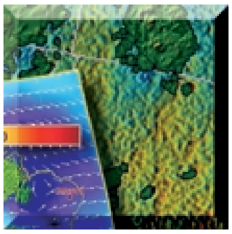

Flood and Coastal Zone Monitoring in Bangladesh with Radarsat ScanSAR: Technical Experience and Institutional Challenges

Dirk Werle, Timothy C. Martin, and Khaled Hasan

In Bangladesh, river floods, monsoon rains, and tropical cyclones are an integral part of the annual hydrological cycle, regularly affecting the livelihood and well-being of more than 100 million people. During years of severe flooding, for example in 1987, 1988, and 1998, the country was transformed by intermittent inland seas that occupied as much as 60% of its land surface. Wide swath synthetic aperture radar (SAR) data acquired by the Canadian Radarsat have shown considerable potential as a monitoring tool, particularly during the monsoon season, to assess flood extent and damage, as well as flood impact on agricultural production, fisheries resources, and navigation. For Bangladesh to fully reap the benefits of wide swath SAR for flood monitoring and coastal zone management, good institutional relations among the scientists, donor agencies, and the government of Bangladesh are critical. (Keywords: Bangladesh, Flood monitoring, Radarsat ScanSAR.)

INTRODUCTION

Bangladesh lies at the confluence of three major rivers: the Ganges, the Brahmaputra-Jamuna, and the Meghna, which are all part of the Himalayan drainage system. Figure 1 shows the vast catchment area of these rivers. The country occupies only a very small, yet highly vulnerable portion of the system at its lower end. More than 90% of the water originates from mainly monsoon precipitation outside its boundaries, while less than 10% is from the monsoon rains within its borders.[1] Each year, large amounts of sediments are deposited along the river banks and in the floodplains, continuously shaping and reshaping the enormous delta at the head of the Bay of Bengal.

Flood events have a profound influence on the life and welfare of many people in Bangladesh. The population density on the vast, fertile floodplains and in the coastal zone is one of the highest in the world, and pressure on resources is increasing owing to the expanding population and the developing economy. A moderate monsoon flood usually brings adequate crop yields and a successful catch from one of the world's most productive floodplain fisheries. However, excessive

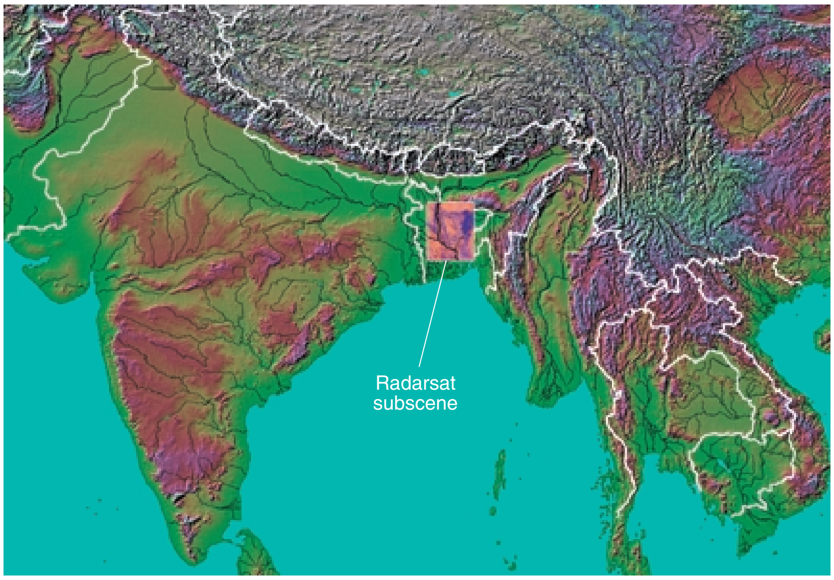

Figure 1. The Ganges, Brahmaputra-Jamuna, and Meghna river systems of Bangladesh in the regional context of the Himalayan drainage system and location of the Radarsat subscene (insert, see Fig. 3). (Map courtesy of Ray Sterner, APL.)

flooding kills people and livestock and damages property; unusually light flooding leaves many areas without crops, a drastically reduced fishery, and insufficient groundwater levels to sustain irrigation throughout the dry season. Normal monsoon floods will inundate about 30% of Bangladesh's floodplains, but during excessive flood years, such as 1988 and 1998, flooding can exceed 60% of the entire land surface.

However, the actual extent, depth, and duration of the monsoon flood are largely unknown, because it builds up and recedes over a period of several months from May to October. Consequently, it is critical to develop the means to accurately characterize and monitor annual flooding for two reasons: to improve short-term emergency response measures and to predict how interventions on the landscape will impact the depth and duration of the flood in the medium and long term. This information could be very useful in supporting the development of a long-term national water management plan.[2]

The situation is somewhat more challenging considering the nature, extent, and duration of flooding problems in the coastal zone. The landfall of tropical cyclones along the Bay of Bengal can result in extensive damage within a very short time. The catastrophic cyclone of 1991, which killed more than 125,000 people, showed that storm and tidal surges affecting the flat coastal plains and low-lying islands can reach 6 to 7 m in height and advance many kilometers inland at a rapid rate of about 2.5 m/s. Wind speeds can exceed 70 m/s. Such events pose an enormous risk to the growing population in these areas.

Several programs have attempted to characterize flooding events in the Ganges, Brahmaputra-Jamuna, and Meghna river systems by using hydrologic mathematical models. Since there is only a limited amount of reliable field information for verification purposes, the utility of these models for characterizing floodplain dynamics is debatable. Some cloud-free, high-resolution optical satellite images of the monsoon floods are on record for part of the country. However, they are of very limited use, because there are only a few to cover the complex floodplain environmental conditions in both space and time. Although several studies of the coastal zone have investigated the usefulness of remote sensing for shoreline characterization and change detection, there has been no attempt to date to utilize satellite remote sensing to capture the floods resulting from storm surges. This situation has been largely due to the short duration of these events and the rather long response times for remote sensing data acquisition and delivery.

Recently, wide swath synthetic aperture radar (SAR), and more specifically, the 500-km-wide ScanSAR mode of the Canadian Radarsat,[3] has become a focal point of several studies investigating more reliable methods of mapping and monitoring floods in Bangladesh.[4–8] These investigations have been performed as modestly funded R&D and demonstration projects. As a developing country, Bangladesh has had little experience with the application of modern satellite radar technology and must rely almost entirely on foreign financial resources if it desires to implement and support the systematic and operational use of this technology. In this article, we discuss ScanSAR in the context of recent satellite radar work in Bangladesh. Then we outline potential applications of wide swath SAR from a resource management and emergency response point of view. The article concludes with observations and comments on current opportunities and difficulties in adapting imaging radar technology within the framework of institutional, financial, and human resource development in Bangladesh.

WIDE SWATH SAR FOR FLOOD MONITORING

Experimentally, wide swath SAR imagery has been applied to flood monitoring in Bangladesh ever since the Radarsat ScanSAR product became commercially available in 1996. As indicated in Table 1, more than

Table 1. Radarsat scenes acquired over Bangladesh, 1996–1998.

Mode, swath width (km); resolution (m)	1996	1997	1998	Total
Fine, 50; 10	6	6	7	19
Standard, 100; 25	2	2	2	6
Wide, 150; 25	1	1	0	2
ScanSAR, 300; 50	5	8	12	25
ScanSAR, 500; 100	2	2	3	7
Total number of scenes	16	19	24	59

(Source: personal communication, A. Ramirez, Radarsat International, Feb 1999.)

50% of all Radarsat scenes acquired over Bangladesh during the first 3 years of satellite operations were acquired in ScanSAR mode, and approximately one-third of all scenes were acquired in fine mode. One investigation compared fine mode and ScanSAR narrow imagery of the same area during the height of the monsoon flood of 1996.[4] The digital image analysis revealed that the ScanSAR classification accuracy of flooded and nonflooded areas during times of extensive flooding was very encouraging. In fact, it was comparable to the accuracy achieved with fine (resolution) mode. For example, in almost 90% of all cases, the ScanSAR narrow (300-km swath width) and fine mode classifications for flooded terrain during 19 and 20 August 1996 were in agreement with the ground reference data. The result also compares favorably with previous European Remote Sensing satellite (ERS)-1 SAR data analysis, which provided accuracies ranging between 70 and 90% for a variety of flooded terrain features during the monsoon flood of 1993.[4,9]

These findings have implications for the radar application potential and the choice of suitable radar data products, particularly with regard to nationwide and multitemporal data requirements in Bangladesh. The result is also attractive to potential operational users and investigators familiar with the 100-km swath (or less) radar imagery, which was the norm for satellite SAR coverage before the introduction of ScanSAR. The spatial coverages for both the 100-km-wide ERS-1 and -2 SAR or Radarsat standard mode and the ≈300-km-wide ScanSAR narrow swath were compared. It was found that the ERS completes nationwide coverage after approximately 4 weeks, involving six orbital passes and the equivalent of 25 scenes with a nominal resolution of 25 m.[10] In the case of ScanSAR narrow, nationwide coverage can be completed within 1 week, involving either two orbital passes with four scenes at a 50-m resolution or only a single pass and one scene in ScanSAR wide mode with a 500-km swath and a 100-m resolution.[11] Therefore, because of its monitoring capability, data handling, and the financial perspective, the ScanSAR data product offers more frequent and better synoptic coverage (albeit at reduced resolution) at substantial cost savings.

Given the spatial and temporal scales of flooding in Bangladesh, ScanSAR appears to be the preferred SAR imaging mode to effectively monitor the flood dynamics weekly during the monsoon period. However, in Bangladesh, such high-frequency ScanSAR data acquisition and data handling capability has not yet been tested; previous R&D investigations and demonstration projects relied on the 24-day Radarsat repeat cycle in order to keep wide-area coverage and radar illumination conditions at a constant.

From a technical point of view, the value of the Radarsat-1 ScanSAR imagery acquired over Bangladesh to date has been hampered by two factors: (1) the previously uncalibrated beams of the 8-bit data product limited its use to analog interpretation and change detection exercises rather than quantitative digital analysis, and (2) the analog-to-digital converter (ADC) problem resulted in a loss of image quality and value, when widespread flooding was involved. The ADC effect was associated repeatedly with flooding in the Sylhet Depression in the northeastern portion of the country. The ADC effect is usually experienced in coastal areas with large open water surfaces in the near-range portion of the radar beam.[12] (See also Vachon et al., this issue.)

APPLICATION POTENTIAL

From the operational point of view, the use of wide swath SAR data for monsoon flood monitoring in Bangladesh has proven to be practical for three reasons. First, it provides synoptic and sufficiently frequent coverage on a nationwide scale, unaffected by cloud cover. Second, the digital data format of the Radarsat system is potentially conducive to fast delivery, i.e., within hours of data acquisition. Third, ScanSAR has performed a useful pathfinder role for follow-up and more detailed area coverage. For instance, the buildup and oscillations of the severe 1998 flood levels exceeded what is considered the danger level for an unprecedented 65 days. The hydrographic data shown in Fig. 2 demonstrate that the rising and falling water levels of the 1998 peak flood can be monitored by the ScanSAR, although only a few scenes had been requested by the authorities in Bangladesh during the latter stage of the 1998 flood.

Data acquisition opportunities generally occur every 4 to 5 days, whereas individual flood peaks appear to

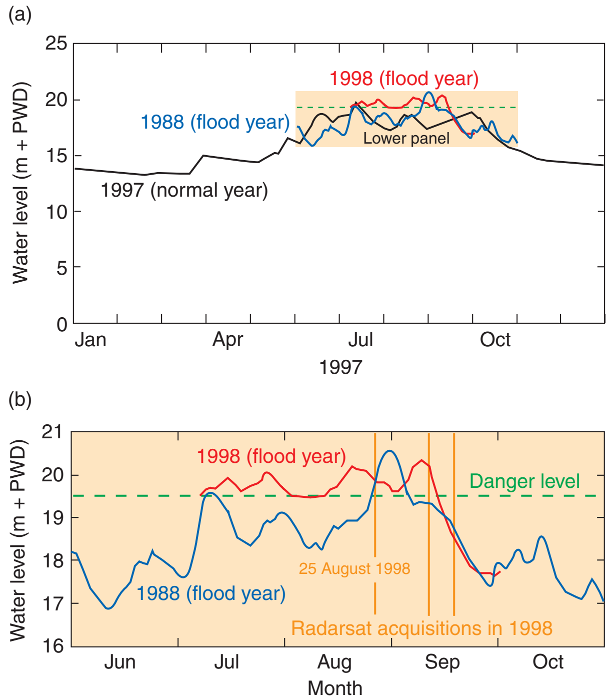

Figure 2. Comparison of water levels of the Jamuna River at Bahadurabad during (a) a normal year (Jan–Dec 1997) and (b) the exceptional 1988 and 1998 monsoon floods (Jun–Nov). The danger level (19.5 m) as well as several Radarsat ScanSAR data acquisition dates for the 1998 flood season are indicated (PWD = Public Works Department data). (Source: EGIS Project, Dhaka, Bangladesh, 1998.)

be more than 10 days apart. Within that time period of individual flood peaks, there is also opportunity to schedule data acquisitions at fine or standard mode to cover affected areas in greater spatial detail. Figure 2b shows that actual Radarsat ScanSAR data acquisitions in August and September coincided with flood conditions above the danger level and the peak flood event. Such imagery provides a unique and invaluable, almost nationwide, overview of the flood extent at a time of greatest calamity (Fig. 3). Subsequent image analyses and time series prepared for briefings to government officials made a convincing case for the usefulness of wide swath SAR for flood assessment in Bangladesh.

Systematic and operational use of satellite radar is potentially of direct benefit to government and nongovernment organizations, planners, researchers and academics, donor-funded programs, and development projects.[13] Several potential Radarsat applications have emerged. Table 2 indicates that flood monitoring is the main application of Radarsat, followed by agricultural planning (etc.), river dynamics and monitoring, and offshore environmental surveillance. However, the state of readiness to integrate radar data into ongoing operational activities is generally low. Activities related to monitoring monsoon floods and river morphology are the only exceptions. Here, ScanSAR data have high value as a support tool for strategic decision making and nationwide flood emergency response measures. Apart from emergency situations, wide swath radar is equally important for water resources analysis and management where it helps to address three critical issues: (1) seasonal hydrological change in the floodplain on a regional scale; (2) the relationships among hydrological regime, vegetation cover, land use, and inland fisheries; and (3) predictions (through coupling with hydrodynamic models) of the effects of interventions such as flood embankments on floodplain hydrology.

By contrast, it is very difficult to capture with existing satellite SAR systems the actual flooding related to storm surge events lasting on the order of a few days, or, in extreme cases, only hours. The limitations are twofold: (1) relatively long satellite revisit cycle(s) and activation times to actually capture the event and relay the image data in a timely fashion; and, to some extent, (2) discrimination of nonflooded terrain versus inundated coastal land surfaces under usually high wind speed conditions. The chances for the latter situation increase with the use of large radar incidence angles; small incidence angles favor detection of wave and wind fields. Under these conditions, it would be more difficult to distinguish their radar-bright signature from those of the coastal land areas.

Table 2. Assessment of Radarsat ScanSAR application potential and state of readiness in Bangladesh.

Radarsat ScanSAR application	Potential	State of readiness
Monsoon flood monitoring and disaster management	High	Moderate
Agriculture planning, management, and damage assessment	Moderate	Low
Inland fishery, aquaculture, and wetland resource management	High	Low
Environmental planning for infrastructure and energy	Low	Low
River dynamics and monitoring	Moderate	Moderate
Coastal geomorphology; storm surge monitoring	Low	Low
Offshore environmental surveillance	Moderate	Low

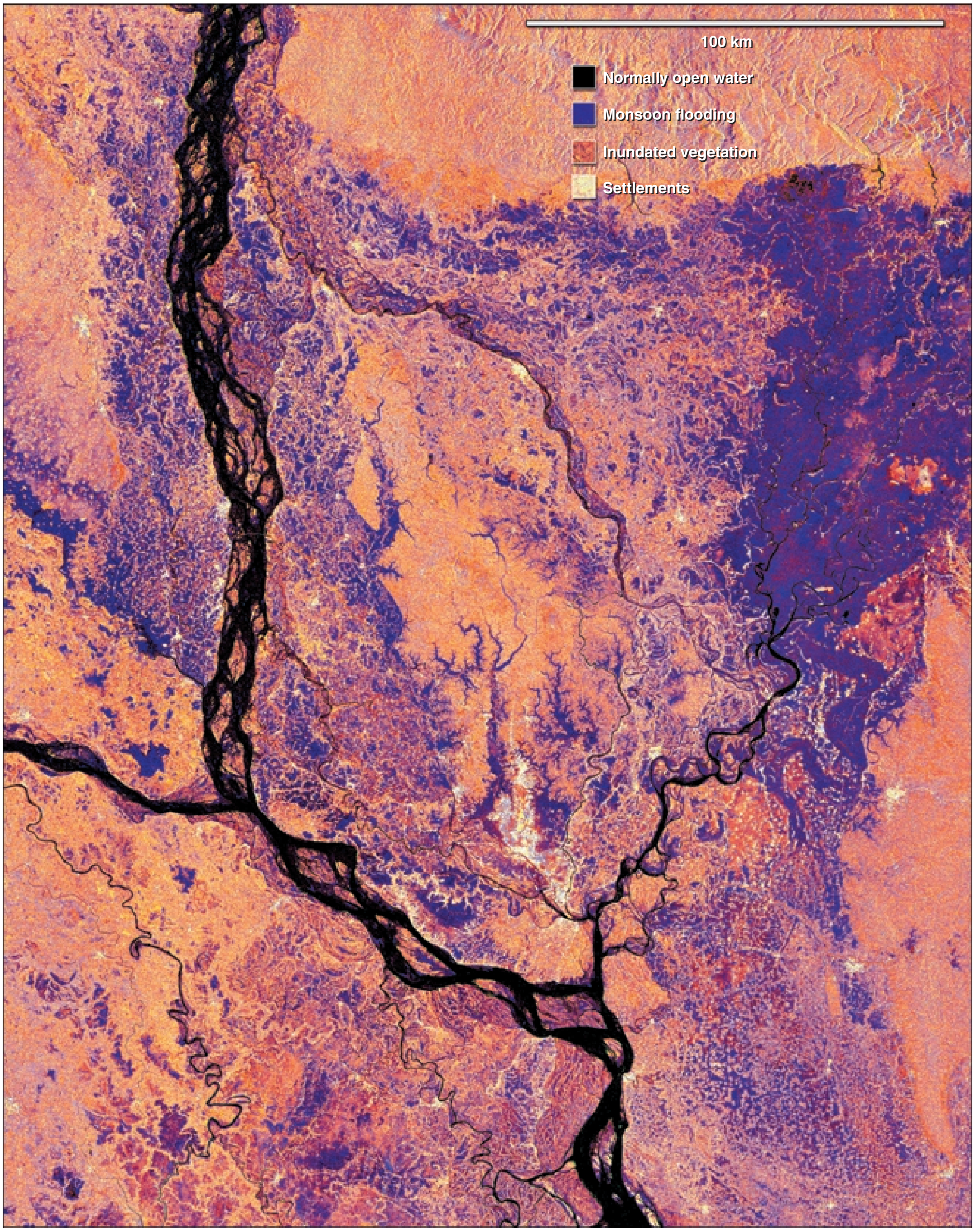

Figure 3. Multitemporal Radarsat composite SAR image map of central Bangladesh constructed from ScanSAR wide data acquired during severe monsoon flooding on 25 August 1998, and ScanSAR narrow data acquired during the dry season on 21 March 1999. See Ref. 13 for detail, Fig. 1 for regional context. (Source: SPARRSO/CIDA/CCRS/Ærde, © CSA, 1998 and 1999.)

The current 48-h response time for Radarsat-1 SAR data acquisition programming is inadequate for sudden events like storm surges, assuming that the area of interest is readily accessible by the radar. Also, the weekly coverage of the Bay of Bengal by Radarsat is insufficient for making a substantive contribution to short-term emergency response operations. However, the sea surface conditions (e.g., wind and wave fields related to these destructive events) could potentially be assessed even within the current time constraints. More imaging opportunities may present themselves with the denser coverage pattern afforded by a coordinated constellation of wide swath SAR satellites (e.g., the Radarsat-1 and -2 and the Advanced SAR [ASAR] onboard the planned European Envisat).

ADAPTATION FOR OPERATIONAL USE

In Bangladesh, several research and demonstration projects have been successfully carried out over the past 5 years involving satellite radar data as the primary source of input. However, ScanSAR imagery has not been used operationally for monitoring flood events, land use, and the coastal areas of the country. The process of integrating the radar data stream into day-to-day resource management and emergency response operations has been hampered by both institutional and technical constraints. Effective and widespread use of ScanSAR-type data products hinges on resolving administrative and technical problems.

The designated national governmental focal point for remote sensing matters in Bangladesh is the Space Research and Remote Sensing Organization. It is responsible to the Ministry of Defense, but also is involved with applications in resource management and environmental monitoring. In addition to the local government activities, several international donor initiatives have been undertaken. Examples include the U.S. Agency for International Development–funded Flood Action Program 19 Geographical Information System (GIS) Project and the Dutch-funded Environmental GIS Project (EGIS II), supporting the Ministry of Water Resources and other agencies. Thus, as in many other developing countries, aerospace and remote sensing affairs of Bangladesh are officially within the civilian and military domains of government, but are opening up to participation by development projects and private sector companies.

The path from applied research and development to operational use is further complicated by the fact that civilian government institutions involved with flood forecasting and damage assessment in Bangladesh are not financially able to invest in an operational, radar-based flood monitoring system. The financial resources needed for the adaptation and implementation of much-needed technologies are very scarce. Many government agencies and potential radar remote sensing users operate on a very low budget. Apart from the actual acquisition of SAR data, there are other major cost factors to consider, including human resources and training, reliable software and hardware, archival and distribution facilities, as well as regular maintenance to sustain an operational system.

Despite current limitations, international donors are enthusiastic about the potential of radar remote sensing technology. During the devastating flood of 1998, United Nations and Canadian International Development Agency funds supported initiatives led by the EGIS II Project and by the Space Research and Remote Sensing Organization. Both institutions were able to demonstrate the effectiveness of multitemporal Radarsat ScanSAR data as a flood-mapping tool. Many governmental and nongovernmental organizations were found to be ardent users of thematic maps of the 1998 flood extent and applied the data in their disaster management and postflood relief and rehabilitation efforts. As a result, institutes such as the Flood Forecasting and Warning Center and the Surface Water Modeling Center are interested in satellite SAR as a unique data source to validate and calibrate their mathematical models. Furthermore, cooperation among donors, government organizations, and the private sector has recently led to the temporary installation of a European-built portable ground station in Dhaka. The facility is capable of receiving 100-km wide swaths of ERS-2 SAR data in near–real time for a 9-month trial period during the 1999 monsoon season. Such initiatives are instrumental in building operational SAR monitoring capacity and experience in Bangladesh.

With European and Canadian commitments to launch their Envisat and Radarsat-2 satellites in the 2000 and 2002 time frames, respectively, ScanSAR data continuity appears to be established for at least another 5 to 7 years. This is important and reassuring for users who plan to integrate these data into their operations. From a technical perspective, the main constraint appears to be the timely transfer of ScanSAR imagery to and within Bangladesh during times of emergency. Whereas the SAR data can be processed within less than 2 h of reception at the Canadian Data Processing Facility, the limited bandwidth of Bangladesh telecommunications lines currently restricts prompt delivery of the imagery to the user. This delay and subsequent lag time for image processing, analysis, and information product generation compromise the operational utility of the data. The value of the imagery for short-term emergency response measures is significantly diminished after a few days, and in the case of coastal tidal surges, even after several hours from data acquisition. It is expected that new compression techniques implemented at the Canadian facility will substantially improve the data transmission times and thus reduce or alleviate the processing problem for Bangladesh users.

CONCLUSION

Currently available wide swath SAR data, such as Radarsat ScanSAR imagery, are well suited for application in Bangladesh to address urgent environmental monitoring requirements, particularly for regularly occurring monsoon floods, and to monitor the annual hydrological cycle. Research and demonstration projects have shown that the information derived from such imagery can be very valuable to operational users for planning flood-related emergency response measures; monitoring flood dynamics, inland fisheries, and aquaculture; and validating and calibrating hydrological models. The successful monitoring activities based on Radarsat ScanSAR during the devastating flood of 1998 highlighted the value of SAR technology, not only for potential user agencies, but also for their institutional backers within government and international donor organizations. Several implementation issues remain unresolved, including financial and institutional arrangements, as well as technical difficulties associated with the timely transfer of SAR data processed in near–real time to support operational emergency response activities for flooded areas and coastal storm surges in Bangladesh.

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