Utilization of NASA Satellite Remote Sensing Program in Developing Space-borne Warning Systems for Natural Disaster Risk Management

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1. NASA EOS program

From space we can study all of the elements of our home planet, from a broader perspective than we can on Earth. The NASA Earth Observing System (EOS) program is a major component of NASA's Earth-Sun System Missions. The EOS (http://eos.gsfc.nasa.gov/) program includes a series of satellites, a science component, and a data system supporting a coordinated series of polar-orbiting and low inclination satellites for long-term global observations of the land surface, biosphere, solid Earth, atmosphere, and oceans, which is enabling an improved understanding of the Earth as an integrated system. The focus of EOS is to assess Earth's climate and environmental change. Particularly, natural hazards such as storms, forest fires, and atmospheric changes are observed as well as erosion and city development. The effects of the melting glaciers, due to global warming, can also be observed. Our Earth is constantly changing, and NASA EOS satellites are constantly acquiring imagery and taking measurements so that we can understand those ongoing changes and will have the ability to predict what will happen in the future. This article briefs recent development of EOS, with focus on Earth's precipitation measuring mission (Section 2), its application to natural hazards (Section 3), and its ultimate goal—space-borne early warning system for natural hazards (Section 4).

2. Global Precipitation Monitoring System

During the past twenty-five years information from a number of satellites has been compiled to give a better understanding of how precipitation is distributed across our planet. Rainfall measurement from satellites has been an active field of study for decades. Both visible/infrared and microwave radiometers are used to infer precipitation. The World Climate Research Programme established the Global Precipitation Climatology Project that has been succeeding in producing precipitation data of 2.5 x 2.5 (latitude-longitude) monthly accumulations of estimates over the last three decades. More accurate and higher spatio-temporal resolution of precipitation information is critical in understanding the balance of Earth's energy and water cycle exchange that drives global changes and water resources applications. One of the major efforts toward this direction is the development of Precipitation Estimation from Remote Sensed Information using Artificial Neural Network-Cloud Classification System. The PERSIANN-CCS extracts local and regional cloud features from infrared (10.7 mm) geostationary satellite imagery in estimating finer-scale (0.04° x 0.04°, and 30 min) rainfall distribution. Later, an automated neural network for satellite–based rainfall estimation, entitled Self-Organizing Nonlinear Output model, was developed to adjust the mapping functions by using passive microwave precipitation estimates from Low-Earth Orbiting satellite platforms. Real-time data from the current version of PERSIANN-CCS is available online (http://hydis8.eng.uci.edu/CCS/). Further investigation of this research extends to a new development: "Satellite-based precipitation estimation using watershed segmentation and growing hierarchical self-organizing map". This methodology draws on techniques from machine learning and morphology to produce high-resolution, short-duration rainfall estimates in an automated fashion. First, cloud systems are identified from geostationary infrared imagery using morphology based watershed segmentation algorithm. Second, a novel pattern recognition technique, Growing Hierarchical Self-Organizing Mapping, is used to classify clouds into a number of clusters with hierarchical architecture. Finally, each cloud cluster is associated with co-registered passive microwave rainfall observations through a cumulative histogram matching approach. The network was initially trained using remotely sensed geostationary infrared satellite imagery and hourly ground-radar data in lieu of a dense constellation of polar-orbiting spacecraft such as the proposed global precipitation measurement (GPM) mission.

Other examples of recent development include NASA TRMM-based Multi-satellite Precipitation Analysis (TMPA), which provides a calibration-based sequential scheme for combining precipitation estimates from multiple satellites, as well as gauge analyses where feasible, at fine scales (0.25°x0.25°and 3-hourly) over the latitude band 50°N-S (http://trmm.gsfc.nasa.gov). It is anticipated that the TRMM will be continued by the development of the GPM (http://gpm.gsfc.nasa.gov). The TRMM-like GPM is envisioned as a constellation of operational and dedicated research satellites to provide global precipitation estimation (90°N-S). The success of multi-satellite precipitation estimation program provides a real-time monitoring of global precipitation at every 30-minutes resolution, which has been suitable as a supplement of the *in situ* data in providing precipitation information for wide applications.

3. Use of Satellite Remote Sensing Techniques in Natural Hazard Mitigation

Using a variety of advanced satellite remote sensing products, scientists approached the study of how the NASA space-based Earth observations can be applied to build disaster early detection systems that promise to protect lives, particularly from the hazards of impending hurricane, floods and landslides. Flood and associated landslides are one of the most widespread natural hazards on Earth, responsible for thousands of deaths and billions of dollars in property damage every year. The havoc of these disasters is felt most acutely in parts of the world without extensive ground observation networks. Satellite remote sensing data are perhaps the best source of information in many countries for monitoring such hazards. Recent new developments are poised to offer a potential solution to the significant challenge of creating cost-effective early warning systems needed most particularly in conventional data scarce areas.

3.1 Mapping Severe Flood Events from space-based precipitation estimation

In many countries around the world, satellite-based precipitation estimation may be the best source of rainfall data due to insufficient hydrometeorological networks, long delays in data transmission and absence of data sharing in many trans-boundary river basins. Satellite remote sensing data acquired and processed in real-time can now provide the information needed to monitor severe flood events around the world by integrating satellite-derived forcing data with hydrological models. Scientists in NASA Goddard put forward practical methods of mapping floods globally using a combination of satellite remote sensing datasets. The three major components included in the framework are 1)

NASA TRMM- based Multi-satellite Precipitation Analysis (http://trmm.gsfc.nasa.gov); 2) characterization of land surface including digital elevation from NASA SRTM, topography-derived hydrologic parameters such as flow direction, flow accumulation, basin, and river network etc.; and 3) spatially distributed hydrological models to generate surface runoff and route excess precipitation. The key to computational efficiency of transferring space-borne observations into operational monitoring system lies in the simplification of complex flood prediction models. While these simplifications introduce some computational errors, it is demonstrated through sensitivity analysis that the errors are minor compared to the benefits accrued from computation efficiency.

One good example of such application is flood forecasting for international river basins. There are around 263 international river basins (IRB) listed by UNESCO. For flood forecasting in the lower riparian nations of these IRB, real-time rainfall data from upstream nations is naturally the most critical factor governing the forecasting effectiveness. However, many upstream nations fail to provide data to the lower riparian nations due to a lack of in-situ rainfall measurement infrastructure or a lack of a treaty for real-time sharing of rainfall data. A potential solution is therefore to use satellites that inherently measure rainfall across political boundaries. The motivation stemmed from the critical challenge in identifying the specific IRBs that would benefit from a pre-programmed satellite-based forecasting system in anticipation of the NASA GPM mission.

3.2 Global Landslide Monitoring

Landslides triggered by rainfall can possibly be foreseen in real time by jointly using rainfall intensity-duration thresholds and information related to land surface susceptibility. One highlight of remote sensing applications is to examine the possibility of development of a real-time monitoring/warning system for global landslides triggered by intense rainfall. Scientists in NASA Goddard outlined an experimental monitoring system for global rainfall-triggered landslide occurrence. A global landslide susceptibility map was first derived using SRTM derived elevation and slopes, MODIS land cover classification data, soil texture, and soil types. This map is then overlain with the near real-time TRMM multi-satellite rainfall data to identify when landslide-prone areas receive heavy rainfall. Success of the results provides a basis to develop an early warning system for global landslide potential.

4. Toward Space-borne Early Warning Systems

It has been established by experience that the most effective means to reduce the property damage and life loss caused by natural hazards is the use of disaster early warning systems. However, no system currently exists at either a global scale to monitor/detect these conditions due to the lack of extensive ground-based observing network in many parts of the world. Recent advances in satellite remote sensing technology and increasing availability of high-resolution geospatial products around the globe have provided an unprecedented opportunity for such a study. Satellite observations can be of essential value improving our understanding of the occurrence of these hazardous events and in possibly lessening their impact on the local economies and reducing injuries, if they can be focused to create more reliable warning systems in cost-effective ways. In this regard, Scientists in NASA and other agencies have been taking initiatives in addressing these opportunities and challenges. Two operational real-time monitoring systems for floods (http://trmm.gsfc.nasa.gov/publications_dir/potential_flood.html) and landslide potential (http://trmm.gsfc.nasa.gov/publications_dir/potential_landslide.html) have been displayed on the NASA websites, respectively. A major outcome of this work is the availability of a first-time global assessment of flood and landslide risk, which is only possible because of the utilization of satellite remote sensing products. This experimental system can be updated continuously due to the availability of new satellite remote sensing products.

The research listed above is an initial step in addressing these opportunities and challenges. For example, floods and associated landslides account for the largest number of natural disasters and affect more people than any other types of natural disasters around the world. Recent mitigation approaches build on the success of the existing prediction techniques by combining new satellite-based data sets of global precipitation and land surface characteristics (e.g., elevation, soil, vegetation) to improve existing decision support system and expand them into regional or even global flood and landslide detection/monitoring/forecasting systems for disaster management, preparedness, and mitigation activities around globe. The space-borne operational systems reported here, if pursued through wide interdisciplinary efforts as recommended herein, bear the promise to expand many local monitoring systems into a global real-time decision-making support system for disaster preparedness and risk management across the world.

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主要学术成就

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