Applications of Remotely Sensed Data in Flood Prediction and Monitoring: Report of the CEOS Disaster Management Support Group Flood Team

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Abstract - The potential of high and low resolution polar and geostationary orbital Earth Resource Satellites have been shown to be an excellent tool for providing hydrological information. Operational geostationary meteorological satellites have the capability to provide precipitation estimates and soil wetness indices at the global scale, while polar orbital satellites can provide the quantification of catchment physical characteristics, such as topography and land use, and catchment variables such as soil moisture and snow cover. There have been many demonstrations of the operational use of these satellites for detailed monitoring and mapping of floods and post-flood damage assessment.

This paper addresses the use of Earth Observation satellites for flood managers, flash flood analysis and prediction, and the user community. A remote sensing management cycle is presented that involves: (1) prevention where history, corporate memory, and climatology are important; (2) mitigation that insulates people or infrastructure from hazards; (3) pre-flood which is the preparation and forecast stage where remote sensing is essential; (4) response (during the flood) where "actions to be taken is of key importance and weather NOWCASTS (0 - 3 hour prediction of precipitation) using remote sensing is extremely useful; and (5) recovery (post flood) which is the post-mortem stage where damage assessment, procedures, and numerical weather prediction and hydrological models are validated.

Gaps in our remote sensing capabilities, future improvements and requirements, and the requirement for demonstration projects to illustrate and educate the end-user community on the capabilities of satellite remotely sensed data to provide information during all of the phases of the disaster cycle are discussed.

1.0 INTODUCTION

Recent statistics show that worldwide disasters have been on the increase. Greater damage is occurring, more lives are being lost and the overall frequency of the occurrence as well as the severity of disasters is on the rise. At the same time, the advances in space technologies, particularly remote sensing, have significantly improved and become more operationally oriented and readily available. However, studies have also shown that the use of remote sensing data, systems and services is still far from widely applied within the disaster management context. The disaster management community has expressed an interest and willingness to incorporate remote sensing technologies into its operations, provided that the remote sensing sector can demonstrate the operational utility.

This paper addresses the use of Earth Observation satellites for flood managers. Ideas and concepts for this paper were generated from several Committee on Earth Observation Satellites (CEOS) disaster management support group meetings and individual communications that included a comprehensive discussion on Flood Hazard and Remote Sensing [1].

2.0 FLOODS

With respect to the cycle of disaster management, two main fields of interest can be defined for the use of remote sensing data in the flood domain. First, a detailed mapping approach is required for the production of hazard assessment maps and for input to various types of hydrological models. These mapping approaches are used at the regional and local scales whereby the user requirements are related to detailed mapping for updating (and sometimes creating) risk and damage assessment maps. These maps contribute to the hazard and vulnerability aspects of flooding. Secondly, a larger scale approach that looks at the general flood situation within a river catchment or coastal belt, with the aim of identifying areas at greatest risk and in need of immediate assistance is of interest. In this case, remote sensing may contribute to the initialization of numerical weather prediction models and weather forecasts, as well as mapping inundated areas at the regional level.

Hydrologic models for flood prediction typically use multiple gridded spatial datasets for input and this often requires interpolation and merging of point, spatial (gridded) and occasionally linear (flight surveys) data. Topographic and drainage characteristics such as surface slope, orientation, roughness and river length are usually also estimated using digital topographic data which is commonly available from Federal or Provincial/State Government sources or directly from remotely sensed data. The satellite-derived hydrologic data of most significance include land cover, areal extent of water, snow cover and water equivalent, soil moisture, precipitation and evaporation indicators such as leaf stress and area. As well as the integration tools being available, the data also must be available in near real-time (NRT), within minutes or hours, presumably being delivered via the Internet. These data sets can be large and often require specialized Geographic Information Systems (GIS) for efficient processing and management

3.0 FUTURE IMPROVEMENTS AND REQUIREMENTS

The next major improvement in hydrological modelling, and the improved disaster surveillance and resource management that would come from it, will be in the digital integration of near real-time *in situ* data, imagery and spatial data into the day-to-day operation of the watershed models for flood prediction. As described, remote sensing can contribute to the complex problem of flood management. However, gaps still exist and remote sensing data is not being used to its full potential. Improvements can be divided into four categories: methodology, science, technology, and data management.

3.1 METHODOLOGY

There is a need for a coherent integration with all other disciplines that are operating in flood hazards. Often in the past, providers of data have been working in a vacuum and not interacting with the user community. Providers must start considering data acquisition and analysis, scientific interpretation of natural phenomena, and the needs of users. In the case of floods, where there are many information "Gaps", an integration of both the remote sensing and traditional techniques is strongly recommended for the benefit of the final users. With respect to flood hazards, the main methodological improvements recommended are: an integrated approach with other disciplines (data fusion); this includes R&D on integrated approaches of Hydrologic models, remote sensing, and GIS; resulting methodologies can lead to improved valorization of remote sensing data, a differentiated approach according to the typology of the event (flood plain, flash floods, dam breaks, ice jams, storm surge), an integrated approach between flood and slope instability, as different aspects of the same dynamic system, the drainage basin, and improved GIS integration.

3.2 SCIENCE

The full benefit of remote sensing for applications related to flooding is likely to come from the integration of data from a variety of sensors operating in wavelengths from microwave to visible and infrared. This will pose new challenges in the development of inversion models to quantify the hydrological variable being observed and in the use of geographic information systems to relate these spatial and temporal data sets.

In order to make satellite-derived precipitation algorithms more robust, calibration and validation must take place for various types of precipitation systems (extra tropical and tropical). Improvements are needed in ground truth precipitation measurements so the satellite algorithms can become more mature and reliable. Precipitation measurements from the Tropical Rainfall Mapping Mission (TRMM) and meso-networks around the world will provide such information. Ideally, microwave measurements will help provide a robust methodology in which histograms and probability matching will be used to continuously update GOES precipitation measurements both with respect to intensity and location. Thus, advanced precipitation algorithms will only come by using multi spectral and multi sensor data combined with ancillary information. In addition, the newly developed physically based distributed hydrological models will need to be refined to make full use of the high spatial and temporal frequencies of the observations which may be obtained. In addressing these challenges we will gain a better understanding of hydrologic processes at local, regional and global scales.

3.3 TECHNOLOGY

Enhancements needed in the field of technology include; increased frequency of coverage, improve coverage access and delivery, increase the resolution of DTM for local applications (>1 m); have the ability to access information from all available data sources, formulate procedures that effect awareness, access, and products and services, meteorological satellites with higher resolution sensors both in time and space and place microwave sensors onboard operational geostationary meteorological satellites.

Another barrier to the implementation of remote sensing is the lack of technical expertise and a suitable “tool-kit” in the end-user community. This can be overcome in part by the private sector service industry and government agencies providing this service, however training and technology transfer initiatives will be required. The “cost” associated with information extraction from remote sensing data can pose a significant barrier to acceptance for the end user. This is due to high data costs, and significant expertise requirements that question the benefit of using remotely sensed data.

This can be further complicated by scale issues for the application of regional versus local coverage requirements for the agency or group responsible for mapping or monitoring the event. In general, the low cost AVHRR data is a very attractive data source but can only meet coarse regional coverage requirements. While the higher resolution SPOT, Landsat TM and RADARSAT-1 SAR sensors can provide a better map scale, the cost for the data is considerable. For large scale mapping requirements, only the recent advent of the 1-meter data from IKONOS is sufficient but the cost and reliability of data acquisition is often prohibitive

A good way to improve the utility of the data is to increase its usage. Current prices for high-resolution satellite data sets are often times too high to allow for routine use. Perhaps an increase in marketing can increase volume to the point where prices become more affordable for routine and contingency operational use.

3.4 DATA MANAGEMENT

The requirements mentioned earlier in this report state the need for higher spatial and temporal resolution of remote sensor data sets from an increasing number for satellite platforms. Inherent in these requirements is the need for enhanced data management techniques and technologies. The graphical nature of satellite data and associated products means that larger and more efficient data networks are needed along with state-of-the-art data compression capability. Satellite data must also be compatible with GIS software to maximize utility.

There is also a strong need for improving: local capacity, education and training, international coordination to response, and international data service to be able to facilitate the access to data that is understandable. Few end-users will be experts in the field of remote-sensing techniques. Thus, there is a need for an increase in education and outreach on the increasing number of data types and products that are available and the potential uses for each. Equally important is the need to communicate to the end-users the strengths and limitations of each product so that disaster managers make decisions based on the appropriate understanding of the data.

4.0 DEMONSTRATION PROJECT

The Flood Hazard Team proposes that demonstration projects are required to illustrate and educate the end-user community on the capabilities of satellite remotely sensed data to provide information during all of the phases of the disaster cycle. The Team recommends leveraging the opportunities created by the Unispace III International Charter with other ongoing activities such as, but not limited to, the Global Disaster Information Network, the Open-GIS Consortium, the Red River Disaster Information Network and the Canadian GeoConnections initiatives. As developed and developing countries have differing current capabilities with respect to flood forecast, response and recovery it is envisioned that two demonstration projects should be conducted to address the different levels of infrastructure available. Possible demonstration sites identified by the Team include Central America, the Red River (United States/Canada) and the Oder River in Europe.

In order to properly execute the demonstration projects there will be a requirement to gain an understanding of the current operations and requirements of the end users, which may be satisfied wholly, or partly with remotely sensed data. This activity would be a two-way education process conducted in preparation for the demonstration, well in advance of any actual flood event to facilitate a mutual understanding of information/product requirements and the mechanisms to communicate the information at local, regional and national scales. This should not be limited to products derived solely from remotely sensed data but rather should integrate meteorological, in situ and other geospatial data. Lastly, to ensure that there is a high international visibility, the Team recommends that the demonstrations should have a public relations component incorporated into the demonstration.

5.0 CONCLUSIONS

The use of remote sensing data for input to flood management applications has been repeatedly demonstrated and will continue to increase as the number of satellites and data providers increase. This will decrease the cost of the data while increasing availability and access to information, which will therefore increase the use of remote sensing in flood management applications.

There are several key areas for research and development to further enhance the use of remote sensing in disaster management. These include the best approach for combining multi-scale data; the use of models to extract geo-physical parameters from remote sensing data, and the use of *in situ* networks and observations for supporting these applications. The use of disaster simulations to develop, test, and implement effective approaches for the integration of remote sensing and GIS in flood applications is strongly recommended.

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REFERENCES

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