Fearnside *et al.*, 1990) has shown that annual monitoring of the gross area cleared can give a much more accurate and reliable picture of the deforestation problem and particularly its spatial characteristics than previous estimates which did not rely on earth observation satellite data. In the Brazilian case this has led to changes in national policy which have resulted in a pronounced decrease in annual deforestation. This monitoring uses data from optical satellites, primarily Landsat. Coverage is incomplete because of cloud cover. The evaluation of radar remote sensing for mapping forest clearing has been an important task because of its ability to see through clouds.

In an effort to develop this area of application, we have investigated the use of a number of C-band SAR data sources to detect openings in moist tropical forests (Ahern *et al.*, 1993b). The smallest openings, typically 0.25 to 3 ha in size, are often associated with shifting cultivation practices. These were reliably detected with 7-look airborne SAR with 6 m resolution in range and azimuth. Openings in the range 1 - 10 ha in area, associated with settlements in extractive reserves in Brazil were also reliably detected with the high resolution airborne data. These small openings were not visible on simulated or actual satellite SAR images with four looks and 25 to 30 m resolution.

Agricultural settlement projects typically create many contiguous openings which total 100 to 1000 ha or more in area. These were reliably detected with both airborne and satellite images. However, mapping of boundaries was found to be much more accurate with the higher resolution airborne data than with the actual and simulated satellite data.

Land clearing for cattle ranching creates large rectangular openings, each often thousands of ha in size. These clearings were, in general, reliably detected and mapped with all of the data sources evaluated. However, detection and mapping with C-Band satellite SAR data is more difficult while the land is still in the process of conversion to pasture, and again when it is overgrown at an early stage of primary succession. Under these conditions, the average backscatter from the cleared land is often similar to that of the surrounding forest. This finding indicates that the most reliable mapping of clearings may be possible if radar data is acquired annually, to detect each pasture in its "clean pasture" stage when it has the highest contrast with its surroundings.

These findings indicate that RADARSAT can make a very significant contribution to monitoring the two most important types of deforestation in the Americas: agricultural settlement and conversion of forest land to pastures. It also may be able to play an important role in distinguishing between areas which are regenerating to forest from those which are being maintained as non-forest. RADARSAT and optical data will be complementary since C-Band SAR is more sensitive to early stages of regeneration, while optical data are more sensitive to later stages.

2.2 Synoptic geological and geomorphological mapping

Although airborne imaging radars have been used for geological mapping for more than twenty years in Brazil, the advent of orbital radar remote sensing has opened new alternatives for geological exploration in tropical rainforest regions. The SAREX project has been used to evaluate airborne and simulated satellite C-SAR data with observing geometry similar to the ERS-1 and RADARSAT configurations. It has reconfirmed the role of SAR as a fundamental tool for geological mapping in this difficult terrain. Lithostratigraphic units were detectable in the Carajás Mineral Province of Brazil based on SAR interpretation in comparison with published large scale geological maps. In addition, unknown sub-divisions were also identified and checked in the field. The project has shown that radar backscatter is extremely sensitive to look direction and incidence angles (Paradella *et al.*, 1994a). We thus expect RADARSAT to provide more information than is available from satellites which have more restricted imaging geometry (e.g. ERS-1, JERS-1).

ERS-1 data has also been analyzed for the same area. In regions of high relief these data show strong image distortion due to foreshortening and layover. This is caused by the ERS-1 low incidence angle (23°). The high incidence angles available from RADARSAT (up to 60°) will diminish the geometric distortion of high-relief regions. In addition, its multiple look angle capability will provide the means of stereo imaging (illumination from the same side with different incidence angles). Thus, RADARSAT stereo radar imagery offers the geologist the advantage of both overlapping aerial photographs and the terrain discrimination of radar. In addition, the high resolution (up to 11 x 9 m) will probably allow RADARSAT to play an important role in monitoring the changing sizes and shapes of open pits and the environmental impacts related to mining activities.

The ability to use vegetation backscatter responses to infer bedrock characteristics in the tropical rainforest is of key interest. In the Carajás area, recent geobotanical studies have indicated that the upland rainforest vegetation is mainly controlled by variations in the geology (Paradella *et al.*, 1994b). Thus the potential exists for conducting geobotanical studies using microwave data, particularly focusing on the relationship between radar texture and vegetation community composition as influenced by topopograpy and lithology.

2.3 Coastal zone (shoreline and vegetation) monitoring;

Research from the SAREX experiment and the ERS-1 research program has shown that SAR provides useful information for a variety of coastal zone applications. Potential capabilities of SAR remote sensing include coastal classification, mapping of natural vegetation (e.g. mangroves) and change detection (e.g. roads, clearings and near shore structures), shoreline mapping, as well as surface and subsurface feature detection. This research has also demonstrated the potential for ship and oilspill detection under suitable seastate conditions (wind speeds of 4 to 6 m/s).

In the SAREX experiment coastal features and mangrove forests were identified in Costa Rica (Montero, 1993; Bjerkelund *et al.*, 1993) and Guyana (Singhroy, 1994) from airborne SAR data, as well as in simulated RADARSAT Standard Mode data. Canopy texture was identified as an important indicator in distinguishing the mangrove forests from adjacent rainforest and pastureland. The ability to delineate the inter-tidal ecotone provided additional information on the mangrove habitat.

Radar mapping for map revision was also investigated under SAREX found to be a promising potential application (Bjerkelund *et al.*, 1993). Along a section of the Costa Rican coastline significant estuarine activity had occurred within the intertidal zone and the shoreline position had receded along certain portions of the coast, and advanced in other areas. Features identified on the imagery included submerged mud flats, former deltaic drainage patterns, remnant inlets, beach and dune ridges, old oxbow meanders, estuarine zones, and aquaculture sites. However, delineation of the shoreline was difficult in some instances due to speckle and a lack of contrast between wind roughened water and the adjacent land. This problem can be overcome with shallower incidence angle data or a blending of optical data with SAR. The advantage of radar satellite data is to make multi-temporal comparisons over an area of interest to monitor coastal evolution.
Research with ERS-1 data has shown the potential for coastal wetland classification. Differences between vegetated and non-vegetated tidal flats can be defined based on tontal variations caused by differences in radar backscatter. Varying tones could be used to distinguish between tidal grass, swamp, and forest (Tittley *et al.*, 1993)

2.4 Monitoring flooding and its consequences

Floodplains can be areas of rich biodiversity and productivity, but are also often areas where human populations disrupt natural patterns. In turn, unusual levels of flooding can seriously disrupt human activities. Investigations in preparation for RADARSAT have evaluated the ability of ERS-1 and simulated RADARSAT data to map extensive flooding of major rivers. These investigations have shown this application to be easy to implement and very effective in terms of the cost and benefit of the information (Leconte and Pultz, 1991).

The creation of hydroeletric reservoirs often affects large areas in the tropics. Some adverse consequences (inundation of large areas, dislocation of populations, disruption of fisheries) have been anticipated and countered to varying degrees. Others (excessive growth of aquatic plants, creation of breeding grounds for parasites, pathenogens, and their vectors) have not been anticipated and have created severe hardships for surrounding communities. Remote sensing and GIS technologies offer an important opportunity to monitor the consequences of flooding by existing reservoirs and thus anticipate and mitigate the effects of future projects.

The SAREX-92 experiment at the Tucuruí reservoir in the Brazilian Amazon investigated the ability of airborne and ERS-1 data to be used to distinguish open water, flooded trees, and aquatic vegetation ("macrophytes") (Novo *et al.*, 1993). This study determined that both ERS-1 and airborne SAR data are effective at delineating open water. Both data sources can depict flooded trees, but a lower density of trees could be detected with the airborne data than with the ERS-1 data. Single band, single polarization radar images provided by ERS-1 can detect large areas of floating macrophytes, but cannot distinguish between different species. The higher resolution multipolarization (HH, VV, HV, VH) data from the CV-580 SAR could be used to distinguish four of the five macrophyte species found in the test area.

3. Market Perspective

Throughout the tropical world, information technology requirements are growing rapidly. Included among current requirements is increasing attention to remote sensing and geographic information system (GIS) technologies, areas where Canada ranks among the world leaders. To date, Canada's trade with tropical countries has been relatively small but significant. It is anticipated that in some countries these technology markets are developing to the point where strong local markets will soon exist.

3.1 A Perspective

The market potential in the remote sensing and GIS sectors is increasing as a result of some twenty years of scientific and operational developments with airborne and optical sensors. Although this is a relatively short timespan in comparison to techniques employed in other disciplines, much progress has been made in systems development, interpretation techniques and data-retrieval methodologies. However, there continues to be significant distance between the research of remote sensing applications and its use in the day-to-day problem solving environment of end-users. An important element of the operationalization process is to bridge this gap. How can we communicate the strengths and weaknesses of remote sensing techniques to the user community? How can we assure ourselves that research results are transformed by users to solve environmental and resource problems? And how can we combine disparate research results and empirical techniques into a solution to the user's problem?

3.2 Opportunities for RADARSAT

While RADARSAT is only one element of the substantial requirement for information technology in the tropics, it presents a great potential. As an information source, RADARSAT will be of benefit both in the area of resource montoring and prudent resource exploitation. One of the most significant advantages of SAR data in general is the ability to acquire data through cloud and haze. This is a particularly attractive feature in tropical regions where consistent acquistion of optical data is limited. The ability to ensure acquistion on a given date (within the constraints of the satellite's orbital characteristics) means that it is feasible to utilize remote sensing technology for applications where reliable data acquisition is of foremost importance. Within the context of RADARSAT, the wide choice of resolution and swath width combined with the flexibility of numerous operating modes will enhance the ability to acquire data at an appropriate scale, resolution, and imaging geometry for a given application. For several of the application areas noted earlier, including monitoring changes to the forest cover and coastal zone, RADARSAT can provide repeat coverage of large areas. In this context, national and international agencies tasked with the acquisition of baseline environmental information, routine environmental monitoring and environmental protection will have access to an effective information tool.

3.3 Effective Utilization of RADARSAT Data

The development of a viable market for RADARSAT data in the tropics will be based on its unique characteristics utilized in combination with other information sources as required to produce cost-effective solutions for operational applications. An important aspect of the operationalization process is to understand how best to combine these multiple sets and to develop techniques for doing so in a routine fashion.

4. THE ROAD AHEAD

The studies conducted to date have been sufficiently encouraging to justify additional efforts to promote the utilization of RADARSAT for a variety of applications in tropical forestland environments. The process of bringing RADARSAT data into routine operation must consider several important issues including the user interface, user preparation, product development, demonstation and pilot projects, and continued applications development.

4.1 The User Interface

Since the early design stages, the emphasis of the RADARSAT program has been towards the development of a tool which is of value to the operational user community. The same considerations are being given to the post-launch data ordering network. RSI will operate an ordering system that will coordinate interaction with the Mission Control Centre, foreign ground reception stations and all non-RADARSAT partner customers. The data ordering and distribution network is being designed to provide standard products to customers in a timely fashion. In preparation for the availability of RADARSAT data, RSI is talking to the major vendors of image analysis software to ensure easy data input into their products.

4.2 User Preparation

Two groups provide a focus for developing the tropical forestland market for RADARSAT imagery sales--senior policy makers and project managers of environmental monitoring and natural resource development agencies (Branson *et al.*, 1993). The RSI approach to reaching these groups encompasses the following points:

* establish contacts with the local scientific community to learn about applications research and to identify potential user-groups;

* forge links with agencies who provide remote sensing applications training and support services to end-user groups;

* assess the state of readiness of the client to acquire RADARSAT imagery and create a program of preparation with the client.

* draw upon the rich expertise of the Canadian value-added industry. Many companies exist in Canada which have acquired experience in tropical countries using remote sensing techniques in natural resource exploration and environmental monitoring.

* create demonstration projects in collaboration with end-users and the Canadian value-added community.

4.3 Product Development

The development of new products will continue after the launch of RADARSAT. While the specific areas of development will be guided by application requirements, some of the topics for early consideration will undoubtedly focus on issues such as geometric and radiometric correction for terrain relief, methods for data fusion, specialized filters for image enhancement and techniques for integration of imagery and derived products into a GIS environment.

4.4 Demonstration and Pilot Projects

Undoubtedly many technical and operational questions will remain after the launch of RADARSAT. Not the least of these, is to evaluate the cost effectiveness of satellite remote sensing. There is no substitute for operational demonstrations to evaluate the utility of RADARSAT for a given application. Demonstration projects serve two purposes: 1) to uncover and remove problem areas which inhibit actual application, and 2) to produce case study examples which in turn can be used to demonstrate the utility of RADARSAT data to potential users.

An international announcement of opportunities entitled "Application Development and Research Opportunities" (ADRO) is currently being organized by the Canadian Space Agency, CCRS, RSI and NASA. It will provide a sub-program specifically devoted to the demonstration of potential operational applications of RADARSAT.

4.5 Continued Application Development

This paper has discussed some of the larger applications of RADARSAT data which have been identified through RADARSAT preparatory projects. As contacts with researchers and managers responsible for tropical forestlands increase, other potential applications will be identified, and many opportunities will arise. It will be important to pursue the most promising of these for additional applications development efforts.

5. ACKNOWLEDGEMENTS

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