SCIENCE AND TECHNOLOGY LESSONS LEARNED FROM THE DECEMBER 26, 2004 INDIAN OCEAN DISASTER

INTERIM REPORT OF THE SUBCOMMITTEE ON DISASTER REDUCTION

The Charge

Following the Indian Ocean earthquake and tsunami, the Subcommittee on Disaster Reduction (SDR) was asked to identify the science and technology lessons learned from the disaster. Consistent with the SDR's mission to promote a disaster resilient America, the Subcommittee decided to portray the lessons learned in an all-hazards context and to emphasize the opportunities to leverage current efforts and understanding.

A Call for Action

Briefly, the science and technology lessons learned from the Indian Ocean tsunami of December 26, 2004 are:

1. **It can happen.** A tsunami of this size can devastate life, property, infrastructure, and economic balance for generations to come.

2. **It can happen here.** The tectonic setting off the northwest coast of North America is very similar to the conditions that gave rise to the Sumatra earthquake. For the past decade scientists in the United States have known of this dangerous situation. Now, government officials and others responsible for public safety and security must build on existing efforts to address the risks and improve public recognition of this threat.

3. **It can happen quickly.** Because of the proximity of the tsunami-generating earthquake zones off the coasts of the Pacific Northwest, Alaska, and the Caribbean, there will be fewer than twenty minutes in some cases to develop, broadcast, and respond to a warning.

4. **Disaster is not inevitable.** Tsunami risk assessments, mitigation practices, warning systems and procedures, public awareness, and warning response training must be developed and maintained for all coastal areas of the United States subject to the tsunami threat.

The Threat: What's at Stake?

The December 26, 2004 event in the Indian Ocean was rare – a magnitude 9.0 earthquake with an undersea source that triggered a massive tsunami. Though the probability of this event was low, the impacts were high. According to reports by the United Nations, the tsunami resulted in approximately 300,000 dead and missing, and damages exceeding $13 billion (U.S.). Even as the United States provides humanitarian aid and technical assistance to the affected areas, we also must learn from the event to ensure our own preparedness.

Earthquakes generate ninety percent of all tsunamis, either directly or through seismically-triggered submarine landslides, and most tsunamis that have caused significant loss of life and property damage have been earthquake generated. The vast majority of tsunamis are caused by large earthquakes occurring around the Pacific Rim or "ring of fire," placing the U.S. West Coast, Alaska, Hawaii, and U.S. island territories at risk. Hawaii has been struck repeatedly, and coastal communities in Alaska experienced severe damage from tsunamis generated by the magnitude 9.2 subduction-zone 1964 Good Friday earthquake. The greatest tsunami risk to the United States is posed by the 680-mile undersea fault known as the Cascadia Subduction Zone off the coast of Washington, Oregon, and northern California. In 1700, this fault generated a magnitude 9.0 earthquake and, because of continuing motion of the Earth's tectonic plates, it has been accumulating strain ever since. Tsunamis also have been generated in the Caribbean Sea, presenting a hazard to Puerto Rico and the U.S. Virgin Islands, and earthquake-triggered subsea landslides have generated local tsunamis along the Atlantic coast of North America.

Once generated, a tsunami may travel across the ocean at about 500 miles per hour, making warning time directly proportionate to distance. Today, a Cascadia Subduction Zone earthquake could generate a tsunami similar to the Indian Ocean tsunami with as few as ten to twenty minutes of warning to the residents in coastal communities.

The Opportunity: What Did We Learn?

The following themes emerged in the aftermath of the Indian Ocean disaster and require focused Federal investment and attention:

1. *The need for risk assessment of threatened communities is compelling.* Tsunami hazard simulation and modeling techniques - coupled with assessments of tsunami impacts and risk - must be improved to more accurately and efficiently identify ways to avoid loss of life and property.
2. *Effective tsunami detection, forecasting and warning demand networks of working sensors.* Advanced sensing equipment, rapid data analysis, and effective warning broadcast systems should be in place and functional for all oceans. All data must be available in real time and to all stakeholders.
3. *Warnings must provide clear instruction and must reach everyone at risk.* Emergency communication systems and programs to educate and inform the public of the threat of tsunami hazards need to be in place for all at-risk communities, not just those that have experienced tsunami threats in the past.
4. *Measures taken to reduce the threat of tsunamis and earthquakes must be adopted as parts of a comprehensive all-hazards plan.* All systems designed for tsunami preparedness, response and recovery should be integrated into a comprehensive action-based plan for addressing all types of hazards and vulnerabilities.
5. *International efforts to reduce the threat of tsunamis and other hazards must address both national and regional challenges.* It is vital that all programs designed to aid in the warning, detection and response to tsunamis and other hazards promote international, national and regional cooperation and the interoperability of all systems and infrastructures.
6. *There is a critical need to invest in organization and preparation for and response to hazard events.* From a science and technology perspective, it should be a priority to understand the decisions that lead to these investments, or lack thereof. After all, actions communities can take to be more prepared are well-known and yet communities are not prepared or organized appropriately.
7. *Research should enable better understanding and predictive capability for the future.* Evaluate current data and models to understand the future investments needed for improved tsunami-related detection, forecasting and impact analysis needs.

How Can Science and Technology Be Applied to Reduce the Threat?

Science and technology investment decisions intended to reduce the threat of tsunamis and earthquakes must be made within a carefully-crafted strategic framework and within the context of an all-hazards approach. Specifically, we can leverage science and technology and the lessons learned from the Indian Ocean tsunami to reduce U.S. vulnerability in the following ways:

RISK ASSESSMENT. The dynamics of tsunamis and other low probability/high impact hazards need to be better understood through enhanced risk assessment and more advanced simulation and modeling.

Risk assessment requires:

- Collecting detailed geological, geophysical, and oceanographic information from recent tsunamis;
- Offshore mapping that characterizes potential tsunami sources;
- Near shore and on land elevation mapping to develop and constrain tsunami inundation models; and
- Identifying and mapping preserved tsunami deposits to assess past event frequencies and future probabilities of major tsunamis.

These data provide the basis for high resolution coastal bathymetric and topographic mapping and advanced scientific modeling to estimate loss of life, threat to public health, structural damage, environmental damage, and economic disruption. Much is known about earthquake behavior and tsunami propagation, but scientists can greatly improve their forecasts by learning from this tsunami. Prior to this tsunami, no entity had tsunami warning responsibilities for the Indian Ocean and no numerical models existed to forewarn populations of the expected impact. Simulations have since been created to accurately estimate damage and were tested successfully in the weeks following the tsunami.

Risk assessment takes place both before and during disaster events and must be completed for every U.S. community threatened by tsunamis, beginning with those most at-risk and concluding with those least at-risk. Currently, risk assessments do not exist or are based on bathymetry data from nautical charts, which are sometimes quite dated (10-20 years in some cases) and do not include coastal topographic measurements. Higher resolution coastal mapping would improve assessments of the severity and extent of inland flood devastation.

DETECTION. Networks of sensors, monitoring devices and satellites need to be in place to send useable, real-time information to national and local authorities and emergency responders.

Tsunami detection depends upon identifying the tsunamigenic nature of earthquakes. Scientists must find ways - from incoming geophysical and oceanographic data - to make this identification as quickly as possible. Considerable effort already has resulted in meeting the timely response challenge, as warning centers are now able to rapidly estimate the earthquake's size using dense networks of high-quality seismographic instruments and issue messages about the earthquake's potential for destructive tsunami generation within ten to twenty minutes. Though this information provides important clues about the earthquake's tsunami-generating potential, gaining detailed estimates of the earthquake's depth and character of fault rupture continues to be a challenge. This is especially true for the largest earthquakes (magnitude 9.0 or greater), which have the highest potential for generating a destructive tsunami and are likely to show complicated rupture processes in which energy is released over different time and space distributions.

Since most earthquakes do not generate tsunamis, sea level data play a critical role by confirming the existence of a tsunami. In the Pacific, more than one hundred tide gauge stations transmit data in near-real time and are maintained by many countries and organizations. In the Indian Ocean, there are now ten stations, most of which are in the western Indian Ocean as part of the United Nations Educational, Scientific and Cultural Organization (UNESCO) Intergovernmental Oceanographic Commission Global Sea Level Observing System (IOC/GLOSS). They are reporting in near-real time to the Pacific Tsunami Warning Center (PTWC) and were not available on December 26, 2004. Sea level or tide gauges are useful in detecting the presence of a tsunami, but tide gauge data are dominated by the local harbor effects and have little value in predicting the impact of a detected tsunami at other locations.

To predict tsunami impacts, the tsunami must be measured in the deep ocean, free from the harbor effects. Currently, there are no deep-ocean tsunami detection systems (tsunameters) installed in the Indian Ocean and only seven installed in the Pacific Ocean. It is necessary to install a dense network of coastal sea level stations complemented by strategically-deployed deep-ocean tsunami detection instruments to detect and monitor tsunami waves. These data must be sampled at high enough frequencies to record tsunamis, must be available in real, or near-real-time to the warning centers, and must be systematically maintained to assure maximum station up-time.

WARNING. Effective networks of communication need to be in place so that clear and actionable warning messages can be delivered to at-risk populations. A comprehensive, interoperable, real-time tsunami detection, forecast and warning system is critical and should be developed in the context of Global Earth Observation System of Systems (GEOSS) and the UNESCO/IOC. A tsunami warning system should not be a stand-alone system, but instead must be integrated into a comprehensive action-oriented plan for addressing all types of hazards and vulnerabilities.

Tsunami forecasts are based on deep ocean measurement of tsunamis in real–time. The data are assimilated into models to provide site-specific forecasts in time to evacuate threatened populations. Combined measurement and modeling technologies have demonstrated forecasting skill for several tsunamis at Hilo, Hawaii, and should be expanded to all U.S. coastal population centers. Expansion of the network of deep ocean tsunameters coupled with site specific inundation models is urgently required to provide an effective tsunami forecast and warning system for the United States.

To obtain more accurate earthquake locations, a denser deployment of seismic stations is required and those stations need to provide their data in real time. For example, the density of Federation of Digital Seismographic Networks stations can be improved in the Indian Ocean by installing at least one station in every Indian Ocean nation and providing these data in real time to the warning centers. Similarly, there also is an opportunity to improve service to Micronesia and American possessions in the western Pacific Ocean and the seismically-active area of the southwest Pacific. Operations can be expanded to include the North Atlantic Ocean, particularly the Caribbean. This expansion requires the deployment of new or upgraded existing deep-ocean tsunami detection instruments, seismic stations and an upgrade to all warning centers to accept data from all available stations.

To address the critical need for reliable and rapid warnings of locally generated tsunamis, the seismological and geodetic communities must continue their efforts to develop better methods to rapidly assess the tsunamigenic potential of an earthquake. In addition to earthquake location, depth, and magnitude estimates, tsunami warning centers should integrate into their operational procedures the use of advanced seismological products such as rapid moment tensor computations (which suggest displacement of the sea floor), displacement records from continuous GPS instruments on shore, and ShakeMaps that reveal the extent of earthquake rupture along continental margins.

Effective warnings are dependent upon human factors – in the promulgation and in the effective use of the information by at-risk individuals. Individuals can choose to heed the warning or not, to take action or not. If organizations are not operating, if employees are not trained, if fast response procedures are not designed in advance, awareness will not translate into effective local warning.

Any system of warnings dissemination should take into account the complexity and vulnerability of local infrastructures so that warnings are not hampered by failures in local utilities, transportation systems and communications networks. Additionally, an effective warning dissemination system should take into account the demographics of the at-risk population to ensure all segments of the population receive timely warning information.

SITUATIONAL AWARENESS. All people affected by impending hazards should be made aware of the threat they face, take warning messages seriously, and, if assistance is required, be afforded (and fully knowledgeable of) a mechanism to obtain safe haven.

As part of efforts to improve warning systems, we must leverage the social sciences. It is critical that we learn how people decide to heed or not heed a warning and how effective informal communications take place (or are hindered). Moreover, the U.S. must prepare individuals for a tsunami on the East Coast where, like the countries of the Indian Ocean prior to December 26, 2004, there is neither a history of tsunami nor education programs. Today, existing warning signs along the East Coast are sparse and designed for hurricane evacuation (which is a slow evacuation even with foreknowledge).

Education and public outreach are key to successful situational awareness. The impact of the December 26, 2004, tsunami on tourists is a reminder that education should not be limited to coastal communities but also should include the broader population. As mentioned earlier, once the warning is disseminated and received by all at-risk individuals, response plans need to account for the entire demographics of the population—especially the poor, seniors, the disabled, and individuals in poor health—ensuring the entire at-risk population has a mechanism to obtain safe haven and is aware (educated) of these pre-planned procedures. Finally situational awareness requires that the at-risk population understand the nature of the hazard so they will understand when it is over. For example, tsunamis frequently occur as multiple waves, and it is critical that coastal populations not return to vulnerable locations until the hazard has truly passed.

RESPONSE PLAN. Tsunami response should be incorporated into multi-hazard emergency response plans with emergency responders properly trained to deal with all types of potential hazards.

Some South Asia locales had no public training or infrastructure and no organization for disaster response. More effective capabilities could have saved lives, and this may be true in the U.S. as well. In advance of disasters, profiles of populations and infrastructures are needed, including hospitals and other critical facilities, so that informed decisions can be made about where and how to distribute assistance for maximum effectiveness. Having detailed information in advance about populations, structures, businesses, and other institutions can also enable later assessment of the effects of a disaster so that lessons can be drawn about how to move forward and how best to reduce the effects of future disasters.

READY PUBLIC. The public should be made aware of all hazardous natural phenomena and appropriate actions in the event of an emergency. On December 26, 2004 when the ocean receded in Indonesia, people went out onto the beach only to be washed away. They were not well educated about the nature of tsunamis or that the proper response would be to immediately seek high ground. Community-level decision-making in which informed individuals are engaged beforehand to develop and participate in reducing potential risk through pre-disaster education and mitigation activities can be an effective mechanism for ensuring that the public will respond appropriately and immediately upon knowledge of an approaching destructive hazard.

The importance of immediate local response and improvisation is consonant with current appreciation of disasters in general - most lives are saved in the immediate aftermath of an event by people who are not trained but are present, motivated, and willing to try to help. Effective preparation for, response to, and recovery from many types of disaster can be enhanced if we can learn more about these sorts of emergent behaviors and how to enable them. It is important domestically to understand the forces that inhibit collective care in disaster situations and to leverage those findings to enhance individual likelihood to care for one another in the immediate aftermath of any sort of disaster.

LESSONS LEARNED. As this document demonstrates, each event presents new knowledge and the potential for breakthroughs in science and technology. We must learn from each event, and continue to apply our knowledge to enhance disaster resilience. It also is important that scientists be able to collect data in the field as soon as possible after an event of this sort. Collecting data on wave run-up and inundation, scour and deposition, subsidence, liquefaction, or other factors will have an impact on understanding the event, and still support the implementation of effective mitigation measures.

The December 26, 2004 tsunami not only demonstrated the vulnerability of the Indian Ocean region to low probability, high consequence events but also reminded the U.S. and Nations around the world to take a fresh, pragmatic look at our vulnerability to all hazards. This should entail not only a look at the probabilities associated with specific hazards, but the potential impacts as well.

International Cooperation

Hazards do not respect political boundaries. International efforts to reduce the threat of tsunamis must promote cooperation in all areas of disaster management including capacity building, education and training, and real-time interoperability with other national, territorial, regional and international observation networks and system. International efforts to develop monitoring and warning systems should build on existing programs like GEOSS and the UNESCO/IOC, taking an all-hazards approach.

The UNESCO/IOC has undertaken the leadership role in the coordination of a global tsunami warning system, starting first with the implementation of the Indian Ocean Tsunami Warning and Mitigation System while continuing to strengthen the system in the Pacific where the majority of tsunamis are known to occur. Activities also are being undertaken by nations in the Caribbean and Mediterranean. Working with the IOC, the NOAA NWS Pacific Tsunami Warning Center is enhancing the Pacific detection and warning system. NOAA also hosts the IOC's International Tsunami Information Centre, which provides technical oversight of the warning system; works with nations to establish new regional and national warning systems; and works as an information resource for the development and distribution of educational and preparedness materials.

Conclusion

The low probability, high impact threat posed by tsunamis and great (highly disastrous) earthquakes must be addressed at the local, regional, national and international levels. As with any major hazard, measures taken to reduce the threat of tsunamis and earthquakes must be adopted as part of a comprehensive all-hazards plan to address the risks and vulnerabilities of the community. The risk to life and property will be reduced with enhanced risk assessment; improved detection, forecast and warning systems in all oceans; and effective warnings used appropriately by individuals and emergency responders.

All of these areas require improvements in our understanding of tsunami sources, propagation, and coastal impacts through increased research. Specifically:

- The need for targeted risk assessment of threatened communities is compelling.
- Effective tsunami detection, forecasting and warning demands dense networks of real-time working sensors.
- Warnings must provide clear instruction and must reach everyone at risk.
- Measures taken to reduce the threat of tsunamis and earthquakes must be adopted as part of a comprehensive all-hazards plan.
- International efforts to reduce the threat of tsunamis and other hazards must address local, national and regional challenges.