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Mr. Chairman and Members of the Committee, I thank you for the invitation to provide testimony on the recent tsunami tragedy in the Indian Ocean, and strategies for reducing the risk from tsunamis and other natural disasters in the United States and world-wide.

I am a seismologist holding the position of Doherty Senior Research Scientist at the Lamont-Doherty Earth Observatory of Columbia University, in Palisades, New York. I am also the Associate Director for Seismology, Geology, and Tectonophysics at the Observatory. I am the Director of the Center for Hazards and Risk Research in the Earth Institute at Columbia. As Director, I have overseen research in natural hazard risk assessment and management, including the preparation of major reports for the World Bank on the exposures of populations and country economies to multiple natural hazards.

The magnitude 9.0 Sumatra-Andaman Islands Earthquake of 26 December, 2004 and the resultant basin-wide tsunami in the Indian Ocean killed more than 212,000 people and has exposed millions more to additional risks from injury, disease, loss of livelihood, increased vulnerability to recurrent natural hazards and other disruptions to their cultural and civil institutions. In coastal areas known to have suffered significant casualties from the tsunami and where relief efforts are now focused, the estimates of the exposed population living within one kilometer of the coast or within two kilometers of the coast are 2.1 and 4.2 million people, respectively (compilation by Balk, Gorokhovich and Levy, 2005, Center for Earth Science Information Network (CIESIN) at Columbia University, unpublished report to various relief agencies). Economic damages, and economic losses resulting from damage to ecosystems, are also severe. For example, in published reports released just last week, a preliminary estimate by the Asian Development Bank places the economic losses to Indonesia alone at $4.45 billion. These estimates suggest that initial economic damage reports, which were based on quick evaluations of the geographic exposure of major economic activity and insured property, did not fully reflect the spectrum of long-lasting economic impacts. Preliminary needs assessments by the United Nations, the World Bank, and other international development organizations will be completed soon, but early results suggest that the region's recovery from the disaster will be long and complicated. Experience with this tsunami and other natural disasters in the Indian Ocean suggests that vulnerability to natural disasters is and will continue to be a major problem for people and countries in the region. The potential exposure of Indian Ocean coastal populations to oceanographic and meteorological hazards, such as tsunamis and typhoons, is great. Our compilations indicate that 10.6 million people live within one kilometer of the coastlines around the Bay of Bengal and eastern Indian Ocean, and 19.2 million people live within two kilometers.

It is understandable, then, with such grave damage and casualties, that the United States and the rest of the developed world have responded to the humanitarian emergency with compassion and largess. These efforts are now known to have had a significant impact on the emergency needs of the people and governments in the region. It is also understandable that the first response of the scientific and technical communities, including those agencies that have operational responsibilities for tsunami warnings, has been to emphasize the expansion of existing tsunami warning systems to provide global coverage. This technical response is justified by the benefits of adequate warning when compared to the expected life and economic loss from extreme geophysical, oceanographic and meteorological events. Indeed, the costs of the system proposed by the Administration are modest when compared with the potential losses. However, it is important to note that the mortality and economic losses from other natural hazards are also large, occur more frequently, and could also benefit from improved and sustained programs of global and regional environmental observations and monitoring, and the concomitant programs of basic research that must accompany the acquisition of new data.

*The major causes of tsunamis and tsunami prediction*

Statistical analysis of past tsunami occurrences, which are recorded either in the historic or geologic records, is one of the most reliable ways of assessing tsunami hazard risk. However, tsunamis are caused by a range of complex natural phenomena, making the prediction of any future tsunami difficult. Improvements in the forecasting and characterization of the main tsunamigenic events will improve tsunami risk assessments.

Tsunamis are caused by the sudden displacement of extremely large volumes of water by undersea earthquakes, coastal and submarine landslides, volcanic explosions, coastal glacier or ice sheet collapses, and meteorite impacts. There is evidence in the geologic record for each of these sources. However, the largest destructive tsunamis in recorded history are caused most frequently by earthquake, landslide and volcanic events. We call these “source events.”

The first source of uncertainty in predicting future tsunami occurrence is the uncertainty associated with predicting the occurrences of source events. Large events that produce extreme tsunamis are themselves rare, and the modern instrumental record is not yet long enough to provide high quality quantitative observations of extreme events. For example, one difficulty in predicting earthquake-generated tsunamis is our limited understanding of the dynamics of great earthquakes. When we can forecast great events, we may be able to forecast tsunamis, but this is not now achievable unambiguously. Nevertheless, the Sumatra-Andaman Islands Earthquake is the first magnitude 9 event to be captured by modern high-fidelity seismic networks, especially the Global Seismographic Network (GSN) operated by the Incorporated Research Institutions for Seismology (IRIS), an academic consortium supported by the National Science Foundation in collaboration with the U.S Geological Survey. Research on this earthquake, much of it to be funded by the NSF and the external grants program of the USGS, will without doubt enlarge the body of knowledge about great earthquakes, including why they are different from merely large earthquakes. This research will help immeasurably in understanding the processes within large subduction zones that produce great shallow megathrusts. It is difficult to predict whether this will lead to the ability to predict the precise timing of a tsunamigenic earthquake, but identification of probable locations and estimation of decade-scale probabilistic risk are achievable goals.

Submarine and coastal landslides are beginning to be understood in theory. There is a vigorous international community of theoretical and observational geomorphologists who have compiled an impressive track record of research. However, landslides are complex phenomena whose impacts on humans may be quantified by examining the geological and historical record for past occurrence. This can produce risk factors in a probabilistic sense, but, again, it is difficult to predict the precise timing, location, and size of a future event. This probabilistic assessment has been done in a preliminary fashion, globally, for landslides on land (Norwegian Geotechnical Institute, referenced in Dilley, Chen, Deichmann and Lerner-Lam, 2005, Global Natural Disaster Risk Hotspots, Report to The World Bank, Hazard Management Unit, in press), but a systematic assessment of undersea slide probabilities has not yet been achieved.

Among the major tsunami source events, it is often suggested that volcanic eruptions are relatively amenable, both in theory and practice, to monitoring and prediction. Most vulcanologists believe that individual volcanoes can be well characterized and incipient eruptions can be accurately detected, provided that the volcano is heavily instrumented and constantly monitored. The U.S. Geological Survey follows this approach through its various Volcano Observatories, and there are a few other examples around the globe where progress has been made. However, it takes years of continuous observation to “fingerprint” an individual volcano to the extent that eruptions can be foreseen, and it is not pragmatic to do this globally. Of course, not every volcano, not even the most dangerous ones, is instrumented adequately. It should be a high priority to identify the most dangerous volcanoes in terms of their tsunamigenic potential, and observe them accordingly. However, predicting an eruption, and predicting the nature of volcanic mass flank movement that could cause a tsunami are two different things. The latter is related more to landslide dynamics and should be connected to that area of inquiry and monitoring.

In contrast to source dynamics, the theory of tsunami propagation in the open ocean is reasonably well understood, but uncertainties arise from unmapped small-scale variations in ocean and coastal bathymetry, complexities in the excitation of the tsunami at its source, and in its amplitude or “run-up” at the shoreline. The “source function” of the tsunami can be understood in general terms as the area of the seafloor that is vertically displaced by a submarine earthquake, or by the size and velocity of a submarine, volcanic or coastal landslide, or by the explosive force of a volcanic event. Any uncertainty in measuring the size of these source functions leads to uncertainty in predicting the amplitude of a tsunami.

Amplitude uncertainty is further enlarged by uncertainties in ocean and coastal bathymetry and coastline topography. Variations in coastal bathymetry can focus or defocus tsunami energy, and small-scale features in the on-shore topography can lead both to excessive run ups and safe harbor from the onslaught of the tsunami surge.

In contrast to the tsunami source events and run-up amplitudes, the progress of a tsunami wave across an ocean basin is rather more predictable. Once a tsunami wave is generated, it travels through the ocean at a speed that is proportional to the square root of the ocean depth. While our detailed knowledge of ocean bathymetry is limited, enough is known about the larger scale variations in ocean depth to accurately predict the arrival time of a tsunami once it is generated. This time is sufficiently long for ocean crossing tsunamis that warning systems based on the detection of the open-water tsunami wave make sense. Even in the case of source events proximal to a vulnerable coast, tsunami propagation in shallow water is slow enough so that at least some simple and quickly delivered warnings could save lives.

Predicting tsunami damage is more difficult, because the physical properties of potential tsunamis must be convolved with population densities, the fragilities of the built environment, and other difficult measures of physical, economic and social vulnerabilities. Nevertheless, it is interesting that initial tsunami models of the Indian Ocean event did a reasonably good job of explaining the observed damage. In large measure, the relatively low impact on Bangladesh, for example, was due to predictable physics of the tsunami propagation. Similarly, the large impacts in Southeast India and Sri Lanka are, in a gross sense, predicted by these rudimentary models. On the other hand, the destruction in Aceh Province in Indonesia, though expected (and nearly complete) because of proximity to the source region of the earthquake, would be difficult to predict in detail.

This combination of uncertainties reinforces the need for warning systems to have an oceanographic component combined with rapid source event identification and characterization. It also emphasizes the need to build local and regional capacity to make effective use of a warning when it is received.

*History of Major Tsunamis*

Tsunami size may be measured by physical parameters such as maximum run-up height and total number of shoreline incursions. Figures 1 and 2 show these parameters for the largest tsunamis in well-researched historical databases of disasters. Observed run-ups and incursions are not yet tabulated for the Indian Ocean tsunami. It is apparent in these figures that the tsunami run-ups and incursions in the Aleutian Islands and continental Alaska are among the largest recorded. (The Mt. St. Helens run-up is included to illustrate the near-source effect of a catastrophic volcanic landslide although, in this case, the effect was localized.) Preliminary reports from survey teams suggest that the run-up heights in the Indian Ocean probably did not achieve these levels, but that the total number of on-shore incursions will probably approach the observed maximum. Figure 3 shows historical tsunami mortality, including recent data from the Indian Ocean, which places this event as the most deadly tsunami ever recorded.

Taken together, these charts illustrate that the total destruction caused by a tsunami is not just a function of run-up height, which is controlled by local bathymetry and topography, but more a function of the tsunami's geographic scope and the overlap with the geography of human habitation. From the point of view of tsunami risk assessment, this makes the obvious point that we should be concerned with the exposure of densely populated and economically productive low-lying areas near coastlines.

The causes of these largest tsunamis are either large underwater thrusting earthquakes or cataclysmic volcanic eruptions, and the observed mortality and physical impacts are known to occur along coastlines far from the event as well as those in close proximity. Thus the potential exposure of low-lying coastal areas must encompass an assessment of possible source events throughout the ocean basins.

Great thrusting earthquakes in the Atlantic Ocean are rare compared with occurrences in the Pacific, because there are only a few places in the Atlantic where the tectonic plates that make up the crust of the Earth are colliding. The most famous of these is the Lisbon earthquake of 1755, which generated a destructive tsunami along the coasts of western Europe and northwestern Africa. This tsunami was also observed in the eastern Caribbean.

Thrusting earthquakes are observed along the eastern boundaries of the Caribbean plate and in the Scotia Arc at the southern tip of South America. Some of these earthquakes have generated tsunamis in the past, although the effects have been regional or local. Lander et al. (2002) have published a list of observed "wave events" in the Caribbean and judge 27 of these to be "true" tsunamis and another nine to be "very likely true" tsunamis. The last destructive tsunami in the Caribbean occurred in August, 1946, the consequence of a magnitude 8.1 earthquake, and killed a reported 1600 people. Tsunami waves from this event were observed along the eastern coast of the United States. Recently published work by ten Brink and Lin (USGS and Woods Hole Oceanographic Institution, *Journal of Geophysical Research*, December 2004) confirm the current potential for large tsunamigenic earthquakes near Puerto Rico, the U.S. Virgin Islands, and Hispaniola.

A more problematic scenario in the Atlantic is the generation of tsunamis by extreme events such as intraplate earthquakes, submarine landslides on the continental shelf, and the collapse of volcanic edifices. Two examples are the 1886 Charleston Earthquake and the 1929 Grand Banks Earthquake, both of which produced regionally observed and damaging tsunamis. These events do not fall readily within the plate tectonic framework that governs much of our understanding of great earthquakes. In intraplate settings, the smaller earthquakes that would allow seismologists to effectively characterize potential earthquake source zones are relatively infrequent, and it can take decades to accumulate enough high quality data to develop a recurrence or probability model. The situation is even more problematic for submarine landslides and edifice collapse. Some of these potential tsunami source events could be triggered by just moderate earthquakes, by gravitational instability, by the release of trapped gas, or by large meteorological storms. Thus the lack of major colliding plate boundaries, as in the "Ring of Fire" around the Pacific, does not suggest that the Atlantic Ocean Basin is geologically "quiet." On the contrary, geologic mapping of the continental shelf, when done with sufficient resolution, shows an active landscape modified by sudden mass movements. Much more work needs to be done to quantify these potential tsunami source events.

The potential instability of the volcanic edifice on Cumbre Vieja in the Canary Islands should be taken seriously. This is one of the most active volcanoes in the Atlantic, and Ward and Day (UC Santa Cruz, *Geophysical Research Letters*, 2001) constructed a collapse scenario that could in principle create a meters-high inundation of the eastern seaboard of the United States. While there are many unknown factors, including the potential size of the edifice collapse, the possibility of a damaging or devastating tsunami cannot be dismissed. While more geophysical work is certainly warranted, precautionary monitoring of the volcano could detect imminent collapse, and oceanographic monitoring in the Atlantic Ocean could detect the approach of a destructive tsunami in time to issue a warning.

In the absence of deterministic predictions, tsunami scenario modeling serves the purpose of parameterizing the potential range of tsunami source events and impacts.

*Weighing the risks of tsunamis and other natural disasters.*

A systems approach to comparative risk analysis for multiple natural hazards is emerging in importance, as we continue to understand that what causes a natural hazard to turn into a disaster is the exposure and vulnerability of people and their institutions as well as geophysical parameters. Some of the same fragilities that make people vulnerable to hurricanes, typhoons and extreme weather also make them vulnerable to tsunamis and even earthquakes. Thus it is important to understand how reducing vulnerability to one set of hazards can improve resiliency to another set. Leveraging investments in one area of hazard mitigation to improve another is one way in which comparative risk analysis can improve the use of limited resources.

Global multiple hazard analyses have been completed recently by the United Nations Development Program and by the Columbia Earth Institute in collaboration with the World Bank and other international partners (for example, Dilley et al., 2005). Figure 4 shows a compilation of globally-normalized multiple hazard mortality from Dilley et al. (2005). Figure 5 shows the same analysis in detail for North America, the Caribbean, and Central America. By far the most significant mortality risks globally are hydrometeorological hazards in South, East, and Southeast Asia/Southwest Pacific as well as Central and Latin America and the Caribbean, and drought in sub-Saharan Africa. (Significant earthquake and landslide risks dominate parts of the Middle East and Central Asia.) Hydrometeorological mortality risk is significant because the same factors that aggravate this risk also aggravate the risk from tsunamis. The United States, despite its exposure to multiple hazards, has a relatively low mortality on a global scale. Figures 6 and 7 show the same multiple hazard compilation for aggregate economic risk. The United States risk is elevated in absolute terms because of the geographic distribution of people and assets on both coasts. Figures 8 and 9 show the same compilation normalized by country GDP. Again, the U.S. risk is downgraded in relative terms to the rest of the globe. However it is important to note that even in relative terms, the proportional economic risk to the US from geophysical and hydrometeorological hazards on the West and East Coasts respectively is in the top three deciles globally. The mortality risk pattern in Figures 4 and 5 and the relative economic risk pattern in Figures 8 and 9 show similarities, indicating that on a global level, multiple disaster risk is an important issue for developing countries and one of the persistent issues facing the world's poor.

In comparative terms, the geophysical risk along the West Coast of the United States and the hydrometeorological risk along the East Coast of the United States are two expressions of tsunami risk as well. While tsunamis were not included in this calculation (for technical reasons), the proximity of the West Coast and Alaska to the Cascadia and Aleutian Subduction Zones, and its exposure to trans-oceanic Pacific tsunamis, generates a tsunami risk that is highly correlated to the earthquake and hydrometeorological risks. Similarly, the relatively high exposure of the Eastern Seaboard to hydrometeorological disasters suggests that its exposure to trans-Atlantic or Caribbean-generated tsunamis would be high also.

In the Caribbean (c.f. Figures 5, 7, 9), relative mortality, and aggregate and proportionate economic exposure all suggest that multiple-hazard vulnerability reduction should be a necessary component of development. In general, mortality and economic exposure to earthquakes, landslides, extreme weather and hurricanes, and floods in the Caribbean is greater than for tsunamis, on the basis of historical data. However, mitigation strategies for earthquake and hurricane hazards in particular, will have the dual outcome of reducing vulnerabilities to tsunamis as well. When coupled with comprehensive earthquake and ocean observation and real time warning, these strategies should significantly reduce the natural hazard risk faced by people in the Caribbean.

It is in this system context that the United States should weigh the risk of tsunamis against the risk of other natural disasters. The risk from tsunamis is real, but from a historical perspective, the risk from other natural hazards is also real and, in most cases, greater. A tsunami risk reduction program should be part of a comprehensive multihazard risk reduction strategy, in terms of the use of modern observational and monitoring networks, in the establishment of building codes and risk reduction policies, and in the issuance and use of warnings. The costs of mitigation strategies and warning systems, part of a comprehensive suite of risk reduction strategies, should also be weighed against the repetitive costs of disaster recovery and reconstruction in the United States and around the globe. Where it has been systematically computed (for example, by Smyth et al., *Earthquake Spectra,* 2004, for residential buildings in certain earthquakes and other work) the benefit-to-cost ratio of hazard mitigation and warning strategies favors pre-emptive action.

In particular, linkages between tsunami and storm/hurricane warning systems and emergency management operations should be explored.

*The Administration's Proposal for a Tsunami Warning System*

Figure 10 is a timeline, with information from NOAA's Pacific Tsunami Warning Center (PTWC) on the initial earthquake location process, overlain on the records from the Global Seismographic Network (GSN). The timeline indicates that agencies with operational responsibilities were able to locate the Sumatra-Andaman Islands earthquake and assign a preliminary magnitude (MwP = 8.0) within 11 minutes of the origin of the earthquake, using seven stations of the GSN. A public tsunami information bulletin was broadcast by 15 minutes after the origin. Forty-five minutes after the origin, seismic waves from 27 stations of the GSN were analyzed and the magnitude was increased to MwP = 8.5. A second tsunami warning bulletin was released 65 minutes after the origin with the upgraded magnitude and included a statement of tsunami risk near the epicenter. Approximately 6 hours after the origin, seismologists at Harvard, using a different measurement technique and more stations, obtained a magnitude Mw = 8.9, which was refined upward to Mw = 9.0 at about twenty hours after the earthquake. These larger magnitudes were incorporated into later NEIC bulletins.

The continuing analysis and increasing magnitude estimates illustrate the difficulty of characterizing a great earthquake source under operational conditions. (There are related difficulties in characterizing large landslide and volcanic sources as well.) Locating an earthquake is a relatively simple task, but measuring its size, particularly when the area of rupture is large and the rupture process is extended in time, is more difficult. Luckily the Harvard method, and other methods developed by research seismologists, can be operationalized. This has implications for the design of a tsunami warning system.

The first requirement (and the first component of the Administration's proposals for an enhanced tsunami warning system) is the rapid detection and characterization of large undersea earthquakes. This is best done by using a global seismic network such as the GSN (Figure 11) coupled with enhanced capabilities at the NEIC and the existing tsunami warning centers. Three elements of the GSN are important: (1) its global coverage and international relationships, as epitomized by the IRIS and USGS relationships with other nations and international seismological groups; (2) 100% station telemetry allowing real-time retrieval of seismic observations with sufficient redundancy; and (3) its use of very broad-band seismometers that provide superior recordings of seismic signals from great earthquakes. Enhancements to the NEIC should be made to provide true 24/7 capabilities. The NEIC should also operationalize advanced source characterization tools now used by the academic research community. This will ensure more realistic estimates for the largest earthquakes.

The Administration's proposals for enhancements to the NEIC and the GSN, including the installation of new stations in the Caribbean would accomplish most of what is required.

Four components are missing from this part of the Administration's proposal. First, the very broad-band seismometers required to correctly characterize very large earthquakes are nearing the end of their operational lifetime, and the manufacturer may not be in a position to produce replacements. The seismological community is concerned that research and development of the next generation of very broad-band sensors is not taking place in a timely manner. Second, in addition to Caribbean stations, the GSN should be enhanced by selected deployments of submarine seismometers. The characterization of very large subduction zone earthquakes could be enhanced by well-sited ocean bottom broad-band stations. Third, the Administration's proposal makes no mention of the level of and need for continued support for operations and maintenance of the enhanced GSN and NEIC. Fourth, support for peer-reviewed research on large event characterization, best performed by the university community through the National Science Foundation and the external grants program of the USGS, does not appear to be part of the Administration's plan.

A second component of the enhanced tsunami warning system is the deployment of ocean water level sensors and tide gauges that are telemetered to operational centers. The Administration proposes the deployment of additional Deep-ocean Assessment and Reporting of Tsunamis (DART) buoys. The proposed deployment sites in the Administration's plan are good choices. However, it would be prudent to acquire additional DART buoys and deploy them to provide operational redundancy. Additionally, there are some questions about the reliability of current DART buoy design. Three of the six buoys currently deployed are not operational. The Administration proposal does not include any funds for research and development work for an improved DART buoy system. The initial deployments should be followed by an engineering research and development effort to improve buoy performance. Long-term stable sources of funding for operations and maintenance of the DART buoys and concomitant technology should also be a part of the Administration's proposal. I am not aware of the details of how new tide gauges will be deployed and how they will be telemetered to a central monitoring facility and cannot comment on that aspect at this time.

A third component of a tsunami warning system is the engagement of regional, state and local agencies to design the most effective way of distributing a tsunami warning and pre-emptive investments in strategies to reduce tsunami vulnerability. Most emergency management agencies place the highest priority on this aspect of warning systems. Existing tsunami and storm warning programs overseen by NOAA should be highlighted, strengthened where necessary, and continuing revenue streams identified. The incorporation of new research results, inundation maps, risk assessments and other products should be rigorous and timely. The Administration's proposal does not address these specific issues, although they may be addressed elsewhere. These elements will be particularly important in the extension of the tsunami warning system to less-developed countries.

The Administration's proposal should be leveraged in two major ways. First, a tsunami warning system should be part of a more comprehensive real-time environmental monitoring and observation system with global coverage. Planning documents for the GEOSS (Global Earth Observation System of Systems) allude to this hazard reduction functionality. The proposed tsunami warning system can be used as an exercise within the GEOSS framework to identify and illustrate likely efficiencies, difficulties, and integration issues for the larger system. Additionally, the earth observation community should be motivated to develop specific plans to incorporate other sensor technology into the DART systems as a pilot opportunity. Second, in addition to expanding the monitoring capacity, the development of a tsunami warning system should be leveraged to spur the development of multiple hazard warning or monitoring systems for hazards that pose a quantitatively greater risk and more persistent risk than tsunamis. A good place to start would be to develop a spectrum of coastal hazard monitoring technologies to deal with the geophysical and meteorological hazards faced by Hawaii, Alaska, and the East and West Coasts. Moreover, the expansion of NEIC capabilities should include funding of the Advanced National Seismic System to the appropriated level, to enhance not just tsunami monitoring but achieve the required level of earthquake monitoring and earthquake hazard reduction for the Nation.

The Administration's proposal does not have a specific component of assessment, nor is there a specific component on data archiving and post-warning analysis. The tsunami warning system should be open to periodic review by both the operational and research communities, to promote the integration of new research results into operational capabilities. This assessment should include the NEIC where appropriate. Data archiving is necessary, not just for research purposes, but to provide the quantitative basis for assessments.

Finally, it bears mention that the foundation of hazard mitigation is basic research in geophysical, oceanographic, atmospheric and environmental sciences. It is puzzling that the Administration's proposal does not amplify the fundamental role that the National Science Foundation plays in providing this research for the Nation and the world. In fact, without the investments that the NSF has made in the GSN, in earthquake science, and in oceanographic science and observations, the Administration would not now be in a position to so quickly design and deploy an enhanced tsunami warning system. Tsunami source characterization, propagation and run-up scenarios are just a few of the areas where additional research could provide benefits.

*The role of the US in an Indian Ocean and world-wide tsunami warning network.*

The World Conference on Disaster Reduction in Kobe, Japan, has just ended with the release of the Hyogo Framework for Action: 2005-2015. This non-binding framework calls for the reduction of natural hazard vulnerabilities, and asks countries with significant hazard exposure to place vulnerability reduction on their agendas. The Framework also calls for global and regional collaboration where appropriate. Environmental monitoring and hazard warning systems are areas where regional cooperation is important and appropriate.

From the work of the Earth Institute and other sources, we know that the Central and South Asia, East and Southeast Asia, the Caribbean, Central America and Latin America, Sub-Saharan Africa, all face significant exposures from multiple hazards in terms of mortality and economic impact. The United States is in an excellent position to take an international leadership role in supporting a cooperative and collaborative agenda of environmental monitoring, hazard reduction, and international capacity building in environmental science and technology.

The U.S can take a leadership role in the following ways:

1. Encourage country-level needs assessments, in collaboration with ongoing efforts by the United Nations and World Bank through their post-disaster activities, of multiple hazard vulnerabilities, and use these needs assessments to provide a prioritization framework for international projects in natural hazard observation, monitoring and warning systems, and natural hazard mitigation;
2. Use an international framework such as GEOSS to incorporate tsunami warning as a confidence building measure among the parties. Some of this may be done with bilateral agreements, or in partnership with other developed countries such as Japan, Australia and others. The rapid deployment of the US and Indian Ocean systems now being proposed by the US and other countries should comprise a pilot project for the implementation of the GEOSS framework. The technology and operational components of a tsunami warning system are very well-defined and, with some effort devoted to technical and data integration, a global warning system could provide the concrete accomplishment needed to energize further international development of GEOSS;
3. Leverage tsunami warning technology, particularly the observational components comprising the GSN and DART buoys, to encourage development of country-level technical capacity to collect, archive and share environmental, meteorological and geophysical data according to international standards;
4. Develop an international framework for funding streams for continued operations and maintenance of observing systems. Some of this may be done with regional partnerships;
5. Develop standards for data exchange and data integration in an international framework. A good example is the IRIS consortium, which has successfully combined both operational and research components in an international structure;
6. Work with the international scientific and technical communities, including academic communities, to promote basic and applied research in natural hazard phenomena and risk reduction and management.

In brief, the U.S. leadership role should not be confined to technical leadership. We have the ability to link our scientific and technical excellence to the longer-term disaster reduction and development goals of less-developed countries. This can be done by specifically demonstrating how implementation of a global tsunami warning system in the short term can improve longer-term prospects for risk-conscious development.

Mr. Chairman and Members of the Committee, I thank you once again for the opportunity to provide testimony on this important initiative.

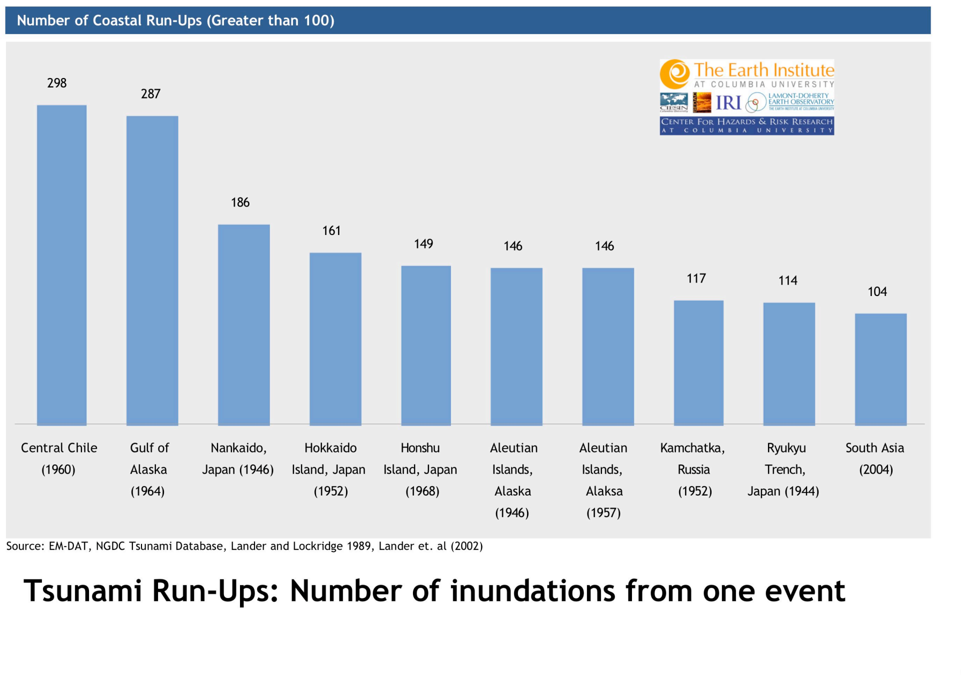


FIGURE 1: Observed tsunami inundations, compiled from several sources. South Asian inundations compiled from initial assessment reports, which are preliminary.

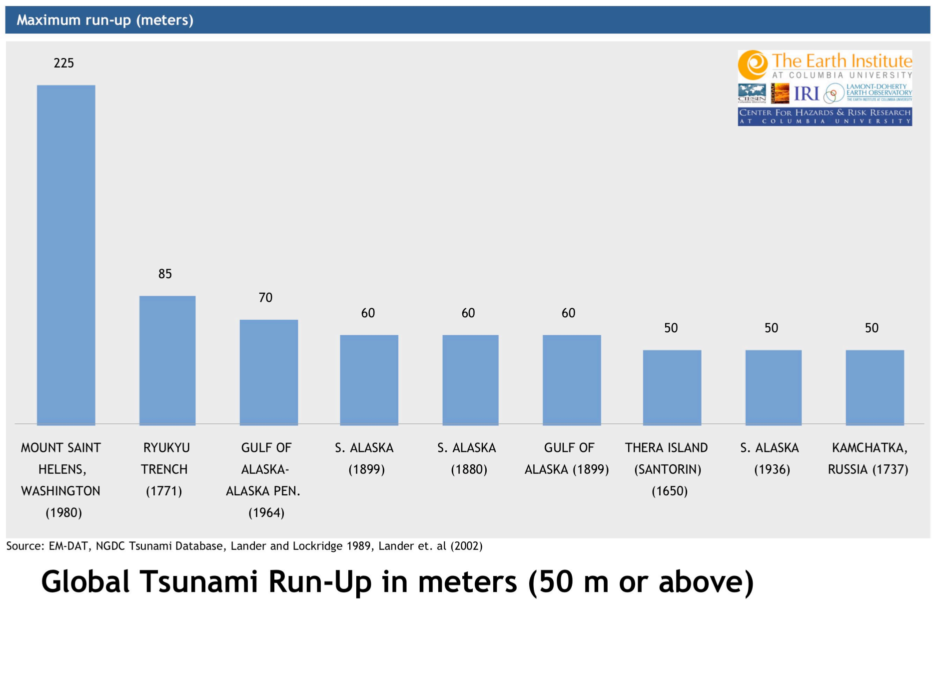


FIGURE 2: Observed tsunami run-ups (height above shoreline) compiled from several sources. The Mt. St. Helens run-up, though spectacular, was localized and presented for purposes of illustration.

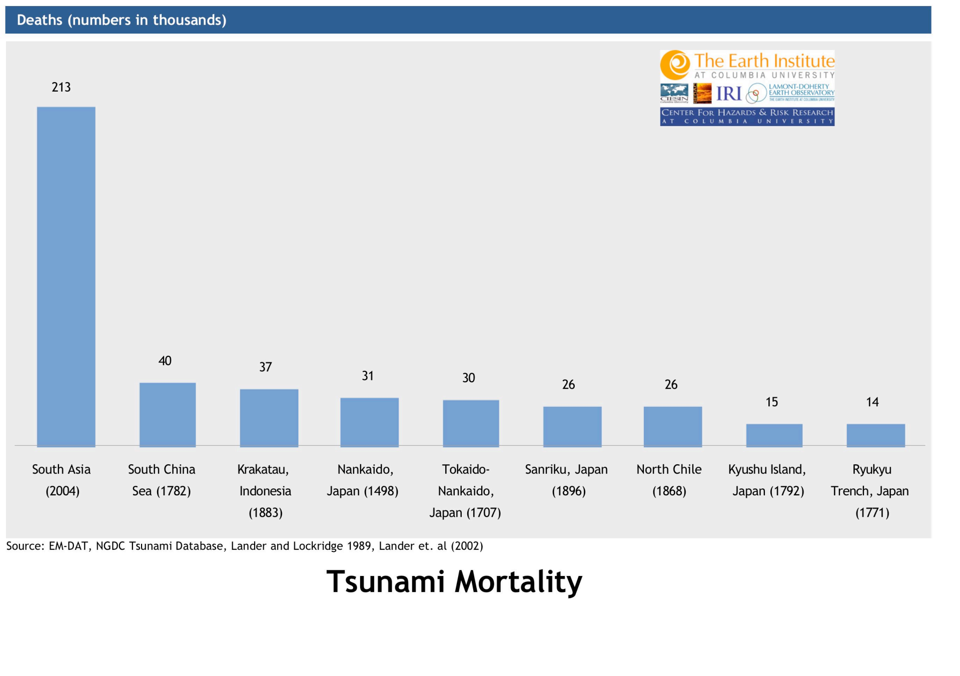


FIGURE 3: Tsunami deaths compiled from several sources. The South Asian tsunami ranks as the deadliest recorded tsunami event, although other natural disasters have caused greater casualties.

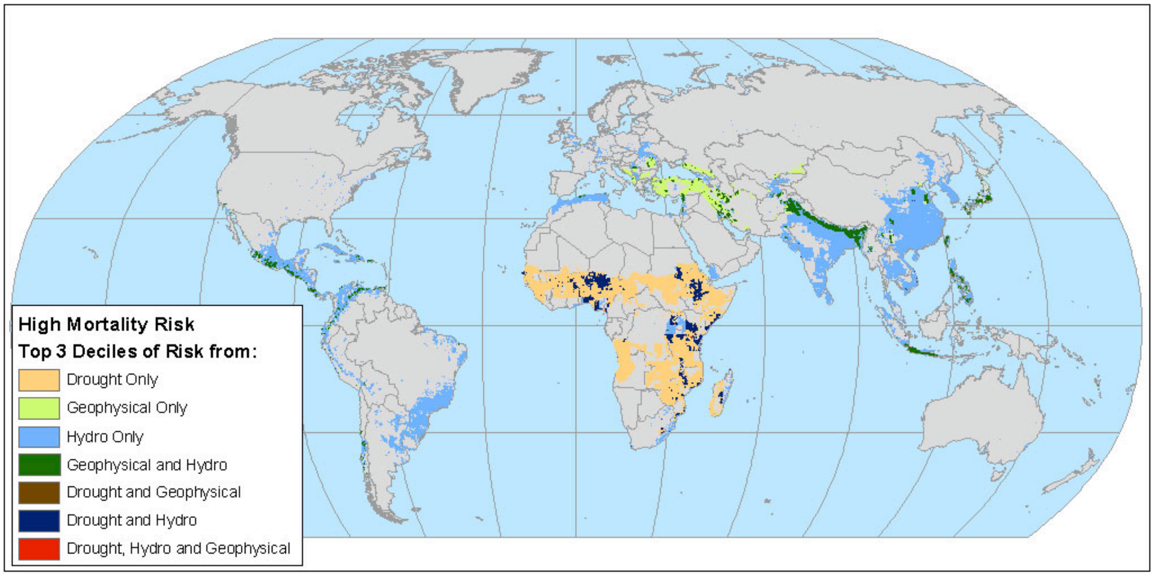


FIGURE 4: Greatest mortality risk (top three deciles, calculated globally) for different combinations of natural hazards. Data for earthquakes, landslides, volcanoes, storms, floods and drought compiled by Dilley et al., 2005. Earthquakes, landslides and volcanoes are included in the "geophysical" category, floods and storms in "hydrometeorological" category.

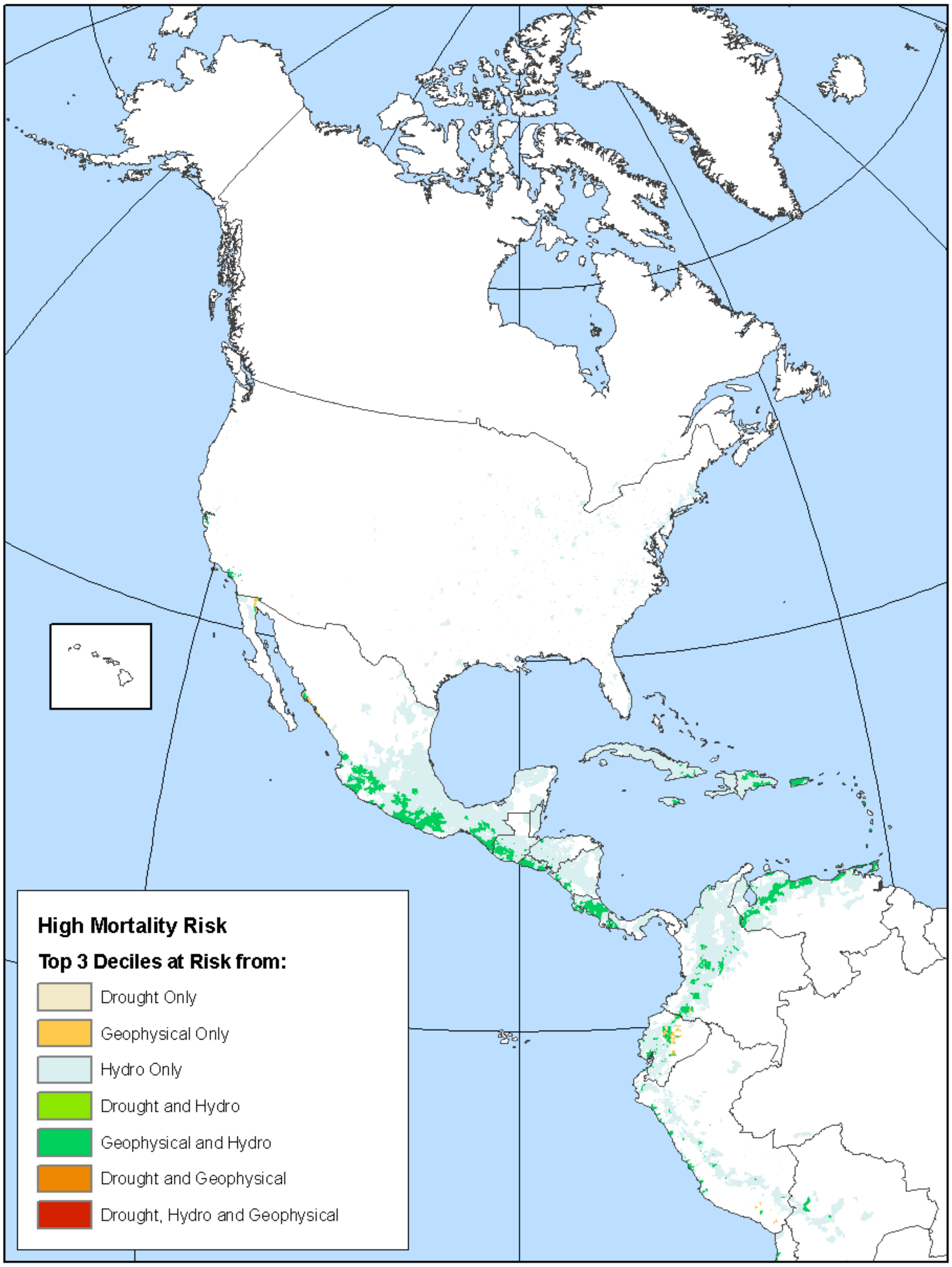


FIGURE 5: Same data as in Figure 4, plotted to emphasize North America, Caribbean, Central and Latin America.

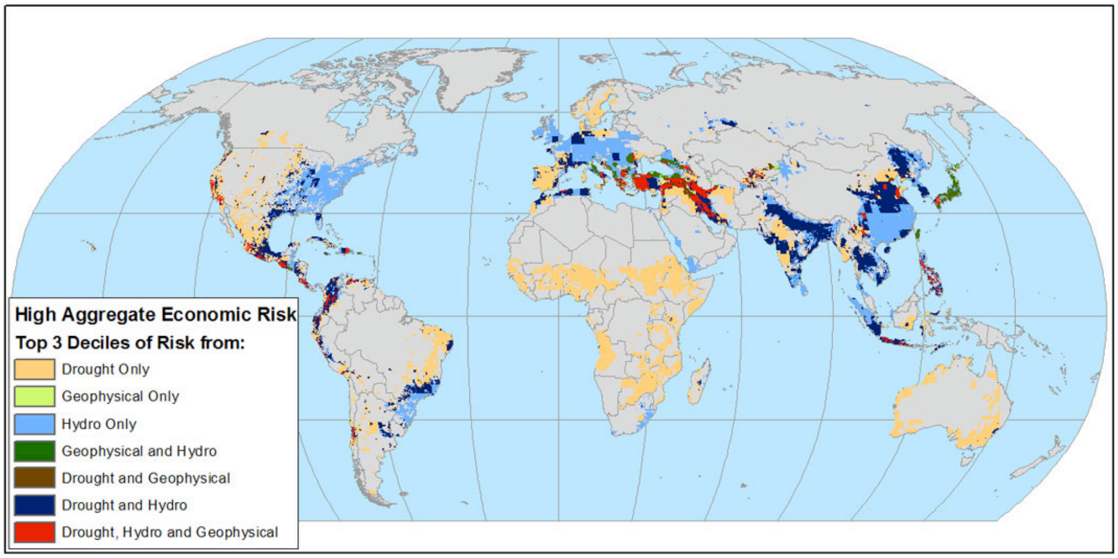


FIGURE 6: Greatest absolute aggregate economic risk (top three deciles, calculated globally) for various combinations of hazards. From Dilley et al., 2005.

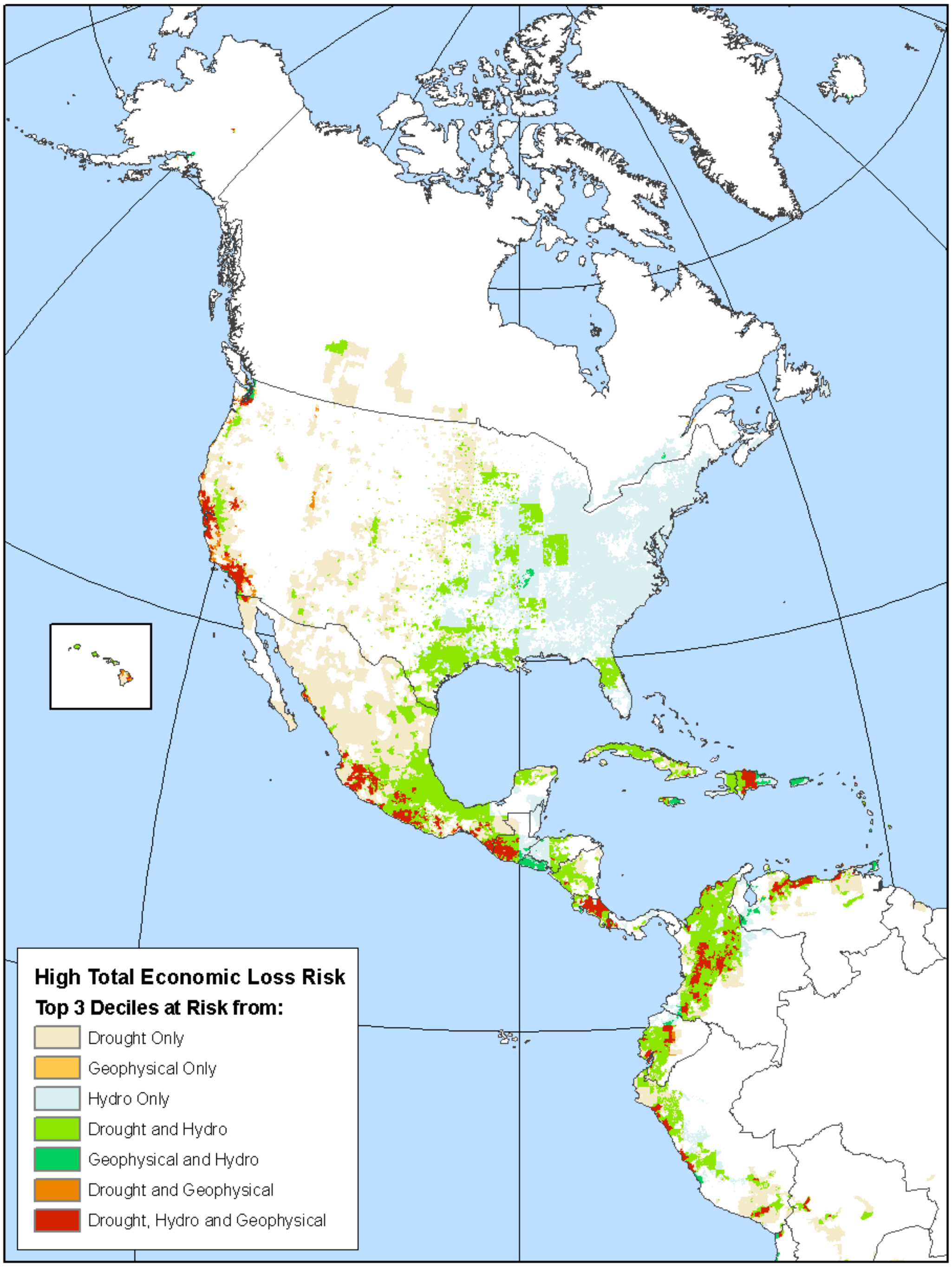


FIGURE 7: Same data as in Figure 6.

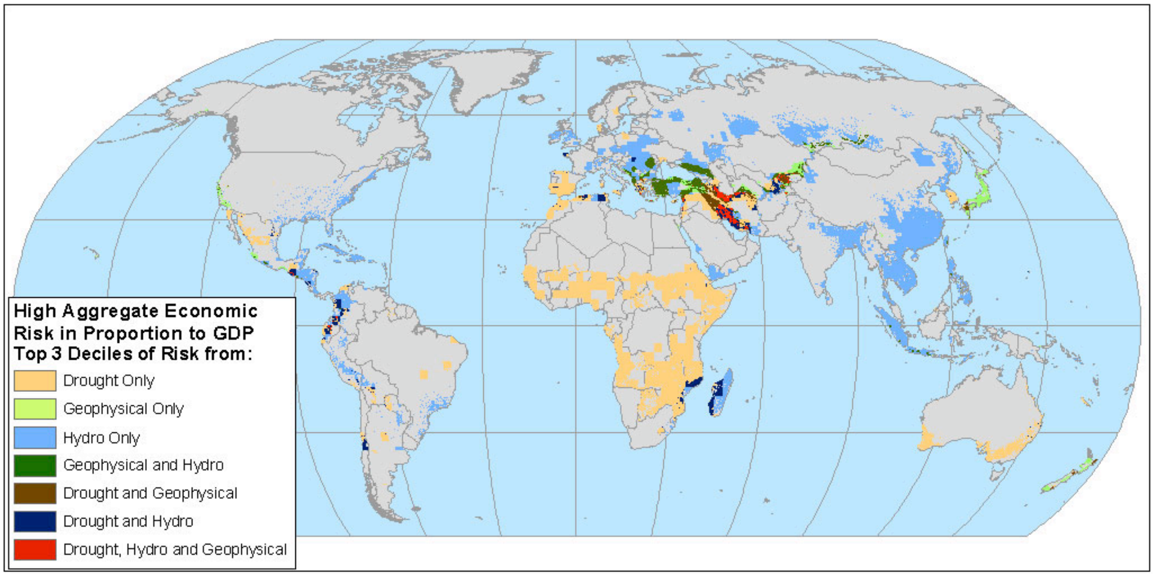


FIGURE 8: Greatest relative aggregate economic risk (top three deciles, calculated globally, normalized by country GDP). From Dilley et al. 2005.

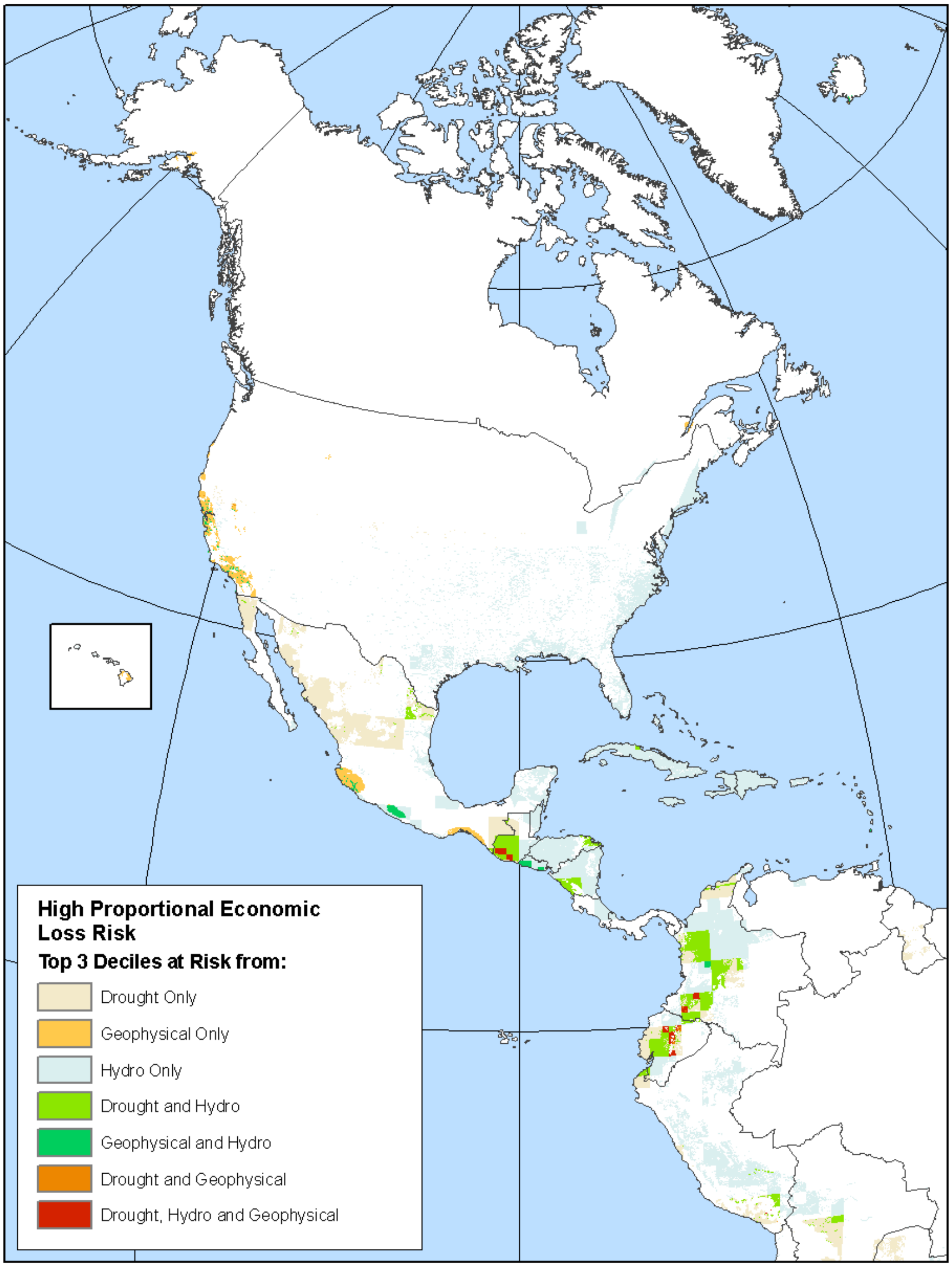


FIGURE 9: Same data as in Figure 8.

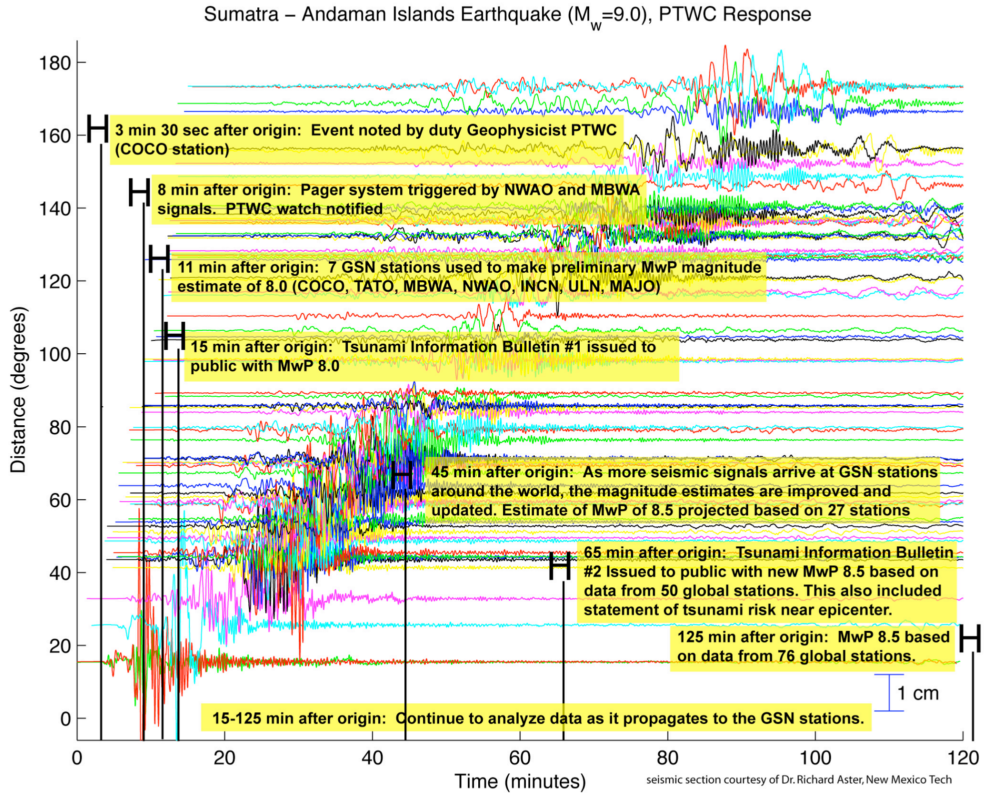


FIGURE 10: Record section compiled from GSN seismograms. (GSN is operated by IRIS, in collaboration with UCSD/Scripps and USGS, with support from NSF.) Comments reflect known operational response of the PTWC.

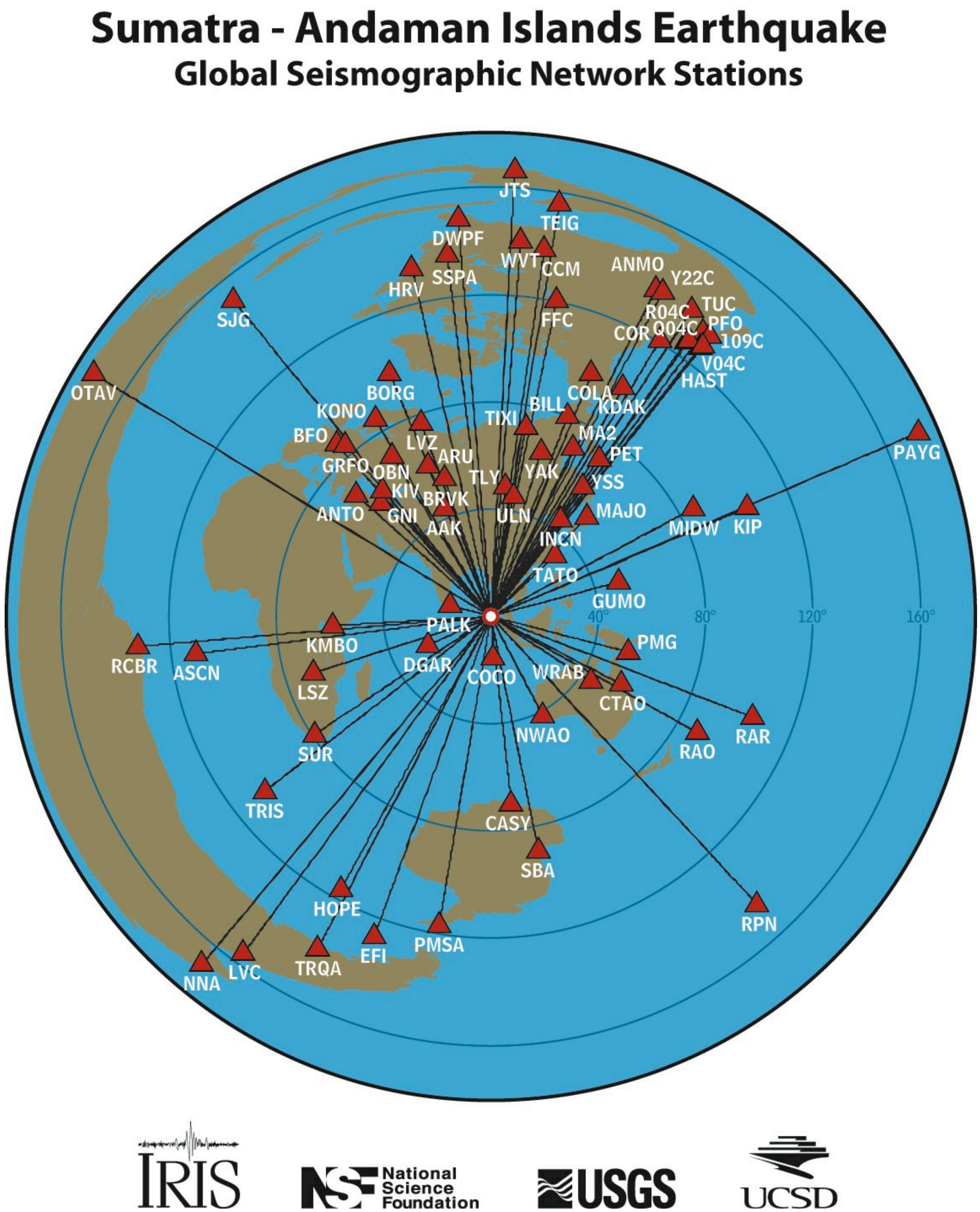


FIGURE 11: Stations of the GSN. The GSN is both a research and an operational network.

Short Bio

Arthur Lerner-Lam, Ph.D.

Arthur Lerner-Lam is a Doherty Senior Research Scientist and Associate Director for Seismology, Geology, and Tectonophysics at the Lamont-Doherty Earth Observatory of Columbia University, in Palisades, New York. A seismologist, he has studied and published on the interactions between crust and mantle, the thickness of continental plates, the structure of mountain belts and crustal rifts, and active seismicity. He has done fieldwork in the Middle East, Central Asia, the Southwest Pacific, and throughout the United States, and in recent years has lectured and written on natural hazards and society. He is the founding Director of the new Columbia Center for Hazards and Risk Research, part of the Columbia Earth Institute. The "Hazards Center" brings together experts from the physical sciences, the social sciences, and the policy communities to develop approaches for reducing the vulnerability of society to natural and man-made disasters. In establishing this Center, Columbia is developing the intellectual basis for sound, science-based policies in hazard mitigation, and to provide educational and degree opportunities for students of both physical sciences and social sciences interested in natural hazards. Many of the research results of the Hazards Center are focused on reducing the vulnerability of poor and developing countries to environmental stress and natural hazards. Dr. Lerner-Lam and his colleagues and students support the activities of the United Nations, the World Bank, and other international institutions concerned with alleviating poverty and promoting sustainable development.

Dr. Lerner-Lam has been a reviewer of research proposals for the National Science Foundation, the Departments of Defense and Energy, the United States Geological Survey, and private foundations. He has also been a peer reviewer for journals and other publications in his field. He has served on many national and international committees, most recently as a member of the Board of Directors and Chair of the Planning Committee for the Incorporated Research Institutions for Seismology (IRIS).

Dr. Lerner-Lam received his undergraduate degree in geological sciences from Princeton University. His doctorate in geophysical sciences was received from the University of California, San Diego at the Scripps Institution of Oceanography. He has held Post-doctoral positions at Scripps and MIT, and has been at Columbia since 1985.

Dr. Lerner-Lam lives in Tenafly, NJ with his wife and three children.

January 24, 2005

Sherwood L. Boehlert
Chairman
U.S. House of Representatives' Committee on Science

Dear Mr. Boehlert:

The information below identifies the sources and amounts of federal funding that has directly supported the subject matter that I will be testifying before the Committee on January 26, 2005.

The following funds were received by me serving as PI or Co-PI at centers and units within the Earth Institute at Columbia University:

**Total for Fiscal Years 2002, 2003, 2004**

*National Science Foundation*

| | | |
|---|---|---|
| OCE-9977437 | $1,100,611 | Development of an Ocean Bottom Seismometer Instrument Pool for Imaging the Earth's Interior and Monitoring its Dynamics |
| OCE-9907756 | $2,700,818 | Operation of an Ocean Bottom Seismic Instrument Pool at Lamont-Doherty Earth Observatory for the Benefit of the Community |
| INT-0104310 | $30,000 | US-Egypt Cooperative Research: Seismic Hazard Mitigation and Soil Strength Mapping for Land Use Planning in Tushka Area, Upper Egypt |
| EAR-9910554 | $912,973 | Collaborative Research: CAT/SCAN (Calabria-Apennine-Tyrrhenian/Subduction-Collision-Accretion Network |

The following funds were received by investigators working at centers and units within the Earth Institute at Columbia University, whose research has contributed to my testimony:

**Total for Fiscal Years 2002, 2003, 2004**

| | |
|---|---|
| National Science Foundation | $7,244,038 |
| U.S. Geological Survey | $386,737 |
| NOAA | $27,416,135 |

Sincerely,

Arthur Lerner-Lam

Arthur Lerner-Lam