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GUEST EDITORIAL

Need for developing effective early warning systems for natural disasters using space technology

Recent disasters including the deadly one of Kedarnath have brought into focus the role of space technology, in particular earth observation (remote sensing) into sharp focus. Natural disasters are deadly events caused by natural phenomena and bring damage to human societies. They are inevitable and difficult to predict. Increasing human habitation in areas vulnerable to natural hazards is perhaps leading to greater damage to property and human life. Although it is difficult to say whether the number of disasters has increased over the years, number of disasters of higher intensity has increased. While an earthquake may destroy a very large area in a few seconds, landslides may damage a small area in a few minutes, floods may affect a very large area in a few hours to days and drought shall affect a large region in a few weeks to months. In recent years, extreme rainfall events (>150 mm rain) have been on rise. Any Early Warning System should comprise four major components, i.e. risk knowledge, development of monitoring and predicting systems, quick dissemination of information and efficient response strategies.

All components of space technology, viz. earth observation (remote sensing), satellite meteorology, satellite communication and global navigation satellite systems play an important role in disaster management. Satellite communication provides the critical path for relief in emergency and disaster situations, *in-situ* observation network, transfer of data and products in near real time to decision makers/managers. Satellite navigation provides the crucial location information. Successful implementation of an Early Warning System was witnessed recently during the *Phailin* cyclone hitting the Odisha coast at Gopalpur on 12 October 2013. However, it is important to understand overall efficacy of presently available earth observation data in all phases of disaster management: early warning, preparedness, monitoring, response, recovery and mitigation. Degree of utility in different disasters varies.

Geophysical disasters include earthquakes, volcanic eruptions, tsunamis, landslides and avalanches. Geohazards driven directly by the geological processes involve ground deformation. The impact of these disasters is generally sudden and very strong, providing very little time for disaster response, especially evacuation planning. Earthquakes are short-lived, menacing and the most feared natural hazards because of their sudden impact and devastation in a matter of few seconds. Currently earth observation data has shown capability in identifying earthquake-prone areas, hazard zonation, damage assessment and mitigation but are limited in the warning phase. There are many earthquake precursors which are amenable to remote sensing. Statistically significant correlations between thermal observations from satellites and seismic activity have been observed. Sudden rise in temperature in a few days to week before the earthquake occurrence has been observed in a number of earthquake events. However many of these are done in a hind cast mode and not really in a predictive mode for issuing warnings. Electromagnetic phenomena in a wide frequency range do take place prior to any earthquake and these are detected by specially designed sensors onboard the satellites. Satellite-based EM precursors are one of the promising areas in earthquake prediction research. Major earthquakes are associated with observable surface deformations of the order of meters. Synergistic use of space-borne synthetic aperture radar interferometry and GPS measurements at specific locations do provide a powerful tool to observe surface deformations on a continuous basis. Early warning of volcanic eruption requires monitoring land surface temperature, surface deformation, gas emission and seismic signals. Detection of thermal anomalies associated with volcanoes is currently done using data from many satellites. Landslides are triggered by earthquakes and heavy rain falls. Rainfall-threshold based models are used for early warning of landslides. Early warning of tsunamis depends on the detection of the earthquake, observations from the ocean bottom pressure recorders, knowledge of coastal bathymetry and use of appropriate models. Satellite altimeters do observe the sea level variability but lack spatial and temporal coverage necessary to be useful operationally in the detection of tsunami.

Hydrometeorological disasters include cyclones, storm surges, tornadoes, floods, droughts and forest fires. Earth observation data, in particular microwave data has been extensively used in mapping flood inundation areas. Early warning of floods requires advance forecast of precipitation, its quantum, knowledge of topography, soil properties, dense network of river gauges and high-resolution digital elevation models. Remote sensing satellites do provide information on some of these parameters. Advance prediction of rainfall, its quantum, rate and certainty is still a challenge. Flash floods are entirely a different story. Prediction of cyclone track, landfall and intensity is greatly facilitated by the space observations. Geostationary platforms are providing an ideal platform to have constant eye on the genesis, growth and movement of these systems. Over the decades, improvements in the prediction of landfall points and in advance have helped greatly in reducing the human causalities although perhaps not in the loss to property. Remote sensing data have been extensively used in drought monitoring and its severity assessment. Early warning of impeding drought is clearly linked to the short, medium and long-term prediction of rainfall at different spatial scales. Detection of forest fire, estimating the extent of fire-damaged areas and identifying fire-prone areas are now routinely addressed by satellite data.

Earth observation data has been extensively used in many disaster situations for damage assessment and in taking up mitigation measures. However their role and efficacy in building early warning systems has been varied depending on the complexity of physical phenomenon that lead to the onset/trigger of that particular disaster. Satellites do not provide all the measurements required and, even if they do, they are not necessarily at the required spatial and temporal resolutions. It is necessary to identify specific sensors for different observations. Optical and near-infrared band data can map land use or assess agricultural droughts. Detection of thermal anomalies requires sensors operating in thermal infrared region. They also need to have necessary sensitivity to detect temperature differences of the order of a fraction of a degree. Floods are generally accompanied by cloud coverage of the region. So, mapping flood inundation would necessarily demand microwave data. To identify cyclone's eye which is essential to accurately predict its track, it is necessary to have a microwave sensor. Landslide studies depend on accurate high resolution digital elevation models, which require data collected by stereo viewing optical sensors or interferometric synthetic aperture radars or light detection and ranging instruments. Better prediction of weather phenomena requires knowledge of temperature and humidity profiles through sounding instruments.

There is often an awkward trade-off between temporal and spatial resolutions. Monitoring of natural disasters demands detailed and continuous data. Geostationary satellites provide data over large areas every half an hour and are appropriate for detecting, monitoring and providing early warning for some of the meteorological disasters such as tropical cyclones. However, they do not provide adequate spatial and spectral resolution for most of the other disasters. Polar sun-synchronous satellites provide global coverage and data with adequate spatial and spectral resolution and are appropriate for detecting and monitoring a disaster event as well as for assessing damage due to floods, fires, landslides, etc. However they lack adequate temporal resolution. Satellites with microwave payloads provide information over cloud-covered regions. However they are very few in number to be at the place of disaster at the right time. Satellites with specific payloads for early warning of natural disasters like those monitoring subtle changes in surface topography, detecting thermal, magnetic and gravity anomalies and specific earthquake precursors are very few in number and grossly inadequate for operational use. A possible constellation should include two SAR and three optical missions, i.e. five satellites in a plane. There should be agile satellites as well with better revisit ability providing high resolution. This two SAR-3 optical satellites constellation in one plane can lead to 60% global coverage by optical payloads and 40% global coverage by microwave on a daily basis. Repetition of this pattern in 4-planes ensures revisit period of 3 hours.

The International Charter on Space and Major Disasters supported by major space agencies aims at providing a unified system of space data acquisition and delivery to those affected by natural or man-made disasters through authorized users. Sentinel-Asia, UN-SPIDER and GMES–SAFER are other initiatives. Disaster Monitoring Constellation, a concept initiated by the Surrey Satellite Technology Limited, is attempting to build a series of small satellites dedicated to disaster monitoring. No single space agency may have the resources to build the constellations necessary to meet the needs on its own. So, it is important to build virtual constellations in a collaborative mode by different space agencies. It is also necessary to build systems to make available value added products and services in near real-time. Strengthening of emergency communication infrastructure, adopting more generous data sharing policy at international level, development of decision support tools and capacity building at different levels to ensure proper utilization of what space offers are necessary. Development of sensors and systems to provide critical observations/precursors is necessary. But more importantly understanding the physical processes, and building credible early warning models is need of the hour.

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