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ABSTRACT

The objective of the SAREX-92 project is to learn how to use satellite synthetic aperture radar (SAR) data (possibly supplemented by other data) for environmental monitoring and improved natural resource management in tropical forest environments. While many of the investigations utilizing SAREX-92 data are still in progress, it is possible to generalize the findings to date, and to apply these to plans for using data from ERS-1, ERS-2, RADARSAT, and subsequent radar satellites.

The discussion is arranged by application area: natural vegetation, agriculture, geology/geomorphology, hydrology, coastal applications, urban applications, and cartography. For each application we summarize the findings of investigators who participated in Canada's Tropical Forest Initiative (TFI) in Costa Rica, Brazil, Venezuela, and Guyana. From this we highlight the conclusions that may be drawn from these studies as they relate to the operational use of SAR data, particularly from radar satellites.

SAREX-92 has fostered growth in the remote sensing community towards knowledge of the capabilities and limitations of C-band SAR data in the moist tropics. Based on an extensive data base and a wide variety of studies, we now know several promising tropical applications of C-band radar data, and which problems to investigate further. Also important, we are in a better position, both through technology and infrastructure, to work with resource managers who need the information C-band SAR can offer.

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INTRODUCTION

In 1991 the European Space Agency undertook the South America Radar Experiment (SAREX) wherein a team of Canadian, European, and Latin American investigators executed a program of C-band SAR data acquisition and interpretation. This was aimed at increasing the understanding of potential applications of C-band SAR in tropical rainforest environments, leading to increasing the use of this technology for natural resource management.

SAREX was an outgrowth of the Tropical Forest Initiative (TFI), which was initiated by the Canada Centre for Remote Sensing in 1989. This project was designed to investigate, jointly with Latin American scientists, the use of C-band radar in monitoring tropical forests and their environs in Latin America.

The philosophical basis for the TFI, and the framework for continuing progress in similar projects encouraged by Canada, is that it is a Latin American project for the benefits of Latin Americans. It is not simply another remote sensing exercise by non-Latin American scientists using data from the tropics. The focus was designed to be from the point of view of the host countries.

The objective of the SAREX project is to learn how to use satellite synthetic aperture radar (SAR) data, (possibly supplemented with airborne SAR, other remote sensing and non remote sensing data) for environmental monitoring and improved natural resource management in tropical forest environments. While many of the investigations utilizing SAREX-92 data are still in progress, it is possible to generalize the findings to date, and to apply these to plans for using data from ERS-1, ERS-2, RADARSAT, and subsequent radar satellites.

The most important phase of any remote sensing project is data analysis and exploitation, stages which come after the initial data collection. In Latin America, this essential follow-through phase was supported by the International Development Research Centre (IDRC) of Canada in Costa Rica and the Canadian International Development Agency (CIDA) in Brazil. Much of the data analysis and interpretation is being carried out by the Latin American institutions of the various authors.

REVIEW OF SAREX APPLICATIONS RESULTS

In this paper we review the most important results reported by SAREX investigators, drawing from them lessons concerning the utility of satellite and airborne C-Band SAR for resource management in tropical environments. The details of these investigations have been documented (see References) and will not be repeated here. The data sources used include three modes of the Canada Centre for Remote Sensing C-SAR system (Livingstone, *et al.*, 19??) and the ERS-1 Active Microwave Instrument (ref). Many of the results are particularly relevant to the appropriate use of RADARSAT data (ref). The characteristics of these data sources are summarized in Table 1.
Most of these investigations used visual interpretation of hard-copy data products as the primary method of assessment.

Natural Vegetation

As we approach the end of the twentieth century, increasing populations and increasing demands for exploitable resources are resulting in the destruction and degradation of natural vegetation and natural lands in many parts of the world (Repetto, 1988). Natural vegetation provides resources, which can be exploited indefinitely (if done carefully), and numerous other benefits, including stabilization of slopes, prevention of soil and shoreline erosion and stream siltation, preservation of water quality and minimization of flooding, and provision of habitat for a diverse biota of plants and animals.

TFI investigators were able to distinguish several classes of natural vegetation, and identify and delineate agricultural clearings in areas of primary rainforest (Table 2). Numerous investigators (e.g., Kux *et al.* 1993; Shimabukuro *et al.*,1993; and Ahern *et al.*, 1993a; in Brazil, Singhroy, 1994; and van der Sanden and Hoekman, 1993 in Guyana, and Tenorio, 1993; and Ochanitrillo, 1993 in Costa Rica) report positive results for the detection and mapping of primary rainforest. Many of these authors point out that primary rainforest has a characteristic texture on radar images, which seems to reflect the "broccoli-like" structure of the top surface of the canopy, a well-documented feature of primary rainforests in many parts of the world. The visibility of this texture depends on the spatial resolution of the SAR imagery, the incidence angle, and on the number of looks per resolution cell. As such, it is most visible on the high resolution (Nadir and Narrow Mode) airborne data, but has also been observed on the lower resolution Wide Mode data and even on a simulated RADARSAT Fine Mode image (Ahern *et al.*, 1993a). However, the spatial resolution and incidence angle combination of ERS-1 data is not adequate to make the characteristic texture of primary rainforest visible. With the highest resolution airborne data, texture differences have been shown to provide information related to different rainforest types (Shaimbukuro *et al.*, 1993; Van der Sanden and Hoekman, 1993). For instance, when clearings in primary rainforest are allowed to regenerate naturally, the radar backscatter increases to the same average gray level as the surrounding primary forest within a few years. However, for many decades during regeneration the forest has a different canopy

Table 1. The parameters of the various sensors/modes which produced the data for the studies whose results are reported in this paper. (RADARSAT images are simulated from C-SAR data.)

Sensor	C-SAR Nadir	C-SAR Wide	C-SAR Narrow	ERS-1	RADARSAT Fine	RADARSAT Standard
Band	C-band 5.66 cm	C-band 5.66 cm	C-band 5.66 cm	C-band 5.66 cm	C-band 5.66 cm	C-band 5.66 cm
Polarization	HH	HH	HH	VV	HH	HH
Incidence angle range	20°-74° usable	45°-85°	45°-76°	20°-26°	45°-76°	45°-85°
Resolution, ground range (m)	6	20	6	25	10	27.1
Resolution, azimuth (m)	6	10	6	22	10	24.1
Pixel spacing, range (m)	4.0	15.0	4.0	12.5	6.25	12.5
Pixel spacing, azimuth (m)	3.87	6.9	3.87	12.5	6.25	12.5
number of looks	7	7	7	4	1	4

Tables of features identified on airborne and satellite SAR images

These tables summarize the findings of many of the SAREX investigators which have been published or presented by December, 1993. For each feature identified, we indicate the number of studies and country (1B = one study in Brazil, 2CR = two studies in Costa Rica, and so on), and the data source (Nadir/Narrow = C-SAR nadir or narrow mode data, Wide = C-SAR wide mode data, Satellite = simulated (Radarsat) or actual (ERS-1) satellite data). When negative results have been reported these are indicated with parentheses, e.g. (1CR).

Table 2. Natural vegetation features identified.

Feature Identified	Nadir/ Narrow	Wide	Satellite
Primary rainforest	3CR,2B,1V	2B,1V,1G	1B
Primary dry tropical forest	2CR		
Mangroves	2CR	1G	1CR
Natural forest regeneration	3CR,2B	1B	1B
Detailed vegetation type	(1CR)	(1CR,1B)	
Deciduous vs evergreen forest	(1CR)		
Forest plantations	1CR	1G	
Riparian vegetation	1CR		
Shrubland vegetation	1CR		
Large clearings	2B	2B	2B
Medium clearings	1B	1B, 1G	1B
Small clearings	1B,1V,1CR	1B,1V	(1B,1V)

Table 3. Agriculture features identified

Feature Identified	Nadir/ Narrow	Wide	Satellite
Cultivated areas and pasture	3CR,1B	1CR,1B, 1G	1B
Crop Types			
Sugarcane	2CR	1G	
Rice	2CR	1G	
Bananas	4CR		1CR
Pasture	4CR		
Trees in pasture	2CR,1B		
Tillage	1CR		
Crop development	4CR		
Crop damage	1CR		
Windbreaks	1CR		
Relative soil moisture		1G	

texture, which can be either smoother or rougher than the primary forest (Shimbukuro *et al.*, 1993; Ahern *et al.*, 1993a; Ochanitrillo, 1993; Bjerkelund *et al.*, 1993).

Because of the importance of protecting primary rainforest vegetation, the detection and mapping of clearings is of particular interest. TFI investigators have reported on the detection and mapping of large, medium and small agricultural clearings (Kux *et al. 1993;* Shimabukuro *et al.*, 1993; and Ahern *et al.* 1993a; Singhroy, 1994; Tenorio, 1993). Clearings smaller than 1 ha can be detected readily on the high resolution airborne data, while medium and larger agricultural clearings were discernable on actual and simulated satellite images. The shape and context of a forest clearing often provides strong evidence of its cause, so once again high spatial resolution is valuable.

There is little difference in radar tone between primary forest, incompletely cleared areas, and areas of early natural regeneration. Since the incidence angle and spatial resolution may be inadequate to portray texture differences, ERS-1 and simulated Standard Mode RADARSAT images have been found only to differentiate clearings which are being actively used for agricultural purposes (pasture or crops). The areas of cleared parcels are thus systematically underestimated.

Forest plantations have been identified on images from Costa Rica (Tenorio, 1993) and Guyana (Singhroy, 1994). In this case, their shape provides the diagnostic information in addition to tone and texture.

Coastal mangrove forests have been identified in Costa Rica (Montero, 1993; Bjerkelund *et al.*, 1993) and Guyana (Singhroy, 1994), even with simulated RADARSAT Standard Mode data (unpublished). Canopy texture is an important indicator, as is the proximity of the sea and the appearance of level shoreline topography, which permits the tidal flooding necessary for the growth of mangroves. Combined with previous studies that report success in detecting and mapping mangroves with SAR data (Lewis and MacDonald, 1972; Thompson and Dams, 1990), this evidence indicates that spaceborne radars should prove effective in mapping and monitoring coastal mangroves. Given the very important role mangroves play in preventing coastal erosion and providing habitat for aquatic species, this may become one of the most important natural vegetation applications for spaceborne radars.

The only TFI test area containing dry tropical forest was found in the province of Guanacaste, Costa Rica. Costa Rican investigators have found high resolution airborne data very suitable for mapping these dry forests (Ochanitrillo, 1993; Fallas and Morera, 1993), but reported considerably less success with Wide Mode airborne data (Moya and Martínez, 1993).

Investigations using dry-season imagery in the dry tropical forest region of Costa Rica (Fallas and Morera, 1993) were successful in detecting burned areas, but unsuccessful in differentiating deciduous from evergreen forest. Investigations in Canada (Ahern *et al.*, 1993b) suggest that the use of multi-season data might provide improved discrimination between deciduous and evergreen types.

The presence or absence of riparian vegetation provides important information for managing erosion, maintaining water quality, and preventing siltation of streams and reservoirs. Only one SAREX study, in Costa Rica, (Tenorio, 1993) investigated the detection of riparian vegetation, reporting positive results. More work is needed in this area.

Several SAREX investigators have combined SAREX radar data with images from Landsat or SPOT (Kux *et al.*, 1993; Shimabukuro *et al.*, 1993; Bjerkelund *et al.*, 1993; Benach and Araya, 1993). One very effective approach is to use intensity information from the radar, which emphasizes topography, with colour information from the optical satellites, which emphasizes vegetation cover. The combined data allow an interpreter to relate the types and pattern of vegetation to its topographic environment which controls growing conditions, development patterns, etc. Since radar data can be obtained much more frequently than optical data in the moist tropics, an attractive strategy will be for resource managers to obtain baseline information from combined optical/radar data, and then update this information with radar alone until the next optical data are available.

Agriculture

Investigators in Costa Rica (Moya and Martínez, 1993; Benach and Araya, 1993; Benach, 1993; Fallas and Morera, 1993; Montero, 1993; Bjerkelund *et al.*, 1993; Beaulieu *et al.*, 1993) and Guyana (Singhroy, 1994) reported good results in detecting agricultural areas on high and low resolution airborne imagery (Table 3). This table also indicates the typical tropical crop types which can be distinguished. ERS-1 data has been found to be capable of mapping agricultural settlement projects in Brazil (Ahern *et al.*, 1993a), although with reduced accuracy compared to airborne data. While individual crop types (particularly bananas) can be determined in some cases, the investigators were particularly impressed with the changes in SAR backscatter as a function of development of certain crops (Fallas and Morera, 1993; Tenorio, 1993; Beaulieu *et al.*, 1993). Timely information on crop development can be vital in times of drought, flooding, or other abnormal conditions. One Costa Rican investigation reported very encouraging progress in removing the geometric and radiometric effects introduced by topography in an agricultural area (Leclerc *et al.*, 1993). After applying correction, it was possible to distinguish fields with vegetation cover, fields with litter (crop residue), and bare fields (Beaulieu, 1993). Such information is very valuable in minimizing erosion of soil on slopes.

Geology and Geomorphology

The radar images from all sites clearly show several distinctive features which are of great importance in developing and revising geological interpretations (Table 4).

In the Venezuelan study area, several features are important from a regional geological mapping perspective (Campbell, *et al.*, 1993). These include the identification of lithologic boundaries between deformed sequences. Local and regional synforms and antiforms are apparent, some of which stretch over tens of kilometres. Local and regional foliation patterns and joint and fracture patterns can also be delineated clearly. Major regional faults which show considerable lateral displacement, and smaller faults which displace deformed supracrustals and die out along strike, are readily identified. Graben-defined valleys within specific regional lithological units can be identified through their influence on some drainage patterns. In flat-lying sedimentary sequences, changes in slope and resulting response to the radar can be used to define a crude stratigraphy. The change in the deformation pattern between older and younger overlying sediments can be used to outline the position of unconformities between sequences. It is noteworthy that viewing the same scene in two different polarizations (HH and VV) provides a pseudo-stereo image which was of great assistance in carrying out some of the interpretations.

Mineralization deposits in Serra dos Carajas in Brazil are readily identified through their effects on the vegetation (Paradella, 1993).

In areas and regions dominated by volcanic landforms, the radar data has been used to upgrade and improve existing geological maps and interpretations, particularly through the definition and refinement of linear fault trends (Arredondo, 1993; López *et al.*, 1993; Bustos and Astorga, 1993).

There has also been some success in developing a "pseudo-stratigraphy" based on the response of the radar to the landforms of the various pyroclastics, epiclastics, extrusives, and associated vegetation. However, by far the largest drawback to the use of radar in volcanic-dominated terrain is the extent of shadowing, which could be overcome with satellite data, but at the expense of the fine detail which is highly important for the interpretation.

In coastal marine areas, it has been possible to identify regressive beach ridges and trace these through a wide variety of vegetated terrain (Singhroy, 1994). In areas of thick Recent sedimentary cover, faults in the basement can be inferred from stream and river patterns where they depart abruptly from their normal meandering pattern. In many cases the location of these reactivated faults can be projected over long distances beneath the tropical forest cover, due to changes in geomorphology and minor drainage systems which both appear to be in part fault-controlled.

On the coastal areas of Guyana, marine beach ridges, alluvial plains, river meanders, and areas of mudflats identified from the SAR images have improved the geomorphological mapping in the region. Identification of areas of coastal erosion and deposition have assisted coastal engineers in the definition of priority areas for repairing and reinforcing the coastal dykes.

Thus SAR data provide a new view which permits a reconnaissance-level overview of poorly mapped areas and indicates priority areas for exploration and development. Even in thoroughly studied areas, SAR images often reveal previously unrecognized features which aid in the completion of geologic maps and provide additional information for resource management and planning.

Hydrology

Numerous investigators have reported on their ability to delineate drainage networks using SAREX data (Tenorio, 1993; García, 1993; Toutin and Elizondo, 1993; Campbell *et al.*, 1993; Kux *et al.*, 1993; Shimabukuro *et al.*, 1993)(Table 5). As expected, the lower resolution satellite data miss many of the finer stream channels which can be observed on the high resolution airborne data (Shimabukuro *et al.*, 1993). The use of stereo viewing has a definite advantage for mapping stream channels (Toutin and Elizondo, 1993). The timely use of radar data to map flooding is expected to be an important application.

Investigators in Costa Rica (García, 1993) and Brazil (Novo *et al.*, 1993) have reported positive results in detecting boundaries of flooded areas with high and low resolution (Nadir and Wide Modes) airborne radar data. Brazilian investigations (Novo *et al.*, 1993) have pointed the way for SAR to monitor the rise and fall of rivers and reservoirs, and the development of several types of macrophytes. Watershed erosion and streamflow models require good topographic and ground cover information, which can potentially be provided by SAR information (alone or in concert with other data sources), but further work is needed to develop this complex application.

Table 4. Geology and geomorphology features identified

Feature Identified	Nadir/ Narrow	Wide	Satellite
Structure			
Lineaments	5CR, 1B	1V	
faults (active)	2CR	1CR	
faults (inactive)	1CR,1B	1CR	
faults (reactivated)	1B		
foliation(s)		1V	
layering		V	
orientation(s)	1B	1V	
folding	1B	1V	
multi-folding	1B		
Lithology			
discrimination	(1B,1CR)	1V	
boundary definitions	1CR, (1B)	1V	
intrusive/extrusive	1CR		
dyke/sill	1B	1V	
identification		1V	
Stratigraphy			
bedding		1V	
attitude		1V	
thickness		1V	
lateral relationships		1V	
unconformities		1V	
Landforms and terrain			
drainage density	2B	1G	
granitic terrain	1B		
alluvial plains	1B	1G	
beach ridges		1G	
river meanders	2B		
point bars	1B		
volcanic landforms	5CR		
Landslides	1CR		

Table 5. Hydrology features identified

Feature Identified	Nadir/ Narrow	Wide	Satellite
Drainage network	2CR	1V,2B,1G	1B
Swamps	(1CR)		
Flooded areas	1B	1B,1G	

Table 6. Coastal features identified

Feature Identified	Nadir/ Narrow	Wide	Satellite
Erosion and deposition	2CR	1G	
Lagoons and estuaries	1CR		

Coastal Features

Much of the world's population lives near coastlines and can be adversely affected by coastal changes. Coastal erosion and deposition are natural phenomena, but their effects can be exacerbated by ill-conceived human interference. Two studies in Costa Rica (Montero, 1993; Bjerkelund *et al.*, 1993) and one in Guyana (Singhroy, 1994) have shown the utility of airborne data for detecting and mapping shoreline erosion and deposition (Table 6). The Costa Rican studies have also shown that the airborne data can be used to map changes in lagoons and estuaries. It is important that these studies be extended to assessment of satellite data for these applications.

Cartography

Only one study investigated the use of SAREX data for cartography (Toutin and Elizondo, 1993). Using Nadir Mode airborne data, this study reported planimetric errors of 25 m root-mean-square (rms) for roads and forest edges, 50 m rms for streams, and altimetric errors of 30 m rms. This compares favourably with published accuracy figures for the Intera Starmap system (Mercer and Griffiths, 1993).

Toutin and Elizondo (1993) determined that the smaller but more constant convergence angle available with the Narrow Mode is be preferable to the larger but rapidly varying convergence angle which occurs when correlating two overlapping Nadir Mode flight lines. He also determined that roads and streams could be identified and delineated much more easily with stereo imagery than with monoscopic imagery. Users of RADARSAT data will likely find stereo pairs useful for improved interpretation.

Other Applications

Four studies in Costa Rica (Clúa *et al.*, 1993; Montero, 1993; Fallas and Morera, 1993; Moya and Martínez, 1993) and one in Guyana (Singhroy, 1994) have reported the detection of towns on the airborne SAREX data. Detailed studies (Clúa *et al.*, 1993) show that radar reflectivity is greatly affected by the orientation of the urban grid relative to the radar illumination. Extrapolation to the spaceborne case is difficult because of the sensitivity of the radar image, not only to the azimuthal orientation, and incidence angle, but also the construction materials, and the spacing between streets, and the presence of urban vegetation. Detection of roads, particularly in rural areas, depends greatly on the contrast between the road and the surrounding terrain (Fallas and Morera, 1993; Bjerkelund *et al.*, 1993). One study, in Costa Rica, reported detection of features of archaeological interest in the high resolution airborne data (Asch, 1993).

IMPLICATIONS FOR OPERATIONAL USE OF SPACEBORNE SAR

Because of the large difference in spatial resolution, number of looks, and incidence angle between the SAREX airborne data and spaceborne SAR data it is difficult to make quantitative predictions for most applications. However, we do have some results using actual ERS-1 data and simulated RADARSAT data for guidance.

Many of the geological and geomorphological opportunities indicated by the SAREX investigators will be similar for satellite data. However, in general the optimum applications will be for larger areas at smaller scales. The ability of RADARSAT to acquire data at multiple incidence angles will provide an opportunity to use two or more incidence angles to get additional information, or to pick the optimum incidence angle for a particular terrain type. In addition, its ability to acquire data on ascending as well as descending passes will provide two different aspect angles that can be used to provide additional geological and geomorphological information.

The use of satellite SAR will probably be satisfactory for identifying areas of agricultural land use. Crop area and crop development applications will depend on the field sizes and on the economic value of crop type and crop development information. In many countries fields are small, and satellite SAR will probably provide little useful information, with the possible exception of RADARSAT Fine Mode data. Monitoring of commercial crops which are grown in large fields over wide areas may be an important application area.

Monitoring shoreline changes, changes in mangrove forests, and improving models of erosion and deposition are among the most promising applications identified by SAREX investigators, particularly since the need for corrections for topography will be limited or negligible.

Although SAREX studies have shown promising results for urban areas and cartography, these applications are likely to be primarily a domain for airborne SAR; the resolution of the upcoming generation of satellite SARs will generally not provide acceptable results.

The most promising applications in hydrology appear to be mapping of drainage networks, and delineation of flooded areas. The former is likely to remain a primary application area of airborne SAR because of the mapping resolution generally required, while the latter can be performed by both airborne and satellite sensors. The use of satellite SAR to monitor the rise and fall of rivers, and the seasonal development of macrophytes appears to be a promising application. SAR may also have a valuable role in providing ground cover information for runoff models, but further work is needed to develop this application.

SAREX investigations have pointed out a number of important SAR applications related to natural vegetation. It appears that satellite SAR can play an important role in monitoring the clearing of primary rainforest vegetation, particularly for conversion to agricultural land use. The ability of RADARSAT to monitor large areas at low resolution and subsequently map small areas of activity at high resolution will be an important asset. Multitemporal monitoring will be able to detect areas which are abandoned and regenerating naturally. Monitoring the presence of riparian vegetation will aid in protecting water quality, while monitoring vegetation on steep slopes will enable resource managers to decrease soil erosion, protect water quality, and reduce siltation of reservoirs. The latter application will require correction for geometric and radiometric effects of topography; more work is required in this area.

Many SAREX investigators have found that image texture provides more information than image tone for distinguishing different types of natural vegetation. This finding indicates that high resolution airborne data will be more appropriate than satellite SAR data for such applications.

Finally, a number of investigators have shown that it is very useful to combine SAR and optical data in areas with extensive natural vegetation. The optical data provide information on the vegetation type, while the SAR data provide information on its topographic context, and offer the opportunity for more frequent updates.

CONCLUSIONS

As many previous studies with radar have noted, SAR imagery is particularly well suited for geological and geomorphological interpretation. We have been able to interpret regional and local structures such as faults, folds, lithologies, and stratigraphy in Venezuela, and mineralization deposits in Brazil. Geomorphological features such as drainage networks, floodplains, abandoned meanders, features from various stages of plateau dissection, and erosional, depositional, and reactivated orogenic features have all been identified and interpreted. Experienced interpreters are able to infer a wealth of information about vegetation, soils, and surficial geology from such evidence, much of which is directly applicable to resource management.

Tonal variations in radar images often are dominated by topography, in which case vegetation information is a secondary feature. As a consequence, the vegetation is more difficult to interpret. However, we have found that tropical rainforests have distinctive spatial texture in high resolution airborne SAR images, a texture which remains usefully visible even on simulated RADARSAT fine resolution mode imagery. In contrast, cleared areas have a very smooth texture, which helps to identify them even when tone differences are minimal. The shapes and sizes of clearings often indicate their cause. We expect changes in cleared areas, seen through a sequence of images, to provide additional causal information. In areas dominated by human activity, features such as field patterns and windbreaks are visible; often these are important features in resource management.

Hilly and mountainous terrain make vegetation discrimination even more difficult, but we have made some progress toward removing the radiometric and geometric effects of topography to expose more clearly the radiometric signature of the overlying vegetation.

SAREX investigators have found SAR data to be particularly effective for monitoring shoreline changes. Since cloud cover is of little concern for this sensor, flooding caused by the rise and fall of rivers and reservoirs for the first time can be monitored by imaging radar systems throughout the annual cycle, leading to improved management of aquatic resources. Likewise, cyclic blooms of macrophytes in eutrophic water bodies, which can lead to a variety of environmental problems, may be closely monitored with radar. Mangrove forests have been found to be readily identifiable on SAREX images, and are of great importance for their contributions to biological production and shoreline protection.

RADARSAT's ability to acquire data at variable incidence angles will be an important asset. The amount of geomorphological information which can be extracted from a SAR image has been found to depend on the incidence angle. Information content of an image pair is usually enhanced when images from different incidence angles are viewed stereoscopically. With incidence angle control, RADARSAT data acquisition can be optimized for the prevailing terrain slope and orientation in a region. Multiple incidence angle images can be used for SAR stereo viewing.

Swath width may be traded for resolution with RADARSAT. This may permit wide-area-monitoring at low resolution (ScanSAR Wide and ScanSAR Narrow Modes), with high-resolution (Standard and Fine Modes) mapping of areas of activity. This should be a particularly attractive feature for monitoring tropical deforestation.

Several SAREX investigators have combined SAREX radar data which emphasizes topography, with colour information from Landsat or SPOT, which emphasizes vegetation cover. The combined data allow an interpreter to relate the types and pattern of vegetation to its topographic environment which controls growing conditions, development patterns, etc. Since radar data can be obtained much more frequently than optical data in the moist tropics, an attractive strategy emerges: baseline information may be obtained from combined optical/radar data, and then updated with radar data alone until the next optical data are available.

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