# Improved Observations for Disaster Reduction: Near-Term Opportunity Plan

UNITED STATES GROUP ON EARTH OBSERVATIONS

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## 1. PREFACE

This plan was prepared jointly by the U.S. Group on Earth Observations[1] and Subcommittee on Disaster Reduction[2] and is one of six near-term opportunities identified in the *Strategic Plan for the U.S. Integrated Earth Observation System.*[3] Near-term opportunities in this context are: identifying observing systems or integration of components that meet high priority societal needs, are making improvements to inadequate existing systems that can be completed within 5 years and have tangible, measurable results. Further, the plans provide a framework for prioritizing actions and addressing critical gaps that will maximize the return on investments. The near-term opportunities are:

- Improved Observations for Disaster Warnings (published September 2006);
- Global Land Observation System (in development);
- Sea Level Observation System (in development);
- National Integrated Drought Information System (published September 2006);
- Air Quality Assessment and Forecast System (published September 2006); and
- Architecture and Data Management (in development).

## 2. THE OPPORTUNITY

Observations are integral to reducing losses from natural hazards and improving resilience by producing information that is needed throughout the disaster cycle: from forecasts and warnings to facilitating pre-event deployment and rapid response. These vital data are also required to support the longer-term processes of mitigation, land-use planning, recovery, and rebuilding.

In order to emphasize the need for earth observation systems to fit within an integrated, end-to-end, disaster reduction framework, multi-hazard demonstration projects are proposed for two regions at high risk: the Pacific states and the Gulf of Mexico coast. These projects are a means to show rapid progress with modest investments, thereby demonstrating proof of concept with benchmarks for success in areas vulnerable to catastrophic natural hazard events. Figure 1 illustrates the observation systems that will be brought to bear in the demonstration projects to deliver the following products and services:

- Real-time earthquake information delivery for targeting rapid emergency response;
- Improved tsunami and coastal inundation forecast and warning capability;
- Rapid detection of conditions allowing forecasting of volcanic eruptions, especially ash-forming events endangering aviation; and
- Prototype early warning system for debris flows and landslides in wildfire-impacted areas.

These observation systems were identified as key gaps in the U.S. Integrated Earth Observation System (IEOS) planning process:

- Ground-based networks have consistently been identified as either not extensive enough or in danger of serious deterioration over the next decade. Although new technology is available to improve observation capabilities for hazard loss reduction, the challenge is to deploy these systems to provide systematic, widespread coverage for regions with significant risk.
- High-resolution digital topography emerges as a key unmet need for many hazards. The most widely cited inadequacy in satellite data is lack of access to Synthetic Aperture Radar (SAR) data to provide all-weather day/night imaging, monitor surface deformation, and determine inundation extent.

In addition to the multi-hazard demonstration projects, the near-term opportunity emphasizes the need for integrated earthquake and coastal inundation observation systems to close these gaps nationwide. A final section on Next Steps identifies longer-term opportunities in wildland fire assessment and the next-generation geodetic network, calling for near-term progress in planning to take advantage of future opportunities.

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[1] The United States Group on Earth Observations (USGEO) was established in March 2005 as a standing subcommittee of the National Science and Technology Council Committee on Environment and Natural Resources.

[2] Chartered in 1988, the Subcommittee on Disaster Reduction is a subcommittee of the Committee on Environment and Natural Resources, an element of the President's National Science and Technology Council.

[3] http://usgeo.gov/docs/EOCStrategic_Plan.pdf

The multi-hazard observation system opportunities include integration of existing data management systems across regional, multi-agency, multi-state as well as multi-hazard data systems for access. These projects will work together to provide interoperability, common metadata, and consistent data policy to ensure the robust data management capabilities and requirements needed for successful demonstration.

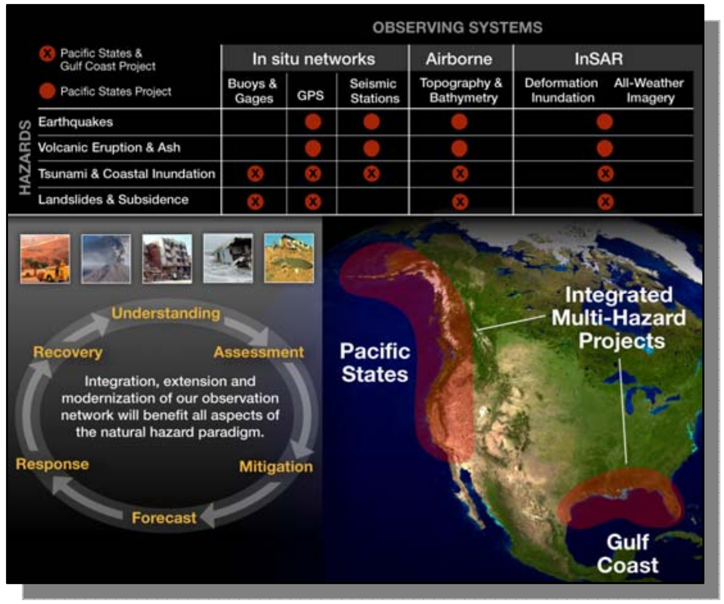

Figure 1. Integrated multi-hazard demonstration projects

The principal agencies involved in this NTO are the National Aeronautics and Space Administration (NASA), the National Oceanic and Atmospheric Administration (NOAA), the National Science Foundation (NSF), and the U.S. Geological Survey (USGS). The ultimate ability of hazard observation systems to deliver any societal benefit depends on close cooperation with the Federal Emergency Management Agency (FEMA) and its state and local counterparts. Other participating agencies include the U.S. Army Corps of Engineers (USACE), the Environmental Protection Agency (EPA) and U.S. Department of Agriculture Forest Service (USFS).

### 2.1 Why Now?

From the Indian Ocean to the Gulf of Mexico, we are continually reminded of both the tragedy and the wide-spread economic consequences of low-probability but high-risk extreme events. Hurricanes Katrina and Rita demonstrated this in all-too-graphic terms, with more than a thousand dead[4] and millions more displaced from their homes,[5] the most since the U.S. Civil War.[6] These high-risk disasters devastate local lives and economies. They also produce a significant strain on the public treasury. Katrina's cost is estimated to rise to an excess of $100 billion[7] and the nation's projected Gross Domestic Product this year will be significantly reduced as a result of the storm.[8] To cope with these costs, governments must displace other important public priorities. While Katrina was certainly extreme in its impacts, the risk it posed was not unique.

Unfortunately, we cannot reduce the number of extreme events like Katrina, but we can and must reduce the short-term and long-term public costs associated with these events. Important steps in doing so are network modernization and improved system integration. These steps will provide decision-makers with improved forecasting, which in turn supports risk assessment, improved mitigation strategies, and rapid warnings so lives can be saved and disaster averted. The National Science and Technology Council's Subcommittee on Disaster Reduction June 2005 report, *Grand Challenges in Disaster Reduction*, identifies six themes in moving towards a disaster resilient society. Implementing the Near-Term Opportunities identified in this document will make substantial progress on the first three:

1. Provide hazard and disaster information where and when it is needed;
2. Understand the natural processes that produce hazards; and
3. Develop hazard mitigation strategies and technologies.

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[4] CNN, "Katrina's Official Death Toll Tops 1,000," September 21, 2005.
[5] New York Times, "Miles of Traffic as Texans Heed Order to Leave," September 23, 2005; ABC News, "Life's OK – 'But it's Not New Orleans," February 26, 2006
[6] *National Science Teachers Association WebNews Digest*, "Educators Respond to Teaching Crisis Caused by Recent Hurricanes;" November 2, 2005.
[7] *Washington Post*, "*Two-Thirds of Katrina Donations Exhausted*;" February 27, 2006.
[8] *BusinessWeek Online*, "Katrina's 'Unique' Economic Impact," September 7, 2005.

**Earthquakes** represent the largest single potential source for casualties and damage from a natural hazard in the United States. The Indian Ocean disaster underscored U.S. vulnerability to earthquakes of similar size along the coast of the Pacific Northwest and Alaska, and brought home the risk posed by infrequent but catastrophic events. The $40 billion cost of the magnitude-6.7 Northridge earthquake in 1994 demonstrated the impact that a considerably smaller event can have on an urban area.[9]

**Coastal inundation** due to tsunamis and severe storms, including hurricanes, is a leading cause of public (i.e., National Flood Insurance Program) and private casualty insurance losses in the United States. The December 2004 Indian Ocean tsunami, the 2004 Atlantic tropical storm season (insured loses more than $22 billion in 16 states and Puerto Rico, affecting nearly 2.5 million policyholders),[10] and the flooding of New Orleans from Katrina merely serve to underscore the severity of these events and their effects on lives, the economy, and the environment.

**Volcanoes** The United States is also one of the most volcanically active countries in the world. Approximately 103 U.S. volcanoes pose moderate or greater threats to people, property, and infrastructure on the ground, and to jet aircraft in the air.[11] Increasing air transport in the northern Pacific region, plus expanding population and infrastructure, mean that our exposure to volcanic hazards is increasing.

**Landslides and subsidence** affect every sState, causing more than $1 billion worth of damage and more than 25 deaths each year,[12] as well as threatening critical infrastructure and housing. An additional complication from wildfires, which can cause devastation over vast areas of land, is their effect on slope stability. On December 25, 2003, flooding and debris flows from recently burned hillslopes in California resulted in the death of 16 people, and damages totaling $26.5 million for road repair and other flood damage clean-up and reconstruction areas, including the removal of 4.1 million cubic meters of material deposited in debris-retention basins.[13]

In addition to humanitarian concerns, international disasters also adversely impact the U.S. economy by disrupting production and supply. These effects are felt with increasing speed and severity due to globalization. The development of effective warning systems for disaster reduction in the United States also will function to help our economy become more resilient to disasters abroad.

### 2.2 Major Components

Delivering the products and services identified for this near-term opportunity will require the integration of several existing and proposed systems. Integration is facilitated by the fact that individual components of the observing system service multiple hazards. Table 1 identifies the hardware components, data management capabilities and requirements, and associated modeling capabilities and requirements needed. These components contribute to integrated systems for earthquakes, tsunami and coastal inundation, volcanoes, and a prototype system for debris flows. The list also includes those components required to ensure interoperability and hardening of communications and warning systems, critical factors for systems to successfully meet their intended mission goals, as graphically demonstrated by the communications failures associated with Hurricane Katrina. Finally, the table notes those components that provide consistency in how information is communicated, recognizing the importance of delivering hazard information in a manner that has maximum utility for first-responders and others on the front lines of disaster management.

In order to integrate the data, information, and tools needed for emergency managers and other key customers, a portal will be established, making use of existing systems where possible. When it comes to hazards, emergency managers will be on the front lines and must have the capabilities at hand to provide information where and when it is needed. This portal will provide an Internet window into essential information, service, and application assets.

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[9] PBS, "*Savage Earth: Learning from Earthquakes*"
[10] http://www.nbc6.net/weather/3766401/detail.html
[11] Simkin, T. and Siebert, L., *Volcanoes of the World*; Geoscience Press, Inc., Tucson Arizona
[12] http://landslides.usgs.gov/
[13] Hungr, O. and Jacob, M. *Debris-Flow Hazards and Related Phenomena*, Spring-Praxis Books in Geophysical Sciences, p. 321-344.

| *Major Components* / *Products and Services* | Rapid earthquake information delivery for improved response | Enhance tsunami and coastal inundation forecast and warning capability | Rapid detection of volcanic eruptions , especially ash-forming events affecting aviation | Prototype debris-flow early warning system for wildfire-impacted areas. | Ensure interoperability and hardening of communication and warning systems | Provide consistency in how information is communicated |
|---|---|---|---|---|---|---|
| **Hardware components** | | | | | | |
| Improved array of deep-ocean tsunami detectors; coastal ocean buoys; coastal tide, water-level, and stream gauges feeding real-time data into online forecast models | | X | | | X | X |
| Modernized, real-time seismic network infrastructure | X | X | X | | X | X |
| Interferometric synthetic aperture radar (InSAR) satellite targeted for land deformation | X | X | X | X | | |
| Develop and deploy airborne repeat-pass InSAR capability to monitor seismic/volcanic targets and inundation events | X | X | X | X | | |
| Continuity of moderate-resolution imaging capabilities | | X | X | X | | |
| Dense streamflow and precipitation gauge deployment in burned areas for monitoring debris-flow conditions | | | | X | | |
| Integrated, real-time observation capabilities for high-threat volcanoes (continuous strain recording, explosion detection, gas sensors, acoustic lahar detectors) | | | X | | X | X |
| Upgrade/modernize geodetic (GPS and reference) networks to provide integrated and systematic performance | X | X | X | X | X | X |
| Surveys and mapping for high-resolution topography and shallow bathymetry | X | X | X | X | | |
| Robust, broadband telemetry and data transmission infrastructure | X | X | X | X | X | |
| **Data management capabilities and requirements** | | | | | | |
| Collaborative international operations. Enhanced use of international observing capabilities to supplement U.S. satellites. Enhancement of International Charter on Disasters to encourage pre-event monitoring of hazards (e.g. restless volcanoes) for which there are precursory signals | X | X | X | X | X | |
| Implementation of applicable data exchange mechanisms and standards among all regional, national and global all-hazard warning systems. Participation in the Common Alerting Protocol (CAP) | X | X | X | X | X | X |
| Multi-hazard SAR/InSAR data management and processing system with automation | X | X | X | X | X | |
| Apply GIS-based and other Decision Support System formats with appropriate reference datums for forecasts and warnings | X | X | X | X | X | X |
| Ensure adequate archiving systems in place to ensure continued utility of observation data | X | X | X | X | X | |
| **Associated modeling capabilities and requirements** | | | | | | |
| Develop community-level models for risk and vulnerability assessments | X | X | X | X | | X |
| Develop improved models for interpretation of surface deformation to better constrain characterization of geophysical processes | X | X | X | X | | |

Table 1. Major components required for NTO products and services

## 3. GULF OF MEXICO INTEGRATED MULTI-HAZARD DEMONSTRATION PROJECT

The Gulf of Mexico region is particularly vulnerable to the devastating impacts of coastal inundation, whether seismic or meteorological. Tsunami-related inundation is a concern, with possible slumping of the Puerto Rico Trench in the Atlantic Ocean affecting the Caribbean and Florida as well as the south Atlantic, and possible secondary impacts in the Gulf region. Hurricane Katrina's record 28-foot storm surge[14] and widespread catastrophic flooding underscore the vulnerability of this low-lying region to inundation, whether seismic or meteorological. The region's critical coastal infrastructure (oil and gas platforms and refineries [1.5 million barrels produced per day][15] ports, hospitals, etc.) is extremely vulnerable to these impacts. FY2004 and 2005 were extremely active years for coastal flooding.

The President's Ocean Action Plan (OAP) calls for an effort led by the National Science and Technology Council Joint Subcommittee on Ocean Science and Technology to coordinate Federal and Federally-supported mapping activities for the U.S. coastal and ocean environment. The OAP calls for establishing the Global Earth Observation System of Systems (GEOSS) and the U.S. coastal component, the Integrated Ocean Observing System (IOOS). The OAP also calls for a special interagency partnership with the governors of the five Gulf of Mexico (GOMEX) states (Texas, Louisiana, Alabama, Mississippi, and Florida). Given these priorities and the region's vulnerabilities, GOMEX is the most appropriate regional demonstration site for the effective updating and linking of Coastal Digital Elevation Models with coastal observing systems.

By integrating and utilizing multi-hazard observing systems, decision-makers will be better informed and prepared to handle potential disasters. The GOMEX project will demonstrate the efficacy and viability of multi-hazard observing systems, including enhancing the network of elevation benchmarks (i.e. Continuously Operating Reference System (CORS), coordinating shallow water bathymetric surveys (e.g. Light Detection and Ranging, or LiDAR), and developing storm surge and flooding models using existing and new data and observations in high risk areas.

### 3.1 Existing Components

In Fiscal Year (FY) 2005, NOAA undertook a needs assessment to understand the requirements of interoperable observations, models, and decision support tools to improve storm-related planning, response, and recovery in northern GOMEX. Program and budget partners include USGS, Department of Interior Minerals Management Service, FEMA, USACE, and EPA. The FY 2006 budget for the IOOS broadens the focus on accelerating coastal inundation forecasting, buoy system improvements, next generation storm surge model development, and data transformation tool development for the Gulf of Mexico. This will include leveraging USGS investments in stream gauge enhancements, as well as USACE wave gauge installations in the Gulf of Mexico region.

### 3.2 Additional Components Required

An *all-hazards* approach will be undertaken through regional and product expansion of the application of interoperable observations, models, and decision-support tools to improve planning, response, and recovery. This expansion will include:

- NOAA's Coasts, Estuaries, and Oceans (CEO) and MTS programs enhancement of the buoy, C-MAN and water-level station networks in the FY 2007 – 2011 timeframe;
- NOAA intends to develop a GOMEX Coastal Hazards Information Center to leverage the geospatial capabilities within the region and facilitate the extension of coastal hazards planning and mitigation;
- NOAA's Coastal Storms Program will begin a regional demonstration that will provide enhanced observations, inundation models, and decision-support tools to aid in coastal hazards forecasting, planning and mitigation;
- USGS is proposing vulnerability assessments of hurricane-threatened U.S. coasts to different hurricane types and intensities; and
- Increased coastal LiDAR surveying – a joint effort by NOAA, USGS, NASA and USACE.

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[14] http://www.magazine.noaa.gov/stories/mag178.htm
[15] http://api-ec.api.org/media/index.cfm?objectid=134704E4-9EF8-4392-A41CC2E202D8FC61&method=display_body&er=1&bitmask=001007006000000000

## 4. PACIFIC STATES INTEGRATED MULTI-HAZARD DEMONSTRATION PROJECT

The states bordering the Pacific Ocean face the full range of natural hazards targeted in this near-term opportunity. Demonstration projects will focus initially on southern California and the Pacific Northwest but with clear applicability to the rest of this restless region.

For FY 2007, a multi-hazard demonstration project is being proposed in southern California to integrate information with products about several hazards to improve the usefulness of the information in reducing losses. Southern California represents half the earthquake risk in the United States, with numerous faults capable of generating losses topping a quarter trillion dollars; but it also is at risk for flash floods, wildfires and resulting debris flows, and coastal hazards including vulnerability to tsunamis. Scientists at USGS and Federal partner agencies, particularly NOAA and FEMA, will work with emergency managers and the public to develop the integrated information products that individuals need to prepare for and recover from natural disasters. This will be accomplished by merging information and products about disparate hazards into decision-support products that are more user-friendly and support land-use planning, hazards mitigation, emergency response, and business recovery. This project is intended to be a model for future efforts in other regions.

As a key part of this project, USGS and NOAA will cooperatively develop and operate a prototype flash flood and debris-flow warning system for burned areas within southern California. The prototype initially will utilize the National Weather Service Flash Flood Monitoring and Prediction operational framework for meteorological data analyses, comparison with rainfall intensity-duration thresholds, and information and warning dissemination. The system also will include a new capability to provide map results on a publicly available risk-assessment and early warning website, updated throughout significant storm events.

Tsunamis are also a concern for southern California, particularly the need for adequate warning in this heavily populated region. The NOAA Coastal Storms Program (CSP) makes inundation and flooding products a major focus. The CSP southern California effort began in 2005 and is funding development of datum transformations for the region. Products should be available by 2008.

The Pacific Northwest is home to some of the highest-threat volcanoes in the nation and represents a near-term opportunity to demonstrate the value of strengthening integrated observation capabilities to address that threat. The re-awakening of Mt. St. Helens in September 2004 was a reminder of the awesome power of volcanic eruptions, their potential to devastate adjacent areas, and to threaten aviation. Where monitoring instruments and methods are in place at a hazardous volcano *in advance of the onset of unrest*, communities at risk can be forewarned with sufficient time and information to undertake mitigation measures.

In April 2005, the USGS released a report (USGS Open-File Report 2005-1164) that systematically assessed the relative threat posed by all young volcanic centers in the U.S. and its territories to set priorities for the greatest improvement in public safety. The report identified 103 U.S. volcanoes as posing high to moderate threats to life and property and called for establishing a National Volcano Early Warning System (NVEWS) to address serious monitoring gaps and bring high-threat volcanoes up to a level of monitoring commensurate with the threats they pose. Seven of the ten highest threat volcanoes are located in the Pacific Northwest, and all of them have significant observation gaps that must be considered when deciding whether to provide some monitoring at lower threat volcanoes. The seven include Mt. St. Helens (WA), Rainier (WA), Hood (OR), Shasta (CA), South Sister (OR), Lassen (CA), and Crater Lake (OR). Although of lesser threat, it may also be important to monitor Baker (WA) and Glacier Peak (WA).

The NVEWS report primarily evaluates the need for *in situ* (seismic, deformation, gas, hydrologic) monitoring, but also indicates where remote-sensing support is needed. Testing models of volcanic behavior and making reliable forecasts of events requires an integrated observation system including GPS, digital broadband seismometers, digital telemetry, the Internet, InSAR, and a new suite of physico-chemical sensors. Table 2 in the Appendix focuses specifically on filling the gaps to enable rapid detection of volcanic eruptions and ash-forming events endangering aviation.

## 4.1 Existing Components

The southern California component of this demonstration project builds on existing dense seismic and geodetic networks in the region supported by USGS, NSF, NASA and the State of California. The USGS and its partners operate the California Integrated Seismic Network, the Southern California Integrated GPS Network, and a flood-monitoring system. Reimbursable funding from USFS funded studies of the ecologic impacts of the 2003 fires. USGS recently acquired a LiDAR dataset of the southern San Andreas fault in partnership with NASA. The project also takes advantage of an extensive earthquake modeling cyberinfrastructure through the Southern California Earthquake Center, a university consortium jointly supported by NSF and USGS.

Responsibility for monitoring volcanic unrest and activity in the United States rests largely with the Volcano Hazards Program of the USGS. Tracking of volcanic ash and aerosol clouds is conducted by NOAA in cooperation with the USGS, with the Washington and Anchorage Volcanic Ash Advisory Centers (VAAC) having primary responsibility for issuing warnings to the Federal Aviation Administration (FAA). Recent efforts by the USGS have expanded monitoring networks, especially in the Aleutian Islands, so that 50 volcanoes now are tracked by monitoring networks. However, there still are many volcanoes where monitoring is either lacking or suboptimal. Also, responsibility for these networks is dispersed among five volcano observatories, and the existing networks are not fully integrated at the national level.

## 4.2 Additional Components Required

As with the Gulf of Mexico project, an *all-hazards* approach will be undertaken, to include:

- Improved streamgauge and precipitation alert sensors for a prototype flash flood and debris flow warning system for burned areas within southern California;
- An integrated GIS system developed by USGS in cooperation with emergency managers of FEMA, OES, and the counties to make their science more useful;
- Tools that local and state emergency managers can layer in their own GIS systems to map hazards to their facilities;
- Modern seismic and geodetic networks in southern California to conduct focused hazard characterization efforts on the southern San Andreas Fault;
- NOAA and USGS inundation and flooding models and products for southern California; and
- Expanded USGS volcano monitoring networks in the Pacific Northwest, as laid out in the NVEWS report; including interferometric SAR as a means of monitoring deformation at dormant volcanoes, even in the absence of *in situ* (GPS) networks.

# 5. INTEGRATED EARTHQUAKE OBSERVATION SYSTEM

By improving our ability to assess, monitor, and rapidly respond to earthquakes, a well-designed, integrated Earth observation system can help reduce the severity of the impact from these events. Recent improvements in hardware and software technology have greatly increased the capabilities of seismic monitoring networks to deliver real-time earthquake information as well as the capabilities of ground and satellite-based deformation monitoring systems such as GPS networks, InSAR and the increasing ability to produce and use high-resolution digital topography derived from LiDAR or SAR imagery. The need for a dedicated InSAR to monitor surface deformation has been widely recognized and was deemed an essential component of EarthScope by the National Research Council (NRC).

Dedicated InSAR also is the highest priority mission recommended by NASA's Solid Earth Science Working Group in *Living on a Restless Planet* and in the review of that finding by the NRC. The recent interim report of the NRC Decadal Survey also encourages progress towards a SAR/InSAR capability. The observational requirements for all the geohazards, including earthquakes, were reviewed as part of the development of the IEOS, and are summarized in the technical reference document that will be posted on the SDR website (www.sdr.gov). Table 3 in the Appendix shows the critical gaps that remain to be filled in order to effectively deliver real-time earthquake information for targeting rapid emergency response.

## 5.1 Existing Components

The 2000 reauthorization of the multi-agency National Earthquake Hazard Reduction Program (NEHRP) tasked the Advanced National Seismic System (ANSS) to modernize and strengthen seismic monitoring in the United States. This initiative, begun in 2002 and 10 percent complete, is improving the performance and integration of the national and regional seismic monitoring networks, with a particular focus on dense networks of urban stations capable of monitoring strong motion both on the ground and in structures. These dense networks enable rapid deployment of ShakeMaps portraying the extent of potentially damaging ground motion following an earthquake. ShakeMaps are generated and served via the Internet within minutes of the earthquake, and are used primarily for emergency response, loss estimation, and public information.

USGS is also working with the NSF EarthScope facility to expand the ANSS *backbone network* to strengthen coast-to-coast earthquake detection. In FY 2005-2006, NSF is funded 17 new ANSS backbone stations and eight station upgrades. This national backbone provides a stable reference for EarthScope's rolling deployment of 400 seismographic stations in stripes across the United States from west to east, combined with a deployment of portable seismic arrays for targeted research projects. Each deployment will last for approximately one year, and then the stations will be removed and re-deployed to the east. The unprecedented density of the deployments will bring a great deal of new data and information about the Earth's structure.

As part of the President's tsunami initiative, USGS seismic systems and operations will provide more robust detection and notification of earthquakes that could trigger tsunamis. USGS is conducting this effort in partnership with NOAA. The software and hardware capabilities of the National Earthquake Information Center, the ANSS nerve center, will be upgraded as will telemetry for the Global Seismographic Network (GSN) in partnership with NSF. Through GSN, USGS also will install new seismic stations in the Caribbean region, complementing NOAA's deployment of Deep-ocean Assessment and Reporting of Tsunami (DART) buoys for rapid tsunami detection and warning.

Geodetic networks provide essential information about movement of the land surface near faults and earthquake source zones. NASA, NSF and USGS work with universities and local agencies to conduct geodetic investigations using GPS and laser-ranging surveys. A dense network of continuous GPS stations has been installed in southern California in a cooperative effort by the NASA, NSF, USGS, and U.C. San Diego to determine the distribution of long-term crustal deformation and the spatial and temporal variations of the strain field. Beginning in FY 2005 and continuing through the duration of this NTO, the Plate Boundary Observatory (PBO) component of NSF's Earthscope facility will expand geodetic networks along the U.S. West Coast's active plate boundary.

Imaging the spatial distribution of surface deformation is revolutionizing our understanding of Earth processes that can lead to hazards and is an essential complement to the *in situ* networks. Research efforts supported by NASA, USGS and NSF using limited quantities of C-band SAR data from international missions (Radarsat-1 and Envisat ASAR) document the potential of a dedicated L-band InSAR to better understand and monitor seismic hazards as well as to evaluate damage after an event. NASA has an airborne repeat-pass InSAR capability under development (confirmation review in November 2005) that could be used to monitor selective areas.

## 5.2 Additional Components Required

ANSS plans call for the addition of 6,000 new seismic monitoring instruments in more than 25 urban centers; 3,000 of these would be deployed in reference sites (i.e., ground-based), and an additional 3,000 in structures. Implementation of ANSS also will result in improved integration of existing networks and the replacement of obsolete equipment at 1,000 stations in regional networks across the country.

NASA, NSF and USGS are investigating the potential of InSAR to quickly and accurately provide wide-area views of pre- and post-earthquake land deformation. Work is under way to develop computational tools necessary to efficiently analyze, interpret, and model InSAR data and to assimilate InSAR data into geophysical models. InSAR results in southern California will be used to augment, check, and, if necessary, correct the independent GPS measurements. When completed, the airborne repeat-pass InSAR could provide monitoring of selected seismic zones and a local rapid-response capability. The principal limitation of SAR data is the lack of continual and affordable satellite data to provide systematic observations of surface deformation. Pre-formulation concepts for such a system have been developed by NASA, NSF and USGS and show that it could be developed in 4 to 5 years.

## 6. INTEGRATED COASTAL INUNDATION OBSERVATION SYSTEM

For the United States to be adequately prepared for all forms of coastal inundation, communities must have timely focused data, forecasts, and decision-support tools. A concerted effort must be made to deploy effective warning systems, respond quickly, implement necessary mitigation measures, and increase public capabilities. More importantly, an *all-hazards* approach must be taken to ensure coastal communities are more resilient.

Increased densification of tsunami and other related coastal observations (both *in situ* and remotely sensed) are needed to drive and enhance an integrated system of models, inundation and evacuation map applications, and other decision-support tools. This includes the need for interoperable high-resolution data (e.g., high-resolution coastal bathymetry and topography) on which tsunami and surge elevations can be overlaid using vertical datum transformation tools (VDatum). Table 4 in the Appendix identifies the observations needed to deliver improved tsunami and coastal inundation forecast and warning capability. An enhanced stream of SAR/InSAR data will improve our ability to evaluate the subsidence component of local sea-level rise and provide timely observations of inundation extent both day/night and independent of cloud-cover that is commonly associated with flooding events.

### 6.1 Existing Components

Detecting and effectively responding to coastal inundation is critical to mitigating its effects. USGS and NSF have global, national- and regional-scale seismic monitoring networks to detect seismic activity with the six currently deployed DART buoys providing information on whether the activity has the potential to cause a tsunami. The National Water Level Observation Network (NWLON) provides near-shore water level observations for tsunamis and storm inundation. Information from these systems is monitored and assessed by the Tsunami Warning Centers and the USGS National Earthquake Information Center, which then disseminate the information through standard procedures and communications between USGS, NOAA, and FEMA, to Primary and Alternate State Warning Points that react based on the information.

NOAA also has been working with Ocean.US to develop the IOOS Regional Associations. These regional observing systems offer a higher resolution capability than Federal systems alone can provide. Many regions have a variety of off- and on-shore monitoring systems that already supply valuable coastal meteorological information to the Global Telecommunications System (30 percent of what the National Data Buoy System feeds to the Global Telecommunications System is coming from these regional observing systems).

### 6.2 Additional Components Required

The United States has a good coastal hazard mitigation network but there are areas in need of improvement. The DART buoy array should be increased to 39 buoys, with seven of those in the Atlantic and Caribbean. Installation must be completed on the 49 coastal sea-level monitoring stations. Additionally, forecast models must continue to be improved and modeling for inundation maps should be completed. An increase in the availability of timely and accurate seismic data through expansion of seismic coverage in the Caribbean, additional telemetry and maintenance for the Global Seismographic Network, and modernization and completion of regional seismic networks in Alaska, California, Hawaii, Oregon, and Washington is necessary.

For more accurate flood forecasts and warnings, the USGS Stream Gauge Network must be expanded and modernized to sufficiently meet decision-maker needs for information on streamflow and levels. In addition, decision-makers need higher resolution shallow water bathymetry and coastal topographic mapping in coastal counties and watersheds. Without them, there are insufficient resources to accurately predict floods and warn at-risk populations, putting more people in danger. For coastal regions outside the United States, the 30-m Shuttle Radar Topography Mission digital topography should be made publicly available to improve run-up models.

For the data to be used effectively, the Tsunami Warning Centers and USGS National Earthquake Information Center must attain and maintain robust 24/7 operations. Existing information dissemination systems such as Emergency Managers Weather Information Network and Radio and InterNET Communications Meteorological and Climate Information should be expanded and their use incorporated into an evacuation notification system.

The conceptual L-band InSAR for surface deformation could also satisfy several of NOAA's observational needs applicable to tsunamis and coastal inundation, and serve as a prototype U.S. operational SAR satellite. The surface deformation observations will improve our knowledge of the location, extent and severity of regional and local subsidence related to fluid withdrawal and compaction of sediments. SAR data also will provide all-weather and day/night imaging capabilities for monitoring inundation and for the detection and tracking of oil spills and leaks from vulnerable coastal and off-shore infrastructure. If NASA, NSF, and USGS decide to develop such a mission, NOAA plans to request funds beginning in FY 2008 to support enhanced capabilities that meet its requirements.

# 7. NEXT STEPS

In the course of developing this near-term opportunity, it is clear that there are related hazards that would benefit from a concerted effort to strengthen earth observation capabilities – in particular wildland fires. It is also clear that even as progress is made on the specific observation capabilities identified in the near-term opportunity, it is crucial that planning move forward to take advantage of longer-term opportunities that require considerable lead time, as is the case for a next-generation geodetic network.

## 7.1 Wildland Fires

Wildland fires continue to be a costly and destructive force in the United States. The 10-year average annual cost for suppression of wildland fires by Federal agencies is nearly $1 billion. Continued development adjacent to forest and rangeland not only results in a greater number of fire starts, but also increases the need to protect more property from the devastating effects of fire. Better earth observation capabilities can assist with wildland fire suppression by improving strategic and tactical allocation of firefighting resources and can assist with prevention of potential fire disasters through improved mitigation and landscape management strategies. Improved monitoring and mapping of wildland fires, fire impacts, hazardous fuels, and land cover change is an important set of products and services that can be delivered through advancements in earth observations and their application to wildland fire suppression and mitigation efforts.

The best potential for reducing the damaging effects of wildland fires on communities and ecosystems, and for long-term reduction in the cost of wildfire suppression, rest in accurate monitoring, mapping, and modeling of fuels, fire hazard, and fire effects across the landscape. This information is critical input for models of fire behavior, emissions, post-fire erosion and flooding, and assessment of other impacts. There are currently a number of observation and monitoring programs in place or being developed for meeting these information needs. For example, the USDA Forest Service and the Department of Interior, along with other collaborators, are developing LANDFIRE (also known as the Landscape Fire and Resource Management Planning Tools Project), which will produce nationwide maps of vegetation, fuels, and other biophysical characteristics to model potential fire behavior conditions. They also recently agreed to implement a nationwide program to map the geographic extent and burn severity of both past and future fire areas. Both of these programs rely heavily on data from LANDSAT satellites for successful execution.

Gaps in such long-term and technically consistent data from U.S. satellites will endanger our future capability to develop, update, and use this critical information; or require the information to be purchased at great cost from other countries if international data-sharing agreements are not developed. In addition, currently approved monitoring programs for fire and fuels do not enable land management agencies to monitor the structure of the fuels, which is one of the most critical determinants of fire behavior. Emerging remote sensing-based monitoring programs, however, will map estimated fuel structure using a series of models. As a result, leveraging remote sensing assets for mapping fuel structure on a landscape level would greatly improve our predictive capabilities for identifying fuel hazard areas that require treatment to prevent catastrophic fires. Active remote sensing technologies such as multi-return LIDAR and InSAR show great potential for such applications.

Another next-step opportunity exists for improving wildland fire detection and monitoring capabilities for future sensors. For example, the current design of the Visible Infrared Imager/Radiometer Suite (VIIRS) sensor, scheduled to fly on-board the National Polar-orbiting Operation Environmental Satellite System series of satellites, has limitations for hot-target detection and characterization. The current technical specifications of the VIIRS long-wave infrared band emphasize characterization of relatively cold temperatures associated with sea surface temperature and atmospheric measurements. Consequently, unlike the Moderate Resolution Imaging Spectroradiometer sensor currently aboard NASA's Terra and Aqua satellites, the VIIRS instrument will suffer in its ability to detect and measure wildland fire characteristics because of the relatively low saturation threshold. Additionally, there is a concern that false detection information will arise. A solution is needed that will benefit the atmospheric and meteorological community as well as research and operational applications for wildland fire and other thermal anomalies.

It should be possible to devise and implement economical solutions to these problems in time for future launches of VIIRS and other space-based thermal imaging sensors. Additional work also is needed to enhance geostationary as well as low-earth-orbiting satellites. Improved spatial and spectral resolution of geostationary sensors and greater re-visit times for orbiting sensors are highly desirable features, and any improvements in these areas would help to supplement existing airborne and ground-based observations.

### 7.2 Next-Generation Geodetic Network

Space Geodesy provides the most accurate global topography and provides spectacular images of earthquake deformation Geodetic GPS has become a critical tool for mapping volcanic inflation, tectonic-driven surface deformation, and other geohazard processes. Unfortunately, the diminishing state of the global geodetic network places long-term comparability and deformation measurements at great risk. Delivering accurate figures on a global basis will require a reference frame at least 10 times more accurate than the current one. The international space agencies and geodetic institutions are charting strategy for the development of the Next Generation Geodetic Network. Total cost of this network is likely to exceed $200 million, but international leveraging could significantly reduce cost to the United States. GEOSS could play a significant role here. Planning needs to begin now for a formulation phase and an implementation phase if these capabilities are to be available in a reasonable timeframe.

## APPENDIX A: NATIONAL VOLCANO EARLY WARNING SYSTEM REQUIREMENTS AND GAPS

| Required Observations | Existing Systems | Filling the Gaps |
|---|---|---|
| Characterize seismicity of volcano(es) or group of volcanoes (magnitude, 3-D location, type of earthquake) to locate quakes to magnitude <0.5; data relayed and processed in real time | Seismic networks at many individual volcanoes plus some regional networks | Many high-threat volcanoes unmonitored or under-monitored. Upgrades (additional short period, 3-component, and broadband seismometers) needed at all volcanoes with minimal or no seismic networks |
| Monitor deformation of volcanic edifice (horizontal, vertical and tilt) | GPS networks and/or EDM, leveling and tilt monitoring networks<br>Borehole strainmeters<br>SAR interferometry | Most high-threat volcanoes are not actively monitored for deformation.<br>C-band SAR data stream inadequate to monitor all volcanoes of interest; L-band SAR/InSAR completely lacking |
| Characterize gas emissions of volcano(es) by species ($SO_2$ and $CO_2$) and flux (near-surface or tropospheric plumes) | COSPEC, LICOR surveys at regular intervals – fixed stations, truck, or aircraft-mounted<br>Satellite imagery with appropriate bands (IR) at moderate resolution<br>FTIR measurements, direct sampling of gases | Few active volcanoes routinely monitored.<br><br>Appropriate satellite imagery (ASTER) scarce. No successor mission known. UV sensors lack sensitivity, resolution needed. |
| Characterize local thermal features of volcanoes (nature, number, location, temperature) | Field observations, plus use of thermocouples, visible and IR pyrometers<br>High-resolution IR imagery using digital IR cameras<br>Moderate resolution airborne IR imagery (TIMS) | Thermal IR bands critical for hazard mapping.<br><br>Needed resolution not possible in most satellite imagery.<br><br>Landsat 7 impaired; no known successor to ASTER doppler radar equipment |
| Detect and monitor volcanic explosions, eruption columns and lahars | Doppler radar (assess column height and density), cloud-to-cloud lightning detectors<br>Acoustic flow monitors (lahars) | Deployment of such equipment very limited<br>Deployment of acoustic flow monitors limited |
| Detect and monitor high-altitude volcanic ash clouds and aerosol plumes | Meteorological satellites (geostationary, polar-orbiting) plus MODIS, TOMS and OMI | Split-window (separate 10.5 and 12 micron bands) needed to recognize ash are lacking on some satellites |
| Acquire baseline topography of volcano(es) | Aerial photography, LiDAR<br>DEMs from SRTM or ASTER imagery | Data still not available or not processed and released for many active volcanoes |
| Make geologic and structural maps of volcano(es); date young deposits; characterize eruptive style and eruptive history of volcano(es) | Field surveys, aerial photography, AVIRIS surveys<br>Moderate or high-resolution multispectral imagery | Landsat 7 impaired; no known successor to ASTER |

## APPENDIX B: INTEGRATED EARTHQUAKE OBSERVATION SYSTEM REQUIREMENTS AND GAPS

| Required Observations | Existing Systems | Filling the Gaps |
|---|---|---|
| Monitor seismicity nationwide to magnitude 3.0, to magnitude 2.0 in seismically active areas | National and regional seismic networks | Upgrade and expand through Advanced National Seismic System (ANSS) |
| Monitor strong ground shaking in all urban areas subject to moderate to high earthquake risk | Dense seismic networks with high dynamic range "strong-motion" sensors | Upgrade and expand through urban area focus of ANSS |
| Monitor response of critical facilities, and of typical buildings of different classes of construction in urban areas subject to moderate to high earthquake risk | Seismic instruments in critical facilities and in typical buildings | Upgrade and expand through urban area focus of ANSS |
| High-resolution topographic mapping in seismically active areas | LiDAR surveys or stereo aerial photography | More comprehensive availability of LiDAR and Digital Elevation Models |
| High-resolution deformation monitoring in seismically active areas | Ground-based networks and surveys using GPS satellite constellation, limited C-band SAR imagery for InSAR | Systematic InSAR data stream (particularly L-band); GPS networks expanded through EarthScope |
| Strain and slow movement (creep) measurements along active faults and near fault zones | Arrays of creep meters, dilatometers and tensor strain meters; limited C-band SAR imagery for InSAR | Systematic InSAR data stream (particularly L-band); wider installation of tensor strain meters through EarthScope |

## APPENDIX C: INTEGRATED COASTAL INUNDATION OBSERVATION SYSTEM REQUIREMENTS AND GAPS

| Required Observations | Existing Systems | Filling the Gaps |
|---|---|---|
| Coastal high-resolution topography | Topographic LiDAR, InSAR, VDATUM, SRTM | Areas lack updated high-resolution topography; public release of international SRTM-30 topography for coastal areas |
| Shallow water bathymetry and navigational obstructions | Ship surveys (e.g. multibeam) Bathymetric LiDAR, VDATUM | Outdated surveys, turbid water bathymetry |
| Deformation/subsidence | Sporadic international C-band SAR | Need orbital L-band InSAR |
| Waves, heights and patterns, wave spectra | Buoys, coastal radar, Volunteer Observer Ship (VOS) program SAR Imagery ($11.4 M in FY 2008) | Insufficient near shore spatial resolution, wave height forecasts, and verification points. |
| Tides/water levels, inundation patterns | Tide gauges (NWLON), USGS river gauges, six Pacific DART tsunami sensors, VDATUM, international SAR data | Outmoded water level measurement; inadequate stream and tide gauge coverage; enhanced SAR data stream for all-weather and day/night monitoring of inundation |
| Currents | Buoys (e.g. with ADCP); coastal radar; radar altimeter | Insufficient spatial resolution near shore |
| Surface Winds (10 meter AGL) | Buoys, CMAN, VOS, NWLON (met), PORTS, coastal ASOS. Scatterometer (QuickScat) + SAR (off-shore only) imagery | Insufficient spatial resolution near shore and lack of verification points at Coastal Waters Forecast Zones. |
| Seismic information for tsunamis | Seismic networks, notification systems | |
| Post-event damage assessment | Ground-based visits, photographic documentation, high-resolution satellite imagery | |
| Sea Temperature - Surface | VOS, fixed Buoy, GOES Imager, POES Imager, PORTS, NWLON | Limited information during extended periods of cloud cover |
| Sea Temperature - Column | ARGOS floats, fixed buoys (limited) | Limited information below 10 cm depth. |

## APPENDIX D: ABOUT THE NATIONAL SCIENCE AND TECHNOLOGY COUNCIL'S U.S. GROUP ON EARTH OBSERVATIONS/SUBCOMMITTEE ON DISASTER REDUCTION TASK GROUP ON IMPROVED OBSERVATIONS FOR DISASTER REDUCTION NEAR-TERM OPPORTUNITIES

| | |
|---|---|
| David Applegate (co-lead) | U.S. Geological Survey (USGS) |
| Margaret Davidson (co-lead) | National Oceanic and Atmospheric Administration (NOAA) |
| Craig Dobson (co-lead) | National Aeronautics and Space Administration (NASA) |
| Steve Ambrose | NASA |
| Ralph Cantral | NOAA |
| Sue Conard | U.S. Forest Service |
| Melba Crawford | Department of State |
| David Green | NOAA |
| Paul Greenfield | U.S. Department of Agriculture |
| Roz Helz | USGS |
| Brenda Jones | USGS |
| David Lambert | National Science Foundation (NSF) |
| John Lyon | U.S. Environmental Protection Agency |
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| Gran Paules | NASA |
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| Kaye Shedlock | NSF |
| Gene Whitney | White House Office of Science and Technology Policy |

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