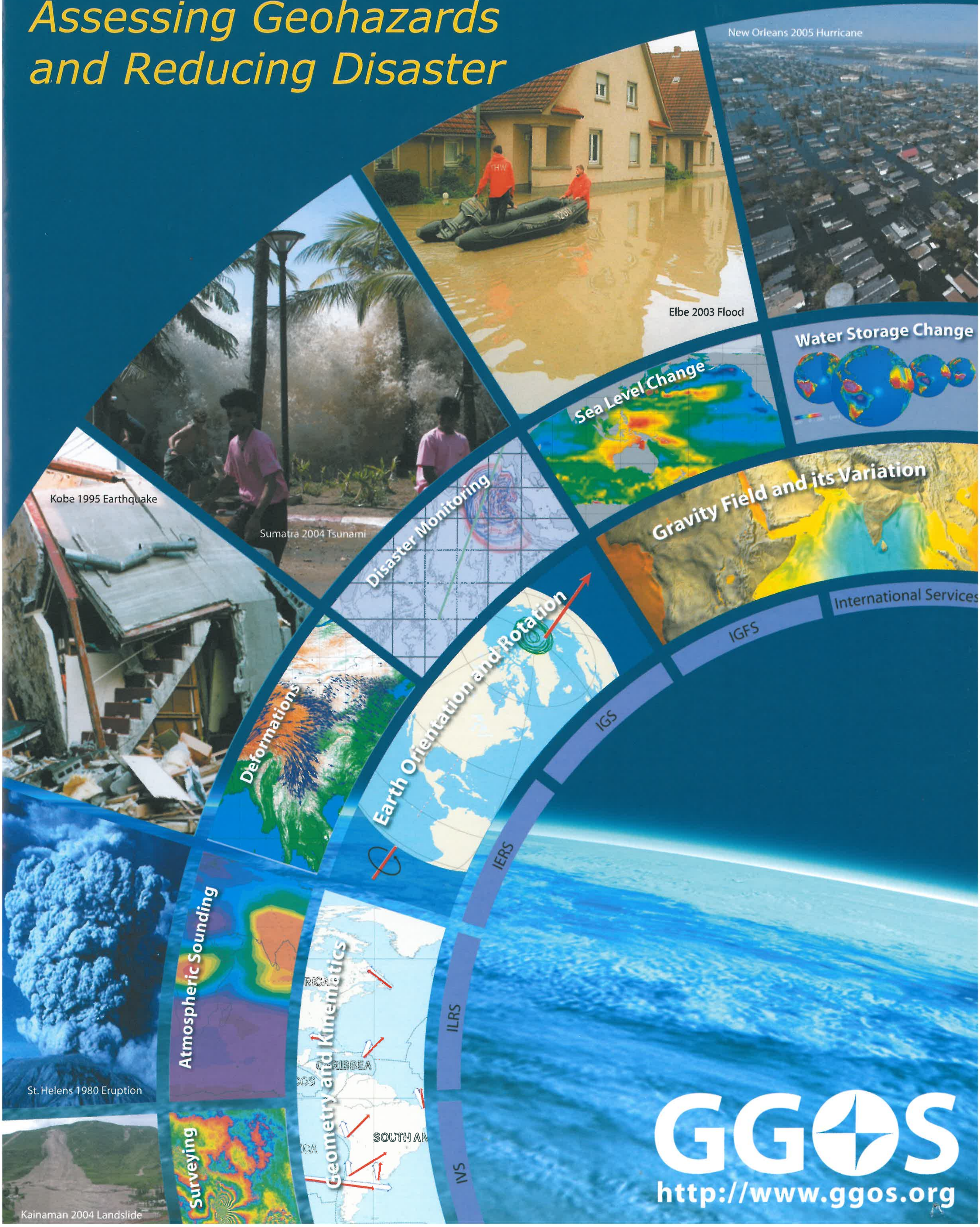
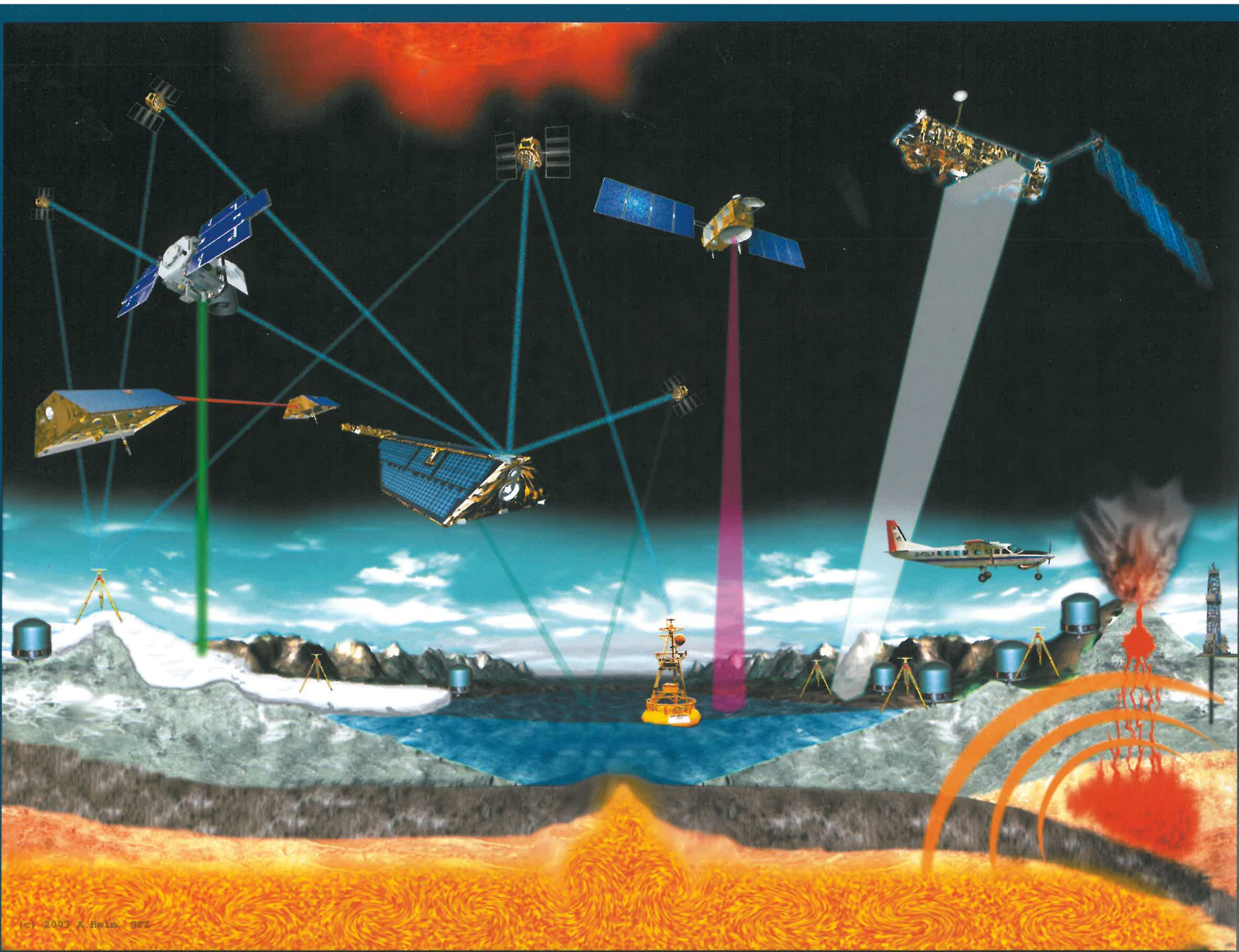
THE GLOBAL GEODETIC OBSERVING SYSTEM

Assessing Geohazards and Reducing Disaster





LANDSLIDES, ROCK FALLS AND SUBSIDENCE

Landslides are a major hazard causing many fatalities and significant damage in many locations. In the past century (1903-2006), landslides killed more than 60,000 people globally, affected more than 10 million people (many of them homeless after the event), and caused damage on the order of 5 billion dollars. Many landslides take place in widespread areas of slope instabilities caused by severe storms, earthquakes, volcanic activity, coastal wave erosion, and wildfires. Landslide danger may be high even as emergency personnel are providing rescue and recovery services. Often, earthquakes are accompanied by landslides, rockfalls, and other surface disruptions that can cause as much or more damage to anthropogenic structures and systems than the earthquakes themselves. These events are difficult to predict, but depend on recent weather conditions (i.e., precipitation and soil moisture), as well as land cover, topography, and earthquake recurrence interval. Steep topography near lakes and fjords has the potential of large waves caused by rockslides into the water below and pose a potential threat in some areas. Moreover, in many mountainous areas, the steep hill sides are a potential threat for the people living at the base of these slopes or for the infrastructure at the bottom of such hills. In many areas, slop slides or slow landslides pose a problem, too.

In order to provide accurate landslide hazard maps, forecasts of landslide occurrence, and information on how to avoid or mitigate landslide impacts, several questions must be considered: Where and when will landslides occur? How big will they be? How fast and how far will they move? What areas will they affect or damage? How frequently do they occur in a given area?

Measurements of surface displacements are crucial for answering these questions. In known instable areas, networks of campaign-type or permanent GNSS stations can be used to detect a change in the motion and thus indicate a potentially perilous situation. However, the recurrence period of land- and rockslides can be long and in many areas the risk is not obvious. InSAR is an emerging technology that allows the determination of surface deformation with high spatial resolution and accuracy in many regions. InSAR is expected to play a leading role in the detection of geohazards and the monitoring of hazardous areas. In particular, the combination of permanent GNSS stations with InSAR is expected to improve the time series of deformation measurements considerably.

VOLCANO ERUPTIONS

Volcanic eruptions are comparable to landslides in number of fatalities and extent of damage. Volcanic eruptions have local to global impacts, and are typically presaged by directly observable events, including seismicity, gas release, and surface deformation. Modern volcano monitoring systems integrate localized monitoring components and remote sensing.

GNSS and gravity measurements are integral parts of any monitoring system of potentially hazardous volcanoes. The combination of these measurements provides a basis for understanding the dynamics of subsurface magma movements and the development of hazardous situations. Surface displacements can indicate magma movements not necessarily associated with increased seismicity.

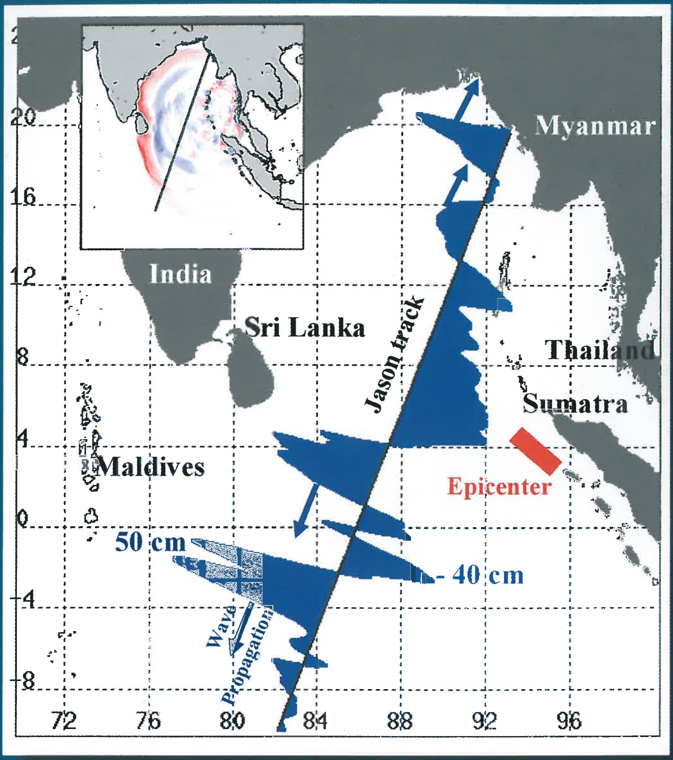
Increasingly, InSAR is applied to the monitoring of volcanoes. However, for early warning purposes, the combination with local GNSS networks is crucial. Unfortunately, many of the hazardous volcanoes are not or not sufficiently monitored. The development of relatively cheap disposable GNSS stations would be an advantage at hazardous volcanoes.

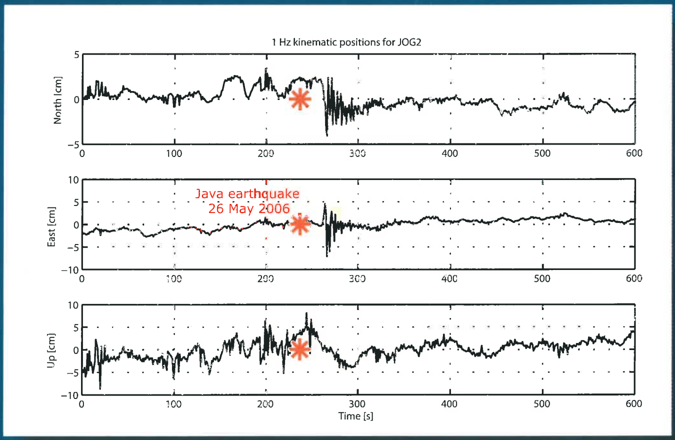
EARTHQUAKES

Earthquakes are a major source of disasters which over the last hundred years (1903-2006) killed nearly 2 million people, affected nearly 100 million people, and caused damage of more than 300 billion US dollars. Increasingly, megacities are developing in areas prone to experience major earthquakes, so making disasters more likely. As in the case of volcano monitoring, local in situ observation systems are increasingly supplemented by continuous and broad scale networks such as the Plate Boundary Observatory (PBO) in the U.S. The GNSS networks provide fundamental observations of the deformation process during the complete earthquake cycle from preseismic to co- and postseismic deformations. Hence, strain rates determined from geodetic observations are increasingly used in hazard assessments. Moreover, image techniques such as InSAR are increasingly supplementing the ground-based techniques.

Much of the geodetic infrastructure is currently focused on research related to the processes causing earthquakes. Increasingly, the geodetic networks also support the rapid detection of earthquakes for early warning and damage reduction (e.g., by rapid shutdown of gas pipelines, stalling of traffic on roads and railroads, shutting down of nuclear power plants, etc. This application requires real-time detection of ground motion with reaction times in the range of a few seconds), as well as rapid damage assessment in support of rescue.

Seismic hazards can also result from mining, filling of reservoirs, and extraction of oil and gas. In order to detect seismic hazards induced by mining, monitoring of the strain rates in the mining area is the appropriate tool. The seismic hazard associated with the filling of large reservoirs is thought to be caused by changes in the subsurface pore pressure and not the loading-induced stress.





TSUNAMIS

Tsunamis are generated by submarine earthquakes, landslides and volcanic eruptions. Although tsunamis are frequent, most have small amplitudes (a few centimeters) and do not pose any danger for coastal areas. Only large earthquakes (moment magnitude greater than 7.5) with an epicenter at shallow depth can excite tsunamis which can result in dangerous coastal wave heights larger than a few meters. Generation of tsunamis by earthquakes is therefore restricted to submarine seismogenic regions with shallow and potentially large earthquakes. However, knowledge of the location of these faults is not sufficient to identify all potentially hazardous areas. Therefore, an important task is the detection of potentially hazardous regions in the ocean.

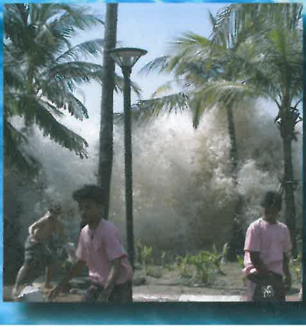
Over the last hundred years, most of the large earthquakes with magnitudes of 8.5 and larger, which are potentially responsible for devastating ocean-wide tsunamis, were located around the Pacific Ocean. However, large tsunamis can also originate in other regions. Smaller tsunamigenic earthquakes occur in many other regions (e.g., the Mediterranean and the Caribbean), and pose a danger for nearby coastal areas. Submarine landslides can happen in large areas of the continental shelves, where sufficient sediments have accumulated to allow turbidity currents to form. In some areas of steep topography and appropriate geology, rockslides can occur. Coastal landslides can result in large waves if sufficient material is involved.

Knowledge of the tsunamigenic source locations is only a first step in establishing the tsunami hazards for a given coast. Most tsunamigenic sources have strong anisotrophy in the propagation of tsunami energy away from the source. Consequently, the tsunami hazard at any point on a coast depends not only on the distance to potential sources, but also the direction with respect to the propagation pattern for a particular source. Moreover, the shape of the coast, its topography and the bathymetry of the ocean basin between the coast and the source are important factors determining the tsunami hazard. Tsunami hazard maps, and more generally, sea level hazards maps, are necessary for planning of a reliable and economically feasible sea level hazard observing system. The experience gained in establishing the Global Seismic Hazard Map, the Global Stress Map, and the Global Strain Map can help in developing the required methodology. Geodetic observations of the kinematics of the Earth's surface that allow the determination of the strain field near subduction zones, are an important input to this hazard assessment.

Geodesy also comes in with respect to the monitoring required for any early warning system. A rapid and precise quantification of earthquake sources is central to tsunami warning systems, because tsunami models are initialized by assuming a displacement field of the ocean floor. After the 2004 Sumatra tsunami, at least seven large undersea earthquakes occurred. Large-scale tsunami warnings were issued for five of them (Nias, March 2005, M 8.7; West California, June 2005, M 7.1; Tonga, May 2006, M 7.8; Kuril Islands, November 2006, M 8.3; and Kuril Islands, January 2007, M 8.1). Although these warnings caused panic in surrounding countries, the events did not generate significant tsunamis. However, the July 2006 West Java event with a magnitude of 7.7 and the April 2007 Solomon earthquake with magnitude 8.0 each generated unexpectedly large local tsunamis that killed more than 600 and 30 people, respectively. In addition to earthquake-magnitudes derived from seismometers static co-seismic displacements determined from GPS stations in the near-field of earthquakes can be used to yield realistic low-latency (order 15 minutes) estimates of the seismic moment and displacement field of the event. This information would be a valuable addition to tsunami warning systems for devastating oceanwide tsunamis. At co-location site, high-rate GNSS measurements monitoring the surface motion during the earthquake may complement the seismometer data.







DISASTERS: REDUCING LOSS OF LIFE AND PROPERTY FROM NATURAL AND HUMAN-MADE DISASTERS

One of the most important services that science can provide to society is understanding, predicting, and reducing of vulnerability to natural hazards. These can be divided into those stemming from the dynamics of the fluid envelope of the Earth such as storms, storm surges and floods, those stemming for the dynamics of the solid Earth, such as earthquakes, volcanoes, sinkholes, subsidence, precarious rocks, rockslides, and landslides, and those resulting from interaction of the solid Earth with its fluid envelop, in particular tsunamis triggered by earthquakes, rockslides, volcanic eruptions, and submarine landslides.

In disaster prevention and mitigation, Earth observations are pivotal in at least three aspects:

1. understanding the processes causing these hazards and assessing their risks for planning and mitigation,

2. monitoring the development of hazardous situations and providing a basis for a decision on early warnings, and

3. determining the extent of a disaster as support for rescue and damage assessment.

The first two aspects are central for early warning systems. A comprehensive and effective early warning system requires four elements, namely

- risk knowledge: a priori knowledge of the likely risk scenarios a community might be faced with;

- monitoring and warning service: the capacity to monitor risks and rapid and reliable decision mechanisms for early warning;

- communication: the ability to disseminate understandable warnings to those at risk;

- response capability: knowledge and preparedness capacity by all partners of the information chain to act appropriately.

GEODESY AND GEOHAZARDS

Geohazards are intimately connected to displacements and deformations of the Earth's surface. Consequently, geodetic observations play a crucial role in all three aspects of disaster prevention and mitigation, including risk knowlegde and the monitoring of hazardous situations required for the implementation of early warning systems. The importance of geodetic observations for these hazards has been emphasized by many. The IGOS-P Geohazards Theme report states that "Geohazards driven directly by geological processes all involve ground deformations. Their common observational requirements are for global, baseline topography and geoscience mapping, against which surface deformations ... can be monitored." Thus, the observations provided by existing global and regional geodetic networks have already transformed our understanding of geohazards, and it is likely that these networks will play an even more important role in the future as their coverage and precision improve. In many regions, observing systems dedicated to geohazards would also have to be flexible in spatial and temporal resolution, as well as readiness on demand. Therefore, in many parts of the world, dedicated ground-based geodetic networks are needed. In addition to the classical, point-oriented geodetic techniques, 2-dimensional imaging techniques such as InSAR are also needed. These techniques allow the monitoring of relevant areas with high spatial resolution, although currently not with the low latency and temporal resolution required for some geohazards applications.

Surface displacements are related to both mass relocations on the surface and geodynamic processes in the solid Earth. Surface displacements are caused, for example, by earthquakes, tectonic processes, magma flow in the crust, and anthropogenic ground water changes. Thus, information on surface displacement provides a basis for, for example, scientific studies of geohazards, hazard assessment, early warning, and resource management.

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