TSUNAMIS: IS THE U.S. PREPARED?

HEARING

BEFORE THE

COMMITTEE ON SCIENCE
HOUSE OF REPRESENTATIVES

ONE HUNDRED NINTH CONGRESS

FIRST SESSION

JANUARY 26, 2005

Serial No. 109–1

Printed for the use of the Committee on Science

Available via the World Wide Web: http://www.house.gov/science

U.S. GOVERNMENT PRINTING OFFICE

98–395PS WASHINGTON : 2005

For sale by the Superintendent of Documents, U.S. Government Printing Office
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TSUNAMIS: IS THE U.S. PREPARED?

WEDNESDAY, JANUARY 26, 2005

HOUSE OF REPRESENTATIVES,
COMMITTEE ON SCIENCE,
Washington, DC.

The Committee met, pursuant to call, at 10:05 a.m., in Room 2318 of the Rayburn House Office Building, Hon. Sherwood L. Boehlert [Chairman of the Committee] presiding.

COMMITTEE ON SCIENCE
U.S. HOUSE OF REPRESENTATIVES

Tsunamis: Is the U.S. Prepared?

Wednesday January 26, 2005

10:00 AM – 12:00 PM
2318 Rayburn House Office Building (WEBCAST)

Witness List

Panel I

Representative Jay Inslee
Member, U.S. House of Representatives

Panel II

Dr. Charles "Chip" Groat
Director
United States Geological Survey

Gen. David L. Johnson (ret.)
Director
National Oceanic and Atmospheric Administration's National Weather Service

Dr. John Orcutt
Deputy Director
Research at the Scripps Institution of Oceanography
President
American Geophysical Union

Dr. Arthur Lerner-Lam
Director
Columbia University Center for Hazards and Risk Research

Mr. Jay Wilson
Coordinator
Earthquake and Tsunami Programs
Plans and Training Section, Oregon Emergency Management

HEARING CHARTER

COMMITTEE ON SCIENCE
U.S. HOUSE OF REPRESENTATIVES

Tsunamis: Is the U.S. Prepared?

WEDNESDAY, JANUARY 26, 2005
10:00 A.M.–12:00 P.M.
2318 RAYBURN HOUSE OFFICE BUILDING

Purpose

On January 26, 2005, the House Committee on Science will hold a hearing to better understand the causes of tsunamis, the risks they may pose to the U.S. and to the rest of the world, and how the U.S. should prepare for them.

Although tsunamis are infrequent, their force and destructive power have recently become all too clear. On December 26, 2004, a magnitude 9.0 undersea earthquake off the west coast of northern Sumatra, Indonesia, unleashed a tsunami that affected more than 12 countries throughout Southeast Asia and stretched as far as the northeastern African coast. Massive tsunami waves hit the Indonesian coast within minutes of the earthquake, and other deadly waves raced across the entire 3,000-mile span of the Indian Ocean Basin within hours. Current estimates indicate that at least 150,000 people were killed, and millions more were injured, displaced or otherwise affected. Experts believe that the earthquake which caused the tsunami was the most powerful in 40 years and the fourth largest in the last century. The death toll appears to be the worst on record for a tsunami.

While no tsunami has caused equivalent devastation in the U.S., tsunamis have hit the U.S. in recent decades, almost all of them generated in the Pacific Ocean.

To protect the U.S., the National Oceanic and Atmospheric Administration (NOAA) operates two tsunami warning centers, one in Alaska and one in Hawaii. The Hawaiian center dates back to 1948, and the entire current warning system, which includes ocean buoys, has been in place since 2001. In response to this recent disaster, on January 14, 2005, the Administration announced an interagency plan to increase U.S. risk assessment, detection, warning and disaster planning for tsunamis. The plan would cost $37.5 million over two fiscal years.

The Committee plans to explore the following overarching questions at the hearing:

1) Which regions of the U.S. and the rest of the world face the greatest risk from tsunamis?
2) What are the best methods to detect tsunamis and provide effective warnings? What are the best methods to educate the U.S. about the risks of tsunamis and how to be prepared for them? How well does the Administration's new tsunami plan incorporate these methods?
3) What should the U.S. do to help the rest of the world better prepare for tsunamis?

Witnesses:

Dr. Charles "Chip" Groat, Director of the United States Geological Survey.

Gen. David L. Johnson (Ret.), Director of the National Ocean and Atmospheric Administration's National Weather Service.

Dr. John Orcutt, Deputy Director for Research at the Scripps Institution of Oceanography, University of California at San Diego, and President of the American Geophysical Union.

Dr. Arthur Lerner-Lam, Director of the Columbia Center for Hazards and Risk Research, Lamont-Doherty Earth Observatory, Columbia University.

Mr. Jay Wilson, Coordinator of Earthquake and Tsunami Programs, Plans and Training Section, Oregon Emergency Management.

Background:

What is a tsunami?

A tsunami is a series of ocean waves that are generated by a violent undersea disturbance or activity, usually an earthquake, but sometimes a volcanic eruption, landslide or even a meteor impact. These events cause tsunamis when they result in the sudden displacement of a large volume of water. Earthquakes displace water by suddenly raising or lowering the sea floor; in the case of the recent earthquake the Earth's crust moved at least an inch and the force was large enough to affect the planet's rotation. Waves from the underwater disruption travel out of the area of origin at speeds above 500 miles per hour for thousands of miles (depending on the depth of the water). The waves are often not visible on the water's surface in the open ocean, but when the waves reach shallower coastal shelves, their speed slows and the waters pile up, gathering enormous force. Usually, it takes an earthquake with a magnitude above 7.5 on the Richter scale to generate a tsunami that causes noticeable damage, and scientists are reluctant to predict that a tsunami has been generated unless an earthquake measures at least 8.0.

Where do tsunamis occur most frequently and why?

Tsunamis can be generated in any of the world's oceans or inland seas, but at least 80 percent of all tsunamis occur in the Pacific Ocean. Tsunamis are concentrated in the Pacific because the geology of the Pacific Rim makes it the area on Earth most susceptible to earthquakes and volcanic eruptions, earning it the nickname "Ring of Fire." The Earth's crust is not a single, fixed entity, but rather is made up of large tectonic plates that slowly move about. Earthquakes and volcanoes most often appear at the points where two or more plates abut each other. The entire Pacific rim is lined with areas in which plates rub up against each other, or where one plate dives back toward the Earth's core, scraping underneath another tectonic plate. The most active areas of the "Ring of Fire" include the coasts off Kamchatka, Japan, the Kuril Islands, Alaska and South America. About six times per century, on average, a tsunami from the "Ring of Fire" region sweeps across the entire Pacific, is reflected from distant shores, and sets the entire ocean in motion for days.

Although infrequent, tsunamis have also occurred in the Atlantic and Indian Oceans, the Mediterranean Sea and even within smaller bodies of water, such as the Sea of Marmara, in Turkey. In the last decade alone, tsunamis that have caused significant damage have occurred in Nicaragua (1992), Indonesia (1992, 1994, 1996), Japan (1993), Philippines (1994), Mexico (1995), Peru (1996, 2001), Papua-New Guinea (1998), Turkey (1999), and Vanuatu (1999).

Brief history of recent tsunamis that have hit the U.S.

In 1918, an earthquake in the Caribbean generated a wave that caused the deaths of 40 people in the Virgin Islands.

In 1946, an earthquake along the Aleutian fault (Alaska) produced waves up to 55 feet high, destroying the Hilo's waterfront (Big Island, Hawaii). The tsunami killed 159 people and caused $255 million (in today's dollars) in damage. In response to this event the Federal Government established the Pacific Tsunami Warning Center in Hawaii in 1948.

In 1957, an Alaskan earthquake produced a Pacific-wide tsunami causing waves of 75 feet on the Alaska's Umnak Island and waves of 50 feet on Hawaii's Kauai Island. No deaths occurred but damage was estimated at $34 million (in today's dollars).

In 1958, an earthquake triggered a landslide in Lituya Bay, Alaska, creating a tsunami with the highest waves in recorded history as trees were stripped to a height of 1,720 feet. However, the tsunami's energy and height diminished rapidly away from the source area and, once in the open ocean, the tsunami was hardly recorded by tide gauge stations.

In 1960, a magnitude 9.5 earthquake, the most powerful earthquake in the 20th century, occurred off the coast of Chile. The resulting Pacific-wide tsunami reached Hawaii with waves as high as 35 feet, causing 61 deaths and $155 million (in today's dollars) in damages.

In 1964, a magnitude 9.2 earthquake, the largest earthquake in the Northern Hemisphere in the 20th century, occurred in Alaska. The resulting tsunami devastated five of Alaska's seven largest communities and nearly destroyed the Alaskan fishing industry. Waves also reached the entire California coastline with heights of seven to 21 feet. Half of the waterfront district in Crescent City, CA was destroyed. The tsunami killed more than 120 people in the U.S. and Canada and caused a total of $515 million in damage (in today's dollars).

How does the U.S. Tsunami Warning System work?

The U.S. Tsunami Warning System is operated by the National Weather Service, which is an agency of NOAA. There are two Pacific Warning Centers: an Alaskan center responsible for Alaska and the West Coast of the U.S., and a Hawaiian center responsible for Hawaii and for acting as the national/international warning center for tsunamis that pose a Pacific-wide threat. The Centers are part of an international Pacific Tsunami Warning System, in which 26 nations participate.

The NOAA Centers are tasked with detecting, locating, and determining the magnitude of earthquakes occurring in the Pacific Basin that could cause a tsunami. Earthquake information is provided by seismic stations operated by NOAA, the U.S. Geological Survey (USGS), universities and other nations. NOAA also operates a series of six Deep-ocean Assessment and Reporting of Tsunamis (DART) buoys and hundreds of coastal sea-level gauges in the Pacific Ocean. Since not all earthquakes cause tsunamis, the DART buoys are critical in verifying that a tsunami has been generated. Before the DART buoys were deployed in 2001, more than half of all tsunami warnings turned out to be false alarms in that either no tsunami occurred at all or the one that was generated was not significant enough to cause any damage. False alarms generate their own costs. For example, in 1986, an evacuation of Honolulu that turned out to be a false alarm cost the State of Hawaii nearly $40 million.

Once a Center has determined that a tsunami has been generated, the Center issues a tsunami warning that includes predicted arrival times for the waves at specific coastal communities. These warnings are submitted to federal, State and local emergency management officials, and the nations that take part in the Pacific Tsunami Warning System, which are responsible for relaying the information to the public.

In 1996, NOAA (along with the USGS, the Federal Emergency and Management Agency, and the States of Alaska, Washington, Oregon, California and Hawaii) created the National Tsunami Hazard Mitigation program. The program is designed to help communities prepare for tsunamis by giving them information on how to respond to warnings, helping them determine exactly what is most at risk from tsunamis in their communities, and developing strategies to mitigate the damage that would occur from a tsunami. For example, the program funds mapping of coastal communities to predict which areas of the community are most at risk from the tsunami. These maps are critical for proper evacuation and community preparedness. Public education is also a crucial element of the program because tsunamis can come ashore within minutes of nearby earthquakes. In those instances, people must know what to do immediately in the event of a "felt" earthquake in a low lying coastal area.

The total budget for NOAA's tsunami programs has risen from about $6.6 million in Fiscal Year (FY) 2002 to $10.3 million in FY 2005.

What are TsunamiReady communities?

The National Weather Service has developed a program to qualify communities as being "TsunamiReady." Communities must meet certain criteria such as having established warning and emergency operations center staffed around the clock, having more than one way to receive tsunami warnings and to alert the public, and having developed a formal tsunami plan that includes emergency evacuation exercises. So far, only 15 communities have qualified as TsunamiReady. Some communities have complained that the program requirements are too rigorous and they do not have the time or funding to fulfill them.

Why was the U.S. Pacific Tsunami Warning Center unable to warn the people of the Indian Ocean Basin about the tsunami on December 26, 2004?

While officials at the U.S. Pacific Tsunami Warning Center immediately received seismic information about the massive earthquake off the coast of Indonesia, they were unable to determine if a tsunami had been generated because there are no DART buoys in the Indian Ocean. In addition, the Center initially thought the earthquake was of a lesser magnitude. However, within 15 minutes, the Center issued a bulletin to the 26 nations of the Pacific Region stating that there was minimal risk to the Pacific Ocean Basin counties. NOAA officials did not know of the actual existence of the tsunami until two and a half hours later when news reports began appearing from Sri Lanka. Also, unlike in the Pacific, no international warning system has been put together to disseminate information about events in the Indian Ocean Basin. However, NOAA officials did contact the State Department to see if it could distribute information. Unfortunately, the State Department was not called until seven hours after the earthquake, but that still may have been enough time to warn communities on the East coast of Africa.

Recent Developments:

On January 14, 2005, the Administration announced a new $37.5 million plan to improve tsunami detection, warning, and community preparedness for the U.S. Under the plan, NOAA would receive $14.5 million in an Emergency Supplemental Appropriation in the current fiscal year and $9.5 million in the proposed FY 2006 budget, which is due to be released February 7, 2005. The money would be used to purchase and deploy 32 DART buoys and 38 new tide gauges around the U.S. and its territories. That equipment would provide additional coverage in the Pacific and initiate coverage in the Atlantic Ocean and the Caribbean. NOAA would also expand its education and outreach efforts, develop tsunami inundation maps for more coastal communities, and enhance tsunami warning distribution through new hardware and software. The USGS would receive $8.1 million in the Emergency Supplemental Appropriation and $5.4 million in the FY 2006 budget to improve seismic monitoring and information delivery from the Global Seismic Network. More information about the plan can be found at *www.noaanews.noaa.gov.*

On January 18, 2005, the United Nations hosted a conference on natural disasters in Kobe, Japan to coincide with the 10th anniversary of the earthquake that ravaged that city. While the discussion was to be about preventing natural disasters in general, the issues surrounding the Indian Ocean earthquake and tsunami dominated the conference. Many nations called for the immediate creation of an Indian Ocean tsunami warning system, but it was unclear what specific actions would be taken.

Much of the discussion was about how to better educate the public about tsunamis. While the technology exists to cover the Indian Ocean and the world with buoys and sensors, experts warn that many of the areas hit by the recent tsunami suffer from deep poverty and lack basic education and communication networks, making it difficult to deliver warnings and promote the proper response. Delegates from Japan, which has the most sophisticated tsunami warning system, said they still have great difficulty in educating the Japanese public about the destructive nature of tsunamis and what to do if they feel an earthquake near the shore.

The Administration has said that its new tsunami warning plan for the U.S. should be part of a global Earth observing system and is working with 54 other countries on what that system should entail.

Issues:

1) The Administration's new improved tsunami warning plan proposes $15 million in new activities for NOAA and USGS in FY06. Given the current fiscal constraints on all federal agencies, the Committee wants to better understand what programs or functions of NOAA and USGS may have to be reduced or eliminated to pay for these new activities.

2) NOAA has six special tsunami detection (DART) buoys deployed in the Pacific Ocean. However, only three of the six DART buoys are currently operational. The Administration's proposal is for NOAA to operate a total of 38 buoys in the Pacific, Atlantic and Caribbean by mid-2007. Why is 50 percent of the current system not functioning and what is NOAA doing about it? What will be the greatest challenges in operating 38 buoys and how will NOAA overcome these challenges?

3) Most of the proposed $37.5 million in the Administration's tsunami warning proposal is for new buoys and seismic equipment. While new technology and detection systems are important, many experts believe that local education and planning may be at least as important and more difficult to execute. What specific activities does the Administration propose to increase local education and planning and is the current proposal too heavily weighed toward technology?

4) Natural disasters occurring along the world's coastlines are causing significantly more damage and deaths. This is caused by the tremendous growth in population and developmental of coastal areas and not by an increased number or intensity of disasters. Should we spend some of our limited resources on reevaluating our land-use policies?

Witness Questions:

In their letters of invitation, the witnesses were asked to address the following questions in their testimony:

Dr. Charles "Chip" Groat, Director of the United States Geological Survey.

Which regions of the U.S. are tsunamis most likely to affect? What are the possible causes of tsunamis forming in the Atlantic or Caribbean basins and what are the likelihoods that they could form there?

What comprises the U.S. seismic network and how does it operate? What role does the seismic network play in the operations of NOAA's Tsunami Warning Centers? What are the greatest challenges and needs in improving our seismic network?

Please describe in detail how USGS would use the $13.5 million proposed in the President's new tsunami warning plan.

What should the U.S. do to help better prepare the world for tsunamis?

Gen. David L. Johnson (Ret.), Director of the National Ocean and Atmospheric Administration's National Weather Service.

Please briefly describe what constitutes the NOAA Tsunami Warning System and the Tsunami Hazard Mitigation Program.

Please provide a step by step account of what happens when a tsunami is suspected by a warning center. What steps were you unable to take after you detected the earthquake on December 26, 2004?

What are the greatest challenges to NOAA in improving the U.S. tsunami warning and hazard mitigation systems?

Please describe how the Administration developed its new tsunami warning proposal and what will NOAA do specifically with the $24 million proposed in the President's new tsunami warning plan.

What role should the U.S. play in helping the world better prepare for tsunamis?

Please include in your written testimony: a status report of the current Deep-ocean Assessment and Reporting of Tsunamis (DART) program; funding levels for all five NOAA tsunami programs from FY 2003–2005; and specific programmatic details of the Administration's new tsunami warning plan including funding levels for the FY05 supplemental request, and the FY06 and FY07 President's Budget request.

Dr. John Orcutt, Deputy Director for Research at the Scripps Institution of Oceanography, University of California at San Diego, and President of the American Geophysical Union.

What is Scripps' role in the worldwide seismic network? When did Scripps know about the earthquake on December 26, 2004 and what was your response?

What are the all of the elements of an adequate tsunami warning system? Does the U.S. warning system currently contain all the elements?

What are the greatest challenges to improving the U.S.'s tsunami detection and warning systems? What is your opinion of the Administration's new proposal to improve the U.S. tsunami warning system? Are there other activities or actions that the plan should have included? If so, what are they?

How would you recommend that an Indian Ocean and worldwide tsunami warning network could be established? What role should the U.S. play in its development?

Dr. Arthur Lerner-Lam, Director of the Columbia Center for Hazards and Risk Research, Lamont-Doherty Earth Observatory, Columbia University.

What are the major causes of tsunamis and why are they so difficult to predict?

Please provide a brief history of the major tsunamis of this past century. What is the largest tsunami ever recorded? What are the possible causes of tsunamis forming in the Atlantic or Caribbean basins and what are the likelihoods that they could form there?

How should the U.S. weigh the risk of tsunamis against the risk of other natural disasters? What is the best use of our limited resources?

What are the greatest challenges to improving the U.S.'s tsunami detection and warning systems? What is your opinion of the Administration's new proposal to improve the U.S. tsunami warning system? Are there other activities or actions that the plan should have included? If so, what are they?

How would you recommend establishing an Indian Ocean and worldwide tsunami warning network? What role should the U.S. play in its development?

Mr. Jay Wilson, Coordinator of Earthquake and Tsunami Programs, Plans and Training Section, Oregon Emergency Management.

Please explain your job in Oregon's Earthquake and Tsunami Planning and Training Office. What are the greatest challenges you face in helping the State and localities prepare for earthquakes and tsunamis?

What is your opinion of NOAA's Tsunami Hazard Mitigation program and NOAA's Tsunami Ready program? Why are there so few communities that participate in the Tsunami Ready program and what can be done to increase participation?

What roles do NOAA, USGS, FEMA play in your activities? How can these agencies be more useful in your efforts?

Please describe inundation maps and how important are they to your ability to plan? Who prepares these maps and who pays for them?

What is your opinion of the Administration's new proposal to improve the U.S.'s tsunami detection and warning programs? Are there ways it can be improved, and if so, what are they?

Chairman BOEHLERT. The hearing will come to order.

The first order of business is to introduce to the audience and our colleagues on our committee, the veterans, some of the newer Members of the Committee. It is my understanding that the Democrats have just organized, and the Committee assignments were just made available late yesterday, so some of the newer Members may not know of their assignment just yet.

But on the Republican side, we are pleased to welcome Dave Reichert from Washington State, Mike Sodrel from Indiana, Michael McCaul from Texas, and Joe Schwarz, who will be joining us shortly from Michigan.

I want to welcome everyone here today, especially our freshmen Members. This is our first Science Committee hearing of the 109th Congress, and also the first Congressional hearing on the Administration's proposals for limiting U.S. vulnerability to tsunami.

It is unfortunate that it took a tragedy of staggering proportions to thrust this issue to the top of the Congressional agenda, and indeed the whole world's agenda. But this newfound attention should help prevent future deaths.

And that is the goal of today's hearing: to determine how the U.S. can best prevent future deaths, both at home and abroad. The Administration is to be applauded for coming forward quickly with a cogent, targeted, and affordable proposal to improve tsunami detection for the U.S. and for its commitment to improve tsunami detection internationally.

But detection is only one piece of the kind of the comprehensive effort that is needed to reduce vulnerability to tsunami. Warning systems, education, research and development, land-use planning, and ecosystem protection are all necessary if any program is to be effective. The Administration acknowledges this, but Congress now needs to evaluate whether the January 14 proposal strikes the appropriate balance among those elements. Shiny new technologies should not blind us to the need for a comprehensive approach.

Today's hearing must also address a number of other questions to help us develop a policy. How much risk does the U.S. actually face from tsunami, and how much would the proposed program reduce that risk? To what extent would the proposed program help save lives and property from a tsunami that was generated right off shore? Will other programs be cut in the President's fiscal year 2006 budget to pay for this new proposal? What, precisely, is the U.S. prepared to do to reduce the vulnerability to tsunami in other parts of the world? How can we best integrate the tsunami program with other hazard mitigation and research programs? A lot of questions there, and that is why we are having this timely hearing to get some answers.

This committee has long experience in putting together efforts to improve the U.S. response to natural disasters. The National Earthquake Hazards Reduction Program, or NEHRP, as we affectionately call it, which we created in 1977, has helped reduce the loss of life and property from earthquakes, and indeed, NEHRP is an essential part of U.S. efforts to prepare for tsunami, because most tsunami are generated by earthquakes. We just reauthorized NEHRP last year and also created a similar program to respond to windstorms.

A lesson I draw from many years of experience with NEHRP is that any successful response program requires a comprehensive approach, strong interagency coordination, and an unswerving focus to ensure that all programs' work will truly reduce the destruction wreaked by future events.

Another lesson I take is the centrality of the National Science Foundation to any successful effort. I think all of our witnesses today mention NSF in their prepared testimony, and I hope the key role of NSF will be reflected in the Administration's fiscal year 2006 budget request.

I think today's hearing will make it clear just how complex the science behind our understanding of tsunami is. I can certainly say that I learned a lot of new vocabulary reading this testimony, as well as discovering that the plural of "tsunami" is "tsunami." But I want to make sure today that we don't get lost in the complexity and keep a steady eye on our goal, which is saving lives.

The devastating events of December 26 are a wake-up call to all of us that we need to do more to prepare for tsunami. But it can't be the kind of wake-up call that leaves us panicked and disoriented. It cannot be a wake-up call that leads us to race to work only to find later that we are wearing mismatched socks and have forgotten our belts. We need to take the time now, starting with this hearing, and guided by the Administration's proposal, to put in place a broad, thoughtful, and sustainable program that can save lives here and around the world.

[The prepared statement of Chairman Boehlert follows:]

PREPARED STATEMENT OF CHAIRMAN SHERWOOD L. BOEHLERT

I want to welcome everyone here today, especially our freshman Members. This is the first Science Committee hearing of the 109th Congress and also the first Congressional hearing on the Administration's proposals for limiting U.S. vulnerability to tsunamis. It is unfortunate that it took a tragedy of staggering proportions to thrust this issue to the top of the Congressional agenda—and indeed the whole world's agenda—but this newfound attention should help prevent future deaths.

And that's the goal of today's hearing—to determine how the U.S. can best prevent future deaths, both at home and abroad. The Administration is to be applauded for coming forward quickly with a cogent, targeted and affordable proposal to improve tsunami detection for the U.S. and for its commitment to improve tsunami detection internationally.

But detection is only one piece of the kind of comprehensive effort that is needed to reduce vulnerability to tsunamis. Warning systems, education, research and development, land-use planning, and ecosystem protection are all necessary if any program is to be effective. The Administration acknowledges this, but Congress now needs to evaluate whether the January 14th proposal strikes the appropriate balance among these elements. Shiny new technologies cannot blind us to the need for a comprehensive approach.

Today's hearing must also address a number of other questions to help us develop a policy. How much risk does the U.S. actually face from tsunamis, and how much would the proposed program reduce that risk? To what extent would the proposed program help save lives and property from a tsunami that was generated right off shore? Will other programs be cut in the President's fiscal year '06 budget to pay for this new proposal? What precisely is the U.S. prepared to do to reduce the vulnerability to tsunamis in other parts of the world? How can we best integrate the tsunami program with other hazard mitigation and research programs?

This committee has long experience in putting together efforts to improve the U.S. response to natural disasters. The National Earthquake Hazards Reduction Program (NEHRP), which we created in 1977, has helped reduce the loss of life and property from earthquakes. And indeed NEHRP is an essential part of U.S. efforts to prepare for tsunamis, because most tsunamis are generated by earthquakes. We just reauthorized NEHRP last year and also created a similar program to respond to windstorms.

A lesson I draw from my years of experience with NEHRP, is that any successful response program requires a comprehensive approach, strong interagency coordination, and an unswerving focus to ensure that all program work will truly reduce the destruction wreaked by future events.

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Chairman BOEHLERT. The Chair now is pleased to recognize the Ranking Member from Tennessee, Mr. Gordon.

Mr. GORDON. Good morning. As usual, I concur with Chairman Boehlert's opening statement, and I want to thank him for calling this important hearing.

As Sherry pointed out, our Caucus did not make appointments until just yesterday evening, so a lot of our new Members aren't here, so I am going to wait until a later time to introduce them. And I also want to take the opportunity to congratulate our Chairman for surviving both a difficult operation and re-election, and we are glad to see you back with us. And to the new Republican Members, I suspect that you all went through pretty difficult elections and partisan, and I hope that you can think of this as a mostly partisan-free zone now, and can concentrate on substance and leave the politics back home. So that is what we try to do here.

But the tsunami that struck seven nations in the Indian Ocean one month ago shocked the world with their awesome destructive power. We can not recover the lost lives, but we can ensure that we are well prepared to deal with the natural disasters here in the United States, and we help—and that we can help other nations to do a better job preparing as well.

Tsunamis are rare events, but large ones can have devastating impacts when they occur. Compared to the cost in life and property, the cost of a tsunami warning and emergency preparation system is very small. The Administration's Tsunami Warning System improvement plan provides $37.5 million to NOAA and the USGS over the next two years to upgrade the Pacific Warning System and deploy a detection system in the Atlantic and Caribbean Basins. The plan provides the basis to cover the coastal U.S., and it is a good start.

However, I am concerned that once the headlines have disappeared and the memories of the recent tragedy have dimmed, we may have deployed a network without sufficient funds to sustain its operational capacities. The current network in the Pacific has six buoys, but three are not operational. Clearly, maintenance is an issue that we need to consider. I also believe we need sufficient sustained support for central public education and State and local emergency preparation programs that translate detection and warning systems into life-saving actions.

Most of the funding in the current proposal is devoted to the procurement and deployment of technology. Mr. Wilson of the Oregon Emergency Management is recommending sustained annual funding of the National Tsunami Hazard Mitigation Program of $7.8 million. We currently spend $4 million. The Administration's proposal includes an additional $5 million over two years. That is $2.6 million less than Mr. Wilson recommends. So the $37.5 million over two years included in the Administration's proposal is a good start, but it does not appear to be a complete proposal.

And from where does the money come? If we are spending money to upgrade and expand the Tsunami Warning System, are we going to pay for it in reductions to other programs, and if so, which ones? These are other—there are other programs at NOAA that are essential to preserve lives and property. Is the Tsunami Warning System going to come at the expense of nationwide implementation of improved flood-forecasting models? Will funding for research to improve tornado and hurricane forecasts be cut? Severe storms and the flooding associated with them occur every year. The forecasting and warning systems for these natural disasters also need to be upgraded and maintained.

So as we design and employ this Tsunami Warning System, we must provide sustainable funding to ensure its continued operation. But we should not sacrifice other equally important NOAA programs and operations in an effort to develop a temporary response to yesterday's crisis. If we are going to do this, we should do it right, and doing it right requires that we know the full initial and annual cost needed to deliver the benefits the public expects from this warning system.

We have an excellent witness panel today. I welcome all of our witnesses to Washington and thank you for appearing before the Committee this morning. And I certainly want to welcome our colleague, Jay Inslee, for being here with us. I look forward to your testimony and to hearing your thoughts on how we can best address the development and the end-to-end emergency warning and response system for tsunamis.

Thank you, Mr. Chairman.

[The prepared statement of Mr. Gordon follows:]

PREPARED STATEMENT OF REPRESENTATIVE BART GORDON

Good Morning. I thank Chairman Boehlert for convening this important hearing.

The tsunamis that struck seven nations in the Indian Ocean one month ago shocked the world with their awesome, destructive power. We cannot recover the lost lives, but we can ensure that we are well-prepared to deal with natural disasters here in the U.S. And we can help other nations to be better prepared as well.

Tsunamis are rare events, but large ones can have devastating impacts when they occur. Compared to the cost in life and property, the cost of a tsunami warning and emergency preparation systems is small.

The Administration's tsunami warning system improvement plan provides $37.5 million dollars to NOAA and USGS over the next two years to upgrade the Pacific warning system and deploy a detection system in the Atlantic and Caribbean basins. The plan provides the basics to cover the coastal U.S. It is a good start.

However, I am concerned that once the headlines have disappeared and the memories of the recent tragedy have dimmed we may have a deployed network without sufficient funds to sustain its operational capabilities. The current network in the Pacific has six buoys, but three are not operating. Clearly, maintenance is an issue we need to consider.

I also believe we need sufficient sustained support for the essential public education and State and local emergency preparedness programs that translate detection and warning into life-saving actions. Most of the funding in the current proposal is devoted to the procurement and deployment of technology.

Mr. Wilson of Oregon Emergency Management is recommending sustained annual funding for the National Tsunami Hazard Mitigation Program of $7.8 million dollars. We currently spend about $4 million. The Administration's proposal includes an additional $5 million over two years—$2.6 million less than Mr. Wilson's recommendation. So, the $37.5 million over two years included in the Administration's proposal is a good start, but does not appear to be a complete proposal.

And where will the money come from? It is no secret that we are in a terrible budget situation. If we are spending money to upgrade and expand the tsunami warning system, are we going to pay for it with reductions to other programs? If so, which ones?

There are other programs at NOAA that are essential to preserve lives and property. Is the tsunami warning system going to come at the expense of nationwide implementation of improved flood forecasting models? Will funding for research to improve tornado and hurricane forecasting be cut? Severe storms and the flooding associated with them occur every year. The forecasting and warning systems for these natural disasters also need to be upgraded and maintained.

As we design and deploy this tsunami warning system, we must provide sustainable funding to ensure its continued operation. But we should not sacrifice other equally important NOAA programs and operations in an effort to develop a temporary response to yesterday's crisis. If we are going to do this, we should do it right. Doing it right requires that we know the full initial and annual costs needed to deliver the benefits the public expects from this warning system.

We have an excellent witness panel. I welcome all of you to Washington and thank you for appearing before the Committee this morning. I look forward to your testimony and to hearing your thoughts on how we can best address the development of an end-to-end emergency warning and response system for tsunamis.

Chairman BOEHLERT. Thank you very much.

And it is with mixed emotions that I make this next announcement, but today is the last official hearing for Martha "Marty" Ralston, who is retiring at the end of this week after 26 years of dedicated service to this committee. And she typifies the professionalism and dedication and commitment of the staff of this committee. And I would ask you to join me in saluting her for that service.

Our first witness on panel one, and our only witness on panel one, is our distinguished colleague, Jay Inslee. Jay is someone who is, I have learned from long experience, very knowledgeable about the subject matter that he involves himself in, and it is a wide range of activities. So to my colleague, I say welcome and we look forward to hearing from you on this very important subject.

How are we doing there? Here we go. High technology at work.

[The prepared statement of Mr. Ehlers follows:]

PREPARED STATEMENT OF REPRESENTATIVE VERNON J. EHLERS

A month ago today one of the most devastating tsunamis ever recorded struck the nations of the Indian Ocean Basin. My prayers continue to go out to the victims of this terrible event. It is a startling reminder of our vulnerability to natural disasters. As people recover from the shock of the tsunami, we naturally begin to ask the questions such as "What can we learn from this to prevent future disasters?" In that vein, I am pleased that Chairman Boehlert organized today's hearing about the state of preparedness for detecting and responding to tsunamis in the United States.

As Chairman of the Environment, Technology, and Standards Subcommittee, I am particularly interested in the role that the National Oceanic and Atmospheric Administration's (NOAA) National Weather Service plays in tsunami detection and warning systems. Currently, NOAA operates a tsunami warning system for the Pacific Ocean. Recently, the Administration announced an interagency plan to increase

U.S. risk assessment, detection, warning, and disaster planning for tsunamis. Under the plan, NOAA would expand its current system nationwide using emergency supplemental appropriations in Fiscal Year (FY) 2005 of $14.5 million and then $9.5 million in FY 2006. While I support the Administration's plan to expand our tsunami detection systems, I am concerned about adequate funding in the out years for maintenance of the system. Currently only three of the six deep-ocean buoys used to detect tsunamis in the Pacific Ocean are working.

Advanced tsunami detection buoys and real-time warning systems will only take us so far. People in coastal areas, and those visiting coastal areas, must learn to recognize the signs of natural disasters like tsunamis and must know how to respond appropriately to warnings. One of the news reports from the Indian Ocean tsunami was about a young school girl who had just learned about tsunamis in class. On vacation with her family, she recognized that the unusually large amount of water receding from the beach was a sign that a tsunami was coming and warned those near by to flee to higher ground. Her efforts saved dozens of lives. We should all know basic signs of natural disasters like this. This is a perfect example of why we must continue to work for improved science education in all of our schools.

Unfortunately, it has taken this tragic event to bring natural disaster response planning to our attention today. However, now that the opportunity is upon us we must act quickly to establish a detection and warning system for the United States, and collaborate intensely on an international system. Not only must we develop an excellent worldwide detection system, but must also do the harder task of implementing a good warning system and training the public to understand and heed the warnings.

[The prepared statement of Mr. Gilchrest follows:]

PREPARED STATEMENT OF REPRESENTATIVE WAYNE T. GILCHREST

Mr. Chairman, I would like to address the tragedy of the recent Indian Ocean Tsunami and the opportunity it presents to examine and address our pressing need to better understand our oceans.

Comprising 70 percent of the Earth's surface area, our oceans support a growing source of protein for many developing countries, promising sources of medicines, and efficient transport of goods between continents and among nations. They also strongly influence our climate and weather and provide economic and unmeasurable quality of life benefits. For proof of this, one only needs to know that the U.S. coasts support over 50 percent of the U.S. population and comprise only 17 percent of our land base.

When South Asia was struck by tsunami waves on December 26, the world's interest in tsunami detection and warning systems was heightened. The impact of these waves was felt around the world, and the tragedy of its immediate effect on Indian Ocean coastlines has painfully exposed our lack of ability to provide early warning and coastal community education and support. Many lifelong residents of Indian Ocean coastal towns fear the sea—the primary source of their livelihoods for generations. It is critical that individuals in high-risk areas are educated about and prepared for tsunamis before they strike. Coastal communities need assurance that technology exists and will be applied to increase warnings for such events and to prepare them for evacuation to avoid catastrophic loss of human life.

In contrast, developed nations use increasing technological sophistication to acquire from the sea its bounty—with little thought for the long-term sustainability of this activity. In time, without increased understanding of our ocean ecosystems and the impact of our harvest and extraction of its resources, developed nations may also come to fear the sea. The antidote to the disease of fear is understanding. New technologies have already led to enormous advances in our understanding of the coastal and marine environment. However, advanced sensors have been deployed only on relatively small scales, and the systems that are deployed have not been coordinated into an integrated system that will optimize our understanding of the oceans.

Since the U.S. hosted the Earth Observation Summit in July 2003, we have been working with our partner nations to adopt a comprehensive, coordinated and sustained Earth Observation System to collect and disseminate data, information and models for more effective and responsible use of our resources as well as to inform decision-makers about impending disasters. Most recently, the U.S. Commission on Ocean Policy made an integrated ocean observing system a top recommendation in its report, *An Ocean Blueprint for the 21st Century.*

Our space exploration and our weather programs show that when our scientists and the Nation support a program and devote time, money and most importantly the human mind into these types of endeavors we are highly successful. The ocean, however, is often referred to as the last frontier, a place where we continue to find new organisms and species and where we still struggle to understand the profound implications for climate changes and more direct impacts of the oceans on our human habitats.

There is perhaps no more motivating event, no louder a voice for attention and understanding than having the ocean engulf human habitats. Our failure to fully develop and utilize our technology to understand our oceans has many more implications, including the potential for permanent damage to fragile and complex ecosystems that have generously provided us with food, medicines, recreation, and other benefits. We are now awake to the power of the ocean, and it is my hope that we will use this opportunity to move more quickly toward integrated data collection and dissemination systems, as well as intensive education of coastal communities, to ensure that we and future generations can look to the sea for inspiration, sustenance, and life-giving support.

I applaud the Administration's commitment to increase global monitoring capacity and public awareness about tsunamis and other disasters, especially in adding capacity to ocean monitoring as part of the Global Earth Observation System of Systems (GEOSS). I look forward to the testimony from our esteemed witnesses and their insight into how best to develop our contribution to GEOSS to best warn coastal communities of potential disasters, how to integrate this system with broader needs for integrated ocean monitoring data, and how best to educate coastal communities about the impacts of the oceans on our lives.

[The prepared statement of Mr. Costello follows:]

PREPARED STATEMENT OF REPRESENTATIVE JERRY F. COSTELLO

Good morning. I want to thank the witnesses for appearing before our committee to discuss the causes of tsunamis, the risks they may pose to the U.S. and to the rest of the world, and how the U.S. should prepare for them. We have all shared the grief and recognized the catastrophic damage caused by the tsunami in South Asia. While Americans have generously responded to the disaster, we also have an important role to play in preventing such horrific loss of life should another underwater earthquake occur.

A tsunami as powerful as the one that devastated South and Southeast Asia has never hit the United States, but that does not mean it could not happen. Even a lesser catastrophe could be deadly, and would only take a minor underwater landslide in the Canary Islands to trigger a big eruption. The Atlantic Ocean, like the Indian Ocean, lacks tsunami sensors. There were no sensors in the Indian Ocean because tsunamis were deemed less likely there, but now we know that 'less likely' is not good enough. Merely detecting a disaster and having the technology to access the magnitude of the earthquake will not minimize the impact of future natural disasters. Experts believe that millions of lives lost in the recent tsunami disaster could have been saved if the Indian Ocean countries had the capabilities to administer warnings about the impending catastrophe to people along the coasts. This claim has caused us to re-examine our own risk assessment and detection systems for tsunamis and I am pleased this committee is having this hearing today in order to address the challenges that lie ahead.

I welcome our panel of witnesses and look forward to their testimony.

[The prepared statement of Ms. Johnson follows:]

PREPARED STATEMENT OF REPRESENTATIVE EDDIE BERNICE JOHNSON

First of all, I would like to thank Chairman Boehlert for calling this important hearing to review how prepared the U.S. is for tsunamis. I also want to thank our distinguished witnesses for agreeing to appear today and answer our questions.

We were all quite disturbed by the catastrophic images that were disseminated worldwide last December. As casualties have risen above the 200,000, our hearts and prayers go out to all the victims and their families.

As we discuss the enormous devastation caused by this natural disaster, the one question we must ask ourselves is could this have been avoided?

We here in the U.S. at least like to believe that thanks to the sophisticated tsunami-detection systems in the Pacific Ocean, we are save from tsunami harm. However, recent reports have suggested that half of our system is in desperate need repair, leaving substantial blind spots in our detection system and our beaches vulnerable.

This is unacceptable. The nations around the Pacific Ocean basin have had a tsunami-warning network in place since the 1940s. Since the mid '90s, the U.S. has had sensors at the bottom of the Pacific Ocean floor capable of detecting destructive waves and signaling to surface buoys, which then radio the information to satellites and onward to scientists. No such Indian Ocean tsunami-warning system was in place.

Equally as important as increasing technology, there should also be an increase in education. There was little public education in low-income countries to the dangers of tsunamis. The public needs to understand and react properly to tsunami warning signs, such as the rattling of an earthquake that initiates the wave, the dramatic recession of water from the beaches, and a deep rumbling that immediately precedes the wave. Information needs to get from federal to State and local agencies—and then be transmitted to the public. Most importantly, the public needs to understand what to do with that information.

I hope the witnesses here today can help us come up with ideas on how exactly to accomplish this.

With that being said, I again thank the Chair and Ranking Member for this hearing.

[The prepared statement of Mr. Davis follows:]

PREPARED STATEMENT OF REPRESENTATIVE LINCOLN DAVIS

Good morning. Thank you, Mr. Chairman and Ranking Member, for the opportunity for us to discuss the Indian Ocean tsunami that occurred on December 26, 2004. Thank you, Witnesses, for your presence today.

It is hard to imagine the destruction caused by that tsunami. My district, in rural Tennessee, seems so far removed from a natural disaster such as this one.

But my constituents, whose loved ones are bravely serving this nation in our military, know the feelings of sorrow and despair when lives are lost. Tornadoes and floods affect our area, and so I can understand the grave importance of having plans in place to predict these forces of nature so that people can prepare as best they can.

I have seen much on the news about the December 26th Tsunami—we all have. But it is my hope today that these witnesses who are experts in their fields will be able to tell us what we can do in the future to better prepare, better predict, better communicate, and better protect people from future tsunamis.

It is frustrating to know that all the world's advanced technologies couldn't save 212,000 people. 212,000 of anything is hard to fathom, and the loss of just one life seems unbearable. Our hearts and prayers go to the families of those affected by this terrible disaster.

Mr. Chairman, thank you and I yield back the balance of my time.

[The prepared statement of Ms. Jackson Lee follows:]

PREPARED STATEMENT OF REPRESENTATIVE SHEILA JACKSON LEE

Mr. Chairman,

I want to thank you for organizing this briefing on how NOAA, USGS, universities, and State agencies can assist with the detection and relief efforts of tsunamis and other natural disasters. Just last week I traveled with my Congressional colleagues to Colombo and Galle in Sri Lanka on a delegation lead by Congressman Joseph Crowley. I saw the devastation caused by the December 26 tsunami which took thousands of lives. I have never witnessed such extensive destruction and loss of life. I hope that the technologies that the Science Committee will help to develop will help to minimized losses in future natural disasters.

I was able to see first hand how USAID workers and U.S. Armed Forces personnel were helping in the effort to provide assistance and rebuild. Despite all the horrific devastation, it was a welcome sight to see American personnel putting so much work and effort into helping the people struck by the tsunami. You could see on the faces of the Sri Lankan people that they were grateful of the efforts being made on their behalf. Those Americans in Galle have served their nation well and we should all be proud of their efforts.

Tsunami Causes and History

Tsunamis are walls of water that inundate coastal areas with little or no warning, often taking many lives and causing extensive property damage. They are initiated by sudden underwater disruptions and in this regard they differ from wind generated waves because the power they pack is not limited to the surface. Tsunamis are usually started as a result of an undersea earthquake, which for years was considered to be the sole cause of tsunamis. Research is now showing that tsunami generation involves intricate interactions between earthquakes, undersea landslides, and sympathetic vibrations between the quake and the ocean above it.

Tsunamis have been known since 426 B.C., and between 1990 and 2001 there were 11 major tsunami events in the Pacific Rim, killing over 4,000 people and causing hundreds of millions in property damage. Previously, the most devastating tsunami occurred in 1755 in the Atlantic which killed 60,000 people and destroyed much of Lisbon. By comparison, the death toll from the Banda Aceh Tsunami could exceed 150,000 on top of the unthinkable numbers of displaced, orphaned, and injured. Subsequent disease and untreated injuries will undoubtedly add to these statistics.

U.S. Assistance

The President has already pledged $350 million in direct support to the affected countries on top of the medical, infrastructure, and logistics support from the U.S. Military. I want to encourage my colleagues in the Congress to work together as we did last Fall to provide nearly $14 billion in relief to the Southeastern states and Caribbean nations following the four devastating hurricanes.

In addition to the technical assistance our U.S. Military is providing for the relief efforts, we want to also make sure that U.S. scientific capability is available to the relief efforts and also in the prediction and warning of future natural disasters.

I also want to recognize the private sector that has shown unprecedented outpouring of generosity with donations of supplies and money. In my own district, I helped to organize a group known as Houston's Solutions for Tsunami Victims held a Medical Relief Drive and Save the Children Effort in Houston on January 9th in which thousands of vital medical supplies were collected and will be delivered to tsunami stricken areas.

Research and Early Warning

Beyond the immediate needs, I want to encourage the Science Committee to work with me in developing programs that will help to minimize losses suffered in future natural disasters. The National Oceanographic and Atmospheric Administration and the U.S. Geological Survey lead the U.S. in the research, monitoring, and warning of tsunamis and other natural disasters. For example, the Deep-ocean Assessment and Reporting of Tsunamis Project (DART) can detect ocean level anomalies as small as ½ inch in 20,000 feet of water to determine if a tsunami event is occurring in the deep sea. This system was useful in avoiding a false alarm in response to an Alaskan earthquake that could have but, did not cause a tsunami. DART stations cost about $250,000 to purchase and around $125,000 per year to maintain. Stations are now located off the coasts of Alaska, the Pacific Northwest, and Chile, but we need to consider how this system can be expanded to other parts of the world. Reliability of the DART system needs to be understood as we consider its deployment worldwide.

Research on the causes of tsunamis is also needed. One of the most severe tsunamis in recent history occurred in Papua New Guinea in July 1998. The initiating earthquake was unexceptional at a magnitude of 7.1—the size of an earthquake that strikes somewhere in the world about every three weeks. Geological modeling strongly suggested that the quake caused an underwater landslide that together triggered the exceptional size tsunami that killed at least 2,500 people. Other preliminary research indicates that under some conditions, tsunamis may be detectable from aircraft or satellites using radar or radiometers miles away from coastal areas.

NASA recently provided me with some preliminary information that their JASON–1 satellite sensors did detect the December 26 tsunami, and I understand that NASA is already collaborating with NOAA in the analysis of this data. While JASON–1 was not designed as part of a tsunami warning system, these data may help to identify new sensor and detection systems for tsunamis that will reliably predict tsunamis with a low rate of false alarms.

ASTER, a cooperative effort between NASA and Japan's Ministry of Economy Trade and Industry, is a satellite sensing system that obtains high-resolution image data in 14 channels over targeted areas of the Earth's surface, as well as black-and-white stereo images. With a revisit time between four and 16 days, ASTER data is already being used to assess the damage to the countries devastated by the tsunami.

Science Committee Opportunities

The preliminary data from NASA indicates that new analyses of data from existing sensing systems may be useful in predicting tsunamis and other impending natural disasters. New types of sensing systems may also help in this regard. *Ab initio* modeling, taking into account all of the data from this tsunami, will be important in understanding how to prevent future devastation. I am looking forward to working with the Science Committee to identify these opportunities for NOAA, USGS, NASA and the other federal science agencies.

Panel I:

STATEMENT OF REPRESENTATIVE JAY INSLEE, MEMBER, U.S. HOUSE OF REPRESENTATIVES

Mr. INSLEE. We are talking about high technology here. You know, people have described this event as a biblical event that brought us here today, and the same Creator that created a world that is so dynamic that can create tragedies like this also created the human mind. And what we are really talking about at this hearing is the use of the human mind to guard us from these future events, future events that we know are going to happen. This is not a hearing about something that is uncertain. There is certainty that we are going to experience earthquakes and tsunamis like this. The only question is when and where.

And you know, Mr. Boehlert, of all of the hearings you have ever had, you, perhaps, never had one that was so timely, because 305 years ago today, January 26, 1700, a few miles off the coast of the Pacific in the United States, the Cascadia subduction zone ruptured, and it created an earthquake probably equal or exceeding that off the coast of Indonesia, and it sent tidal waves, tsunamis perhaps as much as 50 feet high across the Pacific coast in the State of Washington. So 305 years ago today, we experienced in the United States an event very similar in scope and potential tragedy as they did in Indonesia. So you really could not have picked a better day to focus the Nation's attention on this issue.

The bad news is that we are very exposed. This is a personal issue. My District is connected to the Pacific Ocean on the shores of Puget Sound. Washington has an exposed coastline. But we have many areas in the country that have these potential exposures. That is the bad news.

The good news is that we have the scientific capability, due to some extraordinary achievements, some of, I may note, is from my District, that have the capability of really giving us 100 percent protection in a timely real-time warning of tsunamis. So that is the good news. And the good news here, there is a success story already. The United States has already, before a huge tragedy, developed at least the beginnings of a good system with the six buoys we have in the Pacific now already being developed. And that is the success story of some of the advanced thinking of our scientific community of our federal agencies, and they should be complimented for that. Now we need to give them the tools to finish that job. I may note that one of these tools that can detect one inch, these tools that sit on the bottom of the ocean, they are anchored to the sea floor. And they use a transducer developed by someone in the first District of the State of Washington, I may add, Redmond, Washington, they can note in five miles deep water one inch of deviation in the elevation of the water column above them by noticing that pressure distance. This is an incredible technology. We simply need to get it out under the ocean. And that is why we—I look forward to introducing this bill with you, Mr. Boehlert, to do that on a bipartisan basis to get this job done.

We are talking about probably 50 buoys worldwide to provide not only America but the world with this protection. And that is one important point, I think, of this effort is that we need to protect our own coastlines, but we need to use our technological know-how to lead the world in an international system to protect the world's coastlines. And there is at least preliminary thought about using the Hagemeyer Pacific Tsunami Warning Center in Hawaii as the sort of nerve brain to distribute—analyze this information and distribute the warnings worldwide, and I think that is something we should contemplate, because we really are the worldwide leaders.

I want to note just several things that I hope we will keep in mind as we develop this legislation. First, and Mr. Gordon really mentioned it, the need for follow up. This does not simply involve sticking some buoys in the water and calling it a day. And we will be challenged to make sure that this job gets done in several respects. One, the maintenance needs, the ocean is fairly unforgiving. Three of our buoys are down now. We need to make sure we have a rigorous maintenance schedule. And we have to build in redundancy into this system, because some of these buoys are going to be down no matter what we do due to the stresses of the ocean.

Second, and this is very important for, I think, the Committee to think about, is that the buoys don't do the job without a warning and educational system for the people on the shorelines. Sending a signal from a satellite to Hawaii and then down from Hawaii to a certain agency of the Federal Government doesn't do any good if we haven't educated our citizens of what to do and how to get the warning to the beaches and to the schools to get that job done. We started that in the Pacific. I noticed La Push, Washington is exposed. They have got a bus out there to—24 hours a day practically to evacuate kids from an elementary school they have there. So we have the good beginning of that system, but we have got to develop a national system to get that job done.

False alarms. I also want to talk about a benefit of this that is not often contemplated. One of the problems we have with the existing system is that because it doesn't have a sufficient scope, we have false alarms. And when you have false alarms, it costs you humongous amounts of money, if I may use that scientific term. It cost about—Hawaii about $40 million when we had a false alarm in the last couple decades. This—creating a larger system will eliminate or severely reduce false alarms that will make this system work. It will save us a lot of dollars in lost tourism and the like shutting down your economy.

The last note I want to make, people have asked about the cost of this. These are very rare events. The last event that damaged the United States was 305 years ago, so they are quite rare. And people have asked, you know, "Why should we protect against and spend millions of dollars on a rare event?" And the answer is very simple. It is one of the best investments you can make. You know, we have spent hundreds, literally hundreds of billions of dollars on what, up until now, have been some rare events of the terrorism threat. We have a threat now that may be rare but equally devastating, and that is tsunamis. And spending somewhere in the order of $40 million to get this job done, there is really no cheaper investment to save Americans' lives, and we ought to make it.

So I want to thank you, Mr. Boehlert and Mr. Gordon, and I look forward to working with you, and I will answer any questions or general criticisms.

DISCUSSION

Chairman BOEHLERT. I want to thank you for an excellent statement. I want to compliment you for getting, at last count, seven plugs for your District in, and you did very well in your representational capacity.

But you underscored the need for a comprehensive approach. It is something more than just appropriating dollars to get new gadgets, and that is very important. But there has to be an educational program, and it has to be a very comprehensive program. So I thank you for that.

Mr. Gordon, do you have any———

Mr. GORDON. Just concurring and thanking you, Jay. You understand it very well, and you have conveyed that to us and to this group.

Mr. INSLEE. Just one more plug, too. Behind me is Dr. Eddie Bernard. I don't know if he is going to speak today, but he has been an absolute leader in developing this system, and I think we owe our tip of the hats to the scientific personnel who advanced this technology before an earthquake and a tsunami has hit the United States. Those are advanced thinkers.

Thank you, Mr. Chairman.

Chairman BOEHLERT. Thank you very much.

Ms. WOOLSEY. Mr. Chairman?

Chairman BOEHLERT. Yes.

Ms. WOOLSEY. Could I ask our———

Chairman BOEHLERT. Ms. Woolsey.

Ms. WOOLSEY.—esteemed guest a question and make a statement? And maybe you can kind of just, Jay, walk us through this a little bit.

My fear is false security. I mean, you have both said that, and you just said that, Mr. Chairman, and you have covered it, but you didn't tell us how. I mean, I need to—I am sorry I am a cynic, but I can see this all being put in place and then an event occurs and we go, "Oh, we hadn't—we didn't prepare."

Chairman BOEHLERT. Ms. Woolsey, let me point out that not all of the wisdom is vested in the distinguished Representative of the first District of Washington.

Ms. WOOLSEY. But he has got a wonderful mind, and I———

Chairman BOEHLERT. He does, indeed, but we have———

Ms. WOOLSEY. He can tell us. Tell us.

Chairman BOEHLERT.—some of the foremost experts, not just in America, but in the world going to testify today.

Ms. WOOLSEY. Behind him?

Chairman BOEHLERT. Yes, and———

Ms. WOOLSEY. So the—that is my—I have to wait and hear from them?

Chairman BOEHLERT. No, Jay, you can add anything you might care to add right now, but I———

Ms. WOOLSEY. Thank you.

Mr. INSLEE. I think the Chairman is calling for a little humility from the witness, so perhaps I should display that.

No, I just think, in the serious question about—this panel needs to know—to find a way legislatively to build a foundation for funding for the ongoing maintenance and educational needs. And I think, again, it may be easy—it may be a little bit of a no-brainer to put the buoys in. And we are going to have to figure out a way, with the concurrence of other committees, to build in the appropriations and the infrastructure to get, particularly, the educational and the warning systems domestically that are needed, including the Caribbean and even the East Coast, where they are really not—they really don't exist. We have got a rudimentary system in the—in Washington State. We really don't on the Caribbean, pretty much, at all.

So I guess what I would say is I am looking to your great ideas, Lynn.

Ms. WOOLSEY. Okay. Thank you.

Chairman BOEHLERT. Well, thank you very much. And we would welcome your———

Mr. SHERMAN. Mr. Chairman?

Chairman BOEHLERT.—continuing input as we go forward with the development of legislation. Because make no mistake about it, this is not just a hearing. This is the beginning of a journey, and we are going to travel it together, and we are going to develop a comprehensive legislative initiative that we hope will be marketable to our colleagues and the Nation.

Who said—Brad?

Mr. SHERMAN. Yes. I don't know whether Jay wants to respond to this or maybe the panel of experts can work it into their statement. But I would like to know if we have done enough to create mathematical models that could be used on an emergency basis to know an earthquake occurred here, therefore we have to evacuate this area or we might have to evacuate that area. And also, whether we have an early warning system and evacuation system that is integrated, whether it is tsunami, whether it is some other disaster, or whether it is a dirty bomb, that is to say, when we are planning for evacuation and warning, it ought to be a comprehensive system. Perhaps either this witness or the next can focus on that.

Chairman BOEHLERT. Sure. Yeah. Because as you will learn, as the testimony goes forward, I have had the opportunity to look at the testimony, this very important point is being addressed.

Mr. INSLEE. A very quick comment. I am very convinced that, with all of our tremendous ability to evaluate the seismic wave that we can pick up on our seismographs, that is not even close to good enough to really giving us predictive ability of where a wave is going to hit and what its extent is. I think the scientists will back me up on that, I hope. We really need the buoy system to find out if the wave is there, otherwise, you are stuck with continual false alarms. You would have lack of compliance with that issue. You have enormous economic cost. You really need to use this science to find out if the wave really exists, and I look forward to a bipartisan success doing that.

Chairman BOEHLERT. Mr. Gilchrest.

Mr. GILCHREST. Thank you, Mr. Chairman. Just a quick statement here, because I may have to leave shortly for another hearing.

I recently visited, Jay, the Indian Ocean Basin where all of the countries were hit. The destruction was staggering, incomprehensible. The response to that, by the international community, was stunning, and it continues to be that way. When we went to Sri Lanka or India, we asked a number of questions to people whose lives were torn apart. The most curious question and their most curious response was how did this happen and what can we do to prevent it. We asked them did they know how this happened, and they didn't. And whether it was the Buddhists, whether it was the Muslims, whether it was the Hindus, they were all curious, not as to why it happened. They didn't want to associate that with any religious aspect. They wanted to know how it happened, the physics behind the tsunami. And then they wanted to know how they could find out if it was going to happen again.

So we have worldwide interest in this issue. It is a—it revealed the common humanity of all people. Religion was set aside. National origin was set aside. Race was set aside. The idea that humans can get together in this most dynamic process of nature and how the tsunami works.

So Mr. Chairman, and to the Ranking Member, we have huge momentum behind this issue, not only for the United States and all of our coastal areas, but the U.S. can be a leader in the world to protect these vulnerable shorelines.

Mr. INSLEE. Just let me note, what you said about when you asked how did this happen, it sort of pointed out to me the need for education, how important it is for this from a safety standpoint. In 1964, I think, was the Alaska earthquake, and I was living in Seattle at the time, so I saw, and one of my classmates explained how they watched the water recede. All of the water went out of the harbor before the tsunami came back in. And we all knew in Seattle in that classroom that if you ever see Puget Sound go out, you head for the hills. In places in Thailand, the tourists headed for the beaches to watch this abnormal occurrence, which is a, you know, terrible tragedy. It just points out the need for an educational effort that I know the Chair is going to lead us to build.

Chairman BOEHLERT. Thank you very much. Thank you, Mr. Gilchrest. Thank you.

Panel II:

Chairman BOEHLERT. Our second panel today consists of Dr. Charles "Chip" Groat, who is Director of the U.S. Geological Survey, General David L. Johnson, retired, Director of the National Oceanic and Atmospheric Administration's National Weather Service, Dr. John Orcutt, Deputy Director, Research at the Scripps Institution of Oceanography and President of the American Geophysical Union, Dr. Arthur Lerner-Lam, Director, Columbia University Center for Hazards and Risk Research, and for the purpose of an introduction, the Chair recognizes Mr. Wu.

Mr. WU. Thank you, Mr. Chairman. It is my honor to introduce Mr. Jay Wilson of the Oregon Emergency Management Office. But first, I would like to thank the Chairman and the Ranking Member on holding this very timely hearing.

The December 26 tragedy in the Indian Ocean earthquake and the following tsunami was a tremendous tragedy, and we should do all that we can to help in the present situation. And I want to commend people and organizations around this country, particularly some organizations, non-profits and businesses in Oregon, who have generously helped: Northwest Medical Teams, and Medical Teams Northwest. Some for-profit businesses, like Nike and Intel, I am—it is my understanding that the employees at Intel alone have contributed $1 million and matched by $1 million from the Intel Foundation. And I want to thank all Americans for their generous contributions.

And while we deal with the current situation in Indonesia, Sri Lanka, Thailand, and elsewhere, at the same time, we should be very cognizant of the possibility of significant tsunamis occurring in the United States. And as Mr. Inslee previously stated, perhaps the greatest largest tsunami to ever hit our shores occurred 305 years ago today, January 26, 1700, in Oregon and Washington where two tectonic plates come together. And it is—the way that we calculated this date is that there are historic recordings in Japan, thousands of miles away, at a certain date and hour when that tsunami hit the shores of Japan back in 1700. And the geologists and geophysicists tell us that these huge subduction earthquakes can occur on our Pacific Northwest coast every 300 to 1,000 years. That is the current estimate. I note that we are 305 years away from the last occurrence, so we are in the yellow zone, if not the red zone, for another significant event in the Pacific Northwest. Much more recently, there was a 9.2 Richter scale earthquake off Alaska, and it created 19 to 20-foot waves, which flooded seaside Oregon in March of 1964.

With the Pacific Rim's experiences in earthquakes and tsunamis, we, on the West Coast, take this threat very, very seriously. Several Oregon research universities, such as Portland State University, Oregon State University, and the University of Oregon, conduct cutting-edge research in tsunami. And I am also very pleased to say that, along with other Pacific coast states, work together to prepare and educate our citizens on the threats of tsunami. And I would especially like to mention Kennan Beach, Oregon, in my District, as well as Mazzonina and Halem on the border of my colleague's and my District for being some of the four Oregon communities, which are rated as TsunamiReady communities.

It is my pleasure to introduce Mr. Jay Wilson, the distinguished—to this distinguished committee. Mr. Wilson is currently the Earthquake and Tsunami Programs Coordinator for the Oregon Emergency Management Office. He has been working in the emergency management field in California and Oregon, and now works hard to prepare Oregonians for tsunami.

I am very happy to hear that Mr. Wilson's latest work is in the creation of a tsunami educational pilot project in Seaside, Oregon, and at this moment, I would like to yield to my colleague from Oregon, Ms. Darlene Hoosley.

Ms. HOOSLEY. Thank you.

Again, welcome, Mr. Wilson. I had the privileged of spending time with some of the people that you work with as they did a briefing for me in Salem, all of the statewide experts in this area. So I appreciate what Oregon is doing, and that was interesting as I was on a flight a couple of weeks ago, I was sitting next to a gentleman who does a lot of work in this area on—he does it both nationally and internationally. And he leaned over and he said, "Oregon has done the best job of preparing of any state." So I think you should feel good about that.

We also had a series of hearings on the central coast to see what they were doing and how prepared they were. I was pleased by the work that we have done. There is a lot more work that needs to be done. But in each of these hearings, we had all of the emergency management people. We had first responders as well as elected officials and community members talking about what each of those two counties have done, which are the central part—central coast, Lincoln and Tillamook counties. And one of the things I would like to do, Mr. Chair and Mr. Ranking Member, is when we talked, these groups came up with several really fabulous ideas. I asked them to go back and meet again and put those in ranking order. And what I would like to do, Mr. Chair, is introduce those to the Committee so that we may use the———

Chairman BOEHLERT. Thank you very much. The Committee———

Ms. HOOSLEY. And again, thank you.

Chairman BOEHLERT.—will be most receptive. Thank you, everyone.

Now let us get to our distinguished witnesses. And we would ask that you summarize your statements in five minutes or so. The Chair will not be arbitrary. It is too important a subject. But if you condense your testimony, because we have your full written testimony, which will be part of the official record, that will allow more time for those of us who need to be better educated to take part in this exercise.

So with that, Dr. Groat, you are first up.

STATEMENT OF DR. CHARLES "CHIP" G. GROAT, DIRECTOR, UNITED STATES GEOLOGICAL SURVEY, U.S. DEPARTMENT OF THE INTERIOR

Dr. GROAT. Thank you, Mr. Chairman.

Thank you for the opportunity to reflect on the recent tragedy in South Asia and important to us here, in the United States, and what can be done to reduce the threat that tsunamis and earthquakes pose to coastal communities in the United States as well as around the globe.

Events, such as this one, and we are also reminded by the four hurricanes that crossed Florida this past summer, recent volcanic activity at Mount St. Helen's, point out our vulnerability to natural hazards. And those natural hazards, such as all of these, are inevitable. They are geologically and meteorologically inevitable, but as has been pointed out several times, the consequences are not inevitable if we prepare for them.

As we move forward, we have got to bear in mind that we are being confronted here with multiple hazards. Both the tsunami and the earthquake have to be considered in planning our responses and in instructing our scientific understanding as we move that forward in the name of public safety.

The December 26, 2004 magnitude 9 earthquake that struck the coast of Sumatra, was initiated 20 miles beneath the sea floor off the western coast, and it was the fourth largest earthquake to strike the planet since 1900 and the largest since the magnitude 9.2 earthquake struck Alaska in 1964. The devastation caused by both the tsunami and the earthquake are of grand proportions and remind us, again, of the effects of these natural events on lives and property.

As with other giant earthquakes, this one took place in a subduction zone where one of the tectonic plates that make up the Earth's rigid outer layer, is being thrust against another. The size of the earthquake is directly related to the area of the fault that has actually ruptured. This particular rupture was huge. It propagated northward along the plate boundary for almost 750 miles. Along the length of the fault rupture, the sea floor was jolted upward as much as 15 feet, lifting trillions of gallons of sea water, a volume more than 30 times that of the Great Salt Lake and generating a tsunami that swept both east, inundating the coast of Sumatra, Thailand, and Burma, and west, crossing the open ocean at hundreds of miles an hour on its way to the coast of India, Sri Lanka, and eventually eastern Africa. The devastation that struck the coastal Sumatra area can be seen on this pair of land set images from before and after the event.

While not all tsunamis are caused by earthquakes, most are, thus earthquake-monitoring networks play a large role in Tsunami Warning Center operations. It is necessary to determine, based on the interpretation of seismic waves generated by an earthquake, whether tsunami generation is likely or not. This is an extremely important fact, because there are many kinds of earthquakes, and not all that are large even generate tsunamis. So interpretation of the information we get from this monitoring network is critical in informing those responsible for tsunami warnings whether or not there is likely to be one.

To monitor seismic events worldwide, the Global Seismographic Network, the GSN, maintains the constellation of 128 globally distributed, modern seismic sensor. The U.S. Geological Survey operates about $\frac{2}{3}$ of this network, and the University of California, San Diego, operates the other $\frac{1}{3}$ with NSF support. NSF also funds the Incorporated Research Institutions for Seismology (IRIS) Consortium to handle data management and the long-term archiving. As you pointed out, Mr. Chairman, the role of NSF in funding both the monitoring and the science in this important area is extremely important and needs to be continued and increased. In the case of the Sumatra earthquake, automated analysis of data from the Global Seismic Network stations generated the alert of strong recorded amplitudes that were sent to NOAA and to the USGS. At the present time, about 80 percent of this network transmits data in real time that can be used for rapid earthquake analysis and tsunami warnings. A hallmark of our efforts to upgrade this system is to increase our ability to receive this data in real time and to upgrade our capability in the scientific community of analyzing this data very quickly and providing the results of those analyses to people responsible for issuing warnings.

In the United States, we face a major risk from subduction zone earthquakes, like the one that struck Sumatra. The most recent was a magnitude 9.2 earthquake that struck Alaska in 1964. However, the greatest risk, as pointed out by several Members, is in the Pacific northwest. At the 1700 Cascadia subduction zone that was mentioned before, the earthquake along the Pacific coast in Oregon, Washington, California, and British Columbia is particularly notable. This event was of the same general size as the Sumatra earthquake, and it caused coastal marshes to suddenly drop several feet. Based on return interval, USGS scientists and others who work on this aspect of it, have estimated that there is a 10 to 14 percent chance of a repeat of the Cascadia magnitude 9 earthquake and tsunami in the next 50 years, so that gives you some sense of the order of risk that we are facing, as Mr. Wu pointed out.

To monitor earthquakes in the United States, the USGS has begun to install and operate the Advanced National Seismic System, part of the NEHRP process, to provide seismic data to NOAA's Tsunami Warning Centers. The system includes a 63-station Advanced National Seismic System (ANSS) backbone network, which is capable of locating most felt earthquakes nationwide and provides data in near real time to the USGS. Extending our capability in high-hazards areas of the U.S. are 17 regional seismic networks that provide detailed coverage and rapid response both—and local expertise and event analysis and interpretation of this data is an important part of these local networks.

On December 29, the President asked the Departments of Commerce and Interior to determine whether our warning systems are adequately prepared for tsunamis that could affect the United States coasts and the coasts of those interests that the United States has. As a result, the Administration has announced its commitment to implement and improve domestic seismic detection and warning systems. And as part of the President's plan, the USGS will upgrade its ability to provide NOAA with timely interpretation of seismic data from earthquakes, including their potential for tsunami generation by doing the following. And I want to point out here that the point that we can start and then forget is not lost on what we have proposed to do. We are trying to upgrade a system that is important not only to tsunamis, but also to earthquakes, and provide the resources that will continue this system in an advanced state of readiness in the outcoming years so that we do not become complacent and figure we solve the problem with a one-time effect.

So we plan to implement 24 x 7 operations in the National Earthquake Information Center in Golden, Colorado, and upgrade the hardware and software systems in order to improve the processing of earthquake data from the U.S. and around the world. As part of this upgrade, we will fully develop what is now a prototype system to estimate the number of people affected by strong ground motion after an earthquake using our ShakeMap model and databases of global population. This PAGER system, which is—stands for the Prompt Assessment of Global Earthquakes for Response, can provide eight agencies and others with a quick estimate of how significant casualties might be well in advance of reports from affected areas where communications may be down, so here again, an important forecasting tool to provide those responsible for response with early information. Thus these improvements at the NEIC, the National Earthquake Information Center, will increase our ability to provide relevant information about earthquake hazards as well as their tsunami generation potential.

We also plan to support research to develop more rapid methods for characterizing earthquakes and discriminating likely tsunamigenic sources, here again, the importance of determining which earthquakes do and will generate tsunamis.

We also plan to improve the detection response time of the Global Seismographic Network by making data from all stations available in real time, using satellite telemetry and improving station up-time through increased maintenance schedules. This again has been pointed out as an extremely important part of any warning system. We have to have the resources to make sure that it is upgraded, that it is maintained, so that it is always ready.

We also intend to improve coverage in the Caribbean region. We will achieve that through the addition of some seismic stations there and upgrades of existing stations through cooperation with international partnerships in that area.

And finally, we will further the use of software developed by the California Integrated Seismic Network, which is a USGS university and State partnership, to speed USGS generated earthquake information directly to local emergency managers with a dual-use capability to also provide that information to NOAA.

And finally, getting to the importance that has been pointed out of understanding what the impacts on our coastal areas will be. Do we understand the nature of the topography, the terrain, the infrastructure that is there in a way that can be fed into models for the generation of projected impacts? We plan, as part of our cooperative effort with NOAA and others, to enhance our capabilities to provide elevation mapping for coastal areas—in the United States and in the Caribbean and provide this information for improved tsunami hazards assessments in the U.S., in general, but particularly in Puerto Rico and the Virgin Islands.

The earthquake which contributed significantly to the loss of lives and property will encourage us to continue forward on the comprehensive NEHRP approach to earthquake loss. Here again, I think a model of interagency cooperation where we, FEMA, NIST, and the National Science Foundation work together to translate good science into hazard reduction programs. So we translate our understanding, through monitoring and research, through such initiatives as the Advanced National Seismic System and also the work of the George Brown, Jr. Network for Earthquake Engineering Simulation. These activities will accelerate the use of new earthquake risk mitigation technologies and the development of improved seismic provisions in building codes.

In closing, Mr. Chairman, the USGS will also continue ongoing collaboration with NOAA, FEMA, and other agencies and universities to improve tsunami hazard assessments and warning through geologic investigations into the history and the potential for tsunami occurrences. We learn about the present from understanding the past, and the records of things that happened prehistory are extremely important, so geologic and geomorphic understandings are gained through active research and active mapping, and we plan to continue that.

Chairman BOEHLERT. Thank you.

Dr. GROAT. We also plan to help provide better products in terms of inundation maps and propagation maps and supply information that will support the very kinds of models that were questioned before. And we will also continue in the Indian Ocean to understand, based on that, what the impacts were there to inform our understanding in the United States.

With that, Mr. Chairman, I will close and be welcoming questions you pose.

[The prepared statement of Dr. Groat follows:]

PREPARED STATEMENT OF CHARLES G. GROAT

Mr. Chairman and Members of the Committee, thank you for this opportunity to discuss the recent tragedy in South Asia and what can be done to reduce the threat that tsunamis and earthquakes pose to coastal communities in the United States and around the globe. Events such as this serve as a tragic reminder of our vulnerability to natural hazards. While the United States is not as vulnerable to tsunamis as other regions of the world, we do face significant risk.

On December 29, the President asked the Departments of Interior and Commerce to determine whether our systems are adequately prepared for a tsunami on our coasts. As a result, the Administration announced its commitment to implement an improved domestic tsunami detection and warning system. As part of the President's plan, the U.S. Geological Survey (USGS) will strengthen its ability to detect global earthquakes both through improvements in the Global Seismographic Network (GSN), which we support jointly with the National Science Foundation (NSF), and through around-the-clock analysis of earthquake events. The changes that are proposed for USGS clearly have a dual purpose, improving our capacity to respond to earthquakes as well as supporting the tsunami warning program of the National Oceanic and Atmospheric Administration (NOAA).

In addition to earthquake monitoring and reporting, the USGS conducts a number of activities aimed at improving tsunami hazard assessments, education, and warnings, including geologic investigations into the history of and potential for tsunami occurrence, coastal and marine mapping, and modeling tsunami generation. Although most tsunamis are caused by earthquakes, they can also be caused by volcanic eruptions, submarine landslides, and onshore landslides that cause large volumes of rock to fall into the water. All of these tsunami-generating hazards can impact the United States. Consequently, a broad range of USGS work in earthquake, volcano and landslide hazards, and coastal and marine geology, contribute to better understanding of tsunami impacts and occurrences.

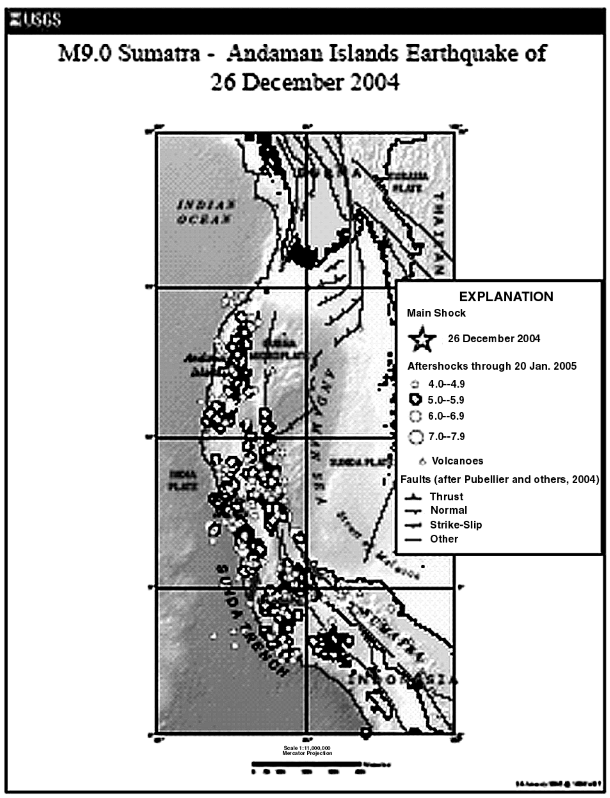
Additionally, USGS is playing a role in relief efforts for nations impacted by the December 26 disaster by providing relief organizations worldwide with pre- and post-tsunami satellite images and image-derived products that incorporate information on population density, elevation, and other relevant topics. These images and products are being used by relief organizations to determine where relief efforts are most critical and how best to carry out those relief operations. In our efforts to assist and improve relief efforts, we work closely with partners at NOAA, the U.S. Agency for International Development, other federal agencies, and in academia. For example, USGS scientists are part of international teams conducting post-tsunami investigations in Sri Lanka and Indonesia with the goal of applying the knowledge developed to other vulnerable areas in the United States and around the globe.

USGS is also working with NOAA and other domestic and global partners through the Global Earth Observing System of Systems (GEOSS) and other mechanisms. Through GEOSS, improved monitoring capabilities must be firmly linked into all-hazards warning systems and, the most important link in the chain, public education and mitigation programs. As we move forward, we must bear in mind that this was an earthquake disaster as well as a tsunami disaster, and we must learn from both. This is not just a scientific endeavor; it is a matter of public safety.

Earthquake and Tsunami of December 26, 2004

This was the second year in a row in which a deadly earthquake occurred near the end of the year. In 2003, a magnitude 6.6 quake struck Iran's ancient city of Bam, killing over 30,000 people. In 2004, the deadly quake was a magnitude 9 earthquake that initiated 20 miles below the seafloor off the western coast of Sumatra, the fourth largest earthquake to strike the planet since 1900 and the largest since a magnitude 9.2 earthquake struck Alaska in 1964. The earthquake and resulting tsunami killed more than 150,000 people around the Indian Ocean, two-thirds of them in northern Sumatra, whose inhabitants experienced not only the severe shaking from the earthquake but also the tsunami's full force.

As with other giant earthquakes, this one took place along a subduction zone, where one of the tectonic plates that make up the Earth's rigid outer layer is being thrust beneath another (see Figure 1). The Sunda trench is the seafloor expression of such a plate boundary where the Indian plate is thrusting under the overriding Burma plate. The size of an earthquake is directly related to the area of the fault that is ruptured. This rupture propagated northward along the plate boundary fault for over 750 miles beneath the Nicobar and Andaman Islands almost to Burma with a width of over 100 miles and slip along the fault averaging several tens of feet.



It is difficult to comprehend the scope of a magnitude 9 earthquake. When we hear the term earthquake magnitude, we think of the Richter scale, which was the first of several scales developed to measure the earthquake size from the seismic waves they generate. These scales are logarithmic such that each whole number represents an order of magnitude larger in the seismic waves generated. So a magnitude 7 earthquake is 10 times larger than a magnitude 6 and 100 times larger than a magnitude 5. However, the amount of energy released goes up much faster. This magnitude 9 earthquake released 32 times more energy than a magnitude 8 earthquake and 1000 times more energy than a magnitude 7 earthquake such as the one that struck the San Francisco Bay area in 1989. The energy released by the Sumatra earthquake is roughly equal to that released by all the earthquakes, of every size, everywhere in the world since the mid-1990s. It's important to remember that our own coasts, Alaska in 1964 and the Pacific Northwest in 1700, were the site of earthquakes as large as the Sumatra earthquake.

A great deal of that energy was transferred to the Indian Ocean's waters and ultimately to its surrounding shores. Along the length of the fault rupture, the seafloor was jolted upward by as much as 15 feet, lifting trillions of gallons of sea water—a volume more than 30 times that of the Great Salt Lake—and generating the tsunami that swept both east, inundating the coast of Sumatra, Thailand and Burma, and west, crossing the open ocean at hundreds of miles per hour on its way to the coasts of India, Sri Lanka, and eventually eastern Africa.

Tsunamis strike the Indian Ocean less frequently than the Pacific Ocean, which is ringed by subduction zones, but there have been at least a half dozen Indian Ocean tsunamis caused by earthquakes in the past 200 years. What had been the deadliest tsunami in the region was not caused by an earthquake but by the explosion of Krakatau volcano in 1883. The tsunami generated by the collapse of that volcano killed 36,000 people on Java, Sumatra and neighboring islands.

It is important to emphasize that not all large subsea earthquakes generate tsunamis. For example, four days before the Sumatra earthquake, a magnitude 8.1 earthquake struck the seafloor south of New Zealand near the Macquarie Islands. Instead of generating a thrusting motion as in a subduction zone, this earthquake occurred on a strike-slip fault, moving side to side like the San Andreas Fault, a motion much less efficient at creating a tsunami. No tsunami was generated. Even earthquakes generated in subduction zones may not produce tsunami, depending on whether the fault rupture reaches the seafloor, the amount of displacement on the fault and other factors. One of the key roles of a tsunami detection system is to avoid false warnings that cause costly and unnecessary evacuations that can undermine people's willingness to heed warnings in the future. In addition to buoys and tide gauges, seismic data may be able to provide an additional check, and research in this area could improve our ability to recognize tsunami-causing events in minutes.

U.S. earthquake monitoring networks and their role in tsunami warning center operations

To monitor earthquakes in the United States, the USGS has begun to install and operate the Advanced National Seismic System (ANSS), which was established by the National Earthquake Hazard Reduction Program (NEHRP) in 2000 (P.L. 106–503). The system includes a 63-station ANSS Backbone Network, which is capable of locating most felt earthquakes nationwide and provides data in near-real-time to USGS. Extending our capability in high-hazard areas of the country are 17 regional seismic networks that provide detailed coverage and rapid response, local expertise in event analysis and interpretation, and data. Our ANSS partnerships—which include universities, State government agencies and NSF—greatly leverage USGS seismic monitoring capabilities. The key products of the system are rapid and accurate earthquake locations and magnitudes, delivered directly to users for emergency response.

In several of the highest-risk urban areas in the United States, dense arrays of seismic sensors designed to record strong ground motion have been deployed under ANSS. These areas include the Los Angeles, San Francisco, Seattle, Anchorage and Salt Lake City metropolitan regions. When triggered by an earthquake, data from these sensors are automatically processed into detailed maps of ground shaking ("ShakeMaps"), which in turn feed loss estimation and emergency response. Also, because earthquake losses are closely tied to the vulnerability of buildings and other structures, USGS monitors earthquake shaking in structures in support of engineering research, performance-based design, and rapid post-earthquake damage evaluations. If placed in certain critical facilities, these sensors can contribute to critical post-earthquake response decisions.

USGS has set a minimum performance goal of determining automated locations and seismic magnitudes within four minutes or less in the U.S. This is exceeded in many ANSS regions; for example, the magnitude 6.5 San Simeon, California, earthquake of December, 2003, was automatically located within 30 seconds. Earthquake data, including locations, magnitudes, other characterizations and, where requested, the actual seismograms, are automatically transmitted from USGS and regional centers to federal response departments and agencies such as the NOAA tsunami warning centers, the Department of Homeland Security, including the Federal Emergency Management Agency (FEMA), State governments, local emergency managers, utility operators, several private sector entities, and the public and media. USGS does not currently have 24 × 7 earthquake analysis, but analysts are on-call in the event of a large earthquake worldwide. The Administration has recently proposed 24 × 7 operations as a key needed improvement in response to the Indian Ocean tsunami disaster.

To monitor seismic events worldwide, the Global Seismographic Network (GSN) maintains a constellation of 128 globally distributed, modern seismic sensors. USGS operates about two-thirds of this network, and the University of California, San Diego, operates the other third with NSF support. NSF also funds the IRIS (Incorporated Research Institutions for Seismology) Consortium to handle data management and long-term archiving. Two GSN stations were the first to detect the December 26, 2004, Sumatra earthquake, and automated analysis of these data generated the "alerts" of strong recorded amplitudes sent to NOAA and USGS. At the present time, about 80 percent of GSN stations transmit real-time data that can be used for rapid earthquake analysis and tsunami warning. The Administration is requesting funding to extend the GSN's real-time data communications, as well as to improve station uptime through more frequent maintenance. These changes will result in improved tsunami warning in the United States and globally.

Through the National Tsunami Hazard Mitigation Program, the USGS, NOAA, FEMA, and five western States (Alaska, California, Hawaii, Oregon and Washington) have worked to enhance the quality and quantity of seismic data provided to the NOAA tsunami warning centers and how this data is used at the State and local level. This program has funded USGS to upgrade seismic equipment for regional seismic networks in northern California, Oregon, Washington, Alaska and Hawaii. The seismic data recorded by the USGS nationally and globally are relayed to the NOAA tsunami warning centers. USGS and NOAA also exchange earthquake locations and magnitude estimates, with USGS providing the final authoritative magnitudes of events. USGS is also working with emergency managers in the Pacific Northwest to support public warning systems in coastal communities there.

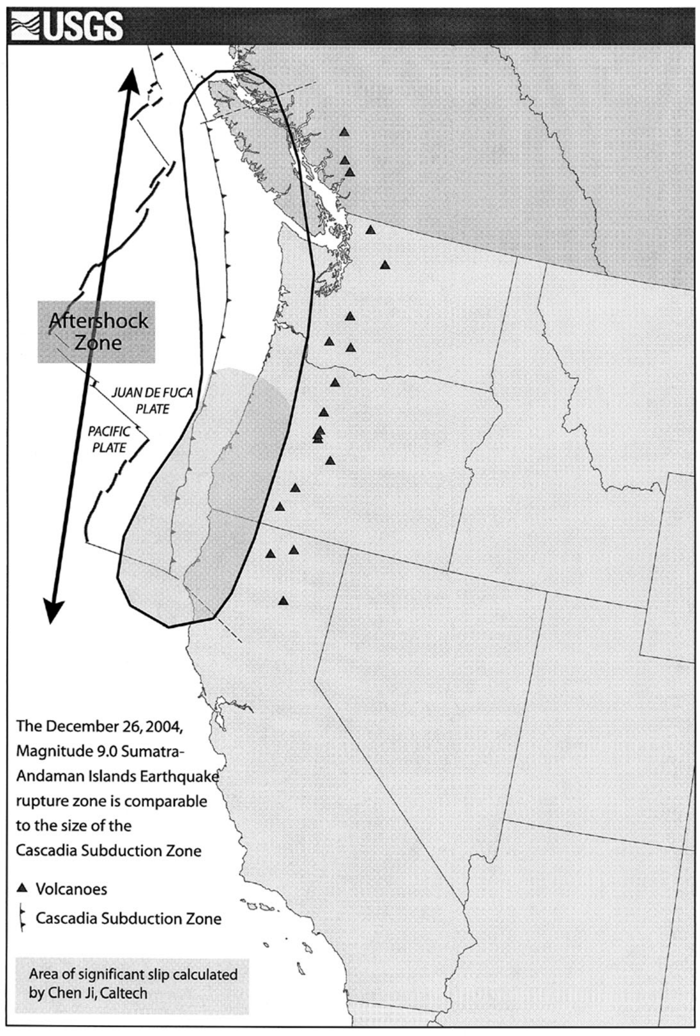
Improving earthquake monitoring in the United States—with consequent improvements to public safety and the reduction of earthquake losses—can be achieved through the modernization and expansion of the ANSS, including expansion of seismic sensor networks nationwide, the upgrading of the associated data processing and analysis facilities, and the development of new earthquake products. Funding over the past three years has focused on installation of over 500 new seismic sensors in high-risk urban areas. The FY05 appropriation for ANSS is $5.12 million. The President's proposed increase in funding to USGS in response to the tsunami disaster would allow USGS to make critically needed improvements to performance in one key element of ANSS, providing 24 × 7 operations capacity and completing software and hardware upgrades to speed processing times. These improvements will enhance USGS support of NOAA's tsunami warning responsibility.

The threat from tsunamis and great earthquakes in the Pacific

The concentration of U.S. tsunami warning efforts in the Pacific reflects the greater frequency of destructive tsunami in that ocean. Approximately 85 percent of the world's tsunamis occur in the Pacific. This is due to many subduction zones ringing the Pacific basin—the source of submarine earthquakes of large enough magnitude (greater than ~7) to produce tsunami. While Hawaii's position in the middle of the Pacific makes it uniquely vulnerable to ocean-wide tsunami, this chain of volcanic islands also faces a hazard from locally generated tsunami due to local earthquakes or submarine landslides. In 1975, a magnitude 7.2 earthquake just offshore the island of Hawaii caused a tsunami that killed two with maximum runup height (elevation reached by tsunami as they move inland from the shoreline) of 47 feet.

U.S. Insular Areas in the Pacific also face a threat both from ocean-wide tsunami as well as ones generated locally. The volcano Anatahan in the Northern Marianas, which began actively erupting on January 5, 2005, serves as a reminder that inhabitants and U.S. military interests in the Commonwealth of the Northern Mariana Islands and the Territory of Guam are threatened by nine islands with active volcanoes that have the potential to generate hazardous ash plumes as well as tsunamis through eruption-induced collapse. The risks from tsunamis to the inhabited islands are poorly understood, and tsunami inundation modeling is needed to assess the threat represented by such an event.

Our knowledge of what may be the greatest risk to the United States does not come from our tsunami experiences of the last half century, but rather to the detective work of USGS and other scientists in the Pacific Northwest. In contrast to the San Andreas Fault, where the Pacific and North American plates are sliding past one another, a subduction zone known as Cascadia lies offshore further north, its size nearly identical to that of the rupture zone of the Sumatra earthquake (see Figure 2). On January 26, 1700, the Cascadia subduction zone broke in a great earthquake, probably from northernmost California to the middle of Vancouver Island. Along the Pacific coast in Oregon, Washington, California, and British Columbia, this huge event of the same general size of the Sumatra earthquake, caused coastal marshes to suddenly drop down several feet. This change in land elevation was recorded by the vegetation living in and around the coastal marshes. For example, along the Copalis River in Washington State, Western Red Cedar trees that have lifespans of over 1,000 years were suddenly submerged in salt water. Over the next few months, those trees died. By comparing tree rings of the still standing dead trees with nearby trees that were not submerged, paleoseismologists established that the trees were killed during the winter of 1699–1700.



Digging through river bank deposits along the Copalis and other rivers in Cascadia, paleoseismologists found a pervasive, black sand sheet left by the tsunami. Because the sands deposited by the tsunami are transported by the tsunami waves, paleoseismologists can combine the location of tsunami sands with the change in marsh elevation to get an approximate idea of the length of the rupture for the 1700 earthquake. Tsunami sands have been found from Vancouver Island to Humboldt Bay in California.

Once paleoseismologists found evidence of the 1700 event, they combed written records in Japan to see if evidence existed of an unknown tsunami wave. Several villages recorded damage in Japan on January 27, 1700, from a wave that people living along the coast could not associate with strong ground shaking. The coast of Japan had been hit, not unlike Sri Lanka and Somalia, by a distant tsunami, but this tsunami came from the west coast of North America. By modeling the travel time across the Pacific, paleoseismologists were able to establish the exact date of the last Cascadia subduction zone event.

Based on estimates of the return interval, USGS scientists and others have estimated that there is a 10–14 percent chance of a repeat of the Cascadia magnitude 9 earthquake and tsunami event in the next 50 years. Since that initial discovery in the early 1980s, many of the elements of the seismic systems for the Pacific Northwest described above have been put in place along with improved building codes to address the higher expected ground shaking and increased public education through the efforts of State and local emergency managers.

The December 26, 2004, earthquake and tsunami together cause us to focus on the similar threat from the Cascadia subduction zone that faces the Pacific Northwest as well as our long Alaskan coastline. Here I cannot emphasize enough the critical role played by our partners in State and local government, especially the State emergency managers. Largely through the efforts of the National Tsunami Hazard Mitigation Program partnership, much has been accomplished. Seismic systems have been improved, allowing NOAA's West Coast and Alaska Tsunami Warning Center to issue warnings within minutes of a significant offshore earthquake. Inundation maps, graphic representations of estimates of how far inland future tsunami waves are likely to reach, are available for most major communities in northern California, Oregon, and Washington. Working with FEMA, public education has been stressed, and emergency managers have begun installing all-hazard warning systems. USGS is co-funding a $540,000 pilot project in Seaside, Oregon with FEMA and NOAA to develop risk identification products that will help communities understand their actual level of risk from tsunami in a way that could be conveyed on existing flood maps. The goal of the project is to develop techniques that can be used to determine the probability and magnitude of tsunami in other communities along the west coast of the United States.

Tsunami threats in the Atlantic

With respect to tsunami hazard risk to the U.S. East coast, it should be noted that subduction zones are scarce in the Atlantic Ocean. But the Atlantic Ocean is not immune to tsunami. A tsunami following the great 1755 Lisbon earthquake, generated by collision of the African and Eurasian tectonic plates, devastated coasts of Portugal and Morocco, reached the British Isles, and crested as much as 20 feet high in the Caribbean.

In 1929, the magnitude 7.2 Grand Banks earthquake triggered a submarine landslide and tsunami that struck Newfoundland's sparsely settled coast, where it killed 27 people with waves as high as 20 feet. An event like this, involving a submarine landslide, may be the most likely scenario for the Atlantic coast. Scars of past large submarine landslides abound on the continental slope off the U.S. Atlantic coast. As in the 1929 Grand Banks event, some of the slides probably resulted from large earthquakes. If earthquakes are the primary initiator of the observed landslide features, the hazard to the Atlantic coast is limited as large earthquakes rarely occur in the vicinity of the U.S. and Canada Atlantic coast-perhaps once a century, on average (Boston area, 1755; Charleston, 1866; Newfoundland, 1929). Additionally, this type of tsunami would affect a much smaller geographical area than one generated by a subduction zone, and its flooding effect and inundation distance would be limited. Much work is needed, however, to more fully understand the triggering of submarine landslides and the extent of that threat in the Atlantic.

Another tsunami scenario for the Atlantic coast that has been widely publicized is a landslide involving collapse of part of the Cumbre Vieja volcano in the Canary Islands into the sea. While this collapse would be dramatic and might indeed induce a trans-atlantic tsunami, such a collapse may occur only once every hundred thousand years. Furthermore, unlike the West Coast with the abundant record of past ocean-wide tsunami deposits, no such regionally extensive deposits have been found to date along the Atlantic coast.

Tsunami threats in the Caribbean

The Caribbean is subject to a broad range of geologic processes that have the potential to generate tsunami. Indeed, the Caribbean tectonic plate has almost all of the tsunami-generating sources within a small geographical area. Subduction zone earthquakes of the type that generated the Indian Ocean tsunami are found along the Lesser Antilles and the Hispaniola and Puerto Rico trenches. Other moderately large earthquakes due to more local tectonic activity take place probably once a century, such as in Mona Passage (1918 tsunami) and in the Virgin Islands basin (1867 tsunami). Moderate earthquakes occur that may trigger undersea landslides and thus generate tsunami. An active underwater volcano (Kick'em Jenny near Grenada) where sea floor maps show previous episodes of flank collapse also poses a tsunami hazard. Above-water volcanic activity occurs, wherein the Lesser Antilles periodically generate landslides that enter the sea to cause tsunami. And finally, the possibility exists of tele-tsunami from the African-Eurasian plate boundary, such as the great Lisbon earthquake of 1755 described above.

In 1867, an 18-foot high tsunami wave entered St. Thomas' Charlotte Amalie at the same time that a 27-foot wave entered St. Croix's Christiansted Harbor. Were that to occur again today, the 10-fold increase in population density, the cruise ships, petroleum carriers, harbor infrastructure, hotels and beach goers, nearby power plants, petrochemical complexes, marinas, condominiums, and schools, would all be at risk.

On October 11, 1918, the island of Puerto Rico was struck by a magnitude 7.5 earthquake, centered approximately 15 kilometers off the island's northwestern coast, in the Mona Passage. In addition to causing widespread destruction across Puerto Rico, the quake generated a medium sized tsunami that produced runup as high as 18 feet along the western coast of the island and killed 40 people, in addition to the 76 people killed by the earthquake. More than 1,600 people were reportedly killed along the northern coast of the Dominican Republic in 1946 by a tsunami triggered by a magnitude 8.1 earthquake.

In contrast to the Caribbean, the Gulf of Mexico has low tsunami risk. The region is seismically quiet and protected from tsunami generated in either the Atlantic or the Caribbean by Florida, Cuba, and broad continental shelves. Although there have been hurricane-generated subsea landslides as recently as this fall, there is no evidence that they have generated significant tsunami.

Lessons learned: What the United States can do to better prepare itself and the world

Natural hazard events such as the one that struck Sumatra and the countries around the Indian Ocean on December 26, 2004, are geologically inevitable, but their consequences are not. The tsunami is a potent reminder that while the nations surrounding the Pacific Ocean face the highest tsunami hazard, countries around other ocean basins lacking basic tsunami warning systems and mitigation strategies face considerable risk. Reducing that risk requires a broad, comprehensive system including rapid global earthquake and tsunami detection systems, transmission of warnings in standardized formats to emergency officials who already know which coastal areas are vulnerable through inundation mapping and tsunami hazard assessment, and broadcast capabilities to reach a public already educated in the dangers and how to respond. For tsunami crossing an ocean basin, an adequate system of earthquake sensors, Deep-ocean Assessment and Reporting of Tsunamis (DART) buoys, and tide gauges should allow for timely warnings if the rest of the system is in place. For tsunami generated near the coastline, time is considerably more critical. For tsunami warnings to be effective, they must be generated and transmitted to the affected coastline within a few minutes of detection, local emergency responders must be prepared, the population must be informed, and the entire system must be executed without delay.

The Sumatra earthquake and its devastating effects will encourage us to continue forward on the comprehensive NEHRP approach to earthquake loss reduction. USGS is committed to do so in partnership with FEMA, the National Institute of Standards and Technology, and NSF to translate research into results through such initiatives as ANSS, the George E. Brown, Jr. Network for Earthquake Engineering Simulation, the plan to accelerate the use of new earthquake risk mitigation technologies, and development of improved seismic provisions in building codes.

As part of the President's plan to improve tsunami detection and warning systems, the USGS will:

- Implement 24 × 7 operations at the National Earthquake Information Center and upgrade hardware and software systems in order to improve the timeliness of alerts for global earthquakes. As part of the upgrade, USGS will fully develop what is now a prototype system to estimate the number of people affected by strong ground shaking after an earthquake using our ShakeMap model and databases of global population. Known as Prompt Assessment of Global Earthquakes for Response (PAGER), this system can provide aid agencies and others with a quick estimate of how significant the casualties might be well in advance of reports from affected areas where communications may be down.

- Support research to develop more rapid methods for characterizing earthquakes and discriminating likely tsunamigenic sources.
- Improve the detection response time of the Global Seismographic Network by making data from all stations available in real time via satellite telemetry and improving station up-time through increased maintenance schedules. Improved coverage in the Caribbean region will be achieved through the addition of stations and upgrades of existing stations through international partnerships and cooperation.
- Further the use of software developed by the California Integrated Seismic Network (a USGS, university and State partnership) to speed USGS-generated earthquake information directly to local emergency managers with a dual use capability to also provide NOAA tsunami warnings.
- Enhance existing USGS geologic and elevation mapping for coastal areas in the Caribbean. Such mapping is critical to development of improved tsunami hazards assessments for Puerto Rico and the U.S. Virgin Islands.

The USGS will also continue its ongoing efforts to improve tsunami hazard assessment and warnings through geologic investigations into the history of and potential for tsunami occurrence; coastal and marine mapping; modeling tsunami generation, source characterization, and propagation; and development of assessment methods and products such as inundation maps with NOAA, FEMA, and other partners. USGS will also continue strong partnerships with State tsunami and earthquake hazard mitigation groups and contribute to public awareness efforts. An example of the latter is the 2001 publication, USGS Circular 1187, *Surviving a Tsunami: Lessons Learned from Chile, Hawaii and Japan,* which was prepared in cooperation with the Universidad Austral de Chile, University of Tokyo, University of Washington, Geological Survey of Japan, and the Pacific Tsunami Museum. Continuing investigations of the Indian Ocean tsunami provide a critical opportunity to expand our knowledge of tsunami generation and impacts and to evaluate the research and operational requirements for effective hazard planning, warning, and response systems.

Mr. Chairman, I thank you for this opportunity to appear before the Committee and would be happy to answer any questions now or for the record.

BIOGRAPHY FOR CHARLES G. GROAT

On November 13, 1998, Dr. Charles G. Groat became the 13th Director of the U.S. Geological Survey, U.S. Department of the Interior.

Groat is a distinguished professional in the Earth science community with over 25 years of direct involvement in geological studies, energy and minerals resource assessment, ground-water occurrence and protection, geomorphic processes and landform evolution in desert areas, and coastal studies. From May to November 1998, he served as Associate Vice President for Research and Sponsored Projects at the University of Texas at El Paso, following three years as Director of the Center for Environmental Resource Management. He was also Director of the University's Environmental Science and Engineering Ph.D. Program and a Professor of Geological Sciences.

Prior to joining the University of Texas, Dr. Groat served as Executive Director (1992–95) at the Center for Coastal, Energy, and Environmental Resources, at Louisiana State University. He was Executive Director (1990–92) for the American Geological Institute. From 1983–88, he served as assistant to the Secretary of the Louisiana Department of Natural Resources, where he administered the Coastal Zone Management Program, and the Coastal Protection Program.

From 1978–1990, Dr. Groat held positions at Louisiana State University and the Louisiana Department of Natural Resources which included serving as Professor for the Department of Geology and Geophysics, and as Director and State Geologist for the Louisiana Geological Survey. He also served as Associate Professor (1976–78) at the University of Texas at Austin, in the Department of Geological Sciences, and as Associate Director and Acting Director of the Bureau of Economic Geology.

Dr. Groat received a Bachelor of Arts degree in Geology (1962) from the University of Rochester, a Master of Science in Geology (1967) from the University of Massachusetts, and a Ph.D. in Geology (1970) from the University of Texas at Austin.

Among his many professional affiliations, Groat is a member of the Geological Society of America, American Association for the Advancement of Science, American Geophysical Union, and the American Association of Petroleum Geologists. He has also served on over a dozen Earth science boards and committees and has authored and contributed to numerous publications and articles on major issues involving Earth resources and the environment.

Dr. Charles G. Groat was born in Westfield, New York, March 25, 1940. He currently resides in Reston, Virginia, with his wife, Barbara. He has two grown children.

Chairman BOEHLERT. Thank you very much. It was the third "finally" that got me.

Dr. GROAT. Yeah.

Chairman BOEHLERT. Thank you.

Dr. GROAT. I got one "finally" ahead of myself. I am sorry.

Chairman BOEHLERT. Well, no, and it is very important, and you know, and we deal with some of the most sensitive issues of our time, and when we ask people to summarize in 300 seconds or less, I always feel that we sort of cheat ourselves, but we have to be mindful of everybody's schedule and everything else.

So thank you very much, Dr. Groat.

General Johnson.

STATEMENT OF BRIGADIER GENERAL DAVID L. JOHNSON (RETIRED), DIRECTOR, NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION'S NATIONAL WEATHER SERVICE

Brigadier General JOHNSON. Thank you, Chairman Boehlert and Mr. Gordon and Members of the Committee, for the opportunity to testify before you regarding the National Oceanic and Atmospheric Administration, NOAA, activities with regard to the tsunamis. I am Brigadier General David L. Johnson, the Assistant Administrator for Weather Services, and the Director of NOAA's National Weather Service. And I ask that my written testimony be submitted for the record.

As my time here today is limited, I will focus my oral testimony on describing the U.S. tsunami program, NOAA's response to the Indian Ocean tsunami, NOAA's role in the Administration's tsunami warning proposal, and how the United States can help the world prepare for tsunamis.

The U.S. Tsunami Warning System consists of two warning centers, the Richard H. Hagemeyer Pacific Tsunami Warning Center in Ewa Beach, Hawaii, and the West Coast/Alaska Tsunami Warning Center in Palmer, Alaska.

The Hagemeyer Warning Center in Hawaii was established in 1949 in response to the unpredicted 1946 Aleutian tsunami, which killed 165 of our citizens on the Hawaiian Islands. The 1967 Alaska Warning Center was created as a result of 120 deaths from the 1964 Great Alaska earthquake and tsunami that has already been mentioned here today.

These centers are responsible for issuing all tsunami warning, watch, advisory, and information messages to emergency manager officials and to the public. Now NOAA operates six Deep-ocean Assessment and Reporting of Tsunami, or DART, buoys to help issue these accurate warnings. NOAA research activities developed these buoys to measure tsunamis in the deep ocean and to transmit the information back to the Warning Centers. These instruments accurately calculate the size of the tsunami by measuring the pressure wave from the deep ocean floor as it passes, and tsunamis as small as 0.5 centimeters have been measured.

In November of 2003, the DART buoys demonstrated their effectiveness when a large earthquake occurred in the Aleutian Islands and generated a tsunami. The two Warning Centers evaluated the tsunami and confirmed only a small wave. This accurate prediction of the non-destructive tsunami saved Hawaii an estimated $68 million in projected evacuation costs. The Hagemeyer Warning Center also serves as the operational center for the International Tsunami Warning System of the Pacific, which is comprised of 26 member nations around the Pacific Rim. The Hagemeyer Center's primary responsibility is to issue tsunami warnings in the Pacific Basin for tsunamis that can cause damage far away from their source. It is not the Center's responsibility to issue local tsunami warnings from seismic events. For example, if an earthquake occurs off the coast of Japan and a local tsunami is generated, it is Japan's responsibility to issue the local tsunami warning. However, the Hagemeyer Center will warn all participating nations in the Pacific Basin if the Japanese tsunami will cause damage.

NOAA's Tsunami Warning Centers have no authority or responsibility to issue tsunami warnings for the Indian Ocean Basin. However, knowing the concerns Pacific countries have about the potential damage, on Sunday, the 26th of December, 2004, at 8:14 p.m. Eastern Standard Time, and within seven minutes of notification and 15 minutes of the Indonesian earthquake, both centers issued tsunami information bulletins.

Now sea level gauges are also essential elements of the current Tsunami Warning System in the Pacific. When strategically located, they can also be used to quickly confirm the existence or non-existence of tsunami waves following an earthquake to monitor the tsunami's progress and to help estimate the severity of the hazard.

Unfortunately, there was no sea level data or other information available to substantiate or evaluate the Indian Ocean tsunami until hours after the earthquake had happened and when the first news reports began to come in indicating casualties in Sri Lanka and Thailand.

As recently announced by my boss, Admiral Lautenbacher, Under Secretary of Commerce for Oceans and Atmosphere, the United States is now committed to complete the current Tsunami Warning System for the United States by 2007. NOAA's contribution to the plan includes procuring and installing 32 new DART buoys, including 25 in the Pacific and seven in the Atlantic and Caribbean. In addition to the DART buoys, NOAA will procure and install 38 new sea level monitoring and tide gauges, and the Administration has proposed $24 million to NOAA for this effort, including $18.1 million for the Pacific Basin and $5.9 million for the Atlantic/Caribbean/Gulf. With that expansion of the U.S. Tsunami Warning System, NOAA forecasters will be better able to protect the United States 24/7 and will be able to alert communities within minutes of a tsunami-producing event.

I agree education and outreach are key to ensure people take appropriate action when the warnings are issued. NOAA's TsunamiReady program prepares communities to learn from the events of just one month ago and to ensure we educate the public about potential impacts of tsunamis and to ensure every vulnerable coast community is TsunamiReady certified. I solicit your help to make this happen. We are prepared to export this important program to whomever needs it now.

With global attention on this matter, we have a great opportunity to help the world better prepare for tsunamis through the development of a Global Earth Observation System of Systems, or GEOSS. This system would include a real-time seismic monitoring network, a real-time DART network, and a real-time sea level monitoring network. NOAA's Administrator, Vice-Admiral Conrad C. Lautenbacher, will be a member of the U.S. delegation at the Third Earth Observation Summit taking place in Brussels this February. He will ensure the development of a global tsunami warning system is a high priority for the larger Global Earth Observation System of Systems.

We look forward to working with the Congress and other nations around the world to help take the pulse of the planet and to make our world a safer place. And I, too, am happy to take your questions at the end.

Thank you, sir.

[The prepared statement of Brigadier General Johnson follows:]

PREPARED STATEMENT OF DAVID L. JOHNSON

Thank you, Mr. Chairman and Members of the Committee, for the opportunity to testify before you regarding the National Oceanic and Atmospheric Administrations (NOAA) activities with tsunamis. I am Brigadier General (ret.) David L. Johnson, Assistant Administrator for Weather Services and Director of NOAA's National Weather Service.

As the world and our Nation mourn the loss of life from the Indian Ocean tsunami tragedy, we recognize the very real threat of tsunamis and ask, "Could it happen here?" We need to be able to answer that question with a high degree of confidence.

We know a tsunami can affect any community along the coast of the United States. This is particularly true for the Pacific coast, where tsunamis have been more frequent. The recent event in Southeast Asia and Africa highlights the need to address the steps we can take to mitigate the potential impact of such an event here at home.

This catastrophic event focuses the spotlight on the threat tsunamis pose to all coastal communities. If there is some good to come from this tragedy, it is the opportunity that we now have to educate United States citizens about the actions they should take if they receive a tsunami warning.

In this testimony, I will describe our existing tsunami warning program, including a brief overview of our work with the International community; specific actions NOAA took during the recent tsunami; and then briefly outline the Administration's plan for developing a global tsunami warning system.

Tsunamis are natural disasters that can form in all of the world's oceans and inland seas, and in any large body of water near seismic activity. Each region of the world appears to have its own cycle of frequency and pattern for generating tsunamis that range in size from small events (no hazards) to the large and highly destructive events. Eighty-five percent of tsunamis occur in the Pacific Ocean and its marginal seas. This is not surprising as the Pacific Basin covers more than one-third of the Earth's surface and is surrounded by a series of mountain chains, deep-ocean trenches and island arcs called the "ring of fire."

Most seismic activity occurs in this ring of fire where the main tectonic plates forming the floor of the Pacific collide against one another or against the continental plates that surround the ocean basin, forming subduction zones. While tsunamis can be generated by any sudden pressure source in the water, such as a meteor, landslide, etc., most are generated from earthquakes. In the tropical Pacific tsunamis tend to be modest in size. While tsunamis in these areas may be locally devastating, their energy decays rapidly with distance. Usually they are not destructive more than a few hundred kilometers away from their sources. That is not the case with tsunamis generated by great earthquakes in the North Pacific or along the Pacific coast of South America. On the average of six times per century, a tsunami caused by an earthquake in one of these regions sweeps across the entire Pacific Ocean, is reflected from distant shores, and sets the entire ocean in motion for days. Although not as frequent, destructive tsunamis have also been generated in the Atlantic and the Indian Oceans, the Mediterranean Sea and even within smaller bodies of water, such as the Sea of Marmara, in Turkey. There have also been tsunamis in the Caribbean, but the lack of any recent tsunami in that area has lowered the level of interest and hindered establishing a warning program in that area.

According to NOAA's National historical tsunami databases, during the 105-year period from 1900 to 2004:

- 923 tsunamis were observed or recorded in the Pacific Ocean.
- 120 tsunamis caused casualties and damage, most near the source. Of these, at least ten caused widespread destruction throughout the Pacific.
- The greatest number of tsunamis during any one year was 23 in 1938. While most were minor, one event did result in 17 deaths.
- There was no single year during this period that was free of tsunamis.
- 19 percent of all tsunamis were generated in or near Japan; nine percent were generated off Alaska and the west coasts of Canada and the United States; and three percent were generated near Hawaii.

The U.S. Tsunami Warning System consists of two warning centers: the Richard H. Hagemeyer Pacific Tsunami Warning Center (PTWC) in Ewa Beach, Hawaii; and the West Coast/Alaska Tsunami Warning Center (WC/ATWC) in Palmer, Alaska. NOAA conducts research on tsunamis, operates essential ocean buoys and tide gauges to detect tsunamis, and works with other Federal, State, local government agencies and universities as our partners in the tsunami warning mission.

The Richard H. Hagemeyer Pacific Tsunami Warning Center in Hawaii was established in 1949 in response to the unpredicted 1946 Aleutian tsunami, which killed 165 people on the Hawaiian Islands. In 1967, the West Coast/Alaska Tsunami Warning Center in Palmer, Alaska, was created as a result of the 1964 Great Alaska earthquake and tsunami. These centers are responsible for issuing all tsunami warning, watch, advisory, and information messages to emergency management officials and the public throughout their respective areas of responsibility. The Pacific Center covers United States interests and territories throughout the Pacific, including Hawaii, while the West Coast/Alaska Center covers Alaska, and the west coast of North America from British Columbia in Canada, to California.

About 100 water level gauges are used by the Tsunami Warning Centers and are operated by the Unites States and our international partners. These gauges are along the coasts of islands or continents around the Pacific Rim. NOAA operates many of these stations, including 33 from NOAA's National Water Level Observation Network in the Pacific Ocean basin, which are equipped with software to support the Tsunami Warning System. Water levels from these gauges can be sent directly to NOAA Tsunami Warning Centers and others who want the information. NOAA is working to upgrade the nationwide network with a real-time capability to provide a continuous stream of water level data (minute-by-minute) for integration with tsunami warning systems and research applications. NOAA also helps support many coastal gauges located in other countries around the Pacific.

NOAA operates six Deep-ocean Assessment and Reporting of Tsunamis (DART) buoys. NOAA research activities developed these buoys to measure tsunamis in the deep ocean and to transmit the information back to the Warning Centers in near real time. These instruments accurately calculate the size of the tsunami by measuring the pressure it exerts on the deep ocean floor as the wave passes over. Tsunamis as small as 0.5 cm have been measured. NOAA began placing DART buoys in the Pacific Ocean in 2002 and plans to have a complete coverage of potential Pacific tsunami source zones over the next few years.

In November 2003, the buoys demonstrated their effectiveness. A large earthquake occurred in the Aleutian Islands and generated a tsunami. The two Tsunami Warning Centers evaluated the tsunami using coastal gauge data but didn't "stand down" until a reading arrived from the nearest DART buoy confirming only a small tsunami. During post analysis of the event, DART data were used for a model simulation and the output from the simulation accurately predicted the two cm tsunami recorded at Hilo, Hawaii. This NOAA model is still being developed, but an initial version will be transferred to the warning centers for test operations this year. DART data and the forecast model show much promise to help accurately predict tsunami impacts. In the history of Pacific Warning Center, 75 percent of its warnings to Hawaii have been for non-destructive tsunamis. The DART data combined with forecast models promise to significantly reduce false alarm rates as well as provide a better measure of the severity of destructive tsunamis for Hawaii and all other parts of the Pacific. The accurate forecasting of a non-destructive tsunami in November 2003 saved Hawaii an estimated $68M in projected evacuation costs.

The Pacific Center also serves as the operational center for the International Tsunami Warning System of the Pacific, which is comprised of 26 member nations of the Pacific Rim. These members share seismic and water level information with the Pacific Center so the Center can determine whether a tsunami was generated in the Pacific Basin and assess its strength. The Pacific Center's primary responsibility is to issue tsunami warnings for Pacific Basin teletsunamis—tsunamis that can cause damage far away from their source. It is not the Center's responsibility to issue local tsunami warnings from seismic events outside of the United States. For example, if an earthquake occurs off the coast of Japan and a local tsunami is generated, it is Japan's responsibility to issue a local tsunami warning. However, it is the Pacific Center's responsibility to warn all participating nations in the Pacific Basin if the Japanese tsunami will cause damage far from its source.

Only Australia and Indonesia have coastlines bordering both the Pacific and Indian Ocean coasts. None of the other countries impacted by the Indian Ocean tsunami have coasts bordering the Pacific Ocean and therefore they do not receive tsunami bulletins via the automated dissemination network.

Thailand and Indonesia are member states within the International Tsunami Warning System in the Pacific (ITSU), but their participation has been limited. Thailand has no coast along the Pacific, and Indonesia's tsunami threat is primarily outside the Pacific Basin. As a member of the International Coordination Group (ICG) for ITSU, the U.S. has actively encouraged non-member States to become ICG/ITSU members. Under the IGC/ITSU, the U.S. has actively supported the need for global tsunami mitigation actions and will continue to provide support through the development of a Global Earth Observation System of Systems (GEOSS), an effort in which the UNESCO Intergovernmental Oceanographic Commission, the UN International Strategy for Disaster Reduction (ISDR), and a number of other UN agencies and programs participate.

NOAA Tsunami Warning Centers have no authority or responsibility to issue tsunami warnings for the Indian Ocean basin. However, knowing the concern Pacific countries might have about the potential devastating impact a large earthquake and resulting tsunami can inflict, on Sunday, 26 December 2004, at 8:14 p.m. EST, within 15 minutes of the Indonesian earthquake, both centers issued Tsunami Information Bulletins. These bulletins included location and initial magnitude (8.0) information and an assessment that there was no tsunami threat in the Pacific. As the Indian Ocean is outside the NOAA tsunami area of responsibility, NOAA Tsunami Warning Centers have no procedures in place to issue a warning for this region. An hour and five minutes after the earthquake, as additional information came in from seismic monitoring stations around the world, another bulletin was issued by both Centers revising the magnitude of the earthquake to 8.5. This time the bulletin contained a statement that the potential existed for a tsunami near the epicenter. Unfortunately, there was no sea-level data or other information available to substantiate or evaluate a tsunami until three and a half hours after the earthquake when news reports began coming indicating casualties in Sri Lanka and Thailand. At about the same time, data from the one sea-level gauge in the Indian Ocean (Cocos I; west of Australia) was received indicating a 45 cm peak-to-trough non-destructive tsunami.

Sea-level gauges are essential elements of the current Tsunami Warning System in the Pacific. When strategically located, they are used to quickly confirm the existence or non-existence of tsunami waves following an earthquake, to monitor the tsunami's progress, and to help estimate the severity of the hazard. There was no data available from the Indian Ocean to help the warning centers know what was occurring.

An effective tsunami warning system requires (1) an assessment of the tsunami hazard, (2) near real-time seismic and oceanographic (sea-level change) data; (3) high-speed data analysis capabilities; (4) a high-speed tsunami warning communication system; and (5) an established local communications infrastructure for timely and effective dissemination of the warning and evacuation requirements. It is also critical that coastal populations are educated and prepared to respond appropriately to tsunami warnings and calls for evacuations. For the Pacific Basin, these tsunami warning requirements are well known. Unfortunately, for the Indian Ocean basin, they were basically non-existent.

There are currently six DART buoys in the Pacific operated by NOAA—three off the coast of Alaska, two off the coast of the western U.S., and one in the eastern Pacific. These first buoys of the currently envisioned 29 buoy array are an example of a successful transition of buoys from research and development into an operational system. Three of the deployed DART buoys are inoperable and will be repaired as soon as the weather permits.

The government of Chile purchased one DART buoys from NOAA and in now operating off the northwest coast of Chile; another buoy is in the process of being purchased at this time. Japan also operates a few cabled deep ocean sensors off its Pacific coasts. The NOAA buoys represent the only current deep ocean capability available to the Tsunami Warning Centers to detect tsunamis. In July of last year, staff from the Pacific Center had discussions with Japanese representatives about the possibility of allowing PTWC access to data from the Japanese cabled buoys.

While technical equipment is required for detection and communication, equally important are continued research and development, and education and outreach to mitigate potential impacts from tsunamis. People must have the knowledge and information to act during potentially life threatening events. Outreach and education efforts, such as NOAA's own StormReady and TsunamiReady programs, are key components of the U.S. National Tsunami Hazard Mitigation Program (NTHMP). These programs foster interaction between emergency managers and their citizens, provide robust communications systems, and establish planning efforts before certification. NOAA also developed multi-hazard risk and vulnerability assessment training and decision support tools using GIS mapping technology to highlight populations, infrastructure and critical facilities at risk for coastal hazards. These tools and other support are critical to land use planning, pre-disaster planning, mitigation efforts, and targeted dissemination of outreach, education and information about high-risk areas.

The International Strategy for Disaster Reduction (ISDR) was launched by the General Assembly of the United Nations to provide a global framework for action to reduce human, social, economic, and environmental losses due to natural and man-made hazards. The ISDR aims at building disaster-resilient communities, highlighting the importance of disaster reduction as an integral component of sustainable development. ISDR is the focal point within the United Nations system for coordination of strategies and programs for disaster reduction and to ensure synergy between disaster reduction activities and those in the socioeconomic and humanitarian fields. One particularly important role of ISDR is to encourage both policy and awareness activities by promoting national committees dedicated to disaster reduction and by working in close association with regional initiatives. As part of this effort, tsunami hazard maps have been produced for over 300 coastal communities in over 11 countries, including 130 communities throughout the United States.

The United Nation's Education, Scientific, and Cultural Organization's (UNESCO) Intergovernmental Oceanographic Commission (IOC) has developed products to help countries implement tsunami response plans. Road signs and other mitigation products are available through the NTHMP (http://www.pmel.noaa.gov/tsunami-hazard). In summary, Tsunami Response Plans are probably the most cost-effective way to create a tsunami resilient community. To be successful, communities must remain committed to a continuous, long-term education program. Tsunamis are infrequent events and it is important to ensure future generations understand tsunami safety.

Protecting near-shore ecosystems, like coral reefs, is equally important for maintaining disaster-resilient communities. The international media and South Asian officials reported less destruction in locations protected by wave-absorbing healthy coral reefs. NOAA and our federal, State, territorial, and international partners work to protect and preserve coral reef ecosystems.

The United States will continue working closely with the international community to help implement recommended tsunami detection and warning measures for the Indian Ocean Basin and other regions of the world currently without adequate tsunami warning capability. A comprehensive global tsunami warning program requires deploying DART buoys along each of the world's major subduction zones; adding real-time sea-level monitoring/tide gauge stations; establishing Regional Centers for Disaster Reduction, assessing hazards, promoting education and outreach efforts; and conducting research and development.

As recently announced by Vice Admiral Lautenbacher, Under Secretary of Commerce for Oceans and Atmosphere, the Bush Administration has a plan to upgrade the current U.S. Tsunami Warning System. NOAA's contribution to this plan includes procuring and installing 32 new DART buoys, including 25 new buoys in the Pacific and seven new buoys for the Atlantic and Caribbean. We expect to have the complete network of DART buoys installed and operational by mid-2007; 20 buoys should be operational in FY06, with the final 12 in place in FY07. In addition to the DART buoys, NOAA will procure and install 38 new sea level monitoring/tide gauge stations. The Administration has allocated $24M, over the next two years, to NOAA for this effort, including $18.1M for the Pacific Basin and $5.9M for Atlantic/Caribbean/Gulf.

There were many lessons learned from the Indian Ocean tsunami. A key point to make is that, for all coastal communities, the question is not "if" a tsunami will occur, but "when." We know what causes a tsunami to develop, and we know a great deal about how to track them and forecast their path. With expansion of the U.S. Tsunami Warning System, NOAA forecasters will be able to detect nearly 100 percent of tsunamis affecting the United States and will be able to respond and alert communities within minutes of a tsunami-producing event. With expanded education and outreach via NOAA's TsunamiReady program and other efforts, we can rest assured that our coastal communities have the opportunity to learn how to respond to a tsunami event and that we have minimized the threat to American lives.

With global attention on this important matter, we have a great opportunity to help the world better prepare for tsunamis through the development of a Global Earth Observation System of Systems (GEOSS). This system would include a real-time global seismic monitoring network, a real-time DART network, and a near real-time sea level monitoring network. NOAA Administrator, Vice-Admiral Conrad C. Lautenbacher will be a member of the U.S. delegation at the Third Earth Observation Summit (February 16, 2005; Brussels, Belgium) and will work to ensure that the development of a global tsunami warning system is a high priority for the larger Global Earth Observation System of Systems and the Integrated Ocean Observing System.

We look forward to working with Congress and other nations around the world to help take the pulse of the planet and make our world a safer place. Attached to this written testimony submitted for the record is an article published in the *International Tsunami Information Center Tsunami Newsletter,* which provides detailed information about NOAA's Pacific Tsunami Warning Center. Much more information about tsunamis can be found at http://wcatwc.arh.noaa.gov, http://www.pmel.noaa.gov/tsunami/, http://www.prh.noaa.gov/ptwc/, and http://www.ngdc.noaa.gov/spotlight/tsunami/tsunami.html.

Biography for David L. Johnson

David L. Johnson serves as the Assistant Administrator, National Oceanic and Atmospheric Administration (NOAA) for Weather Services (National Weather Service). Johnson heads the Nation's weather service and is responsible for the day-to-day management of NOAA's domestic weather and hydrology operations.

Prior to joining NOAA, Johnson served as the U.S. Air Force director of weather. He retired from the Air Force as a Brigadier General, after a 30-year military career. As Director of Weather, he was one of ten directors at the Headquarters Air Force, Air and Space Operations, and was responsible for developing doctrine, policy, requirements and operational organizations to support Air Force and Army operations worldwide. He also served as one of NOAA's military deputies.

Notably, he organized, trained and equipped forces for the war in Afghanistan and the war in Iraq, and managed a steady flow of accurate and focused environmental information to battlefield commanders. He was a key advisor in the development of the National Polar-orbiting Environmental Operational Satellite System (NPOESS).

Johnson's career is marked by his strong management and fiscal capabilities. During his time as Director of Weather, he led a massive re-engineering effort that revised the organizational structure, training and operations of the 4,000-person career field. Under Johnson's steady hand, retention of weather-career airmen and officers grew to 97 percent, up from 74 percent previously.

Johnson guided the planning, programming and budgeting process implementation at the highest levels in the Air Force and in the Department of Defense. He has a worldwide perspective, having served in leadership positions on the Joint Staff with planning portfolios in Europe/NATO and Asia/Pacific. He secured funding for a new facility for the Air Force Weather Agency to house collection, analysis, modeling and career-field supervision functions.

Prior to his service as the Director of Weather, Johnson flew fighter, transport and special operations aircraft. He has over 3,800 flying hours including 78 combat sorties. Johnson commanded airdrop and air/land operations in Bosnia-Herzegovina and was Deputy Commander of the Joint Task Force for Operation Support Hope in Rwanda. He was selected for early promotion three times.

Johnson is an honor graduate from the University of Kansas with a degree in geography, and earned his Master's degree in human relations from Webster's University. He is a graduate of the National War College, Maxwell School of Citizenship and Public Affairs at Syracuse University, and from the Paul Nitze School of Advanced International Studies at Johns Hopkins University.

Chairman BOEHLERT. Thank you very much, General.

Dr. Orcutt.

STATEMENT OF DR. JOHN A. ORCUTT, DEPUTY DIRECTOR, RESEARCH AT THE SCRIPPS INSTITUTION OF OCEANOGRAPHY; PRESIDENT, AMERICAN GEOPHYSICAL UNION

Dr. ORCUTT. Mr. Chairman and Members of the Committee, thank you very much for inviting me. I am John Orcutt, Deputy Director of Scripps Institutions of Oceanography and President of the American Geophysical Union, the AGU.

On the 26th of December last year, a 1,200-kilometer length of the sea floor ruptured during the Sumatra earthquake. The rupture took at least six minutes to propagate, breaking rock the entire way. The earthquake generated a devastating tsunami, but there was no systematic warning distributed to coastal populations. The event exceeded 500 megatons of explosives.

Adding to the tragedy is our knowledge that so many of the deaths could have been prevented if tsunami detection technologies had been more extensively employed and at-risk populations had been educated about how to react. The power of education is clear. A colleague of mine, Chris Chapman, a British seismologist on holiday in Sri Lanka, understood the drastic rapid retreat of the ocean from the beach signaled the arrival of the tsunami. He convinced his hotel manager to get on the beach with a bullhorn and warn people to direct them to retreat inland or to higher stories of the hotel. Many lives were saved by Chris's perception and persistence.

In a similar story involving, again, a Briton, a 10-year-old British girl, Tilly Smith, was visiting Thailand with her parents. Two weeks earlier, she had done a school project on tsunamis and earthquakes, and with this information alone, she was able to warn and save more than 100 lives. Long time intervals between tsunamis, tens to hundreds of years, poses a great challenge to sustaining education efforts for the entire coastal populations.

In addition to education, of course, expansion of the Global Seismic Network, the GSN, is critical to detect tsunamis triggered by earthquakes. With more seismic stations, we can more readily determine the true size of the event and whether the event is deep and not tsunamigenic or shallow and likely to have caused a tsunami. With a comprehensive network of seismic stations, the important surface waves from an earthquake will begin to arrive about seven minutes after the rupture begins, and information from all parts of the fault surface will be available after about 13 minutes.

Once information from the fault surface has arrived, it is possible to compute this earthquake source mechanism in about a minute. Taking another minute, the source mechanism can be propagated to determine the tsunami's path. This scenario that I have explained of 15 minutes is really very optimistic, because a tsunami can travel at nearly 500 miles an hour. The real Sumatra tsunami would have traveled 125 nautical miles, nearly halfway from its initial break to Sumatra. In many parts of the world, proximity to the origin of the tsunami makes warnings almost impossible. In these cases, an informed population is essential.

For the Caribbean, enhancing GSN coverage is particularly important. The Caribbean Hispaniola and Puerto Rico trenches are sites of past tsunamigenic earthquakes and tsunamis will occur there in the future. To avoid false warnings, false alarms, tsunami model information must be verified using tide gauges and pressure gauges. If several of these had been installed, for example, on the west coast of Sumatra and telemetered to a Warning Center, the tsunami could have been verified well before it reached Sri Lanka, India, Diego Garcia, the Maldives, and Africa.

I have mentioned some of the available technologies that might be deployed. Unfortunately, sustaining tsunami warning infrastructure over many years will be a tremendous challenge. Even in the Pacific, tsunamis do not occur often. Between major tsunamis, the NOAA centers have always had a hard time maintaining their budgets and personnel. The El Niño monitoring array has funding problems even though El Niño occurs every three to seven years and everybody on the planet knows its affects.

The Administration's proposed Tsunami Warning System would deploy many single-purpose buoys. I am extremely concerned about the ability to maintain such a system. I believe a more sustainable approach would be to deploy additional shore-based pressure gauges and integrate the proposed NOAA system with the National Science Foundation's Ocean Observatory Initiative (OOI) plans to include bottom pressure gauges on mid-ocean buoys that serve a wide variety of disciplines.

The OOI also includes plans for sea floor seismic observatories, greatly enhancing the densification of seismic stations I discussed earlier. And off the coast of Washington and Oregon, a planned cabled observatory will include seismic stations and bottom pressure gauges to form a dense tsunami observatory network. The OOI is expected in the President's fiscal year 2006 request for the NSF.

The Administration's plan recommends 24/7/365 operation of the National Earthquake Information Center satellite telemetry to the entire GSN and increasing station coverage. I strongly support these recommendations. Furthermore to have the greatest efficacy, data should be openly available.

Unfortunately, today, current operations and maintenance funding of $5 million a year, $2 million from the NSF and $3 million from the Geological Survey for the GSN, is not adequate. As a result, GSN is deteriorating and requires an additional $5 million a year based on several studies in the IRS and USGS.

Because the Tsunami Warning System will need to be maintained in perpetuity, we must develop strategic knowledge about high-risk tsunami areas to lower long-term costs. In order to accomplish this, NOAA and the Geological Survey's Tsunami Hazard Mapping efforts should be expanded and detailed asymmetry surveys should be undertaken to identify important slumps for monitoring.

We must also explore the development of cheap monitoring technology, exploring the Global Positioning System, or GPS, using ocean buoys and ships is an interesting alternative to pressure gauges to verify a tsunami. Horizontal tsunami motion would be detectable from a buoy or even a ship underway, and costs may be lower using that technology.

As President of AGU, I was asked by the U.N. Environmental Program to write a brief report proposing an Indian Ocean Tsunami Warning System. This report is not complete, but it will include a number of approaches, including increasing the number of GSN stations, developing a Tsunami Warning Center or Centers for the region, improving telemetry to the stations in between the center of the many states in the Indian Ocean, exploiting modern grid-based cyberinfrastructure and installing a large number of telemetered pressure gauges, and installing communications needed to distribute a tsunami warning to the public.

The location and magnitude of the 26th of December Sumatra earthquake was determined in time for mitigating measures to be taken in Sri Lanka, India, the Maldives, and Africa to prevent extensive loss of life. The lack of infrastructure to warn people was, unfortunately, the weak link in the system.

Thank you, again, Mr. Chairman and Members of the Committee. I am happy to answer any questions you may have.

[The prepared statement of Dr. Orcutt follows:]

PREPARED STATEMENT OF JOHN A. ORCUTT

Mr. Chairman and Members of the Committee, thank you very much for inviting me to testify. I am John Orcutt, Deputy Director of Scripps Institution of Oceanography (SIO) at University of California at San Diego (UCSD), Director of the UCSD Center for Earth Observations and Applications, and President of the American Geophysical Union or AGU. The AGU has more than 44,000 members worldwide. Nearly every scientist involved in tsunami studies in any country in the world is likely a member of the AGU.

Over the last sixty years, SIO scientists have played a substantial role in understanding tsunamis. In 1947, Professor Walter Munk, a continuously active scientist/oceanographer, developed and installed the first tsunami-recording instrument. In 1949, Dr. Gaylord Miller, Walter's student, was named the first director of what is now NOAA's Tsunami Warning Center in Hawaii. Dr. Bill Van Dorn, another of Walter's students, was the real pioneer at Scripps in understanding and popularizing knowledge of tsunami.

Scripps continues its tsunami work through the operation of approximately one-third of the Global Seismic Network (GSN), pressure gauges, the study of slope failure and initiation in submarine landslides, and the development of sensitive instrumentation to understand triggering mechanisms of submarine landslides.

What is Scripps' role in the worldwide seismic network? When did Scripps know about the earthquake on December 26, 2004 and what was your response?

With National Science Foundation (NSF) funding, Scripps operates and maintains 40 Project IDA (International Deployment of Accelerometers) GSN stations. Scripps is also responsible for data telemetry (transferring data immediately via phone line, cable, or satellite), quality control, and distribution of data to researchers worldwide via the Incorporated Research Institutions for Seismology (IRIS) Data Management System. The U.S. Geological Survey operates the remaining two-thirds of the GSN.

In 1975, Scripps Project IDA pioneered modern global digital seismic networks by deploying a network of high performance instruments, the forerunner of today's GSN. Cecil Green, founder of Texas Instruments, provided funding for the project and the NSF provided funds to maintain the network.

In 1984, the extraordinary scientific results gleaned from data recorded by that early network and a parallel evolution in electronics technology led to the formation of IRIS and the associated GSN, with Scripps' IDA stations at the core of the fledgling network. With NSF support and continuing support from the Green Foundation for Earth Sciences, the GSN modernized the original IDA instruments and expanded the scope of the global network. Scripps continues to operate some of the original global stations, making IDA the longest operating digital global seismic network in history. The digital recording instrumentation and high performance characteristics of the seismometers pioneered at SIO/UCSD are essential elements of the earthquake and tsunami warning systems in existence today. Because Scripps is usually tasked with deploying global seismic stations at the most difficult sites, all of the Indian Ocean seismic stations and many on the direct periphery are SIO/IDA observatories (See Figure 1).

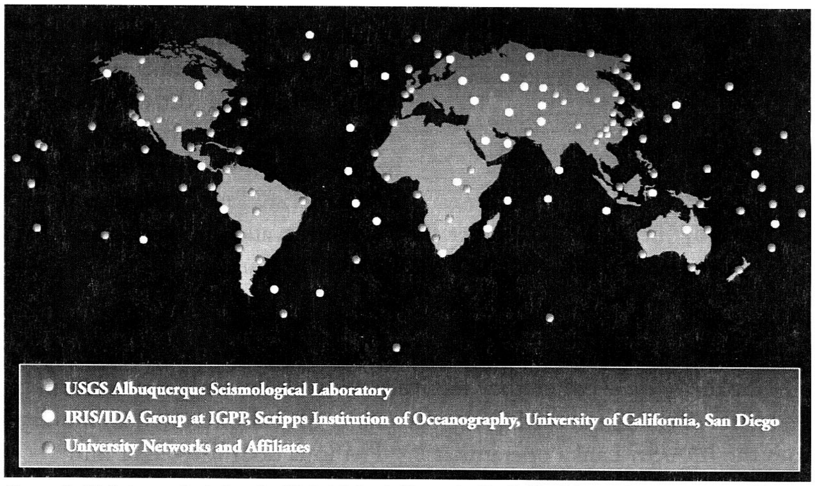


Figure 1: Global map depicting the Global Seismic Network. The bulk of the stations are operated by the USGS (blue) and Scripps' IDA (orange).

Data telemetered from thirty IDA stations are immediately and automatically forwarded by computer to the USGS National Earthquake Information Center (NEIC) in Golden, Colorado and the NOAA tsunami warning centers in Hawaii and Alaska. Those organizations constantly monitor these and other data streams for earthquake signals. Due to their proximity to the event, IDA stations were critical in the early detection of the December 26th earthquake. The two closest global seismic stations, IDA stations on Cocos (Keeling) Island (Figure 2) and Sri Lanka (Figure 3), received signals three minutes, thirty seconds after the quake began. Data from these and other IDA GSN stations in the region were used by the NEIC, and other civil, academic, and military systems to quickly determine the quake's size and location (Figure 4).

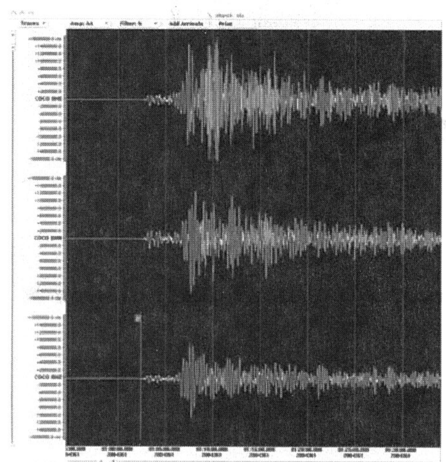


Figure 2: Seismograms recorded at the Scripps/IDA/IRIS station COCO on Cocos (Keeling) Island. The initial arrival on the bottom trace (up-down motion) is the primary or P wave. The second, large arrival on all channels is shear and surface waves traveling significantly lower velocities. The top trace is east-west motion and in the middle, north-south motion. Time increases from left to right. Actual wave amplitudes during the surface and shear waves is nearly 10cm.

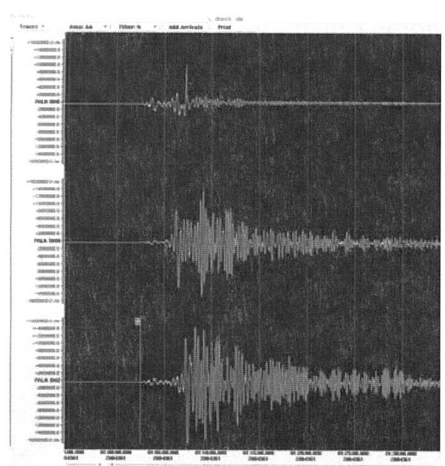


Figure 3: Same as Figure 2 except for the Scripps/IDA/IRIS station on Sri Lanka.

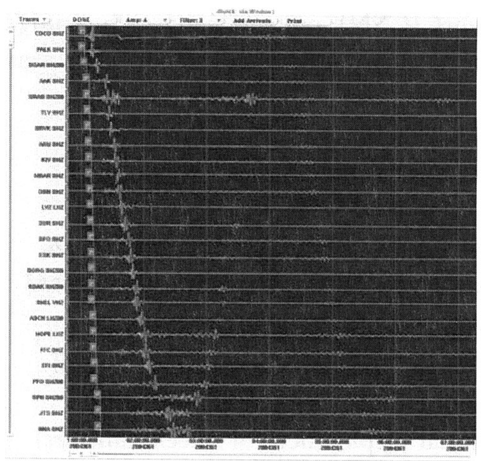


Figure 4: Vertical component seismograms, filtered to eliminate high frequencies, recorded on all telemetered Scripps/IDA/IRIS stations. Distances from the Sumatra source increase from top to bottom and time again advances to the right. The data composite is required to develop a meaningful estimate of the size of the earthquake. Many stations are required to examine the fault from a wide variety of directions.

Scripps personnel do not constantly review incoming data. Scripps staff first learned of the quake at 6:16 PM PST (one hour seventeen minutes after the earthquake) when they received notice via automatic e-mail from the NEIC of the initial earthquake detection. SIO also received an inquiry from the IDA/Sri Lanka operator at 6:57 PM (one hour fifty-eight minutes after the quake) asking whether there had been any earthquakes in or near Sri Lanka. The operator had received many phone calls from local residents who had felt tremors and wanted to know the source. SIO's analyst replied at 7:13 PM with information about the NEIC announcement of the earthquake and a plot of the seismic waves recorded by the IDA station in Sri Lanka.

What are all of the elements of an adequate tsunami warning system? Does the U.S. warning system currently contain all these elements?

The Global Seismic Network (GSN) is critical to tsunami detection associated with earthquakes. The recent Sumatra earthquake substantially displaced the seafloor causing a tsunami with displacements throughout the water column. Smaller events can also excite tsunami via a major underwater landslide triggered by an earthquake. For example, on November 18, 1929, a 7.2 magnitude offshore earthquake triggered the Grand Banks Tsunami. The earthquake caused 200 cubic kilometers of sediment to shift, breaking twelve transatlantic communications cables. Twenty-seven people died in the tsunami and the tsunami run up was as great as twenty-seven meters. More than forty villages were affected and homes, ships, and fishing gear were lost. The tsunami also damaged the seabed leading to poor fish catches through much of the Great Depression.

The 1200-kilometer length of seafloor ruptured in the Sumatra earthquake. The rupture took at least six minutes to propagate, breaking rock the entire way. Sixteen minutes after the earthquake began, the NEIC estimated a 6.2 magnitude earthquake. The low estimate was not because of any system or human malfunction, but because limited information was available (Figure 2).

When a large earthquake occurs, the seismogram appears differently when viewed from different directions. If the fault breaks toward the station, the sum of the rupture velocity and the wave propagation velocity will make the event appear to be compressed in time. On the other hand, if the rupture front propagates away from the seismic station, the two speeds will combine to lengthen the seismogram in time. To fully understand the magnitude of a great earthquake, seismic stations with high fidelity must be available from as many directions as possible. The higher the density of seismic stations, the more rapidly one can determine the accurate size of the event and whether the event is deep and not tsunamigenic, or shallow and likely to have caused a tsunami. In a relatively perfect world, with a large number of seismic stations 15° away from a great earthquake on Earth's surface, the important surface waves will begin to arrive about seven minutes after the rupture begins and information from all parts of the fault surface will be available after about thirteen minutes. While it would be impractical to deploy this array of stations worldwide, it would be possible to have the necessary coverage in high-risk areas. If computation can be speeded to determine the initial fault mechanism in a minute's time (the actual computational challenge is modest), fourteen minutes would be the minimum time needed to develop a full understanding of the earthquake source. Because of the sparse distribution of high-quality seismic stations around the Sumatra earthquake, what is theoretically possible in fourteen minutes took considerably longer.

With a comprehensive network of seismic arrays, once an earthquake source mechanism is known, certainly no earlier than fourteen to fifteen minutes after the earthquake begins, the source mechanism can be coupled to a model that forecasts the path of the tsunami from the earthquake location to islands and continents. Because a tsunami in average ocean depth travels at 200m/s (nearly 500 mph), the real Sumatra tsunami would have traveled 125 nautical miles, or 142 statute miles, nearly half way from the initial break to Banda Aceh on Sumatra. Time would be running out for many even in this idealized case.

The existence of a tsunami associated with a suspect, large earthquake can be verified in a number of ways. Tide gauges and especially pressure gauges are very helpful in this regard. Pressure gauges are simple, inexpensive sensors that last decades. Figure 5 shows a record of a pressure gauge sampled each second at the end of the Scripps pier. This records the Sumatra tsunami thirty-six hours after the earthquake and shows a peak-to-peak amplitude of about twelve centimeters (four inches). Surprisingly, this is the only pressure gauge on the west coast that samples at this high frequency. If several of these had been installed and telemetered on the west coast of Sumatra, the gauges would have been able to verify the tsunami well before it reached Sri Lanka, India, Diego Garcia and the Maldives. Technically and financially, the installation and operation of these gauges is not a major challenge. NOAA has experimented for some years with pressure gauges on the seafloor tended by telemetering buoys overhead—the principle is the same as the pressure gauge in Figure 5. In the President's recently announced program, NOAA proposes to install a number of these DART buoys around the world.

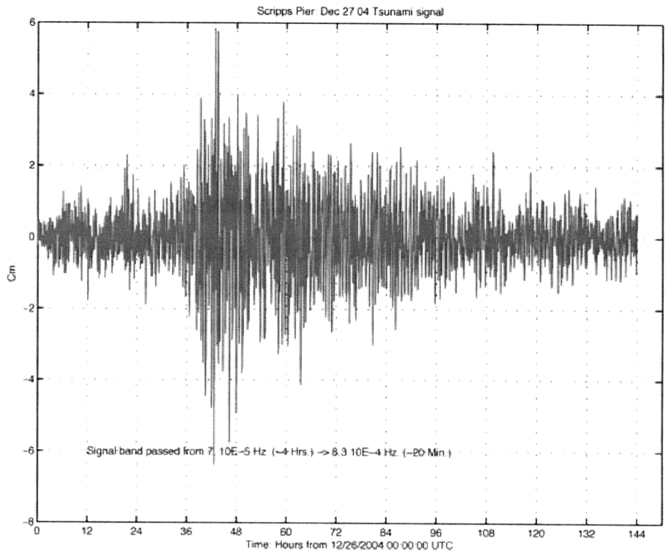


Figure 5: Ocean height from pressure gauge at the end of the Scripps pier sampled once each second. The peak-to-peak amplitude of the tsunami from the Sumatra event is approximately 12cm. The earthquake is approximately 9,000 miles away and the tsunami took about 36 hours to reach Scripps. These pressure gauges are similar to those used on the seafloor with the NOAA DART buoys.

The instrumentation described above summarizes the science and technology necessary to detect a tsunami. The greater challenges to a tsunami warning system, however, are socio-political and involve distributing information to those at risk as well as long-term educational efforts for entire coastal populations. Currently, tsunami-warning centers exist only for the Pacific through NOAA and the NEIC through the USGS. There are no warning centers for the Indian, Atlantic or Caribbean oceans.

The power of education is clearly stated by Dr. Chris Chapman, a close colleague on holiday in Sri Lanka with his wife during the tsunami. Dr. Chapman, a British seismologist, understood that the drastic, rapid retreat of the ocean from the beach signaled the arrival of a tsunami. He and his wife convinced their hotel manager to use his bullhorn to warn everyone to retreat inland or to the higher stories of the hotel. Many lives were saved by Chris' perception and persistence.

In a recent article from AGU's newspaper, EOS, Dr. Chapman states:

> Given the time and distances, there was little we could have done for the neighboring villages. Would an early warning system have helped? Of course, but the situation in the Indian Ocean is very different from the Pacific: The recurrence rate is very low (There appear to be no recent historical events; locals spoke of a tsunami more the 2000 years ago, although I have been unable to check this. With a recurrence rate longer than a generation, how would people have reacted? We had 40 minutes of warning and still did not behave in the most logical fashion); the distances and hence warning times are less than in the Pacific; and some of the countries surrounding the Indian Ocean have fragile infrastructures at best. But given that an early warning system is technically relatively straightforward and inexpensive, of course it should be installed. Perhaps it can be used as a catalyst and driving force for improvements to the local infrastructures rather than just being imposed from outside.

A ten-year-old girl British girl, Tilly Smith, was visiting Thailand with her parents. Two weeks earlier she had done a class project on earthquakes and tsunami and was able to save more than a hundred people because she recognized the warning signs of an impending tsunami.

What are the greatest challenges to improving the U.S. tsunami detection and warming systems? What is your opinion of the Administration's new proposal to improve the U.S. tsunami warning system? Are there other activities or actions that the plan should have included? If so, what are they?

Sustaining tsunami-warning infrastructure over many years is the greatest challenge. For the past thirty-two years as an observational scientist, I have developed, deployed and been responsible for the maintenance of numerous research facilities. Maintaining observing platforms is incredibly difficult, especially when events occur infrequently.

In the case of tsunamis, major events occur at time scales from decades to centuries. Even in the Pacific, tsunamis do not occur often. Between major tsunamis, the NOAA Center in Honolulu always has a hard time maintaining its budget and hiring qualified personnel. The El Niño monitoring array has funding problems even though an El Niño occurs every three to seven years and everyone on the planet is aware of its effects.

The Administration's proposed tsunami warning system would deploy many single-purpose buoys. I am extremely concerned about the ability and willingness of the United States to maintain such a system. Initial system costs are not particularly high; however, annual operations and maintenance costs will equal the initial costs within three to four years when the cost of ship time needed to service buoys is included.

I believe a more sustainable approach would be to deploy additional shore-based pressure gauges and integrate the proposed NOAA system with NSF plans to include bottom pressure gauges on mid-ocean buoys that serve a wide variety of disciplines. NSF's Ocean Observing Initiative (OOI) plans include deployment of seven to twelve buoys capable of multidisciplinary measurements, such as seafloor pressure for tsunami detection and sea level rise. The OOI also includes plans for seafloor seismic observatories of a quality equal to those on land—this would greatly enhance the recommended densification of seismic stations I discussed earlier. For the Northeast Pacific, a planned cabled observatory offshore will include seismic stations as well as bottom pressure gauges to form a dense tsunami observatory network as well as providing the infrastructure for observations relevant to climate, life in extreme environments, physical oceanographic and biological observations in the California current, and coastal sediment dynamics.

Expansion of the Global Seismic Network is necessary to reduce tsunami detection times, at least for tsunamis associated with earthquakes and volcanoes which are the vast majority in terms of numbers. The 137-station GSN is too sparse for the purposes of global tsunami detection. More stations are needed to understand quickly an earthquake's source and its potential to create a tsunami. Furthermore, these additional stations will serve a wide variety of purposes: global earthquake hazard studies, detection and identification of nuclear tests, fault mechanics research, seismicity, and Earth structure from the inner core to the planet's crust. This broad range of scientific and societal uses will help to ensure the system is maintained.

For the Caribbean, enhancing GSN coverage is particularly important. The Caribbean Hispaniola and Puerto Rico trenches are sites of past tsunamigenic earthquakes and will cause future tsunami. Many of the Caribbean's islands are close to these trenches and the impact of a tsunami could be devastating. Steep slopes around the trenches also increase the likelihood of earthquake-triggered underwater landslides in this region. In 1998, such an earthquake-triggered landslide killed 2000 people in Aitape on the north coast of Papua New Guinea. Within the Gulf of Mexico, submarine landslide hazards are substantial although not known to be tsunamigenic. British Petroleum is funding Scripps to develop deep seafloor instrumentation capable of monitoring seafloor movement and landslide initiation. We are currently testing these instruments at a major slump in southern California, the Goleta slump (Figure 6).

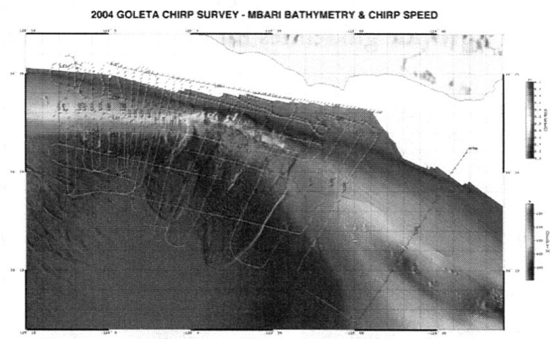


Figure 6: The Goleta slump off Santa Barbara in California including track lines used in the survey. Data are from the Monterey Bay Aquarium Research Institute (MBARI) and Scripps. BP is funding Scripps to develop, test, and deploy instrumentation to monitor this slump and others in the Gulf of Mexico.

The President's plan recommends 24/7/365 operation of the NEIC and establishing satellite telemetry to the entire GSN. I strongly support the recommendation to enhance the quality of NEIC and the satellite telemetry will minimize the time from event to source identification. Currently, in some cases, seismic station telemetry piggybacks on a UN satellite system operated by the UN Comprehensive Test Ban Treaty Organization (CTBTO); development and testing of this system was done at Scripps. Following the Sumatra earthquake, the system was saturated with CTBTO traffic and some of the GSN shared circuits were blocked by this priority traffic. Because the data at the CTBTO are not available publicly, it is important to move from this system as soon as possible. Furthermore, to have the greatest efficacy, data should be openly available to all agencies, governments, and individuals interested in monitoring and processing data. For the Indian Ocean specifically, moving to a satellite telemetry system would immediately resolve data dependability issues with the Sri Lanka, Indonesia, and Seychelles stations. (Figure 7)

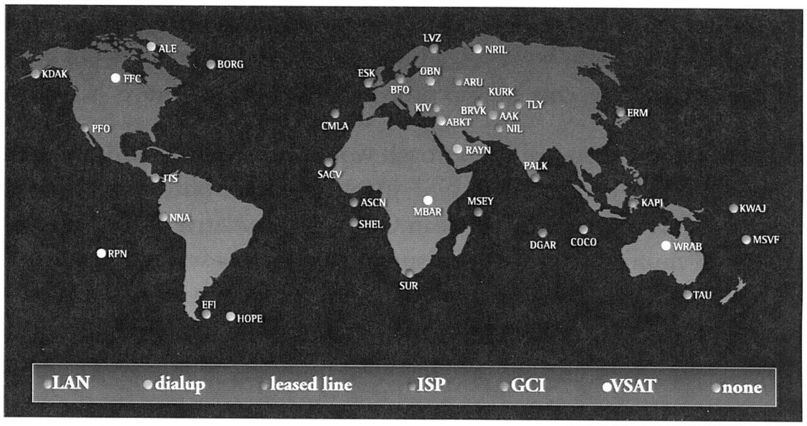


Figure 7: Telemetry technologies for the IDA GSN network. LAN is Local Area Network. *Leased Line is a* leased phone line. *ISP is an* Internet Service Provider. *GCI is the satellite telemetry system used by the UN CTBTO and shared on a not-to-interfere basis by the GSN. VSAT is a satellite telemetry system. Several stations are not telemetered at all (approximately 25%).*

Another GSN issue is how the network is currently funded. NSF provides the support for a third of the GSN and, through IRIS, manages data quality control, archiving, and distribution of all data. The NSF has provided all the capital costs for the GSN stations including those operated and maintained by the USGS. The President's plan for a tsunami warning system does not recognize NSF's role and does not include an augmentation of the NSF budget for GSN growth and modernization.

Finally, current funding of $5 million per year ($2 million NSF/$3 million USGS) for the GSN is inadequate. As a result, GSN is deteriorating and requires an additional $5 million per year for operations and maintenance. IRIS has established, through a series of studies, that GSN O&M costs range from $60,000 to $75,000 per year per station in 1998 dollars. Therefore, the costs to maintain the GSN are $8 to $10 million per year.

The NOAA/USGS tsunami hazard mapping efforts should be expanded. In the case of earthquake-caused tsunami and volcanoes, this is fairly straightforward. Earthquake probabilities could be coupled to tsunami models, which would include the best offshore bathymetry data available. Tsunami run-up could be estimated from the best available topographic maps. At a minimum, topography data from the U.S. Shuttle Radar Topography Mapping (SRTM) at 30-meter postings are available globally; better data are often available from other unclassified resources. The intersection of high probability tsunami run-up estimates with data about population and economic centers would provide guidelines for monitoring requirements; for example, where pressure gauges should be installed. Tsunami risk assessment can then be used to prioritize more detailed topography and bathymetry surveys. Furthermore, governments can use the knowledge for civil works planning, as is done now in the U.S. and especially in California for earthquake hazards.

Hazard mapping for non-earthquake related submarine landslides is more complex. Detailed bathymetry surveys can identify important slumps for monitoring (Figure 8). Continued research in the causes and development of new monitoring technologies are important for understanding their role in tsunami and should be accelerated.

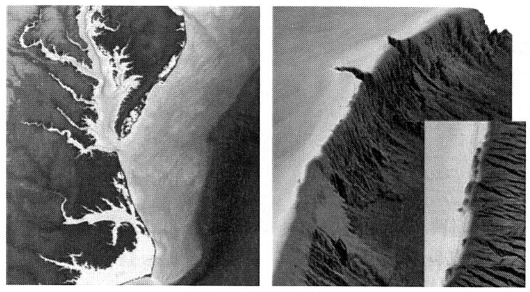


Figure 8: The continental margin of the US is shown on the left and seafloor bathymetry on the right. The breaks at the top of the continental slope may be indicative of slump potential which could possibly lead to a tsunami.

While pressure gauges on the seafloor are well understood, exploiting the Global Positioning System (GPS) using ocean buoys and ships is an interesting tsunami detection alternative not requiring communications with the seafloor. Horizontal resolution with errors less than three centimeters has been achieved on Scripps ships. While GPS vertical resolution is generally five to ten times poorer than horizontal, obviating the detection of passing tsunami in deep water, the horizontal motions are substantially larger than the vertical displacements. The horizontal tsunami motion should be detectable from a buoy or a ship underway. Research should be conducted to investigate this approach for verifying a tsunami at sea as costs may well be lower than the pressure gauge alternative.

A global tsunami warning system requires reliable global communications and effective collaboration among many states. In the past these exchanges occurred by telephone, radio, and, with increasing frequency, e-mail. Moore's Law; after Gordon Moore, founder of Intel, is often used to quantify the exponential growth of the number of transistors on a chip. Generally, this number doubles every eighteen months and computing speed follows not far behind. Less well known is the rate of doubling of network speed, approximately nine months and digital storage, twelve months. Clearly both network speed and memory are outstripping increases in computational capability. In five years time, for example, computer-processing capability will increase by a factor of ten, memory density by thirty-two, and network bandwidth by 100. Today network speeds of 10Gbps (a Gbps is a gigabit per second where a gigabit is a billion bits of data) are available in academia and connect a number of locations in the U.S. using networks such as the National Lambda Rail (NLR) and these speeds extend to Japan, Europe, Korea, and Australia through international projects such as NSF's Pacific Rim Applications and Grid Middleware Assembly (PRAGMA).

It is no longer necessary or even desirable to centralize computing, data archives, visualization tools, and real-time sensor networks because of the tremendous networking speeds available now and in the future. Furthermore, this growth translates into exponential decreases in cost for a constant capability. That is, a terabyte of storage today costs approximately $900 (a terabyte is 1,000,000,000,000 characters). In five years, $900 will purchase 32 TB of storage. Cyberinfrastructure grids connecting nodes for computation, visualization, sensorwebs, and storage must be exploited to create the global tsunami warning system to maximize capability while minimizing costs. The G–8's Global Earth Observing System of Systems (GEOSS) is an excellent candidate for coordinating this effort.

How would you recommend that an Indian Ocean and worldwide tsunami warning network be established? What role should the U.S. play in its development?

As President of the AGU, I was asked by the United Nations Environmental Programme to write a brief report proposing an Indian Ocean tsunami warning system. This report is not complete but, when finished, will include a number of the approaches outlined above. In particular, it will recommend increasing the number of GSN stations in and around the Indian Ocean; developing a tsunami warning center or centers for the region; improving the telemetry to the various stations and between the center and the many states in the Indian Ocean; the installation of a substantial number of telemetered pressure gauges; and the technology needed to inform threatened States, local governments and private citizens of impending tsunami disasters. Education and outreach are critically important to teach children and adults about the dangers and signs of tsunamis. Tsunami hazards mapping must be started as soon as possible to determine where additional sensors, such as buoys with GPS and/or pressure gauges, should be installed and maintained.

The cyberinfrastructure discussed in the previous section can be very helpful in meeting local needs. For example, at the request of the government of the Maldives, we quickly established a web page showing the real-time seismic data from the three GSN stations closest to the Sumatra event. It is possible for people on the Maldives to monitor for aftershocks—an issue of significant concern given the very low island freeboard for nearly all of these islands. It should be possible for interested parties to set up similar virtual observatories for their specific needs without outside help if the grid architecture for global services is adopted.

The location and magnitude of the December 26th Sumatra earthquake was determined in time for mitigating measures to be taken in Sri Lanka, India, the Maldives and Africa to prevent extensive loss of life. The lack of civil infrastructure to warn people was, unfortunately, the weak link in the system. The development of tsunami warning in this area of the world will have to be comprehensive in nature.

BIOGRAPHY FOR JOHN A. ORCUTT

Prof. John A. Orcutt is the Deputy Director for Research at Scripps Institution of Oceanography and heads University of California at San Diego's Center for Earth Observations and Applications. He served as Director of the Cecil and Ida Green Institute of Geophysics and Planetary Physics at Scripps for 18 years. Prof. Orcutt is a graduate of Annapolis (1966) and received his M.Sc. in physics as a Fulbright Scholar at the University of Liverpool. He served as a submariner and advanced to the rank of Commander. He received his Ph.D. in Earth Sciences from Scripps (1976). He has published more than 140 scientific papers and received the Ewing Medal from the U.S. Navy and the American Geophysical Union (AGU) in 1994. He received the Newcomb-Cleveland Prize from the American Association for the Advancement of Science (AAAS) in 1983 for a paper in *Science.* He is one of nine Secretary of the Navy/Chief of Naval Operations Oceanography Chairs and is presently the President of the American Geophysical Union (AGU). He chaired a National Research Council Committee on the Exploration of the Seas the past two years and was a member of the Steering Committee of MEDEA, an organization working with the Director of Central Intelligence in the use of classified data for environmental research. His research interests are the shallow and deep structure of the ocean basins and ridges, the use of seismic data for monitoring nuclear explosions, and the exploitation of information technology for the collection and processing of real-time environmental data. He was the Chair of the National Science Foundation/Consortium for Ocean Research and Education (CORE) Dynamics of Earth and Ocean Systems (DEOS) Committee with an interest in extending long-term observations to sea—a permanent presence in the oceans. He is currently a member of the ORION (Ocean Research Interactive Ocean Network) Executive Steering Committee. He was a member of the Science Advisory Panel to the President's Ocean Policy Commission. He was elected to the American Philosophical Society in 2002; Benjamin Franklin founded the APS in 1743.

Chairman BOEHLERT. Thank you very much.

Dr. Lerner-Lam.

STATEMENT OF DR. ARTHUR L. LERNER–LAM, DIRECTOR, COLUMBIA UNIVERSITY CENTER FOR HAZARDS AND RISK RESEARCH

Dr. LERNER-LAM. Thank you, Mr. Chairman, Mr. Gordon, Members of the Committee. Thank you very much for the opportunity to provide testimony on such an important matter facing us today.

This committee, of course, has long been a supporter of basic science and research in the United States, and this support has enabled many of us to participate in the discussions of the Tsunami Warning System to talk about the role that basic science has in developing such systems and to talk about the role that basic science plays in protecting the population and our societies.

My comments today, I am a seismologist at the Lamont-Doherty Earth Observatory. I am also Director of the Center for Hazards and Risk Research. As a seismologist, I share many of the comments that Dr. Orcutt made. As a Director of a center that is concerned with the use of this information to protect populations, my comments today will be oriented toward how we should perceive the risk of tsunamis in the presence of other natural hazards and risks.

[Slide.]

My first slide shows this tsunami to be an extreme event. The number of deaths as of last Thursday in the South Asian tsunami is well over 200,000, but you can see that persistent tsunamis, particularly in the Pacific, and in some cases, the Indian Ocean, also killed tens of thousands of people.

In some sense, these are extreme events in that they have an extreme impact and are outside of our experience. In another sense, some of the generative events, some of the events that cause these tsunamis, can be forecast in ways that pertain to our understanding of basic science.

We have attempted to do this with a basket of natural disasters, including droughts, earthquakes, landslides, floods, severe storms, and other disasters, and earthquakes. The point of a map like this is to show that the world is, indeed, a dangerous place, that there are areas in the world that have persistent hydrometeorological and geophysical impacts from disasters and that the United States, on a global basis, luckily suffers relatively low mortality.

But in terms of economic risks, the United States has a severe exposure. And again, these exposures to a basket of hazards are significant.

[Slide.]

I would point out in a slide of this sort, that the hydrometeorological disasters, that is the floods and the storms, as well as the geophysical disasters, the landslides and the earthquakes, are decent proxies for what might be expected if a severe tsunami impacted the United States.

Now in some sense, a calculation of this sort is an annualized calculation. This is what we would expect from the normal physics of the Earth. On the other hand, we are faced with the events of December 26, which is, in reality, extreme. And these are extreme events for which we really do not have good statistics. We simply don't have a long enough instrumental record.

In this case, how do we approach the risk? I think there are two approaches. We need to persist in our understanding of the events that happen all of the time and to develop systems that allow us to mitigate the impact of those events, both for the Nation and globally. But we also must take a precautionary approach towards these extreme events, especially when, like the current Tsunami Warning System, the cost of setting a system are low, relative to the enormous impacts that might occur.

Elements of a Tsunami Warning System that should be considered by this committee have been touched on by some of the other testimony, but I will reiterate some of these points.

First, rapid estimation of the size of large tsunami-generating events is an important component. An interesting point about this is that this must be integrated with basic research, for it is research by the National Science Foundation and by the External Grants Program of the U.S. Geological Survey that provides us with the basic knowledge that allows us to characterize these enormous extreme events. It is something that the operational entities need to take advantage of.

Secondly, as has already been stated, we need to maintain the very broadband nature of these Global Seismic Networks, because it is only the broadband nature that allows us to look particularly at these very great earthquakes. We have some specific concerns, which are detailed in my written testimony.

We have already touched on the notion of redundancy, and I will simply state that redundancy is a factor not only of the geographic coverage in both the seismometer and in the buoy systems, but in the engineering, research, and development that must occur for basic elements of these instruments. In my view, the Administration's proposal is lacking in engineering R&D funds.

A second set of elements to consider is the need to ensure sufficient local capacity to use these warnings. We are about to hear some details on that, but I would also point out that this is of significant importance internationally. We already know, the warnings can not be used unless there is infrastructure on the ground, capacity on the ground to use them. And this is a particular problem if the United States is to take a leadership role internationally.

Data archives for performance-based assessments of these systems need to be implemented so that we understand, as in cases in December 26, what might have gone wrong, what needs to be improved, and what other research and technology we need to implement to provide adequate warnings.

And finally, stable support for operations and maintenance as well as engineering research and development needs to be found.

Finally, the leveraging of the Tsunami Warning System ought to be done in two ways. The Tsunami Warning System ought to be a step toward the System of Systems, as we know, GEOSS. What we need to do is to ensure interoperability among the international partners and among the different observing systems, and in fact, the Tsunami Warning System, as proposed, can be a confidence-building measure in that way.

We also need to ensure that the dual goals of both the research and the operational communities are satisfied, and again, the Tsunami Warning System provides that confidence-building measure as a pilot program.

My final remark, that the U.S. ought to show leadership in linking global Earth observations to smart recovery in the Indian Ocean and to sound development elsewhere in the world, because, after all, hazards are problems of the poor, not just of the developed world.

Thank you.

[The prepared statement of Dr. Lerner-Lam follows:]

PREPARED STATEMENT OF ARTHUR L. LERNER-LAM

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 worldwide.

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 multi-hazard 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 six 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 percent 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 preemptive 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 U.S. in an Indian Ocean and Worldwide 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.

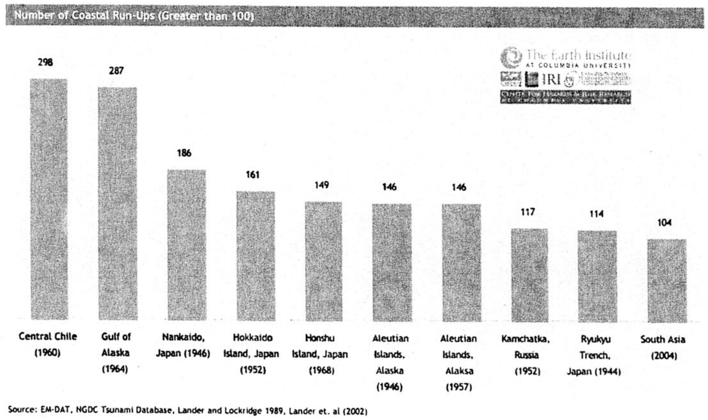
From the work of the Earth Institute and other sources, we know that the Central and South Asia, East and Southeast Asia, the Caribbean, Central America and Latin America, Sub-Saharan Africa, all face significant exposures from multiple hazards in terms of mortality and economic impact. The United States 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 U.S. and Indian Ocean systems now being proposed by the U.S. 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.

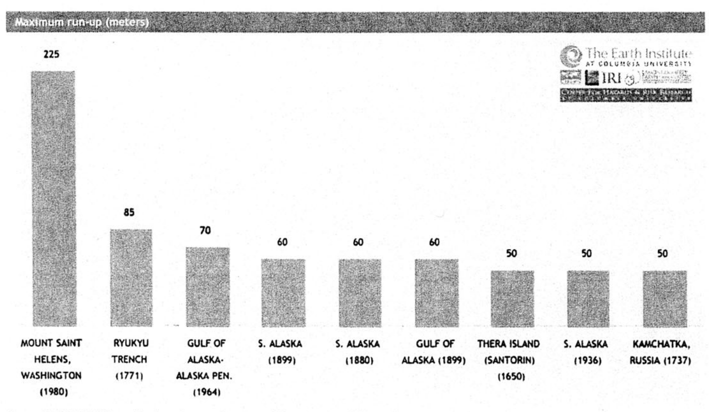
In brief, the U.S. leadership role should not be confined to technical leadership. We have the ability to link our scientific and technical excellence to the longer-term disaster reduction and development goals of less-developed countries. This can be done by specifically demonstrating how implementation 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.



Tsunami Run-Ups: Number of inundations from one event

FIGURE 1



Global Tsunami Run-Up in meters (50 m or above)

FIGURE 2

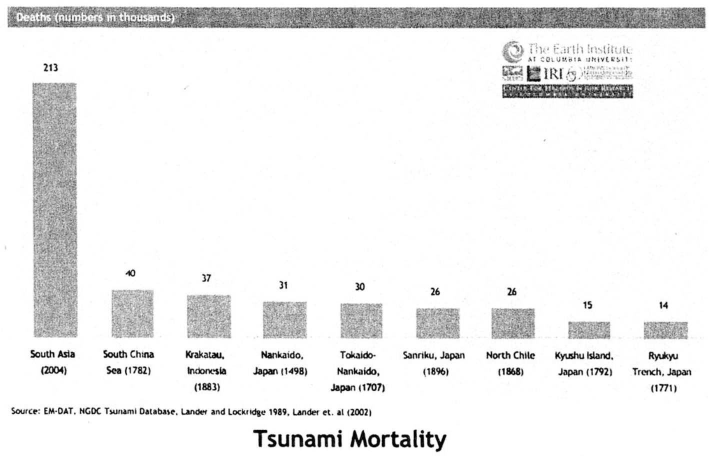


FIGURE 3

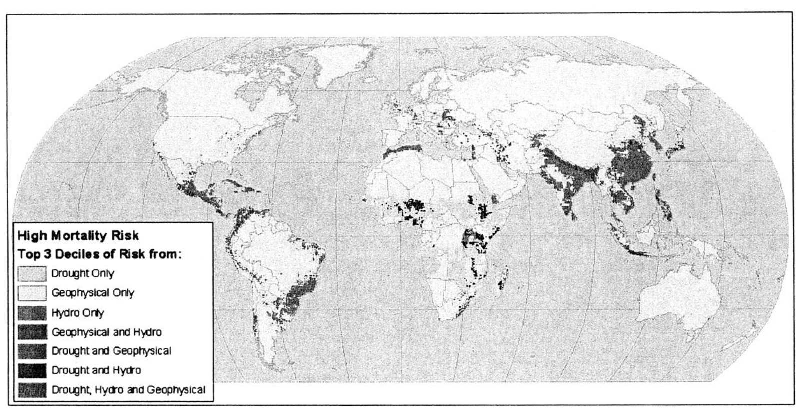


FIGURE 4

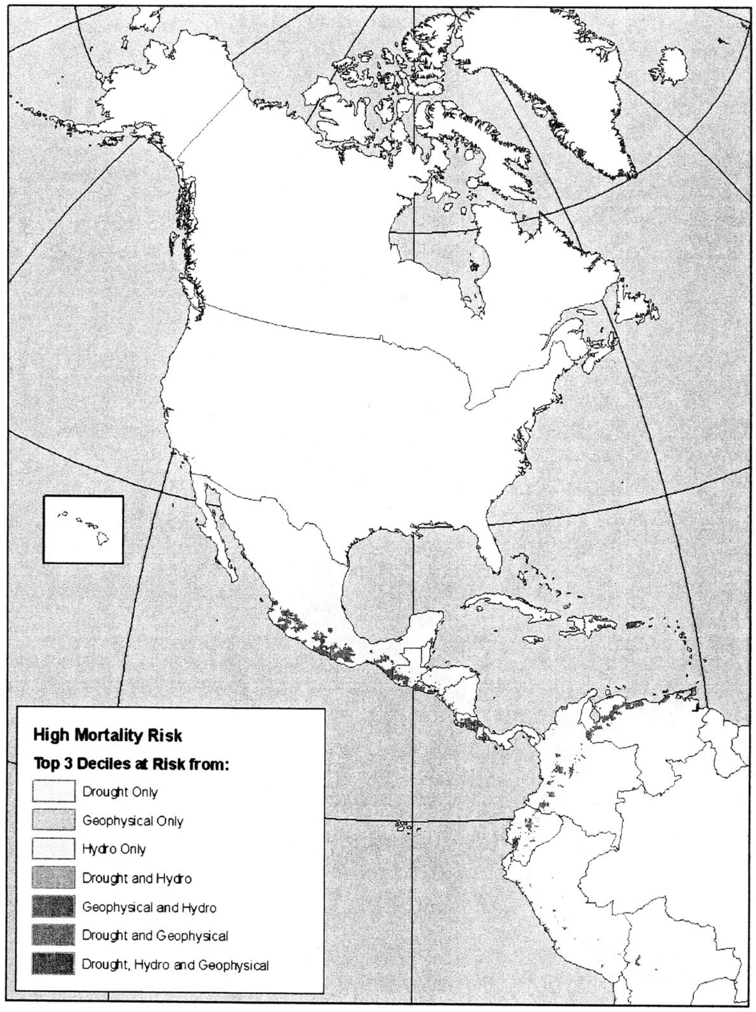

High Mortality Risk
Top 3 Deciles at Risk from:
Drought Only
Geophysical Only
Hydro Only
Drought and Hydro
Geophysical and Hydro
Drought and Geophysical
Drought, Hydro and Geophysical

FIGURE 5

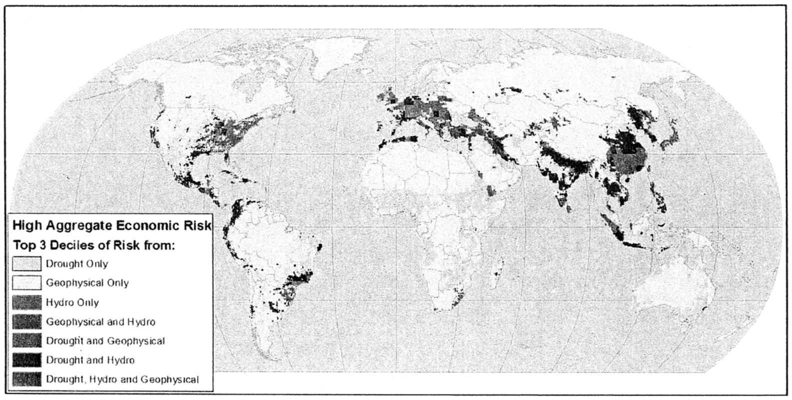

High Aggregate Economic Risk
Top 3 Deciles of Risk from:
Drought Only
Geophysical Only
Hydro Only
Geophysical and Hydro
Drought and Geophysical
Drought and Hydro
Drought, Hydro and Geophysical

FIGURE 6

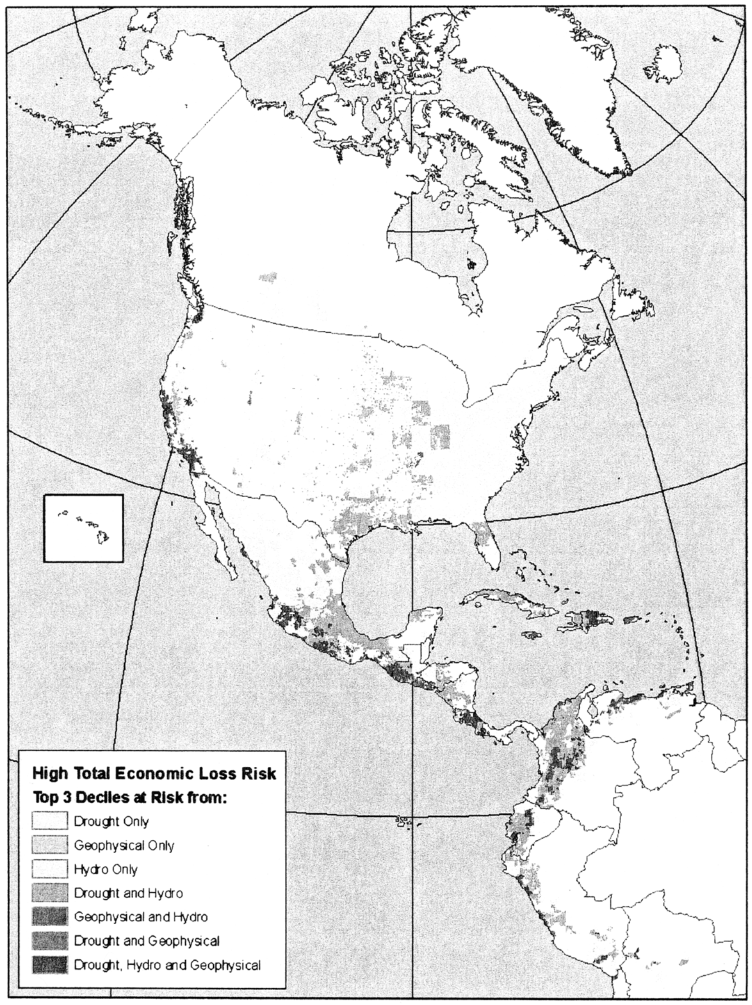

High Total Economic Loss Risk
Top 3 Deciles at Risk from:
Drought Only
Geophysical Only
Hydro Only
Drought and Hydro
Geophysical and Hydro
Drought and Geophysical
Drought, Hydro and Geophysical

FIGURE 7

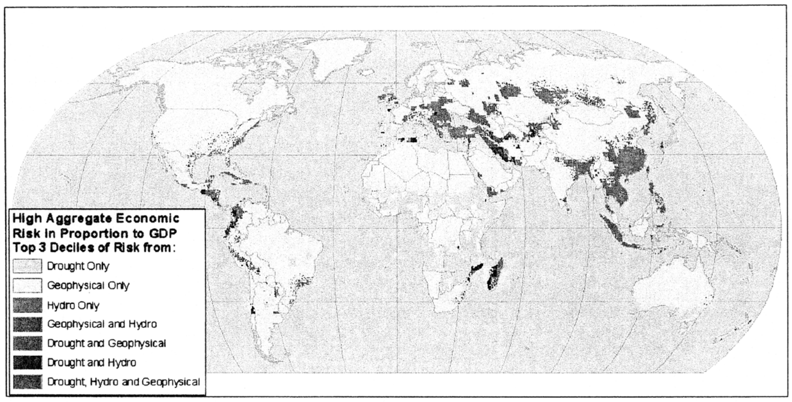

High Aggregate Economic
Risk in Proportion to GDP
Top 3 Deciles of Risk from:
Drought Only
Geophysical Only
Hydro Only
Geophysical and Hydro
Drought and Geophysical
Drought and Hydro
Drought, Hydro and Geophysical

FIGURE 8

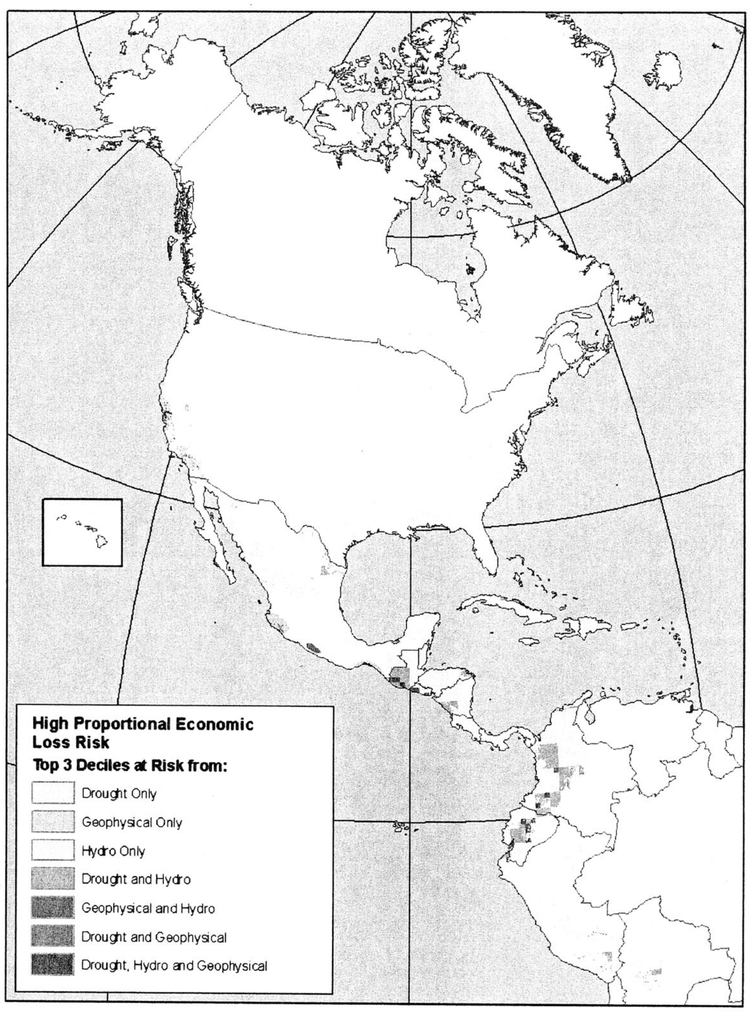
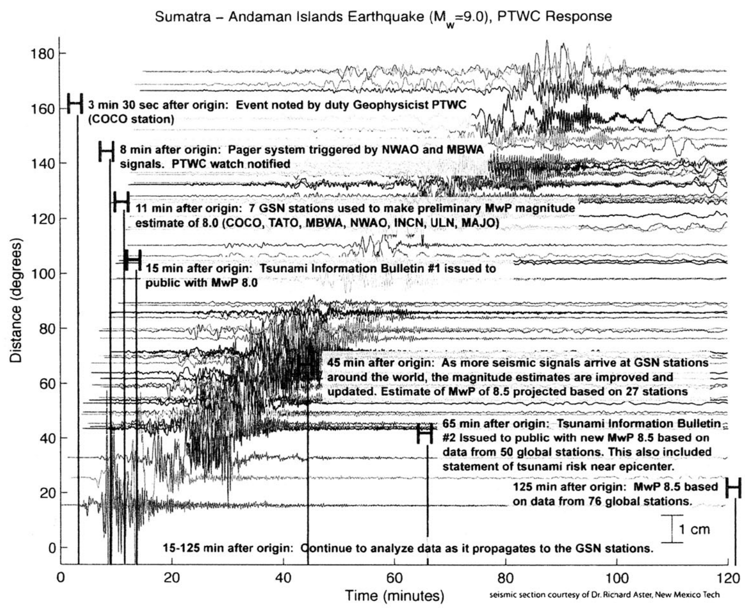

High Proportional Economic Loss Risk
Top 3 Deciles at Risk from:
Drought Only
Geophysical Only
Hydro Only
Drought and Hydro
Geophysical and Hydro
Drought and Geophysical
Drought, Hydro and Geophysical

FIGURE 9



Sumatra - Andaman Islands Earthquake (M_w=9.0), PTWC Response
3 min 30 sec after origin: Event noted by duty Geophysicist PTWC (COCO station)
8 min after origin: Pager system triggered by NWAO and MBWA signals. PTWC watch notified
11 min after origin: 7 GSN stations used to make preliminary MwP magnitude estimate of 8.0 (COCO, TATO, MBWA, NWAO, INCN, ULN, MAJO)
15 min after origin: Tsunami Information Bulletin #1 issued to public with MwP 8.0
45 min after origin: As more seismic signals arrive at GSN stations around the world, the magnitude estimates are improved and updated. Estimate of MwP of 8.5 projected based on 27 stations
65 min after origin: Tsunami Information Bulletin #2 Issued to public with new MwP 8.5 based on data from 50 global stations. This also included statement of tsunami risk near epicenter.
125 min after origin: MwP 8.5 based on data from 76 global stations.
1 cm
15-125 min after origin: Continue to analyze data as it propagates to the GSN stations.
Distance (degrees)
Time (minutes)
seismic section courtesy of Dr. Richard Aster, New Mexico Tech

FIGURE 10

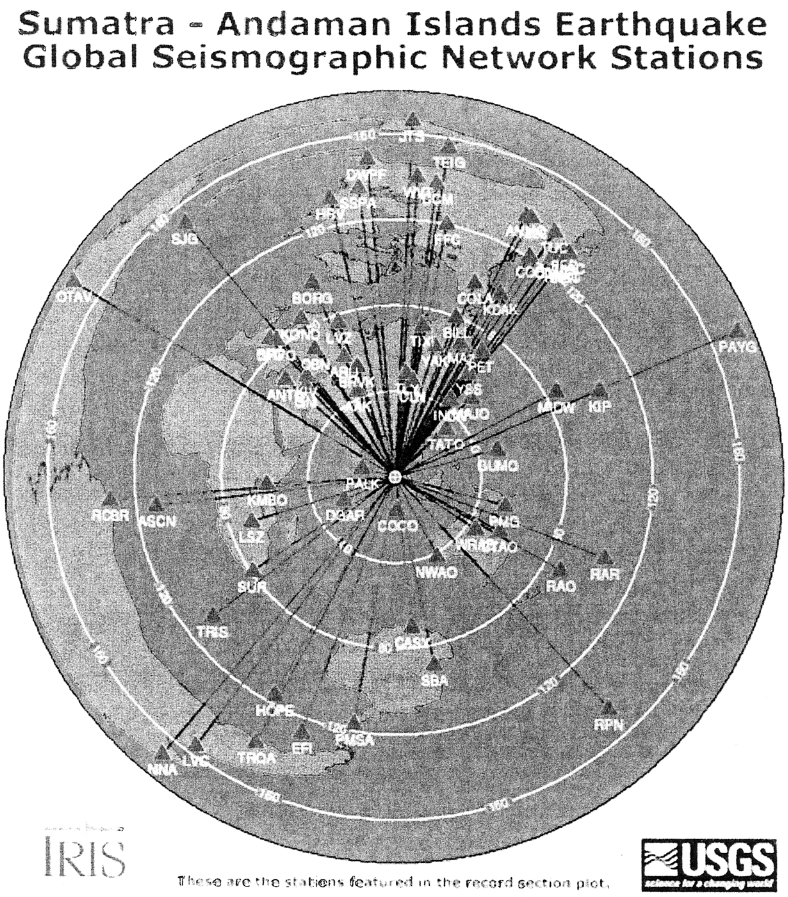


FIGURE 11

BIOGRAPHY FOR ARTHUR LERNER-LAM

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 Postdoctoral 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

Chairman BOEHLERT. Thank you very much.
And Dr.—Mr. Wilson.

STATEMENT OF MR. JAY WILSON, COORDINATOR, EARTHQUAKE AND TSUNAMI PROGRAMS, PLANS AND TRAINING SECTION, OREGON EMERGENCY MANAGEMENT

Mr. WILSON. Good morning, Mr. Chairman and Members of this committee. I am honored by the opportunity to represent the State of Oregon's tsunami programs. I would also like to acknowledge our State partners, Washington, Alaska, Hawaii, and California, which participate in the National Tsunami Hazard Mitigation Program.

[Slide.]

As the Earthquake and Tsunami Program Coordinator for Oregon Emergency Management—oh, I should say next slide.

[Slide.]

I represent this office and the State of Oregon on several statewide, regional, and national earthquake and tsunami councils and commissions. Much of my time is spent conducting education, technical assistance, and program support to local officials and collaborating with State and federal counterparts on related projects and policies.

One of the greatest challenges for the State of Oregon is creating and sustaining a culture of awareness in the populations of coastal residents and coastal visitors so they know instinctively that strong ground shaking at the coast is their signal to evacuate immediately to higher ground. In fact, the most lives saved in the Indian Ocean were due to the educated response of a few people who recognized the signs of an oncoming tsunami.

In the case of the U.S. coastlines, the most cost-effective means of solving this problem is for long-term support of the State tsunami hazard mapping and mitigation programs. We recommend that the National Tsunami Hazard Mitigation Program be permanently funded at the level of at least $7.8 million per year in NOAA's base budget and that $390,000 per year of this support be allocated permanently to each of the five participating member states, a total of about $2 million per year. This is to support long-term tsunami hazard mapping, intensive education programs, and the strengthening of local emergency notification infrastructure.

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[Slide.]

NOAA's National Tsunami Hazard Mitigation Program has been instrumental in increasing the capacity of the five member states to conduct tsunami run-up modeling and mapping and to tailor tsunami education and outreach to local communities. Without this federally-funded program and its portion for each state, there would be little, if any, tsunami programs in our states.

The National Weather Service's TsunamiReady program is an excellent incentive for communities to reach at least a minimum standard of readiness. Reasons for so few participating communities in TsunamiReady could be that this is a relatively new program, but more importantly, program certification requires a large investment of time and resources from the local communities. These investments include installing and maintaining emergency notification infrastructure, posting tsunami signs, evacuation planning, and conducting drills and educational activities. Many coastal communities have limited resources to carry out these program requirements.

Since meeting the program criteria is a local responsibility, TsunamiReady participation should be encouraged by the permanent, increased allocation for the annual tsunami budgets for the five states.

Next slide.

[Slide.]

In 1995, Oregon created legislation that calls for mapping tsunami inundation zones, and this includes limitations on new construction, and requires tsunami drills in K–12 schools within the inundation zones. Tsunami inundation maps are prepared in Oregon by the Oregon Department of Geology and Mineral Industries in collaboration with NOAA and with local partners in academia, principally the Oregon Graduate Institute of Science and Technology.

Based on numerical models of site-specific tsunami behavior, the inundation maps are indispensable. Without them, evacuation planning for complex areas, such as estuaries and bays, are mere guesswork. Inundation maps are supported mainly by NOAA funds through the National Tsunami Hazard Mitigation Program with support by the State, principally with labor-in-kind contributions. Without the federal funds, there is virtually no likelihood that these specialized mapping projects would have been realized.

Next slide.

[Slide.]

The National Tsunami Hazard Mitigation Program has also funded the creation and printing of local evacuation maps produced from the inundation maps. These maps are then distributed as free brochures by local government. Depending on the resources available to local communities, some jurisdictions continue printing the brochures while others, particularly rural, unincorporated communities, often need continual financial aide.

Last slide. No, sorry. Thank you.

[Slide.]

The Administration's proposed detection and warning system is essential for issuance of worldwide warnings about large distant transoceanic tsunami. It is important to note that the current buoy network and the Administration's ocean-wide buoy program would do little to limit loss of life in coastal areas that are right next to tsunami-generating earthquake faults. Travel time from the Cascadia earthquake source to the U.S. West Coast is too short for the proposed system to operate effectively. In fact, the existing buoys are designed and located to detect and measure outgoing tsunami.

Oregon's communities at the coastline have 10 to 30 minutes to react and evacuate following a probable magnitude 9 Cascadia subduction zone earthquake along our coastline. The most cost-effective means of limiting loss of life from locally-produced tsunami is mapping where the dangerous areas are and then implementing a long-term, relentless public education campaign aimed at developing the culture of awareness that will cause people to leave these dangerous areas when they feel a large earthquake at the coast.

Empowering local government and the coastal states to implement this work is the most effective means of solving this problem.

In conclusion, I have just returned from the first International Conference on Urban Disaster Reduction in Kobe, Japan and participated in two days of work sessions with my tsunami program counterparts from Japan. Our joint recommendations focused on the need to increase our level of confidence in the technology that we rely on, to translate more research into direct application, and increase our investment in the culture of awareness. Considering the history of Japan's tsunami countermeasures, it is validating to see that we have universal concerns about our respective societies' needed direction for higher safety.

The proposed increase in tsunami buoys, coupled with an expanded seismic monitoring network, will greatly enhance our nation's ability to detect and warn of potential distant tsunami strikes. But the NOAA DART buoy network does not provide adequate warning time for near-shore tsunami. In fact, it is critical not to rely on their warning in the event of a near-shore earthquake since so little time is available for evacuation.

Please understand that supporting each of the Pacific states' tsunami programs is the most effective way to build the culture of awareness necessary for prompt evacuation before local tsunami and for the notification infrastructure necessary to deliver warnings of approaching distant tsunami.

Thank you.

[The prepared statement of Mr. Wilson follows:]

PREPARED STATEMENT OF JAY WILSON

Introduction

Good morning members of the House Committee on Science. I am honored by the opportunity to represent the State of Oregon's tsunami programs and also acknowledge our State partners, Washington, Alaska, Hawaii, and California, which participate on the National Tsunami Hazard Mitigation Program Steering Group. Although their State tsunami programs have differences from Oregon's, I wish to represent their interests at this hearing as well. It should also be noted that today's date is significant, since the last great Cascadia Subduction Zone earthquake and tsunami occurred on the fault 305 years ago on January 26th in 1700.

1. Please explain your job as the Earthquake and Tsunami Program Coordinator in Oregon Emergency Management. What are the greatest challenges you face in helping the State and localities prepare for earthquakes and tsunamis?

As the Earthquake and Tsunami Program Coordinator for Oregon Emergency Management, I represent this office and the State of Oregon on several statewide, regional and national earthquake and tsunami councils, commissions and consortia, including the National Tsunami Hazard Mitigation Program Steering Group. Much of my time is spent conducting education, technical assistance and program support to local officials regarding earthquake, tsunami and volcano risks and collaborating with State and federal counter parts on related projects and policies.

One of the greatest challenges for the State of Oregon is creating and sustaining a "culture of awareness" in the populations of coastal residents and coastal visitors, so they know instinctively that strong ground shaking at the coast is their signal to evacuate immediately to higher ground. Changing public perception on the tsunami risk—low frequency but high impact makes public education a high priority in raising awareness level and changing people's perceptions of the tsunami risk and personal actions they need to take. This also includes the buy-in from businesses in tsunami hazard zones that have to find a balance between business opportunities and also buy-in to have signage in front of businesses, materials available for the public and the training of employees on actions to take for business survival and protection of customers.

Another part of this challenge is to continue to provide guidance through tsunami inundation mapping, evacuation maps, and signs as to where the dangerous areas are and how to escape to high ground. This culture of awareness is already present in much of the Japanese population, because they have a lot of local tsunamis and undersea earthquakes to reinforce this response. It is currently not the response on the U.S. coast and obviously not on the coast of the Indonesia where less frequent but much more devastating tsunamis can occur.

If an effective education program had been in place and if the local populace in Indonesia had accurate tsunami hazard maps, thousands of lives could have been saved, regardless of an international warning system. The same is true for the U.S. coasts. In fact the most lives saved in the Indian Ocean were due to the educated response of a few people who recognized the signs of an oncoming tsunami.

In the instance of the U.S. coastlines, the most cost-effective means of solving this problem is for long-term support of State tsunami hazard mapping and mitigation programs. We recommend that the National Tsunami Hazard Mitigation Program (NTHMP) be permanently funded at the level of at least $7.8 million per year in NOAA's base budget, and that $390,000 per year of this support be allocated permanently to each of the five Pacific states, Oregon, Washington, California, Alaska and Hawaii (a total of about $2 million per year) to support long-term tsunami hazard mapping, intensive education programs, and the strengthening of local emergency warning infrastructure.

Another challenge is building a strong infrastructure for warning the coastal population, local and visitor, about distant tsunami threats from places like the Aleutians and South America. Distant tsunamis will arrive four hours or more after a tsunami-generating earthquake, so the current international warning system will be effective in issuing warnings. Getting the warnings to everyone on every beach along the Oregon coast requires a comprehensive telecommunications system.

Administrative challenges include working with minimal funding and staffing to develop the tsunami education program—from product development to its delivery to the public/private sector and coastal citizens. Also local emergency managers are over loaded with DHS requirements making it sometimes impossible to support earthquake/tsunami programs—they must be given the funding to support resources needed in the community for the development of a tsunami ready community.

Securing coastal borders of the U.S. should also be made a top priority of the new Homeland Security Department. One of the most effective means of achieving higher security is stationing more police and fire responders along the U.S. coastline. These responders are our first line of defense for both natural and manmade disasters. The Oregon coast is mostly devoid of highway patrol officers, fire stations are sparsely manned (mostly by volunteers), and few National Guard are stationed at the coast; yet tens of thousands of visitors flock to the Oregon coastline from all over the U.S. It is appropriate that the Federal Government partner with the State of Oregon to secure this border and thereby facilitate meaningful emergency response to tsunamis from both distant and local sources. The State needs direct financial federal assistance to put more fire and police personnel on the coast, especially at coastal ports.

The other, almost overwhelming, challenge is making the coastal transportation system less vulnerable to catastrophic failure due to a local earthquake and tsunami. Federal Highway 101 was built in the 1930's and is now beyond its design life. Nearly all of the bridges and culverts on the coast highway are in greater or lesser stages of deterioration. Given a 10–20 percent chance that a magnitude 9 undersea earthquake and tsunami will strike the Oregon, Washington, and northern California coast in the next 50 years, the current highway will be severely damaged and many bridges destroyed, rendering emergency response nearly impossible. Federal leadership to replace key vulnerable bridges along the coast and those linking the coast to the rest of the state is a vital component in making the state more resistant to this inevitable natural disaster.

2. What is your opinion of NOAA's National Tsunami Hazard Mitigation Program (NTHMP) and of NOAA's Tsunami Ready program? Why are there so few communities that participate in the Tsunami Ready program and what can be done to increase participation?

NOAA's National Tsunami Hazard Mitigation Program has been instrumental in increasing the capacity of the five member states to conduct tsunami run up modeling and mapping and to tailor tsunami education and outreach to local communities. Without this federally funded program and the State allocations, there would be little, if any, tsunami programs in our states.

The National Weather Service's TsunamiReady program is an excellent incentive for communities to reach at least a minimum standard of readiness. Reasons for so few participating communities could be that this is a relatively new program, but more importantly, program certification requires a large investment of time and resources from the local communities. These investments include installing and maintaining emergency notification infrastructure, evacuation planning, and conducting drills and education activities. Many coastal communities have limited resources to carry out these program requirements.

Changing behavior and attitudes is not an overnight process and takes many years—therefore, TsunamiReady communities will come on line as products are developed and given to the communities and awareness and preparedness to the tsunami hazard increases—the bottom line, the communities must buy-in to protecting itself from this hazard, even at potential social and economic loss.

Since meeting the program criteria is a local responsibility, TsunamiReady participation could be encouraged by the permanent increased allocation for the annual tsunami budgets for the five states in the National Program as detailed earlier.

3. What roles do NOAA, USGS and FEMA play in your activities? How can these agencies be more useful in your efforts?

NOAA and USGS have been invaluable partners for the states in providing financial, technological, and nationwide networking resources that have resulted in faster and more accurate warning systems for distant tsunami events. NOAA has also been helpful in providing technical assistance for tsunami inundation mapping, as well as offering a centralized repository for computer data developed from mapping of potential tsunami inundation on U.S. coasts. The Advanced National Seismic System (ANSS) of the USGS provides near instant determination of earthquakes. FEMA has offered helpful advice and served in a key coordination role between the states and other federal partners in the National Tsunami Hazard Mitigation Program (NTHMP).

All of these federal agencies could be more helpful to the states by increasing financial and technological support to amplify what the states do best: natural hazards characterization, mapping tsunami evacuation zones in partnership with local cities and counties, emergency response guidance to local government, and earthquake and tsunami education to the local populace.

FEMA could be a more active partner to the states by directly funding State mitigation efforts, including preparedness and response infrastructure (telecommunications, emergency supply caches, State-federal coordination of military and Coast Guard assets, tsunami flood mapping and education). Since 9/11 and the establishment of DHS, FEMA's ability to support tsunami efforts in the states has been considerably reduced and until DHS can fully develop it's programs and funding streams, FEMA who has a very high stake in tsunami response and recovery, will lag behind in its responsibilities to support State efforts.

NOAA would be more effective, if the parts of NOAA that do bathymetric surveys would give the highest priority to surveys of those parts of the U.S. coast that (1) lack detailed bathymetric data, and (2) are most vulnerable to tsunami flooding. Detailed bathymetry, particularly in bays, estuaries, and shallow water at the coast, is one of the major data needs for the State tsunami hazard mapping programs.

USGS would greatly aid State efforts to map tsunami inundation, if they could regularly provide comprehensive digital terrain data through photogrammetry or airborne laser surveys (LIDAR) for the most vulnerable parts of the U.S. coastline lacking such data. This data, when combined with the bathymetry from NOAA, would empower the State tsunami mapping teams with accurate digital elevation data essential to accurate tsunami inundation mapping.

Additionally, there needs be better research on the nature seismic activity between the subduction zone plates. Because of insufficient instrumentation along the coast, the depth and characterization of earthquakes along the edge of the off shore plate boundaries are not well understood.

USGS and NOAA should combine their resources to provide 24-hr/7-day-a-week tsunami warnings from a single location that is relatively invulnerable to the large earthquakes and tsunamis. This location should have a critical mass of geologists, geophysicists, and tsunami experts available to make instant, collaborative decisions 24 hours a day. For example, a collaborative team that included a geologist would have known from the geology of the Indonesian coast that a magnitude 8.5 to 9.0 earthquake at that particular location was most likely a subduction zone event that would almost certainly generate a devastating tsunami. This knowledge base might well have spurred a more robust warning that may well have saved thousands of lives.

4. Please describe inundation maps. How important are they to your ability to plan? Who prepares these maps and who pays for them?

In 1995, Oregon created legislation that called for mapping tsunami inundation zones, that includes limitations on new construction and require tsunami drills in K–12 schools. Inundation maps are prepared in Oregon by the Oregon Department of Geology and Mineral Industries (DOGAMI) in collaboration with NOAA and with local partners in academia, principally the Oregon Graduate Institute of Science and Technology, Oregon Health Sciences University. DOGAMI publishes and widely distributes the maps after review by local government authorities, technical experts, and the publication staff. The inundation maps are indispensable. Without them, evacuation maps for complex areas such as estuaries and bays are mere guesswork.

The first three inundation maps done for Oregon were supported by a combination of USGS National Earthquake Hazard Reduction Program (NEHRP) funds, State funds, and NOAA funding. After about 1997, the inundation maps were supported mainly by NOAA funds through the NTHMP with some support by the State (principally labor in-kind contributions). With State budgets struggling to keep essential public services like the K–12 schools open, there is virtually no likelihood that these specialized mapping projects would have been supported through State or local funds.

NTHMP has also funded the creation and printing of local evacuation maps, produced from inundation maps. These maps are then distributed as free brochures by local government. Depending on the resources available to local communities, some jurisdictions continue printing the brochures, while others, particularly unincorporated rural communities, often need continuing financial aid in order to provide these valuable products to visitors and the local population. Federal funding from NTHMP to the State tsunami mitigation programs has empowered the states to standardize the evacuation map brochures and reprint brochures for these rural communities.

5. What is your opinion of the Administration's new proposal to improve the U.S.'s tsunami detection and warning programs? Are there ways it can be improved, and if so, what are they?

The Administration's proposed detection and warning system is essential for issuance of world wide warnings about large distant (trans-oceanic) tsunami. The Administration's proposal may be more technically robust, and perhaps more cost effective, if the probabilities of various tsunami sources were fully evaluated prior to final buoy siting. This inexpensive initial research would enable NOAA to place the buoy detectors in optimal locations to effectively minimize population exposure to potential tsunami threats. It may result that fewer buoys than are currently being proposed would be required. NOAA or the National Academy of Science could sponsor a panel of experts to review the final buoy site recommendations.

It is critical to note that the current buoy network and Administration's ocean-wide buoy program would do little to nothing to limit loss of life in coastal areas that are right next to tsunami-generating earthquakes faults. Travel time from the Cascadia earthquake source to the U.S. west coast is too short for the proposed system to operate effectively. In fact, the existing buoys are designed and located to only detect and measure outgoing tsunami.

Oregon communities at the coastline have 10 to 30 minutes to react and evacuate following a probable magnitude 9 Cascadia Subduction Zone earthquake. The most cost-effective means of limiting loss of life from locally produced tsunamis is mapping where the dangerous areas are and then implementing a long-term, relentless public education campaign aimed at developing the "culture of awareness" that will cause people to leave these dangerous areas when they feel a large earthquake at the coast. Empowering local government and the coastal states to implement this work is the most effective means of solving the problem.

Financial and scientific support should also be dedicated to develop innovative new warning technologies able to detect and warn of locally produced tsunamis from submarine landslides and from "silent" or "slow" earthquakes that result little or no shaking. Educating people to respond when the Earth shakes does not work for these events. Complementary to developing these new warning technologies is the requirement to conduct a geological assessment of the potential for these types of tsunami-generating sources on the U.S. coastline. These assessments could be completed via cooperative applied research projects performed by State geologic surveys and funded by the U.S. Geological Survey.

Conclusion

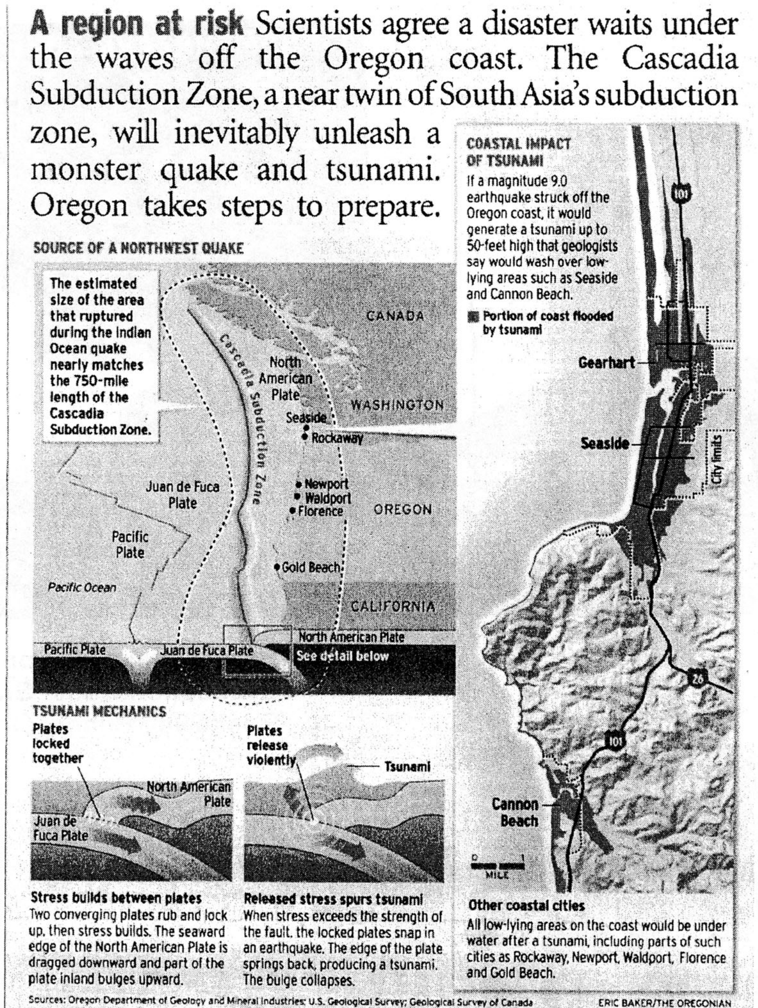
I have just returned from the 1st International Conference on Urban Disaster Reduction in Kobe, Japan and participated in two days of work sessions with my tsunami program counter parts from Japan. Our joint recommendations focused on the need to increase our level of confidence in the technology we rely on, translate more research into direct application, and increase our investment in the "culture of awareness." Considering the history of Japan's tsunami countermeasures, it is validating to see we have universal concerns about our respective societies' needed direction for higher safety.

The proposed increase in tsunami buoys, coupled with an expanded seismic monitoring network will greatly enhance our nations ability to detect and warn of potential distant tsunami strikes. But the NOAA DART buoy network does not provide adequate warning time for near shore tsunami. In fact, it is critical not to rely on their warning in the event of a near shore earthquake, since so little time is available for evacuation.

Please understand that supporting each of the Pacific state's tsunami programs is the most effective way to build the "culture of awareness" necessary for prompt evacuation before local tsunami and for the notification infrastructure necessary to deliver warnings of approaching distant tsunami.

Thank you.

Oregon Girds for Inevitable Disaster



A region at risk Scientists agree a disaster waits under the waves off the Oregon coast. The Cascadia Subduction Zone, a near twin of South Asia's subduction zone, will inevitably unleash a monster quake and tsunami. Oregon takes steps to prepare.

SOURCE OF A NORTHWEST QUAKE

TSUNAMI MECHANICS

Stress builds between plates
Two converging plates rub and lock up, then stress builds. The seaward edge of the North American Plate is dragged downward and part of the plate inland bulges upward.

Released stress spurs tsunami
When stress exceeds the strength of the fault, the locked plates snap in an earthquake. The edge of the plate springs back, producing a tsunami. The bulge collapses.

COASTAL IMPACT OF TSUNAMI
If a magnitude 9.0 earthquake struck off the Oregon coast, it would generate a tsunami up to 50-feet high that geologists say would wash over low-lying areas such as Seaside and Cannon Beach.

■ Portion of coast flooded by tsunami

Other coastal cities
All low-lying areas on the coast would be under water after a tsunami, including parts of such cities as Rockaway, Newport, Waldport, Florence and Gold Beach.

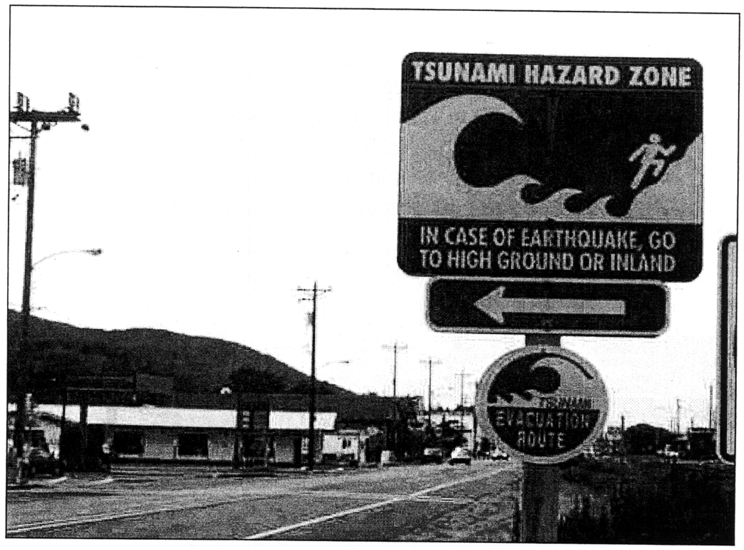
Sources: Oregon Department of Geology and Mineral Industries; U.S. Geological Survey; Geological Survey of Canada

ERIC BAKER/THE OREGONIAN

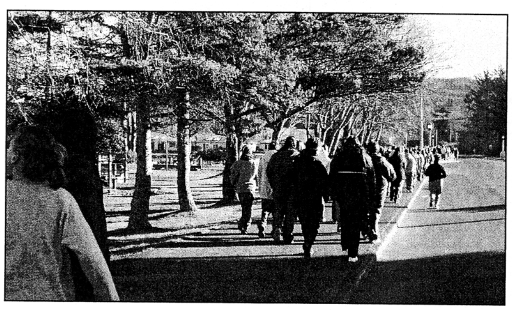
Source: Richard Hill, 1/17/2005
Oregonian, Portland, Oregon

Figure 1.

Tsunami Education Program



Hazard Identification and Evacuation Route Signs: Rockaway Beach, Oregon



Tsunami Evacuation Drill of High School: Seaside, Oregon

Figure 2

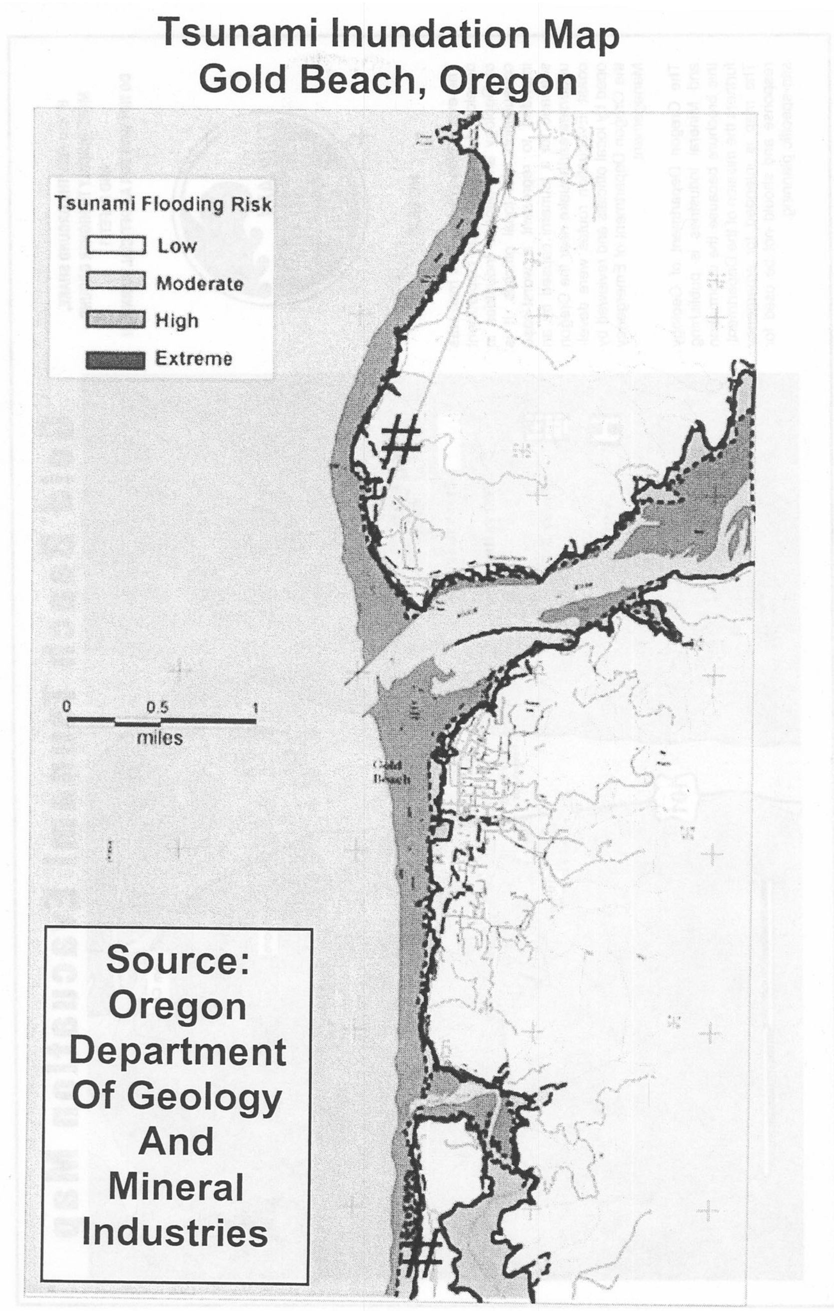

Tsunami Inundation Map
Gold Beach, Oregon
Tsunami Flooding Risk
Low
Moderate
High
Extreme
0
0.5
1
miles
Source:
Oregon
Department
Of Geology
And
Mineral
Industries

Figure 3

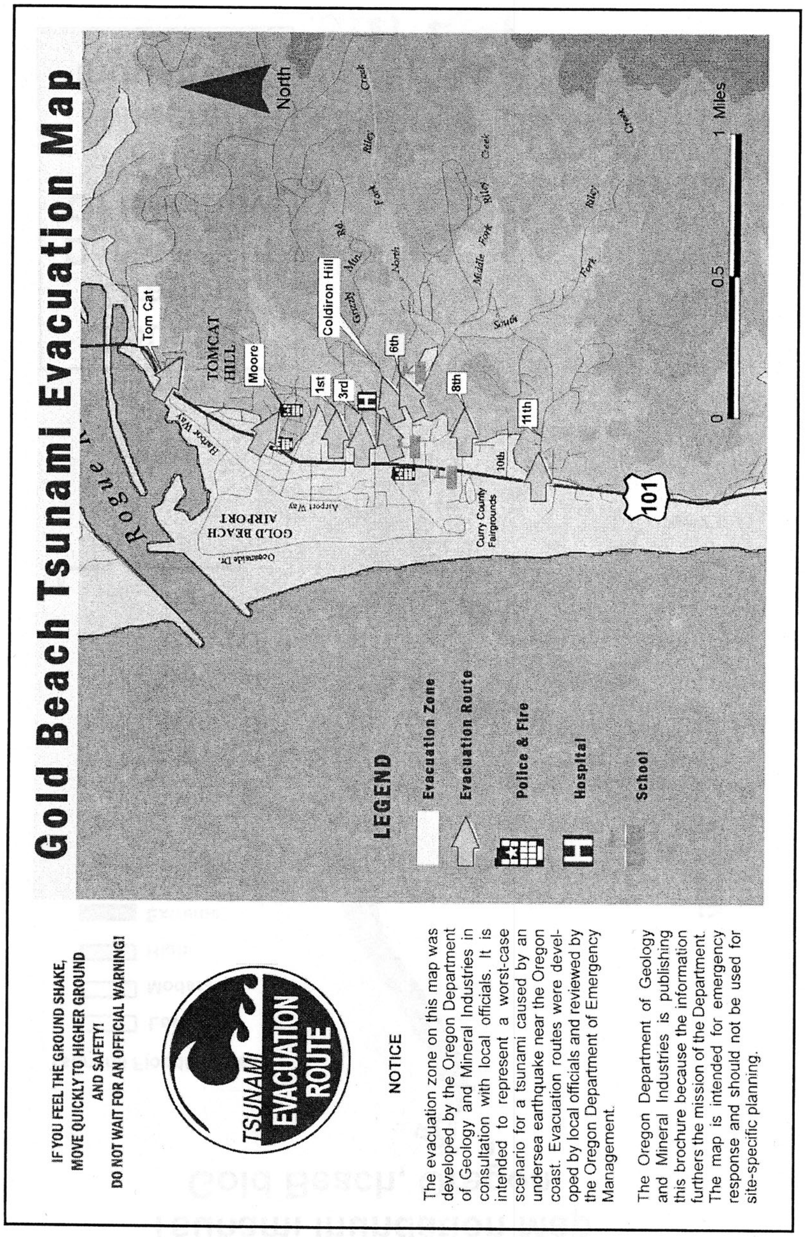

Gold Beach Tsunami Evacuation Map
North
0
0.5
1 Miles
Tom Cat
TOMCAT HILL
Moore
1st
3rd
6th
8th
11th
10th
Coldiron Hill
Rogue R
Harbor Way
GOLD BEACH AIRPORT
Airport Way
Oceanside Dr.
Curry County Fairgrounds
101
LEGEND
Evacuation Zone
Evacuation Route
Police & Fire
Hospital
School
IF YOU FEEL THE GROUND SHAKE, MOVE QUICKLY TO HIGHER GROUND AND SAFETY!
DO NOT WAIT FOR AN OFFICIAL WARNING!
TSUNAMI EVACUATION ROUTE
NOTICE
The evacuation zone on this map was developed by the Oregon Department of Geology and Mineral Industries in consultation with local officials. It is intended to represent a worst-case scenario for a tsunami caused by an undersea earthquake near the Oregon coast. Evacuation routes were developed by local officials and reviewed by the Oregon Department of Emergency Management.
The Oregon Department of Geology and Mineral Industries is publishing this brochure because the information furthers the mission of the Department. The map is intended for emergency response and should not be used for site-specific planning.

Figure 4

BIOGRAPHY FOR JAY WILSON

Work experience

- Earthquake and Tsunami Programs Coordinator with Oregon Emergency Management since July 2004;
- Employed as FEMA reservist for five years, conducting Community Education and Outreach support for Hazard Mitigation Programs;
  - Region X, Bothell, Washington—1.5 years
  - Region IX, San Francisco, California—3 years
- Worked as program coordinator and public affairs assistant for earthquake safety
  - City of Oakland, California—2 years
  - City of Berkeley, California—1 year

Education

M.A. in Geography, San Francisco State University

B.A. in Film, San Francisco State University

DISCUSSION

Chairman BOEHLERT. Thank you very much, Mr. Wilson.

For Dr. Groat and General Johnson, testimony indicated that there is as much as a 20 percent chance of an earthquake as large as last month's occurring on the Pacific Northwest coast of the U.S. within the next 50 years. Does the Pacific coast of the U.S. face a greater risk from tsunami generated right off shore, for example, the Cascadia subduction zone, or from those generated from farther away? If the greater danger is closer to shore, to what extent will the expanded detection system the Administration is proposing be of assistance?

Dr. Groat.

Dr. GROAT. Chairman, from a seismic hazard point of view, the threat of a very large earthquake of the kind that you described close to shore and that Mr. Wilson was concerned about how we deal with the impacts of that is probably at least as likely as something generated further away that would come in at great distances. That is a very tectonically active part of the plate system. And as far as the U.S. is concerned, with the exception of a smaller area in the Caribbean, is the area we need to be the most concerned about, so I don't think we can afford to put all our eggs in any one basket. We have to be worried about the long-term—long-distance tsunamis that the NOAA system is intended to provide warnings about and find measures, as Mr. Wilson described, to deal with the very real likelihood that a large earthquake on the plate boundary will happen within a foreseeable time and to provide the adequate measures to respond to that.

Chairman BOEHLERT. So the sophisticated technology that we have all be talking about wouldn't have time to be operative there. You have got to have a good education system, which speaks to the nature for a comprehensive system, not just buoys some place out there in the Pacific or down in the Caribbean, but we have got to have a good education system so that the Tilly's of the world can see something and understand what is happening.

General Johnson, do you want to address that?

Brigadier General JOHNSON. Yes, sir. I agree 100 percent. When you have the earthquake trigger, the tsunami wave is generated and goes both ways. And if it is right off your coast, it comes towards your coast, and you have those precious minutes with which to react. That is why I agree that an education program has to be part of a comprehensive, end-to-end system. If you buy a buoy, you have got a buoy. If you buy a system, an end-to-end system, you have education that will enable people to react in those precious early minutes.

Chairman BOEHLERT. And why does just about all of the resources go to buoys? I mean, if I see one deficiency, and I don't want to say a deficiency, but I think there should be some more emphasis in a comprehensive plan on education than there is. We applaud the emphasis on technology. You might expect that from this Science Committee, and that is critically important. But there has to be something more in the area of education, as Mr. Wilson points out.

Brigadier General JOHNSON. Sir, I agree that education is a very important part, but you will note that water is a very efficient transmitter of energy. And the tsunami-generation zones are the Pacific Rim in its entirety. And we are, in fact, part of the entire planet, and the things that happen over there can affect us here. So having sensor systems over there as well as here make us part of a comprehensive, worldwide program. We also need to pay attention to the Atlantic and the Caribbean as well.

Chairman BOEHLERT. So———

Brigadier General JOHNSON. It is a smaller probability of occurrence, but with potentially devastating consequences.

Chairman BOEHLERT. Well, could either of you, then, shed some light on what the plan is in education? Is there sufficient evidence to indicate that we are giving it the proper attention?

Brigadier General JOHNSON. I think that a lot of people—sir, I will take it first, if that is okay. I think a lot of people have tsunamis in the middle of their cross-check right now. My concern is, as time goes on, people will lose that awareness. I think we need to codify the National Tsunami Hazard Mitigation Program, get the hazard inundation mapping accomplished so we know where we can go when we decide to evacuate. We need to build the systems now to enable us to detect those trigger events and tell people that they do need to evacuate. We need to be able to communicate that to people. And if it happens on the Cascadia fault zone, it is very probable, Mr. Chairman, that a lot of the infrastructure that we are depending on could be adversely impacted by the earthquake itself. I mean, the radio towers and those kinds of things that would help us disseminate those words may or may not be operational at that point. But I think a comprehensive system that includes the readiness program is certainly part of a prudent system that this nation ought to adopt.

Chairman BOEHLERT. The plan advanced thus far, and I—once again, let me say I applaud the Administration for its initiative. And we are going to be fully supportive and then some.

Brigadier General JOHNSON. Yes, sir.

Chairman BOEHLERT. But how about education? In general, what amount of those resources———

Brigadier General JOHNSON. I have got $1.5 million in the proposal to cover inundation mapping, the TsunamiReady Program and outreach. Sir, this is a level of effort thing. If additional dollars are available, we could do additional mapping and have a greater level———

Chairman BOEHLERT. Does that pass the test of adequacy? $1.5 million in this town is tip money. I mean, I don't mean to pose as a big spender, and you know, the heck with what anybody else says, you are going to deal with this program, because it is in my zone of interest and you are going to provide some adequacy in funding, but $1.5 million?

Brigadier General JOHNSON. $1.5 million in 2007 and then $1 million sustained through the outyears, sir. That is the current proposal.

Chairman BOEHLERT. Okay. Well, maybe we can take the current proposal———

Brigadier General JOHNSON. I am sorry. I misstated. That is 2005 and 2006 and then 2007 and beyond would be the $1 million sustained.

Chairman BOEHLERT. Dr. Groat, do you want to add something?

Dr. GROAT. Yeah. I think Mr. Wilson made an eloquent case for the most effective way to educate people in areas at risk, and that is by providing State and local governments with the resources necessary to do exactly the kind of work that he outlined. The Federal Government can play a role in getting those funds to the right people. The actual education effort comes best from those who are in the affected areas, and it is our responsibility, I think, to make sure that the resources and the technical information that they need to make those plans is available, because they are the continuity. They are the ones who keep things moving. The difficulty with natural hazards is we forget between events. And the———

Chairman BOEHLERT. We really have 15 communities that are TsunamiReady———

Dr. GROAT. Exactly.

Chairman BOEHLERT.—and that are certified, and in all fairness to people at State and local government, they say we keep getting these instructions, mandates, if you will, from Washington, and they are—in our light and self-interest to address them, but where are we going to get the resources?

Dr. GROAT. The resources are critical, Mr. Chairman. There is no question. And unless the emphasis is put on those resources that go for that purpose, it is going to be difficult to do, because they are as resource-dependent as the rest of us are, and Mr. Wilson may have some thoughts about the best way to make that happen.

Mr. WILSON. Thank you, Dr. Groat.

Mr. Chairman, we are currently embarking on a pilot program in the city of Seaside, Oregon, and it is a new approach that we are trying to do, public—community outreach at a very grass roots level. We have gotten funding through the National Tsunami Hazard Mitigation Program and FEMA to hire a person who is working a little over half-time as an on-the-ground coordinator. We are doing surveys before and after an outreach program that we are conducting to try and assess just how effective our messaging and outreach capacity is to try and develop a more model approach for other communities on the coast. But I think what we are finding in this particular program, this pilot program, is the outreach tools that we have in place are effective, but what we don't have is the person on the ground to do the face time with the local community, someone who is there, someone who can basically do a block-by-block type awareness campaign. I think, you know, there is a lot that comes out of the national funding that promotes the warning system and even the infrastructure for disseminating an alert, but it is really on the ground that people have to know what to do. They have to rehearse these drills during the daytime so at 2:00 in the morning, at night, they know where they need to go. There is so much that we try to help our locals with on the ground and they all have limited resources.

Chairman BOEHLERT. My time is expired, and I want to try to stick to the time limits so we give everyone an opportunity to ask questions.

We will go to Mr. Gordon.

Mr. GORDON. Thank you, Mr. Chairman.

As usual, I think you and I are headed pretty much in the same direction. As I said earlier in my statement, I support the goal of this program, and I also want to applaud the swiftness with which the Administration has brought this to us. But I have got two concerns about the proposed budget. First, we have had—little information has been provided about the funds needed to sustain a functional, end-to-end Tsunami Warning System once it is built. And second, what are the offsets for the additional spending in the President's proposal? Dr. Orcutt and Dr. Lerner-Lam both expressed a concern about sustainability of funds for annual operation and maintenance costs of the system. And additionally, Dr. Orcutt indicated a current operation and maintenance shortfall of the GS network of about $5 million. So Dr. Groat and General Johnson, what are your estimates of the annual operation and maintenance of the system? And when I say that, I don't—I am not trying to get you in trouble, but what I would like to do is ask you, you know, what is a realistic budget, not what it has been budgeted? And I say that because if we are to seek additional funds, we would like to do this in an informed way.

Dr. GROAT. Speaking on behalf of the seismic network, as Dr. Orcutt mentioned, there is a need for investment in additional instrumentation. But as you have pointed out, the need to maintain that instrumentation and keep it current is extremely high to keep it up and keep it operating.

Mr. GORDON. Yeah, we have got three that aren't working right now in the—you know, so———

Dr. GROAT. In the buoy system, but———

Mr. GORDON. So correct———

Dr. GROAT.—we have similar problems with our seismometers.

Mr. GORDON. Yeah.

Dr. GROAT. They do go down, and we have to maintain those, and those of us that operate those systems, both the University of California, San Diego, and USGS have difficulty in lean budget years keeping the funds to maintain the systems adequate. I am encouraged, though, Mr. Gordon, in what we know up to this point about the President's proposal for keeping the system fed with funds to maintain the system we have designed in the outyears, 2006 and beyond. Unless we are surprised, I think there will be a recognition that that kind of funding is needed and that we will receive the money necessary to maintain the system that we have implemented. And you asked———

Mr. GORDON. I am sorry. I mean, are you—did you say that you think that there is an adequate amount being budgeted now or that you think it will be recognized later and more will be added? I didn't———

Dr. GROAT. No, I think that there is an adequate amount being budgeted now for 2006, 2007, and beyond to maintain the kind of system that we have described, the incremental addition to it and then the maintenance necessary to make sure that system is functioning in the future. Now does it solve all of our delayed maintenance kinds of problems and so forth? Not necessarily. But unlike some immediate responses to significant events like this where there is a big spike in funding and then nothing in the future, and then we do have the very problems you described, there is the recognition that those funds to maintain the system are necessary. There is the budgeting of those funds, and we are comfortable that we have taken a major step in making sure that happens.

Mr. GORDON. And is that both from mapping and public education rather than just for maintenance of the network?

Dr. GROAT. In our case, it is principally for maintaining the upgraded system at the National Earthquake Information Center. It provides some funds to continue the mapping efforts. It provides some funds to maintain the system that we have now in place.

Mr. GORDON. Some funds or adequate funds?

Dr. GROAT. I think, Mr. Gordon, that they are adequate funds at the level that the system is being deployed. Now I could make some arguments that we need a broader system and a more dense system, particularly in the case of something like the Advanced National Seismic System, and in that case, any surge of funds to build the instruments, put the instruments in place, would need to be matched with additional funds for maintenance. We have not requested, nor are we anticipating receiving, that level of funding at this time.

Mr. GORDON. Okay. And I am concerned that—on a couple things. One, that you apparently don't have adequate funds now for maintenance or you would be—when I say doing a better job, I mean, I don't—I am not trying to—you can only do what you have funds for. But it apparently is not being adequately performed now. And I am concerned about that. I am also concerned about is this going to result in additional offsets? You know, for example, with the tornado warning system now, I mean, I think there are some technologies out there that you know about that if it was brought on board, it would give us a better system for technology. But you can't afford to do that. So you know, are we just making a difficult and inadequate budget worse with this?

Dr. GROAT. Well, let me—I will turn it over to General Johnson in just a second for the NOAA's point of view. From our point of view, with the seismic system, the interpretation of data, the dissemination of data, the increased funds to do that more adequately and to maintain that, we don't anticipate at this time that we will have to offset other programs to make that happen.

Mr. GORDON. Good.

Brigadier General JOHNSON. With regard to NOAA and the sustaining of the buoy and tide gauge network as well as the inundation mapping, we have programmed money to acquire them using the 2005 supplemental and the 2006 President's budget top-line increase. For the 2007 to 2011 time frame, NOAA is going through that budget process right now. I have got commitments from Admiral Lautenbacher to address the tsunami tail to sustain that. I have already highlighted to him that it is $3.75 million for the buoys, a quarter of a million dollars for the tide gauges and ongoing———

Chairman BOEHLERT. $3.75 million for the buoys?

Brigadier General JOHNSON. Yes, sir.

Chairman BOEHLERT. For acquiring new ones?

Brigadier General JOHNSON. No, sir; to maintain the—a 25 array—25 buoy array in the Pacific, which will be installed in the beginning of 2007.

Chairman BOEHLERT. What we have right now, if I may———

Brigadier General JOHNSON. We have six right now.

Chairman BOEHLERT. We have six buoys———

Brigadier General JOHNSON. Yes, sir.

Chairman BOEHLERT.—in the Pacific. Now three of them are not operative.

Brigadier General JOHNSON. Right.

Chairman BOEHLERT. Now I am a baseball fan. If you bat 0.500 in baseball, you are doing pretty good. There is a little place in my District called Cooperstown where I can get you admission if you bat 0.500. But when only three of six are working—functioning properly right now in a warning detection system, that doesn't get you in anybody's hall of fame.

Brigadier General JOHNSON. Yes, sir. They are the first six going to an eventual 29-buoy array. They are transitioning from the research and development phase into operations. And you are right; we have three of them that are down right now. Can I have backup slide 11?

Mr. GORDON. And I assume they are down because the money to have the ship time to go out and take care of them?

Brigadier General JOHNSON. No, sir.

Mr. GORDON. Okay.

Brigadier General JOHNSON. Some of the problem revolves around having a—we had one buoy that had a battery problem out here, and when we went out to service it and pick it up, the cavity in the buoy had an over-pressure indication and we had a little explosion on the buoy. We are in the process—we had a safety standdown. We modified the six other buoys to have a pressure-relief valve in. We also came across some water intrusion into cabling on the new buoys and are in the process of upgrading cables. That is this damage right here. And then people from that part of the Pacific will tell you that from about November to about March, weather is definitely a hazard. And to bear that out, in December, we went out to service a buoy in conditions that were marginal. We were—we felt the need to pursue that before this event happened.

We were out there to service it and actually dinged one of the buoys because of the condition of the seas. So NOAA is not sitting back. You know, we are actively trying to transition these into operations and build the redundancy that was brought up earlier in those areas where weather is going to be a consistent factor.

Mr. GORDON. Thank you. I guess—do any other witnesses want to make a quick, very quick comment on any concerns about any cannibalizing of other programs in terms of being adequately able to do the operation and maintenance with the funds proposed?

Dr. ORCUTT. I might just comment briefly. The part of the world that Eddie Bernard here is working in at the moment is one of the worst possible places to try to do this job. The weather is terrible there almost all of the time, and to ask these—it is asking a great deal of these small buoys to perform at 100 percent of the time, so the weather is certainly something that has a great deal going against you in that environment. But the issue is whether there are sufficient funds in the long-term. And in a way, we can't answer that after fiscal year 2007, but the costs are significant. You can replace the capitol investment in a matter of a few years, because of the maintenance required.

Brigadier General JOHNSON. May I make one additional point, Mr. Chairman?

Chairman BOEHLERT. Sure, General.

Brigadier General JOHNSON. The current buoys are kind of the first generation, and we envision deploying a second generation that will enable two-way communication, include some of these reliability and maintaining improvements that Dr. Bernard's great design, that has already proven its worth. So when we build the new system, it should be a much better system that has the built-in redundancy. Thank you.

Chairman BOEHLERT. Thank you.

Ms. Biggert.

Ms. BIGGERT. Thank you, Mr. Chairman.

General Johnson, and you would probably say that the problem with the buoys could be with the contractor, with the technology, and with funding? All three of those together?

Brigadier General JOHNSON. I think that NOAA experiences challenges when we transition good ideas from research and development into things that are going to be operationalized and, you know, routinely counted on for long periods of time. You know, in a perfect world, we would be able to service the buoys once a year and be done with it and have nothing go wrong. And with the next generation buoy, we are looking at having some built-in test indicators into it, some additional redundancies, and those kinds of things.

Ms. BIGGERT. Thank you.

Let me then just move to another question. On December 26, I think it was reported that two U.S. Tsunami Warning Centers knew of the high likelihood that a tsunami had been generated, given the magnitude of the earthquake. Why wasn't that reported immediately to the State Department or someone that could do something to inform them so that other nations would know that they were in danger?

Brigadier General JOHNSON. The Pacific Tsunami Warning System worked as it was designed, which was to alert the 26 member nations of that consortium of the possible impact. Now the Pacific Tsunami Warning Center is right there in Hawaii, and they also—when they became aware that there was a tsunami wave associated with the earthquake, did take steps to do additional notification. I would hasten to point out that many times significant earthquakes do not generate tsunamis. That is one of the reasons we need to do some more modeling effort and work with our colleagues over at USGS the why-fors and the how-comes there. But at the time, ma'am, when we figured out, through press reports, because we were blind, because we had no sensors in the Indian Ocean, there is no possibility of knowing at that point whether the wave was associated with a big earthquake or not, it was already past Indonesia and Thailand and Sri Lanka and was affecting the east coast of India. And the next big landfall was Diego Garcia, and the Center did, in fact, call Diego Garcia. The Pacific fleet has significant presence in and around Diego Garcia, and we did have consultations with the State Department Operations Center for Madagascar, and we have instituted and codified that procedure so that now, whenever that happens, we are notifying the State Department, and we are also putting out notification through the standard World Meteorological Organization weather channels that are well established to the countries.

Ms. BIGGERT. Let me, maybe, ask the panel what are greatest challenges to establishing a global Tsunami Warning System. And what role should the U.S. play? And does the Administration's plan accomplish that role?

Dr. GROAT. Let me just take a quick shot. And I think the GEOSS process was mentioned, the Global Earth Observing System of Systems in which the U.S. and 55—54 other nations play a significant role. I think the Administration sees that organization, which, as was pointed out, meets in Brussels on the 16th of February, as the place to bring the international community together to design, perhaps, its first truly global system that meets societal needs, which is what the intent of that whole program is. And the U.S. role in that, Admiral Lautenbacher is one of the four co-chairs, would be to provide some of the leadership in the technology and in the application of that technology. But as you might expect, as a result of the event on December 26, international groups all over the world are coming together. There was a meeting in Beijing just recently, and there is another one in Thailand in a week or so, to talk about how they, in their regions, can do this. The real challenge is going to be to turn this into a true system of systems so that warnings are spread around to the people that need them in an effective way, rather than in a fragmented sort of way. So I think the GEOSS approach, which brings the whole community together, is the real opportunity to bind these systems in truly a system that works for everybody.

Ms. BIGGERT. Thank you.

Would anybody else like to comment?

Dr. LERNER-LAM. I will simply add that I agree with those comments, but in my mind, in terms of a global warning system, local engagement is, perhaps, the least understood component of this.

What do we do with the warning once it is issued? I think some of the technical and research problems are well on their way to solution. I would merely add that end-to-end, however, includes everything from the basic research of these great, giant events through the operational component, all of the way to the local engagement. We have seen some testimony about how that might occur in the United States. A coordinated international plan, however, is lacking.

Ms. BIGGERT. Mr. Wilson.

Mr. WILSON. I just have a quick addition to that. One of the things that we are really working on in the—on the Oregon coast is notification to visitors, to tourists. The vulnerability of the tourists in Thailand was a good example of how people who were on vacation who are not a part of the local culture are not thinking about their surroundings. In terms of evacuation in areas that are tourist areas, vertical evacuation versus inland evacuation is something that is being researched and considered. The types of structures that could survive a local magnitude 9 earthquake and then still be able to provide vertical evacuation for seniors, for the disabled, the people who can not get out of harms way with a limited evacuation time. I would just say that for a larger, more comprehensive tsunami system, this is also something that needs to be considered.

Chairman BOEHLERT. General Johnson.

Ms. BIGGERT. Yes, General?

Brigadier General JOHNSON. Dr. Lerner-Lam's chart of mortality due to severe environmental effects was telling. The United States was a conspicuously non-shaded area. We, on average, experience 10,000 severe thunderstorms a year, over 1,000 tornadoes. We set a new record this year for 1,700 tornadoes, and we usually experience about six hurricanes a year.

Ms. BIGGERT. It made flying to Washington very difficult sometimes. Yes.

Brigadier General JOHNSON. Yes, ma'am. And for that, I apologize, on behalf of the Lord.

However, the reason that is an unshaded area is because we have an integrated data-sharing system between all of the different sensor networks, not only for tsunamis, but for weather events, and this is the kind of benefit that our planet needs. The GEOSS is the tool to address not only tsunamis, but severe weather and environmental effects worldwide and we have got a wonderful opportunity with the attention of the world focused right now to capitalize on this opportunity. Thanks.

Ms. BIGGERT. Thank you. Thank you, Mr. Chairman.

Chairman BOEHLERT. Thank you.

General Johnson, just out of curiosity, going back through recorded history, is there any time when an earthquake of the magnitude of this one, 9.0 on the Richter scale, did not cause a tsunami? Not all earthquakes cause tsunami. You know, it depends on the magnitude. But has there ever been any point in history when something of this magnitude failed to result in———

Brigadier General JOHNSON. Yeah. I think USGS has some examples of things that happened just weeks before the tsunami event. But it is very complicated. You know, you have to be off the coast. It needs to be in the water. Usually, it is created because of that up-thrust in the subduction zone or maybe a meteorite or maybe a landslide, that kind of a thing.

Chairman BOEHLERT. But a 9.0—I mean, the simple answer to my question is yes, depending on the circumstances, or———

Dr. GROAT. I think if there were a 9 earthquake of the mechanical type that General Johnson mentioned with the thrusting in an ocean basin margin, the likelihood is almost 1:1 that it would generate a tsunami. Part of our record in the past, while through mapping of deposits on coasts that—where tsunamis have brought those deposits on the shoreline, is that we don't have the comparable record of the exact earthquake event that caused it and therefore don't know the magnitude. So there is not necessarily something magic about 9. It could be a smaller earthquake. I mean, 8s or 7.5s could possibly generate tsunamis of significance.

Chairman BOEHLERT. When did we know it was 9?

Dr. GROAT. When?

Chairman BOEHLERT. Yeah.

Dr. GROAT. It took a while, because, again, back to our seismic station density, it—certain waves—the surface waves have to get to you to do the kind of analysis that is needed to make the intensity.

Chairman BOEHLERT. Minutes? Hours?

Dr. GROAT. Hours, in some cases. We get the early waves, and we get a preliminary analysis, and we generate it in an assumption that it was in the neighborhood of an 8. It wasn't until the surface waves arrived at enough stations that we could interpret data, which was a matter of at least an hour, wasn't it Dave?

Brigadier General JOHNSON. It was an hour and five minutes———

Dr. GROAT. An hour and five minutes.

Brigadier General JOHNSON.—later, Mr. Chairman.

Dr. GROAT. That we knew that it was a 9.

Chairman BOEHLERT. And when—I don't———

Brigadier General JOHNSON. 8.5, yeah. We updated it, and it was actually academic institutions and much later that it turned out to be 9.

Chairman BOEHLERT. I can understand what was happening and maybe a lot of people doing a lot of things, but why seven hours to notification of the State Department?

Brigadier General JOHNSON. Sir, it was a long time before we had high confidence that there was a wave associated with it.

Chairman BOEHLERT. So you didn't want to give a false alarm, because you don't———

Brigadier General JOHNSON. We experienced—from the formation of the Pacific Tsunami Warning Center in 1949, we had a 75 percent false alarm rate. After the inception of the buoy system, we have a very small sample size, but we don't have a false alarm rate to date. Yes, sir, there is a high probability that there is a tsunami wave associated with an earthquake of that magnitude, but it isn't a complete certainty. I think my guys were waiting to get some indications of that fact.

Dr. GROAT. Just to point out, Mr. Chairman, that certain types of earthquakes that are generated by slippage this way can be very large, can be 8s or so, in coastal areas and don't generate tsunamis. So we really do have to have that complete analysis of data that is enhanced by a more dense system, more real-time data, to provide that kind of information that it is or isn't tsunamigenic as quickly as possible.

Chairman BOEHLERT. Which argues for more investment in technology?

Dr. GROAT. It does in that case, yes, sir.

Chairman BOEHLERT. Mr. Wu.

Mr. WU. Thank you, Mr. Chairman.

I would like to follow up on some of your questions and the Ranking Member's questions.

I have great respect for the professionalism of all of your people, but I have to ask the obvious question that—the fact that this earthquake occurred at roughly 8:00 p.m. Eastern Standard Time on Christmas Day, did that have anything to do with slowing down the notification process?

Brigadier General JOHNSON. Sir, I was very lucky. I had a very dedicated guy who was in the office at 3:00 p.m. Honolulu time, or 2:59, and that is why we were able to get the message out to the member countries as quickly as we did. It was 3 minutes before he got the initial message out after his notification. So it was very, very timely. Now with the proposal that the Administration has made, we increased to 24/7. We are not 24/7 right now. We are one shift during the day, and then we have got beepers on people, and I have kind of set up a 5-minute response time to get in the office and be able to send the pre-loaded messages, if an event happens. But we are taking this opportunity in funding to remedy that situation, sir.

Mr. WU. Does anyone else have anything to add to that?

Dr. ORCUTT. I would just like to comment. It has been mentioned a bit before, but I think today it is possible to bring an awful lot of this together more closely using modern information technology to do these things. One of the reasons for recommending satellite telemetry is so that the latency in the delivery of data to the NEIC, for example, is in the order of a few seconds. That kind of latency ought to also characterize communications with the Center and NOAA, with many people, including academia that are also involved in these things. The magnitude 9 did come from an analysis, in fact, I believe at Harvard. These things ought to be linked more closely together to reduce that length of time that we have here of an hour or an hour and a quarter for notification to something that is on the order of substantially less than an hour. That—more seismic stations can mean you might be able to get this job done in 15 minutes, but that is in a very, very ideal sort of world. But the GEOSS, that was mentioned, is a good way to coordinate this effort internationally.

Mr. WU. Well, thank you very much. And I want to jump very quickly to a different topic, because I would like to get two questions in.

And one is to follow up on the set of questions earlier from both the Ranking Member and the Chairman about the appropriate balance between education and investments in new technology. Mr. Wilson, General Johnson, and Dr. Groat, one of the biggest threats to our country in terms of tsunami threat is off the shore of Oregon and Washington. The subduction fault is very close at hand. And while I completely agree with General Johnson's comment that we should be part of a worldwide integrated system, and that is absolutely crucial, I am concerned that we have an appropriate balance between education of folks on the west coast so that they can react to an immediate event as opposed to giving, say, the Japanese warning of a 10-foot wave nine hours later, and, you know, a 50-foot wave coming up on the Oregon shores within 10 minutes for parochial reasons, if no other. You know, I am very concerned about that. Can you all address the appropriate balance in our budget between the investments in buoys and technology and electronic warning systems and sort of sometimes the harder to defend and harder to get dollars, if you will, for "soft things", like education, which may prove absolutely crucial when you have only got 10 minutes from the event to water coming on shore.

Mr. WILSON. I would just like to respond to that, Member Wu, because since I have been in this position, I have had to deal with the concern for false alarms along the coastline, too. And because we communicate that when people feel localized earthquakes along the coast, like a pair of earthquakes that were off shore this past summer along the Oregon coast, I had people in a small town of Waldport, at 11:00 p.m., when they felt a magnitude 4.5, you know, running out of their house, because they were afraid that this was it. And you know, the ability to get an all-clear transmitted to people so that they understand that this was—they had—they responded correctly, but this isn't a tsunami-producing earthquake. That is still a level of technology and a level of confidence that we need to work on for delivery to the people. It is the opposite end of giving them an accurate warning. We also need to be able to give them an accurate all-clear.

Brigadier General JOHNSON. I appreciate the question because it allows me the opportunity to fix something. The numbers of $1.5 million I spoke earlier were specifically for just the Pacific side. On the Atlantic/Caribbean/Gulf side, we have additional dollars, so the total, Mr. Chairman, is $2.75 million in 2005 and $2.5 million and then straight-lined through the outyears for education, inundation, mapping, modeling efforts, and the very important education outreach.

Mr. WU. And Mr. Chairman, if you could indulge me one last question. I think it is———

Chairman BOEHLERT. I would be pleased to indulge my distinguished colleague.

Mr. WU. Thank you very much, Mr. Chairman.

This is of great importance to, I think, everybody on the West Coast, and I take a great interest in it as I spend a lot of time in the coastal parts of my Congressional District. I was watching—I was looking at those inundation maps. And if I am just driving along Highway 101 and something big happens, how high do I have to get, how high do my constituents have to get, how far inland do they have to get? That is something I have never quite known.

Mr. WILSON. Well, that certain level of responsiveness is different in nearly every locality there based on the off shore topography, the local topography, the directionality. It really emphasizes why the site-specific modeling has to be done. We can't just go down the coast and draw a line at a 50-foot contour with any accuracy that—as we have seen and we are just learning, there were areas in there that exceeded that. So we are still trying to make our evacuation mapping as accurate as possible for people. We would hate to tell people they only have to go to 50 feet when, in fact, it may be worse than that.

Mr. WU. More research to be done?

Mr. WILSON. More research.

Brigadier General JOHNSON. And additionally, you don't get one wave. You get multiple successive waves. So—and this is at a time where communication infrastructure may be damaged, so this awareness issue that the emergency managers bring to the end-to-end system is crucial, because you need to know when you can go back, because as we saw in this event, sir, there was about an hour of spacing in between and five huge waves—and is that the last one? How do you know?

Chairman BOEHLERT. Mr. McCaul.

Mr. WU. Thank you very much, Mr. Chairman.

Mr. MCCAUL. Thank you, Mr. Chairman. Thank you, distinguished panelists. I had a question about the—for Dr. Groat and General Johnson with respect to the $37 million the Administration has proposed. Can you, in a very general sense, tell me where that money is allocated with respect to the warning detection system, both to protect the United States but also in a global sense? We talked a lot about GEOSS. Is any of that money going towards a global warning system?

Dr. GROAT. From the seismic aspect of this, a small amount is going to the global perspective in that we intend to bring from 80 percent to 100 percent the real-time transmission of earthquake information from the global network. The—and also the money that is being put towards upgrading our National Earthquake Information Center to bring modern hardware and software there to enhance the processing of both global and domestic seismic information will have the dual benefit of helping the United States in both earthquakes and tsunami concerns, but also that information would be available, on a global sense, shared with others. So it has that dual role. And as far as the maintenance support for that system as well as for the global seismic network, particularly including the Caribbean, that again has some global aspects, but it benefits chiefly the United States and its interests. So our focus is on the United States, but in upgrading the Global Seismic Network's real-time capability and the processing of data from that, it will have some global impacts that are positive as well.

Mr. MCCAUL. Okay.

Brigadier General JOHNSON. I view this as a two-tier approach. One is taking care of national concerns and then the other is applicability into sharing into the larger Global Earth Observation System of Systems where 100 percent of it goes towards protecting U.S. Coasts.

Mr. MCCAUL. Okay.

Brigadier General JOHNSON. It allows you to characterize the extent of the wave, the height of the wave, the propagation of the wave as it transfers up the coast, up towards the Aleutians, if it were to happen at the Cascadia and elsewhere into Hawaii, into American—you know, into our obligations. And because we need to defend America's—or be able to detect it on all of our coastlines, it allows us—as a byproduct, but it allows us to share that data, as Dr. Groat says, with the rest of the world, and we benefit from them. The tsunami that happened off of Sumatra, 26 hours later, gave us a 20-centimeter rise in San Diego 26 hours later. So there is benefit in sharing information. Now that is not of big consequence, at this point, but depending on where that happens, it is valuable to have data shared from around the world, sir.

Mr. MCCAUL. And my second question is what is the time frame for implementation? And will this be tied to a more comprehensive information system as a whole?

Dr. GROAT. Our pledge for implementation are—in current year, with supplemental funds, to do that upgrading to 24/7 to the hardware/software upgrade and to maintain it without your funds. So—and I think, as General Johnson pointed out, they had 2007 plan for their system implementation. So it is sooner than later.

Brigadier General JOHNSON. Yes, sir. 2005 and 2006, I am viewing to have mid-2007 as the implementation for the entire buoy and sea tide gauge program.

Mr. MCCAUL. And will that be tied to a comprehensive information system?

Brigadier General JOHNSON. It will be linked in through the Centers, through the Pacific Tsunami Warning Center, and the backup in Alaska that are mutually redundant and then that information is shared out through the information grids to all of member countries to America, and then we will share that data through GEOSS to the rest of the world.

Mr. MCCAUL. And lastly, for Dr. Lerner-Lam, now I come from a Gulf Coast State, the State of Texas. My constituents will want to know, you know, are we at any sort of risk, either that the Gulf Coast States or the Caribbean States, if you could maybe just highlight what risk there is, if any, of this type of disaster.

Dr. LERNER-LAM. Well, you have a multiple-hazard risk. There is the potential for the sorts of large earthquakes, based on work that the U.S. Geological Survey has done, in the Caribbean. So certainly the Caribbean States have some history, both in the geologic record and the historical record of having tsunami risk. There is not that history in the Gulf Coast, however, of course, you have a meteorological hazard in the Gulf Coast. So one thing to emphasize is that by linking, in some sense, the hurricane preparedness efforts as well as the tsunami preparedness efforts, there may be some economies to scale on that point. So in the rare instance that an extreme event happens or a landslide off the coast happens, you could be prepared.

Mr. MCCAUL. So in other words, a warning detection system would help with respect to other disasters that could occur?

Dr. LERNER-LAM. As well, yes.

Mr. MCCAUL. Okay. Thank you.

Chairman BOEHLERT. Thank you very much.

And here is the deal. We have got a series of votes on the Floor, and we are not going to be presumptuous enough to say well, you can hang around for an hour while we go over there and play

Congresspeople, so after Ms. Jackson Lee has her one minute, we are going to adjourn. And thank you all very much for serving as resources. We will submit some questions in writing to you, because we would like some of your opinions. And General Johnson, you may be interested in an aside, because both the Ranking Member and I said, when you said you have got a five-minute response capability. How can you get there in five minutes? And Counsel pointed out that you have got housing right on—adjacent to the Center, so———

Brigadier General JOHNSON. Yeah, we have got a flophouse that we make the guys stay in, sir.

Mr. WU. And Mr. Chairman, if—I would ask for unanimous consent that opening statements be inserted in the record.

Chairman BOEHLERT. Without objection, so ordered.

And Ms. Jackson Lee, for the final word.

Ms. JACKSON LEE. Thank you, Mr. Chairman. And thank you for your kindness. And this is an important hearing. I have just come back from the region, and I know many of you, or some of you, may have had, I would call it tragic, opportunity to see the enormous devastation and loss. Just for the record, the last tsunami with deaths over 60,000—over 10,000 was in 1755 where there were 60,000 people that lost their lives. I would simply say, Mr. Chairman, that this tragedy cries out for action by the Science Committee. I think we could have done better, and I say this because in talking to some officials, there was a reach to the United States. And my understanding was, because there were no buoys present, that you couldn't detect it and therefore give notice or work. So I think we can do better.

I would also offer to say to you that NASA's JASON I was able to detect some of the tsunami signals, if you will, but there is no system in place to sort of nexus or connect. I think that we can do better by involving NASA. It seems they are somewhat out of the way, if you will, but that is because we have new technology that you can coordinate. So I would simply ask that we have an opportunity for engagement, and if the General can answer or just say can we, General Johnson, look to new technologies and begin to collaborate with other agencies, because I, too, come from the coastal region?

Thank you, Mr. Chairman.

Chairman BOEHLERT. Thank you.

And General, we have to go, because we have to make the vote, and we would appreciate if you would respond in writing. And let me say to my distinguished colleague from Texas, that is the whole reason why we are here. We are determined to do better. They are. We are. That is what we do best. But I will tell you this, also, that while it is in our enlightened self interest to provide leadership to the world, I am a little bit concerned that others aren't as actively engaged as we are and, you know, it is not just our treasury and our technology, although we have got to employ everything possible, we have got to get some of the others. So Mr. Wilson, the Kobe conference, got to follow through on. Japan has got to be starting to share some information with us. Australia, a lot of other nations involved. We are all in this together, and let us do it together.

Ms. JACKSON LEE. Thank you, Mr. Chairman.

Chairman BOEHLERT. With that, the hearing is adjourned.

[Whereupon, at 12:00 p.m., the Committee was adjourned.]

Appendix 1:

Answers to Post-Hearing Questions

ANSWERS TO POST-HEARING QUESTIONS

Responses by Charles "Chip" G. Groat, Director, United States Geological Survey, U.S. Department of the Interior

Q1. Did the Administration conduct any formal or informal outside evaluations of its new proposal, including tsunami detection (DART) buoy placement, assessing other technologies, or talking with states and localities about their major concerns? If so, please provide specifics of the evaluation. If not, why not?

A1. The President has proposed that the U.S. Geological Survey (USGS) upgrade the USGS National Earthquake Information Center (NEIC) and the Global Seismographic Network (GSN), improve distribution of earthquake data, and undertake coastal mapping for tsunami hazard assessment.

The NEIC upgrade and establishment of 24/7 operations are longstanding priorities for the Advanced National Seismic System (ANSS), which was authorized as part of the National Earthquake Hazards Reduction Program (NEHRP) in 2000 and reauthorized in 2004. These plans are laid out in USGS Circular 1188, which was developed in consultation with a broad spectrum of stakeholders and partners in government, academia and the private sector. The ANSS is overseen by an external steering committee that reports to the Scientific Earthquake Studies Advisory Committee.

In the weeks following the earthquake and tsunami, USGS consulted with our partners in the Global Seismographic Network about priority needs and the best means to address those needs. We also drew on existing reports, for example a 1999 USGS-sponsored workshop on "Seismic and Tsunami Hazard in Puerto Rico and the Virgin Islands" attended by international academic, local academic and governmental, and federal agency experts on seismic and tsunami hazard research, engineering, and mitigation (complete workshop proceedings are available at http://pubs.usgs.gov/of/of99-353/tsunamigrp.html) as well as a 2001 proposal for an Intra-Americas Sea Tsunami Warning System by the United Nations Educational, Scientific, and Cultural Organization (UNESCO) Intergovernmental Oceanographic Commission. USGS scientists were already engaged in extensive discussion of coastal mapping priorities with National Oceanic and Atmospheric Administration (NOAA) and Federal Emergency Management Agency (FEMA), discussions that continued with colleagues in academia and government in recent weeks.

Q2. Do you agree with the following recommendations made by the hearing witnesses to improve the Administration's Tsunami Plan?

- *More attention should be paid to education, especially for tsunamis that are either generated close to shore or are generated by events that cannot be felt.*

A. The USGS agrees that public awareness is a critical component in any warning system, whether for tsunamis or other natural disasters. Education is a key focus of the National Tsunami Hazard Mitigation Program (NTHMP), which is a partnership among NOAA, USGS, FEMA, NSF, and the five states bordering the Pacific Ocean.

- *Hazard mapping efforts should be expanded.*

A. The President's proposal calls on USGS to undertake additional coastal mapping for tsunami hazard assessment. That is in addition to work already being done by NTHMP, which is coordinating the preparation of tsunami inundation maps for high-risk coastal communities in Alaska, California, Hawaii, Oregon, and Washington. The USGS provides valuable guidance in the preparation of these maps by: (1) developing high resolution coastal bathymetry and topography; (2) finding, analyzing and interpreting deposits from historic and prehistoric tsunamis to estimate tsunami inundation limits, flow velocities, and recurrence intervals; and, (3) developing hydrodynamic models and simulations of tsunami impacts.

- *More money should be allocated to local warning systems and research to improve them.*

A. The USGS provides principal funding for regional seismic networks in the United States. In coastal areas with significant risk from locally generated tsunamis, such as the Pacific Northwest and Alaska, these networks receive additional support from NOAA through NTHMP. The USGS supports the President's proposal, which adopts a broad approach to improving tsunami warning systems.

- *There should be a greater and more explicit commitment to operation and maintenance cost of the buoys.*

- *Redundant buoys should be purchased and funds should be allocated to developing better buoys.*
- *More work should be done on tsunami probabilities to better site the buoys.*
- *The buoys should be equipped with more instruments to be better integrated into NOAA and NSF research programs.*

A. Because these recommendations specifically address NOAA systems, USGS will leave the response to this recommendation to NOAA.

- *Tsunami efforts should be incorporated into the development of a broader multi-hazard warning system.*

A. The USGS supports the President's proposal that a global tsunami warning system should be developed in the context of the Global Earth Observation System of Systems (GEOSS) and it should be developed in a multi-hazard context to the fullest extent possible. For earthquakes, volcanoes and landslides, the USGS has the lead federal responsibility under the Disaster Relief Act (P.L. 93–288, popularly known as the Stafford Act), to enhance public safety and reduce losses through effective forecasts and warnings based on the best possible scientific information. For tsunami, the USGS provides real-time seismic data from global and regional seismic networks to NOAA, which has the responsibility to issue warnings through its National Weather Service (NWS). While NWS has the statutory responsibility for issuing flood watches and warnings, USGS provides real-time stream flow information to the NWS in support of those activities. The NWS also has responsibility for forecasts and warnings associated with landfall of hurricanes and other coastal storms. The USGS provides information related to the vulnerability of coastal resources and communities to resulting coastal change hazards. In the case of wildfires, USGS partners with a number of federal agency partners to monitor seasonal fire danger condition and provide firefighters with maps of current fire locations, perimeters, and potential spread.

Effective warnings allow people to take actions that save lives, protect property, reduce business disruption, and speed recovery. In addition, prompt alerting of what is happening during and immediately following a natural disaster is also critical. Regardless of the type of hazard, effective warnings require more than the technology to inform the public of the hazard. Their success depends on having response plans in place and pre-event linkages established among Federal, State, and local government agencies, nongovernmental organizations, the private sector, and the media. It is essential that hazard warnings be both accurate and accurately targeted. Accordingly, USGS strives to obtain the best scientific understanding of hazardous phenomena, while also working closely with a wide range of partners to ensure that pre-event linkages are in place so that warnings of impending natural events and assessment of their impact get to the affected communities as rapidly as possible.

For all natural hazards, effective warning requires an integrated system involving information gathering, expert evaluation, generation of accurate warnings, and communication to an educated and informed audience that is prepared to take effective action. Although the specific technologies for detecting earthquakes and tsunamis is largely unique to those hazards, the communication of the warnings derived from those systems take advantage of all-hazard capabilities.

- *The Global Seismic Network should be expanded and should include new kinds of equipment.*

A. The USGS agrees with the need to expand and improve GSN, and the President's proposal provides additional funds to do just that. The USGS supports the incorporation of GSN into the Global Earth Observing System of Systems (GEOSS). The GSN is a multi-use network that supports earthquake monitoring, seismological research, and nuclear test detection. The network's equipment reflects those diverse missions. The USGS expects NSF to take the lead in supporting the development of new seismic sensor technologies.

- *NSF funding should be provided to properly fund the operation and modernization of the Global Seismic Network.*

A. Inasmuch as this refers to funding by NSF, we will defer to NSF on this question.

- *The Advanced National Seismic System should be expanded.*

A. The USGS considers ANSS to be a top priority, and the President's proposal to upgrade NEIC is a key component in the plans for ANSS. Under present funding, USGS is expanding the number of ANSS stations nationwide, including strong-motion sensors in the ground and in buildings in high-hazard urban areas. As additional resources become available, USGS will expand these efforts to additional high-hazard urban areas with an ultimate goal of 26 having sufficient station density to release robust shaking intensity maps and other products within minutes of an earthquake, providing emergency responders with the information they need when they need it.

Q3. What are the biggest gaps in our scientific understanding of tsunamis? How should the Administration address these gaps?

A3. Scientists from USGS are currently working on all three major aspects of tsunami research: generation, propagation and inundation. Of those three, generation and inundation have the most significant gaps in understanding.

Accurately characterizing an earthquake as a tsunami generator means getting an accurate depth, slip distribution, rupture extent, and other parameters. The Sumatra megaquake taught us that this is a challenging task in the time frame of interest for tsunami warning systems. We need to get the most out of the seismic data in order to determine whether unique aspects of tsunami-generating earthquakes can be distinguished, providing information that can augment the deep-sea buoys and tide gauges in tsunami-detection systems. In particular, we need to develop seismic discriminants to quickly identify "tsunami earthquakes," anomalous earthquake that result in larger than expected tsunamis relative to earthquake magnitude.

Although earthquakes cause most tsunamis, underwater landslides triggered by seismic or volcanic activity can produce locally devastating tsunamis. Greater understanding is needed on how landslides generate tsunamis with the goal of predicting whether a given slope will cause a landslide based on its geotechnical properties. Another challenge is better characterization of the size-frequency of landslides in different regions. In light of the concern about the potential for large tsunamis generated by volcanic collapse (for example in the Canary Islands or the south flank of Hawaii's Big Island), we need a means to verify that huge tsunami waves can be generated in the open ocean from measurements of the landslide source itself.

A key uncertainty in preparing inundation maps is the probability of occurrence from a given source. Our ability to forecast impacts depends on improvements in modeling that draw on a robust database of high-quality, comprehensive field data and synthesis from a larger number of tsunamis with different sources (e.g., landslides, faults) in different settings (e.g., open ocean, fjords) to provide the basis and constraints for the models.

Field observations, eyewitness reports and video footage from the Indian Ocean and other recent tsunamis have shown us that tsunami inundation is not well understood. A key gap in our scientific understanding of tsunamis is in how they lose energy once they hit the shoreline until they reach the limit of inundation. Such knowledge is needed to predict how far inland a tsunami will be destructive and deadly, and such predictions are needed to accurately determine zones of high tsunami risk that can be used to develop viable plans to minimize loss of life and property.

Key steps to improve our understanding of inundation and better assist emergency managers, coastal zone planners, and the public include: (1) better near-shore bathymetry in areas known to have tsunami risk; (2) more complex non-linear inundation models; and, (3) additional field studies of recent and ancient tsunamis to compare with inundation models. For the U.S., these efforts should be directed toward the Pacific Northwest, Caribbean, Alaska, Hawaii, Guam, and other U.S. Trust Territories and Possessions. Regional gaps in understanding include: determining the size of the largest tsunamis in the past several thousand years to hit each of these areas; the size of tsunamis generated by the Cascadia Subduction Zone off the Pacific Northwest every 300–900 years and the impacts of such an event on central and southern California; and whether the Atlantic Coast has ever been hit by a large tsunami.

Questions submitted by Representative Bart Gordon

Q1. Circular No. A–ll, Part 7 requires. . .capital asset plan. . .I assume USGS completed the required life-cycle analysis.. . . What range of annual operation and maintenance costs were estimated by USGS for the upgraded GSN network included in the Presidents proposal and submitted to OMB?

A1. The Global Seismographic Network (GSN) is considered to be a Capital Asset of the Federal Government. Within the framework of OMB Circular A–11, Section 7, the GSN has been evaluated by USGS to be a non-major IT investment in an operational/steady state. Such an investment does not require a formal Capital Asset Plan (OMB Exhibit 300). Nevertheless, USGS employs the disciplines of good project management for GSN, and monitors all aspects of the performance of the investment.

With regard to your specific question, USGS has made (and regularly updates) estimates of annual and long-term operations and maintenance (O&M) costs, both for that portion of GSN we operate and for the network as a whole. The most recent comprehensive review of GSN O&M costs was in 2002. The review committee found that to maintain a 90 percent level of data availability will require $82,000 per station per year. This includes funding for labor, travel, spare parts and amortization of equipment. In recent years, inflation costs have been offset by reduced telemetry costs and improved efficiency in station maintenance; this situation is reviewed annually.

Q2. In response to my question. . . What is the additional annual operation and maintenance cost required to solve the network's delayed maintenance problems and maintain the GSN network in good operating condition.

A2. In the President's FY 2006 Budget, an increase in funding for GSN operations and maintenance is requested in the amount of $600,000. This amount would be applied to improve data delivery and station reliability for the USGS-operated GSN stations (currently two-thirds of network stations). With this proposed increase, USGS expects to be able to increase both the GSN stations with telemetry and the data availability for those stations we operate.

The proposed funding increase does not address delayed station maintenance problems. Some of the electronic components of GSN have reached their amortized life expectancy. In particular, power and digital data logger systems now need to be recapitalized. To take advantage of newer technology and to streamline maintenance, GSN program mangers seek to replace all GSN data loggers over the next few years. We estimate the cost of addressing deferred maintenance and recapitalization of system at an average of $13,333 per station per year, or $1,747,000 per year for the full network (USGS+NSF).

The administration expects partner contributions toward the operation and maintenance of GSN stations abroad, and indeed many countries and institutions already provide direct and/or in-kind support for such stations. Our success in establishing and maintaining these contributions is evident in the relatively low cost-per-station average for the current network.

Q3. I understand the current seismic monitors are no longer manufactured. . . What plans are underway to acquire replacement seismometers? Has USGS or NSF identified a potential manufacturer for these seismometers? What is the estimated cost to replace the existing network and over what time frame will this replacement need to take place?

A3. One of several types of GSN-standard seismometers is no longer manufactured, the Strekheisen STS–1, a very-broad-band seismometer used to accurately measure the sizes of the largest earthquakes and to collect accurate data on other geophysical phenomena. In the short term, USGS anticipates that a modification of the mode of emplacement of another Strekheisen seismometer, the STS–2 (still-manufactured), may serve as an interim replacement for the STS–1. We are, therefore, not seeking a new manufacturer at this time, but recognize the need for its replacement in the near future. The USGS expects NSF to take the lead in supporting the development of new seismic sensor technologies.

The USGS has set no timeline for replacing GSN seismometers, as they appear to have very long lives if properly installed and adequately maintained. This question is reviewed semi-annually by the GSN Standing Committee. Amortization of GSN equipment is included in the per-station operation and maintenance figures previously mentioned.

Q4. The President's plan is silent on the role of [NSF]. . . What role will NSF play in the planning and deployment of this expanded tsunami warning system?

A4. From a USGS perspective, our full partnership with NSF in the implementation, expansion and maintenance of the GSN will ensure NSF's engagement in the planning and deployment of the expanded tsunami warning system. For example, we have worked with NSF through its implementing agent for GSN, the IRIS Consortium, in developing the currently proposed GSN enhancement. Coordination of the implementation of the upgrades will be done through the GSN Standing Committee, which reports to NSF through IRIS.

ANSWERS TO POST-HEARING QUESTIONS

Responses by Brigadier General David L. Johnson (Ret.), Director, National Oceanic and Atmospheric Administration's National Weather Service

Q1. Did the Administration conduct any formal or informal outside evaluation of its new proposal, including tsunami detection (DART) buoy placement, assessing other technologies, or talking with states and localities about their major concerns? If so, please provide specifics of the evaluation. If not, why not?

A1. The structure and contents of the Administration's tsunami proposal is based on the existing National Tsunami Hazard Mitigation Program (NTHMP), which has been developed through years of working closely with our State partners and external experts. The Administration's plan was developed, in response to the Indian Ocean Tsunami, in order to expand coverage of the United States. This plan represents an accelerated version of our current efforts in the NTHMP.

NOAA has given careful thought to the placement of DART stations in order to establish a complete DART network that will provide high-quality tsunami data to the NOAA tsunami warning centers for accurate tsunami forecasting. Careful siting of each DART station within the network is required to cover all potential tsunami source zones that could impact the United States. Tsunamis can be highly directional, with a relatively narrow beam of focused energy that could propagate undetected through the network, if tsunameters are too widely spaced. Spacing of approximately 1000 km between each DART station is required to reliably assess the main energy beam of a tsunami generated by a magnitude 8 earthquake.

While other technologies (e.g., GPS water level, and satellite altimetry and synthetic aperture radar) may provide future promise, bottom pressure recorder capabilities are the most accurate instruments available at this time. Discussions with states and localities occur within the National Tsunami Hazard Mitigation Program.

Q2. Recommendations to improve the Administration's Tsunami Plan:

The following is a list of recommendations made by the witnesses to improve the Administration's plan. It would be helpful to have comments on each of the recommendations.

Do you agree with the recommendation that:

- *More attention should be paid to education, especially for tsunamis that are either generated close to shore or are generated by events that cannot be felt.*

A. The Administration's plan includes $2.5M over two years for education and outreach. Part of this funding will support the TsunamiReady Program, which requires active participation by the community to educate the public to recognize hazardous conditions and take actions to keep them safe. Part of the education process requires identifying high-risk areas for determining where to focus education efforts.

- *Hazard mapping efforts should be expanded.*

A. NOAA's activities are on target to meet this recommendation. Our current plan is to complete inundation mapping for all at risk U.S. communities by 2015.

- *More money should be allocated to local warning systems and research to improve them.*

A. It is important to improve local warning systems to protect U.S. communities. However, tsunami warnings are just one of many natural hazards and disasters which can impact our nation. Any comprehensive warning system must address all hazards. NOAA will continue working with the Department of Homeland Security (in particular, the Federal Emergency Management Agency (FEMA)) in the federal effort to develop a comprehensive national warning "system of systems."

- *There should be a greater and more explicit commitment to operation and maintenance costs of the buoys.*

A. The Administration's plan contains sufficient funds to operate and maintain the proposed DART station network. NOAA remains fully committed to operating and maintaining our network of DART stations.

- *Redundant buoys should be purchased and funds should be allocated to developing better buoys.*

A. We agree these issues are critical and NOAA has accounted for some redundancy in our plan. The DART stations are being redesigned with some redundant features built in so they will better withstand the harsh conditions of the northern Pacific. NOAA will maintain three redundant in-water buoys in Alaska, where the sea conditions are particularly harsh and servicing buoys can be difficult. As a part of the Administrations FY 2006 budget, NOAA will be procuring 10 DART buoys as spares available for redeployment as necessary.

- *More work should be done on tsunami probabilities to better site the buoys.*

A. Extensive research has been done on this topic. The DART stations will be located along the major subduction zones, where tsunamigenic earthquakes occur. The planned network of DART stations covers areas susceptible to tsunamis. Additional evaluations are underway to better optimize DART station placement.

- *The buoys should be equipped with more instruments to be better integrated into NOAA and NSF research programs.*

A. NOAA agrees that the DART stations can be useful platforms for other types of observing instruments. The Administration's plan includes $1M for research and development of the next generation of DART stations. NOAA is working to ensure these new DART stations will be capable of accommodating multiple environmental sensors to provide additional environmental data.

- *Tsunami efforts should be incorporated into the development of a broader multi-hazard warning system.*

A. NOAA agrees and will continue to work with DHS/FEMA to facilitate such an effort.

- *The Global Seismic Network should be expanded and should include new kinds of equipment.*

A. The U.S. Geological Survey (USGS) operates the U.S. assets of the Global Seismic Network (GSN) and is best suited to answer this question. However, the Administration's plan includes funding for upgraded seismometers used to improve tsunami detection and includes funding for improvements to the GSN. Most tsunamis are triggered by seismic events, and improvements to the GSN are critical to (1) quickly determine the precise location of the seismic event (2) its precise magnitude and (3) quickly disseminate this information to the National Earthquake Information Center (NEIC) and the NOAA Tsunami Warning Centers.

- *NSF funding should be provided to properly fund the operation and modernization of the Global Seismic Network.*

A. The U.S. Geological Survey operates the U.S. assets of the Global Seismic Network (GSN) and is best suited to answer this question. However, the Administration's plan includes funding for upgraded seismometers used to improve tsunami detection and improvements to the GSN.

- *The Advanced National Seismic System should be expanded.*

A. U.S. Geological Survey runs the Advances National Seismic System and is best suited to answer this question. However, the Administration's plan includes funding for upgraded seismometers used to improve tsunami detection.

Q3. According to the NOAA, the annual operational costs for 38 buoys (in the Administration's plan) will be about $20 million per year. Does that include replacement costs, given that according to the NOAA web site, the average life span of a DART buoy is less than two years?

A3. The Administration's plan proposes 39 buoys, including 29 DART stations in the Pacific, three in-water backups in Alaska, and seven DART stations in the Atlantic and Caribbean. Future operation and maintenance costs for this network will include replacement costs. The level of funding required beyond FY 2006 will be determined through the budget process.

NOAA is taking steps to lengthen the average life span of the DART stations. The DART stations are being redesigned to better withstand the harsh conditions in the Pacific Ocean. Some redundant capabilities built in to the new stations will increase the life span, as will routine maintenance of those stations.

Q4. How does NOAA prioritize what types of activities are funded through the Tsunami Hazard Mitigation Program, such as inundation mapping and education? How will the additional $5 million proposed for the program in the Administration's plan be used?

A4. The Administration's plan includes $4.75M that will be spent on inundation mapping and modeling, as well as education and outreach (e.g., community preparedness activities including TsunamiReady). Of this $4.75M, approximately

$2.25M will be spent on inundation mapping and modeling and $2.5M will go towards public education activities.

The objectives of the National Tsunami Hazard Mitigation Program (NTHMP) were established in the NTHMP Implementation Plan in 1996. This plan can be found at: http://www.pmel.noaa.gov/tsunami-hazard/hazard3.pdf. NTHMP funding decisions are made by the NTHMP Steering Committee, which includes membership from each participating state (Alaska, Hawaii, Washington, Oregon and California), NOAA, Federal Emergency Management Agency and U.S. Geological Survey. Funds are allocated to proposals submitted by the states, federal agencies (including NOAA), and others, by vote of the Steering Committee. Funding decisions are based upon the three NTHMP priorities: Hazard Assessment, Hazard Prediction, and Hazard Mitigation. The NTHMP Steering Committee reviews these priorities annually. The Administration's Plan accelerates all three of these priorities and expands them to include all U.S. communities at risk.

Q5. The Administration's plan is to add DART buoys to the Atlantic and Caribbean. Would either the current Pacific Tsunami Warning Center in Hawaii or the center in Alaska be able to monitor and forecast warnings for the Atlantic and Caribbean?

A5. Yes, either of the current NOAA Tsunami Warning Centers will be able to monitor conditions and issue tele-tsunami warnings for the Atlantic and Caribbean. The key to providing accurate and timely tsunami warnings for the Atlantic and the Caribbean is to have improved tsunami detection and warning capabilities in place. The Administration's plan includes:

- Expanded real-time seismic network for the Caribbean,
- Expanded Caribbean-Atlantic DART systems, Expanded sea-level monitoring network, and
- 24/7 operation of the USGS/NEIC and the U.S. Tsunami Warning Centers.

Once appropriate sensors are in place, the existing Tsunami Warning Centers will be able to monitor conditions and issue tele-tsunami warnings for the Atlantic and the Caribbean. We are exploring other options to address regional concerns, such as international education and outreach efforts, and to address local tsunami warnings.

Q6. What are the biggest gaps in our scientific understanding of tsunamis? How should the Administration address these gaps?

A6. The tsunami phenomenon is fairly well understood from a physics perspective, and numerical models are used to describe how shallow water waves are generated and how they interact with the shore. However, there are some gaps when one considers the entire process, from which earthquakes can cause a tsunami, to knowing the particular bathymetry of the coast, to how far the waves will reach inland. One gap in our scientific understanding of the entire process is the capability to detect and measure tsunami waves crossing the ocean. Another is the understanding of the forces of tsunamis as they flood the coastline. The proposed DART network will go a long way toward filling these gaps as critical data from the network increase our understanding of the offshore forcing mechanisms of tsunamis and increase our open ocean detection capabilities. This information, coupled with field measurements, laboratory experiments, and numerical models of the forces on structures as the tsunami floods the coastline, will further our understanding, and ultimately prediction of, tsunamis. This research effort should include the coordinated efforts of NSF, NOAA, and National Earthquake Hazard Reduction Program. Additional research is also needed to quickly identify the true size, rupture region, and slip distribution of massive tsunamigenic earthquakes, such as the December 26, 2005 Indian Ocean event. Similar events occurred in the Pacific four times in the last century. Research is also needed to quantify uncertainties in numerical model forecasts based on very sparse observational data. The Administration's proposal goes a long way toward addressing these issues.

Questions submitted by Representative Bart Gordon

Q1. Circular No. A– 11, Part 7 requires all agencies to provide a capital asset plan for each major new and on-going major investment, system, or acquisition, and operational asset they manage. As part of the capital asset plan NOAA is required to estimate life-cycle costs of the system with more detail and specificity on, costs as a system approaches the operational stage.

A capital asset is defined as structures, equipment, intellectual property and information technology that are used by the Federal Government and have an estimated useful life of two years or more. Clearly, the combined tsunami buoy and seismic networks required for the tsunami warning system are capital assets. The proposal for expanding the network in the Pacific, deploying a network in the Atlantic and Caribbean, and maintaining 24/7 staffing at the National Tsunami Warning Center requires a capital asset acquisition and the associated operation and maintenance cost to maintain the system.

I assume NOAA completed the required life-cycle analysis as required under Circular No. A–11 to develop the budget request for the FY 2005 Supplemental and as justification for the FY 2006 budget since the proposed upgrades and expansion of the network and the increased staffing represent a change in acquisition, operation and maintenance of a capital asset.

What range of annual operation and maintenance costs were estimated by NOAA for the expanded tsunami warning network included in the President's proposal and submitted to OMB?

A1. The Administration's two-year commitment to strengthen the U.S. Tsunami Warning Program contains funding to procure and deploy new tsunami detection systems and to accelerate hazard assessment and hazard mitigation programs. The level of funding required beyond FY 2006 will be determined through the budget process.

Q2. It appears we have two issues with respect to the requirements for ship time to service the buoy network: the first is whether your budget contains sufficient funds to cover the cost of ship time for servicing. The second is whether NOAA will have ship time available even if sufficient funds are available to cover its cost.

Q2a. Will NOAA have sufficient ships and time available on them to cover all of the current program activities, the expansion of the network in the Pacific, and the establishment of a network in the Atlantic and Caribbean?

A2a. The Administration's plan includes sufficient funds for ship time, either service provided by NOAA vessels or through contract ship support, to maintain the proposed DART station network.

Q2b. What is the estimated ship time per year required to service the expanded Pacific network based upon your experience with the current network?

A2b. Based on our experience with the current DART stations, we estimate that 280 days (230 planned and SO contingency) worth of ship time will be required to service the expanded network of DART stations in the Pacific Basin, given the current information on their planned locations.

Q2c. What is the estimated ship time per year required to service the Atlantic and Caribbean network?

A2c. We estimate that the seven DART stations deployed in the Atlantic and Caribbean will require 58 days (48 planned and 10 contingency) worth of ship time, given the current information on their planned locations.

Q3. How much does our research on hurricane-related storm surges in the Atlantic and Caribbean contribute to our understanding of tsunami hazards in those areas?

A3. NOAA's operational and research efforts for hurricane-related storm surge in the Atlantic and Caribbean has given us a starting point to understand and model the bathymetry of the near-shore environment that can be used to model tsunamis. Using the bathymetric results from the storm surge program will help with the inundation mapping for the East coast, Gulf coast, and Caribbean islands, but it is just a beginning. The physical processes responsible for hurricane surges and tsunamis are vastly different. Tsunamis are a series of waves, or surges, sometimes many hours apart, rather than one storm surge driven by strong winds from a hurricane.

Q4. Tsunami hazard potential is directly affected by the topography of the seafloor between an earthquake's epicenter and a particular coastline. How adequate is our knowledge of the bathymetry along the U.S. coastlines? How does the availability of this information affect the accuracy of inundation maps?

A4. With the exception of a few coastal communities in Alaska, existing U.S. bathymetry data and information are adequate for tsunami modeling to produce tsunami inundation maps.

Q5. The Administration's proposal indicates you will be expanding the Tsunami Ready communities program. Considering that much of the funding for achieving Tsunami Ready status comes from State and local budgets, how does NOAA plan to increase the number of Tsunami Ready communities along the coasts?

A5. NOAA is committed to accelerating and expanding its TsunamiReady community program to all at-risk communities, and expects to have at least 40 additional TsunamiReady communities by the end of FY 2006. The Administration's plan provides $2.5M to NOAA over two years to support public education activities, including community preparedness activities such as the TsunamiReady Program. While NOAA recognizes that achieving TsunamiReady status requires significant State and local support, NOAA will continue working with local communities to leverage existing assets and community warning preparedness programs, which provide the foundation for allowing a community to become "TsunamiReady."

Q6. Mr. Wilson indicated he participates in a multi-state and multi-federal agency group through the National Tsunami Hazard Mitigation Program. Does NOAA intend to establish similar multi-state groups for the Atlantic states to promote the development of tsunami evacuation plans and public education programs? Will a similar approach be taken for U.S. territories? When do you anticipate establishing these working groups?

A6. NOAA would like to expand the NTHMP to include all U.S. States and Territories with communities at risk from a tsunami, but the current structure of the program would have to be modified. Under the current structure, NTHMP funds are distributed to the states and federal agencies by the vote of the NTHMP Steering Committee. Adding 15 states, three territories, and two commonwealths to the current Steering Committee expands the scope of the program and requires us to consider a new governance structure.

Q7. What is the status of inundation mapping for the west coast of the U.S.? Is most of the mapping completed? What about the Atlantic coast and the Caribbean territories? How often do these maps need to be revised?

A7. Based on input from Alaska, California, Hawaii, Oregon and Washington, 21 of 167 planned mapping efforts have been completed. About 15 percent of the west coast inundation mapping, covering 30 percent of the population at risk, is complete. On the east coast and the Caribbean, only Puerto Rico has tsunami inundation maps, which were funded by Sea Grant and the government of Puerto Rico. Revisions to these inundation maps are required only when a major change (more than 10 percent) in near shore bathymetry or coastal topography has occurred.

Q8. The DART system (Deep Ocean Assessment and Reporting of Tsunamis buoys) combined with the Bottom Pressure Recorders (BPR), installed by NOAA in the Pacific Ocean was effective in canceling an evacuation in Hawaii following a 7.5 magnitude Alaskan earthquake in November 2003 that could have, but did not, cause a tsunami. This helped to save tens of millions of dollars, not to mention the potential for personal injury or property damage associated with an unnecessary evacuation. If installed in the Indian Ocean and combined with appropriate warning and evacuation protocols, I can imagine that many lives might have been saved in Sri Lanka and in Thailand. There is also considerable discussion about expanding the DART system to the Atlantic and within the Pacific. Earlier this month, Admiral Lautenbacher (Administrator of National Oceanic and Atmospheric Administration) indicated that three of the six DART buoys are not functioning. He also classified these as "test buoys." The first four DART stations were in place by August 2000. The standard DART surface buoy has a stated design life of one year and the seafloor BPR package has a life of two years.

Q8a. Have the non-functioning DART buoys and BPRs reached their expected life, or did they fail prematurely?

A8a. The term "design life" used in this context does not refer to expected failure of the DART stations, but rather when the power system (batteries) will no longer be sufficient to operate the electronics. Thus the design life of the communication package in the surface buoy was one year and of the bottom pressure unit was two years. The failures mentioned by VADM Lautenbacher were unanticipated and did not result from battery failure.

Q8b. Since 2000, what has been the reliability of the DART buoys?

A8b. The reliability of the DART stations since October 2003, the time when they were transitioned from being operated by NOAA Research to NOAA's National Weather Service, has been 72 percent. This represents the combined number of hours the stations have been operational.

Q8c. BPRs have been deployed in the Pacific (without the DART buoy) since 1985. I understand that they have a designed life of 15–24 months. What is the actual reliability of the BPR.

A8c. It is very difficult to ascertain the reliability of the bottom pressure recorders themselves. The majority of DART BPR failures, since October 2003 (operational date), have not been a result of failure actual pressure unit itself, but rather do to other causes, such as failure of cable connectors. All of the bottom pressure recorders are currently operating.

Q8d. Admiral Lautenbacher classified the DART as a "test" system. With four years of deployment at sea, how much additional testing is required before we can be confident about making the investment in deploying these recorders and buoys worldwide and that the technology is sufficiently reliable to justify the investment?

A8d. NOAA believes the research and development efforts done with the six station DART pathfinder network have defined what can and cannot be accomplished with these detection capabilities. We are in the process of designing built-in redundant capabilities where feasible to ensure a longer lifetime of the stations. We are confident that once the full DART II network is deployed, the U.S. will have an operational configuration providing near 100 percent tsunami detection capability with embedded redundancy.

Q9. The DOD's National Geospatial-Intelligence Agency is making its satellite maps available to the USAID and other government agencies in their relief operations. The National Geospatial-Intelligence Agency also maps ocean contours to support the strategic mission of our submarine fleet. We know from the experience in the devastating 1998 Papua New Guinea tsunami that undersea landslides can dramatically increase the severity of tsunamis. What kind of information is available from the National Geospatial-Intelligence Agency that could be used to identify high-risk tsunami areas? Are there ways to provide this information to NOAA and the others involved with the installation of a tsunami warning system that will not compromise national security?

A9. NOAA will use all available data and information to strengthen the U.S. Tsunami Warning System. The Department of Defense and/or the National Geospatial-Intelligence Agency are best suited to answer these specific compromise national security.

ANSWERS TO POST-HEARING QUESTIONS

Responses by John A. Orcutt, Deputy Director, Research at the Scripps Institution of Oceanography; President, American Geophysical Union

Q1. If you could change one or two things about the Administration's proposal, what would it be and why?

A1. Develop a long-term plan and funding to operate and maintain the DART buoy system given that O&M costs will exceed the initial capital costs in only 3–4 years of operation. Approaches include a plan to increase the breadth of measurements made through collaboration with the NSF Ocean Observatories Initiative and the identification of NOAA funding for O&M.

Include the NSF in funding planning given that they support the O&M for nearly a third of the GSN and have supported the full costs (NSF and USGS) of new station installation and station upgrades in the past two decades.

Q2. Recommendations to improve the Administration's Tsunami Plan:

The following is a list of recommendations made by the witnesses to improve the Administration's plan. It would be helpful to have comments on each of the recommendations.

Do you agree with the recommendation that:

- *More attention should be paid to education, especially for tsunamis that are either generated close to shore or are generated by events that cannot be felt.*

A. Absolutely. In the case of the Indian Ocean the enormous loss of life could have been greatly reduced, almost eliminated, if there had been a long-term plan in place for teaching natural hazards throughout the region. There may be no technical approaches that can save populations near the tsunami source too little time. Seattle is an analogous case in the U.S.

- *Hazard mapping efforts should be expanded.*

A. This is an important activity from inundation estimation to likely sources of tsunamis including earthquake, volcanoes and seafloor slumping. Inundation mapping depends a great deal, for example, on detailed, high-resolution topographic mapping offshore and onshore.

- *More money should be allocated to local warning systems and research to improve them.*

A. Yes, this is probably most important for carrying out the educational goals mentioned above. Local and regional communities could also support the installation, operation and maintenance of technical systems installed including seismograph, tide gauges and cameras.

- *There should be a greater and more explicit commitment to operation and maintenance costs of the buoys.*

A. Yes, this is a major problem for extending the lives of buoys over decades. In a biologically productive environment buoys have to be entirely replaced over the course of a very few years, for example, because of intensive biofouling.

- Redundant buoys should be purchased and funds should be allocated to developing better buoys.

A. A better approach is likely a transition to entirely new buoy designs including those being contemplated for use by the NSF Ocean Observatories Initiative. In the case of Cascadia, the OOI will include seafloor, fiber optical-connected nodes on the seafloor throughout the area precluding the use of buoys entirely for relevant tsunami measurements.

- *More work should be done on tsunami probabilities to better site the buoys.*

A. Yes, first understand the earthquake hazard in an area as well as forecasts of activity to prioritize the installation of buoys.

- *The buoys should be equipped with more instruments to be better integrated into NOAA and NSF research programs.*

A. Yes, I agree. The current small buoys with very limited power and telemetry are not well suited for supporting a broad suite of sensors.

- *Tsunami efforts should be incorporated into the development of a broader multi-hazard warning system.*

- *The Global Seismic Network should be expanded and should include new kinds of equipment.*
- *NSF funding should be provided to properly fund the operation and modernization of the Global Seismic Network.*

A. Yes, the NSF operates approximately one-third of the Global Seismic Network and has, in the past, funded nearly all the costs for new station installations and upgrades for both the NSF and USGS portions of the network. Most of the stations operated in the Indian Ocean are NSF's responsibility.

- *The Advanced National Seismic System should be expanded.*

A. The ANSS has concentrated largely on urban seismology and urban earthquake hazards. Subsequent to my testimony researchers have used many (1200 –1400) seismographs in Japan to map the Sumatra earthquake fault propagation. Had the data been available in real-time, this technique could have significantly reduced the time needed to identify the event as a Great Earthquake. The ANSS could serve the same purpose, but the goals of ANSS will have to be changed substantially.

Q3. What are the biggest gaps in our scientific understanding of tsunamis? How should the Administration address these gaps?

A3. Can seismic measurements alone be used to predict tsunamis? This certainly isn't possible now. Can detailed earthquake source parameterizations be used to predict accurately tsunami generation and propagation? Can acoustic sensors be used to couple observations of fault rupture to tsunami creation? There are a large number of excellent scientific questions to motivate high quality research. Presently, there is no viable research program in the NSF, NOAA, or the USGS nor funding available to university scientists for competition. It's very difficult to develop a scientific career in studying tsunamis. The NSF would be best able to manage such a research program.

Questions submitted by Representative Bart Gordon

Q1. Your testimony provided an estimated $5 million dollar shortfall in annual operation and maintenance costs for the global seismic network (GSN). Dr. Groat indicated the President's future budget allocations would cover operation and maintenance costs for the proposed network upgrades. However, he also stated that funds to address the maintenance backlog were not being allocated. Will the upgrades to the network as outlined in the President's proposal increase the operation and maintenance cost of the network or will they remain the same? If Dr. Groat's assumption is correct, that operation and maintenance cost of the upgraded network will be covered, but the backlog is not, what effect will that have on the sustainability of the network?

A1. Part of the costs for upgrading the GSN are to be devoted to modernization of the connections of the stations to the Internet for near-real-time data delivery. If this is done using modern commercial satellite technologies, the reliability of the network could be greatly increased while at the same time slightly decreasing the actual costs of telemetry. The current medley of communications schemes including phone lines, local Internet Service Providers (ISP), satellite sharing with the UN, and others is an ad hoc collection of methodologies that is difficult to manage and varies widely in costs.

Increasing the number of stations in the GSN will necessarily increase the costs of operating and maintaining the network. As I noted in my testimony, these O&M costs vary from $60,00 to $75,000 per year. The current budget for O&M ($2M from the NSF and $3M from the USGS) is inadequate for maintaining the network given the projected costs of $8M to $1 OM. The UCSD component of the NSF-funded GSN (40 stations) receives approximately $2MJyr for O&M while the projected costs are 40 X $60K = $2.4M/yr to 40 X $75K = $3M so the bulk of the shortfall is in USGS support. The current USGS shortfall of $2M to $4M will grow with an increasing number of stations.

Long-term underfunding of the GSN will have a negative impact on system reliability and, because installed infrastructure will not be regularly modernized, maintenance costs will increase faster than inflation.

Q2. I understand the current seismic monitors are no longer manufactured, the monitors have been in place for a number of years, and they may need to be replaced to maintain the performance goals of data acquisition from the network. Are you aware of any plans at NSF or USGS to acquire replacement seismometers? Has USGS or NSF identified a potential manufacturer for these seismometers? What *is the estimated cost to replace the existing network and over what time frame will this replacement need to take place?*

A2. The seismometers used to establish the GSN built by Swiss and US manufacturers are no longer available. These include the highest quality sensors (Swiss) intended for installation in vaults and borehole sensors (US). The NSF is currently funding a project at Scripps Institution of Oceanography/University of California San Diego to develop a new optical seismometer. The original designer of the Swiss seismometer is working with scientists and engineers at Scripps in this development. The prototype recorded the Sumatra earthquake on 26 December with great fidelity. The seismometer has a substantially larger dynamic range than existing systems and because of the lack of sophisticated electronics, may be less expensive to manufacture.

Several commercial companies, including Guralp (UK), KMI (US), and Nanometrics (Canada) are also developing new seismometers based on classical principles. Their markets, however, are programs such as the Advanced National Seismic System (USGS) and USArray (NSF) that require large numbers of less capable instruments.

Q3. Your points about the National Science Foundation are well-taken. Is this a question of ensuring NSF's participation with NOAA and USGS as the network upgrades and development take place or do you recommend additional research funding at NSF above the current earthquake research program?

A3. Generally, transferring funds between agencies is problematic and I am concerned that limited appreciation for the key role played by the NSF and lack of specificity in the tsunami bill will limit significantly funding needed for upgrading the components of the GSN supported by the NSF.

ANSWERS TO POST-HEARING QUESTIONS

Responses by Arthur L. Lerner-Lam, Director, Columbia University Center for Hazards and Risk Research

Q1. If you could change one or two things about the Administration's proposal, what would it be and why?

A1. The Administration should increase the emphasis on public awareness and education at the State community level, coordinated with comparative risk assessments for coastal regions. This would improve use of warnings, and increase support for mitigation actions. NOAA's TsunamiReady program, which was described at the hearing, is an example that should be expanded in a multi-hazard context. Investments in the tsunami warning system should be part of a broader initiative for multiple hazard monitoring, including integrated ocean observations. Tsunamis, while extreme, are not the most damaging hazard as measured by annualized risk. Risk should inform the deployment of warning and observation systems, hazard reduction programs and mitigation policy. A quick technological fix driven by hindsight may not be the best use of the Nation's resources.

Q2. Recommendations to improve the Administration's tsunami plan:

- *More attention should be paid to public education, especially for tsunamis that are either generated close to shore or are generated by events that cannot be felt.*

A. I agree that more attention should be paid to improving public awareness of natural threats, including tsunamis. This awareness should include concrete instructions for community-based as well as individual preparedness and response. The public education program should include training for first responders, emergency managers, and other local community officials. For cases without adequate warning, such as tsunamis generated close to shore or unobserved tsunami-triggering events, the public's ability to respond is both the first and last line of defense. Schools provide an effective training environment, but the effort could also include public service announcements, free publications, library and museum exhibits, and university outreach. It will be important to provide a conduit between research organizations, particularly those that are mapping potential risks and modeling hazard scenarios, and the public outreach process, so that the most current information is made available proactively.

- *Hazard mapping efforts should be expanded: This is certainly necessary, but should be done on several levels.*

A. One of the most important components of a comprehensive hazard mapping effort is accurate mapping of near-shore topography and bathymetry with improved spatial resolution. The most accurate global data set of topography is the C-band map produced by the Shuttle Radar Topography Mission (SRTM). This map has 30 m resolution, and while the mission provided near global coverage, only the United States coverage is openly available. Elsewhere, only a degraded image with 90 m resolution is available. This is insufficient for accurate coastal hazard mapping on a global basis. The Administration should declassify the SRTM global data set. More can be written about this. High-resolution bathymetric maps are available in selected areas, but the choice of regions to be mapped has been governed by reasons other than risk assessment. The Administration should develop plans to acquire high-resolution bathymetric data in areas prioritized by natural hazard risk. Topographic and bathymetric data should be openly available for research and analysis, because the processing of the raw data for accurate topography and bathymetry, especially near the coastline, is a difficult and error-prone exercise. The development of accurate high-resolution bathymetric and topographic maps at the coastline will benefit from the vigorous attention from research oceanographers and quantitative geomorphologists. The best defense against incorrect maps is an open data philosophy that allows continuing assessment of the quality of the data and the incorporation of new research results into the operational raw data processing. An additional component of hazard mapping is the integration of socio-economic data sets with geophysical hazard maps in order to quantify specific vulnerabilities.

- *More money should be allocated to local warning systems and research to improve them.*

A. I infer that this question refers to the dissemination of authoritative warnings by local communities and the communication of warnings in an informative and community-calibrated way to first responders and the public. I agree with the need for more research on how warnings should be prioritized and characterized so that the public is adequately informed in a manner that suppresses a panic response and achieves the desired results. This is an important area of research in decision theory, decision making under uncertainty, risk perception, and techniques of risk management.

- *There should be greater and more explicit commitment to operations and maintenance costs of the buoys.*

A. The version of the Administration's proposal I reviewed prior to the 26 January hearing was not explicit. There is concern among those with experience with oceanographic instrumentation that the difficult deployment and operating environment in the oceans will exact a toll on even well-designed buoys. NOAA appears to recognize this, but a continuing R&D program for instrument development that would improve the O&M profile of globally dispersed deployments must be part of the Administration's package.

- *Redundant buoys should be purchased and funds should be allocated to developing better buoys.*

A. The Administration should provide funds for a well-scoped instrumentation research and development program. "Better buoys" comprises instruments that last longer and have reduced O&M costs. The term can also refer to improvements to the software that detects the passage of a tsunami wave. Given current deployment plans, concern remains that there is inadequate redundancy in the number of buoys requested.

- *More work should be done on tsunami probabilities to better site the buoys.*

A. This is a complex problem rooted in both tsunami and earthquake science. The Sumatra-Andaman earthquake that generated the Indian Ocean tsunami was the largest earthquake ever recorded by high-fidelity digital seismographs, which were largely put in place beginning in the seventies. As a consequence, the event has spawned a tremendous amount of research on the dynamics of large earthquake sources. We are at a turning point in our understanding about giant earthquakes and our ability to anticipate their occurrence and tsunamigenic potential. However, in the absence of well-founded models of extreme events (rare-occurrence, high-impact), the siting of buoys should be based on providing adequate coverage of potential sites of tsunami genesis along the world's major subduction zones. Past experience is the most justifiable guide. Buoy siting is also governed by the ability of tsunami detection algorithms to characterize the propagating tsunami disturbance in the water. This is reasonably well understood, but there should be constant improvement in the algorithms as more is understood about tsunami propagation. Finally, paleoseismological and paleo-tsunami studies, which determine the spatial and temporal distribution of tsunamis from historical and geological records, can help prioritize placement by developing recurrence histories in major subduction zones. Examples include studies performed along the Cascadia margin, and in other areas around the world. Existing studies should be inventoried, and new ones performed where needed.

- *The buoys should be equipped with more instruments to be better integrated into NOAA and NSF research programs.*

A. While there are many current and pending NOAA and NSF research programs that could benefit from the infrastructure put in place for a tsunami warning system, the current design of the buoys is focused on solving the tsunami problem. In principle, the buoys could be a platform for complementary geophysical observations by providing a modular solution to remote power and telecommunications issues. For example, a seafloor instrument package containing seismometers could be linked to the buoy communications and power platform. The deployment of seafloor seismometers would enhance the capabilities of the Global Seismographic Network for tsunami-generating event detection and characterization. The placement of other sensors, including sensors in the water column, should be explored. However, a better approach might be to develop a broader modular approach to in situ oceanographic instrumentation infrastructure (in which the tsunami buoys could be a component), rather than modify the purpose-built tsunami system.

- *Tsunami efforts should be incorporated into the development of a broader multi-hazard warning system.*

A. This is a good idea in principle. In practice, this strategy is effective when the underlying natural hazards overlap in spatial extent and the nature of their impacts. Once this is established, it is important to look at ways in which the preparation for and response to different hazards overlap. Fundamentally, a tsunami warning system could be integrated into a more expansive integrated ocean and coastal observing system. The most likely candidate for rapid progress is linking tsunami warning instrumentation to coastal storm surge monitoring. Underlying this reasoning is the simple observation that on an annualized basis, other hazards are more frequent and damaging. A single-purpose hazard warning system implemented for an extreme yet infrequent event class will not provide the most cost-effective approach to overall hazard reduction. Design studies should be initiated.

- *The Global Seismic Network should be expanded and should include new kinds of equipment.*

A. The Global Seismic Network should be expanded to include ocean bottom instrumentation, particularly in equatorial ocean basins and the northern Pacific where tsunami generation potential is greatest. The GSN should be improved to provide real time data from 100 percent of its stations with 90 percent reliability. With the exception of these considerations, the GSN has achieved many of its design goals for the research community. Improving its operational utility for warning is the next priority. This can be done by regionally densifying the GSN by forming collaborative relationships with regional and national networks around the world, by adding telemetry to stations without it, and by increasing quality control and maintenance operations to approach 90 percent up-time rates. Other equipment that might be included at GSN sites includes telecommunications nodes, infrasound sensors, magnetic observatories, and complementary geophysical instrumentation such as gravity and magnetic field sensors. The basic GSN system has been designed in a modular fashion that should make the addition of other instrumentation a straightforward engineering exercise.

- *NSF funding should be provided to properly fund the operation and modernization of the GSN.*

A. The GSN serves both research and mission communities, and is one of the foremost examples of such a dual-use network. NSF funds the GSN as part of its commitment to the Nation's research enterprise. The U.S. Geological Survey also participates, with separate funding in its budget for network operations. The Department of Interior's responsibility in providing partial support should be emphasized and the Administration should assure long-term funding for the U.S.G.S. The data management and archive is managed by IRIS and funded by the NSF. This funding should be sustained through the standard NSF process of peer review. Whether NSF should provide funding for a monitoring operation is not at issue: as long as Earth Science Instrumentation and Facilities is sufficiently funded (as long as the NSF R&RA account is sufficient), IRIS can compete in a community peer-review environment for continued operation of the GSN. It is estimated that an additional $10M will be needed over five years to fully fund and modernize the GSN. It is also important to note the quality control of the GSN is critically dependent on the activities of the U.S. university research community in using the data and assessing its quality continuously. This implies that continued health of the GSN is also contingent on funding for basic research in earthquake science and Earth structure, through the NSF, and through the USGS external grants program.

- *The ANSS should be expanded.*

A. Within the U.S., the ANSS comprises a national scale backbone network and a several regional networks with regional operational and outreach responsibilities. Authoritative detection and characterization of events is the responsibility of the National Earthquake Information Center in Golden. The NEIC will be enhanced to provide 24/7 operation under the Administration's plan. However, the capitalization, operations and maintenance of the ANSS are limited by a level of funding well below authorized amounts. For the purposes of a tsunami warning, the ANSS should expand real-time capabilities in the Pacific Northwest, in Alaska, and in the Caribbean, to quickly locate and characterize tsunamigenic earthquakes. In the rest of the country, the ANSS should be fully funded at authorized level so that there can be timely and accurate characterizations of earthquakes within U.S. borders.

Q3. What specific recommendations would you give to the administration on how to use the current momentum to build an international tsunami warning system to test its concept of building a comprehensive global Earth observing system?

A3. A tsunami warning system integrates observations from various in situ geophysical sensors. The successful integration from different systems, including the data format, open data exchange, real time telecommunications, rapid analysis, archiving, and assessment are all components of what should be achieved by a global Earth observing system. The use of satellite remote sensing in rapidly characterizing damage by comparing before and after scenes implies that data integration of geophysical data with socio-economic data should also be operationalized. The most important parts of an international observing system are: (1) the free and open exchange of data from global, national and regional systems so that all information is available for immediate use when needed, and (2) improving the capacity of all nations to use the observations, and tailoring the information products to different national and regional circumstances. The Administration should emphasize that the building of a global observation system should be based on the free and open exchange of all geophysical data, its use in hazards reduction, and its use in research collaborations. International research collaborations will build scientific and technical capacity throughout the world and will build confidence that the exchange of data has local benefits. Ultimately, this exchange of research results will improve the operations of the tsunami and other hazard warning system, improve their use by local communities, and provide a higher level of technical capacity complementing and supporting broader international development goals.

Q4. What are the most serious natural hazard threats facing the United States today? Please provide specific examples of how response plans for these threats could be integrated with the tsunami risk reduction program proposed by the Administration.

A4. Earthquakes, drought, flooding, severe storms and hurricanes, and coastal erosion are all serious natural hazard threats faced by the United States today. The regional distribution of these threats varies of course, but this is reasonably well understood. Threats specific to the coasts include hydrometeorological and earthquake/landslide hazards whose understanding and warning would benefit from an enhanced multiple hazard observation and warning system. The simplest way to integrate the multi-hazard response is to include multiple hazards in the coastal risk mapping that is proposed in the Administration's tsunami program. Once these multiple hazards risk are mapped and a quantitative risk comparison is made, the overlap in preparedness and response strategies could be investigated to provide a synoptic and cost-effective coastal warning system for multiple hazards. A first step would be to integrate storm surge and coastal flooding warnings with severe storm and tsunami warning.

Q5. What are the biggest gaps in our scientific understanding of tsunamis? How should the Administration address these gaps?

A5. The biggest gaps are: occurrence probabilities of different tsunamigenic events, the tsunami source function (how different events actually produce the water disturbance that becomes a tsunami), the dynamics of run-up and near-shore propagation, which are highly non-linear and critically dependent on relatively unknown coastal bathymetry, and data integration to understand the potential impacts of tsunamis on populations, livelihoods, and economic output. The Administration should address these gaps with both basic and applied research programs in earthquake and tsunami research, a coastal bathymetric mapping program, and an applied and basic research program in risk assessment and management. There are specific gaps in the our assessment and understanding of different strategies for making use of the warning on local or community levels. Current programs should be assessed, and social science research should be conducted so that we understand how to best assess and communicate risk, and develop policies to reduce or manage risk. Despite the gaps in our understanding of tsunami and earthquake sources, this does not mean that action on developing warning and observation systems should be delayed. Rather, the Administration should ensure that the basic and applied research enterprise is healthy and conversant with operational problems, so that research results can be communicated to the operations in a timely and effective manner.

Questions submitted by Representative Bart Gordon

Q1. Dr. Orcutt's testimony provided an estimated $5 million dollar shortfall in annual operation and maintenance costs for the global seismic network (GSN). Dr. Groat indicated the President's future budget allocations would cover operation and maintenance costs for the proposed network upgrades. However, he also stated that funds to address the maintenance backlog were not being allocated. Will the upgrades to the network as outlined in the President's proposal increase the operation and maintenance cost of the network or will they remain the same? If Dr. Groat's assumption is correct, that operation and maintenance cost of the *upgraded network will be covered, but the backlog is not, what effect will that have on the sustainability of the network?*

A1. The O&M cost impacts of the upgrades to the GSN, which include achieving 100 percent telemetry and 90 percent up-time, are expected to amount to $5 to $7M/yr. additional, with half allocated to NSF and half allocated to the USGS. However, there is a maintenance backlog that is associated with hardware upgrades to older instruments and maintaining a spare parts inventory. Sustainable operation of the GSN is dependent on clearing the maintenance backlog.

Q2. I understand the current seismic monitors are no longer manufactured, the monitors have been in place for a number of years, and they may need to be replaced to maintain the performance goals of data acquisition from the network. Are you aware of any plans at NSF or USGS to acquire replacement seismometers? Has USGS or NSF identified a potential manufacturer for these seismometers? What is the estimated cost to replace the existing network and over what time frame will this replacement need to take place?

A2. The IRIS consortium funded by the NSF has held several manufacturer discussions and community workshops to address the problem of very-broad-band seismometer obsolescence. However, a manufacturer of replacement instruments has not been identified. This decision and associated research should rightly be funded through the NSF instrumentation and facilities program, because the instruments will be crucial to basic research. Replacement costs for the instruments are likely to be in the range of $10M over five years. The NSF is also running an instrumentation research program, which is funding development of several promising sensor technologies. It is not clear at this time whether these new technologies will be suitable for production sensors in the near future.

Q3. You made a persuasive case for considering a multi-hazard approach to reducing national vulnerabilities. The plan we have before us is designed to address the earthquake and tsunami hazard. What additional features would this plan contain if we were taking a multi-hazard approach? What do you see as the major barriers to adopting a multi-hazard approach to disaster planning and mitigation? How do these barriers differ for the wealthy and less wealthy nations?

A3. Additional features of the plan to address multi-hazard comprise (1) assessment of multi-hazard risks, particularly in the coastal areas of the United States, to determine the geographic and temporal distribution of multiple hazard occurrence and impacts; (2) common approaches for preparedness and response for hazards having similar impact/damage scenarios and common or overlapping risk occurrence; (3) development of integrated geophysical instrument networks with the ability to direct specific real-time data streams to the relevant analytical tools for specific hazard characterization and warning/response; (4) encouraging an all-hazard approach for communities facing multiple risks; first responders and relief teams should be trained in multiple risk management or response so that technical and operational efficiencies and cross-fertilization can be pursued. Major barriers to multi-hazard approach include: (1) a national risk management strategy that focuses on individual hazards, even in regions where risks from several hazards are comparable; (2) dispersal of risk assessment, hazard observation and management functions among different agencies, (3) a heterogeneous public-private environment for implementing risk management policies. Differences between wealthy and less wealthy nations include the understandable tendency for less wealthy nations to discount the risk from future events when weighed against more immediate humanitarian concerns. Further, a "one-size-fits-all" technical approach is less likely to succeed in less-developed countries because of mismatches in technical and administrative capacity. Implementation must be tailored to the social, technical, administrative and cultural conditions in different countries and regions. Also, open data exchange and collaborative research are not yet universally acknowledged by all parties as a foundational element of global multi-hazard observation and warning: many countries seek to develop self-contained systems, which are problematic, as a matter of national pride. Linking natural hazard risk management to broader international economic and political development goals may be one approach to these issues.

Q4. The Global Earth Observation System of Systems (GEOSS) has been mentioned numerous times in connection with this tsunami detection and warning system. However, it is unclear how far along the real planning for GEOSS has come and whether there have been substantive discussions of how the tsunami network would fit into the system. You seem to believe the deployment of this network *could serve as a pilot for GEOSS. How would you envision a pilot program to link these two visions—one of which (GEOSS) seems quite undeveloped?*

A4. I agree that GEOSS plans are dominated by technological descriptions of the system, without a considered science plan that includes natural hazard reduction elements. A tsunami warning system would be an interesting pilot, because a properly formulated warning system would (1) illustrate the technical approaches to integrating diverse data streams from different instrumentation; (2) show how the results of basic research could be applied in a timely and concrete way to the characterization of a difficult phenomenon; (3) show the value of linking basic and applied research collaborations, integrated observations, and open data exchange not only to the safety of wealthy countries, but to the building the scientific and technical capacity of less wealthy ones, and (4) show how information products can be derived to meet the needs of diverse constituencies.

Q5. Your points about the National Science Foundation are well-taken. Is this a question of ensuring NSF's participation with NOAA and USGS as the network upgrades and development take place or do you recommend additional research funding at NSF above the current earthquake research program?

A5. NSF has a role to play in ensuring that the GSN remains healthy, through the competitive peer review process for geoscience instrumentation and facilities that has served IRIS and the GSN so well. Moreover, since we are dealing with new understanding of dangerous phenomena, NSF has a role to play in funding the basic research that ensures that the United States maintains a healthy Earth and environmental science research profile, supporting research in the new technologies for new generations of instrumentation, supporting social science research into risk management, perception, and assessment, and support for the new thinking about how to link science outcomes to broad social goals. A tsunami warning system without basic research would soon be obsolete, ineffective, and a waste. Finally, NSF is the critical link in maintaining the pipeline supplying a technical workforce for, in this case, natural hazards reduction.

Question submitted by Representative Eddie Bernice Johnson

Q1. The advancement of marine seismic research is allowing us to uncover data that never before has been thought possible. The knowledge that can be gained from this research is will paramount in aiding early warning detection systems. However, with limited resources available we need to make sure that the benefit of detection systems is maximized. Marine seismic research is now able to detect megathrusts or faults where larger earthquakes occur within subduction zones, similar to that in the Indian Ocean. This seems to be the first step in implementing an effective detection plan. How close are we to mapping out the locations of these megathrusts so that the most successful actions can be taken?

A1. The technology for mapping the seafloor at high resolution exists, but the costs of doing this comprehensively for the U.S. is generally estimated to be a few hundred million dollars. In a revenue-restricted world, the mapping should be prioritized by the potential exposure of people, their livelihoods, their assets, and the Nation's economic productivity. Thus urban areas, ports, and critical ecosystems should be mapped comprehensively. "Nested mapping," wherein lower-resolution mapping permits a more effective design of high-resolution surveys, may be a productive strategy that can adapt to new information gathered at lower resolution by oceanographers.

ANSWERS TO POST-HEARING QUESTIONS

Responses by Jay Wilson, Coordinator, Earthquake and Tsunami Programs, Plans and Training Section, Oregon Emergency Management

Q1. If you could change one or two things about the Administration's proposal, what would it be and why?

A1. Make the entire tsunami program under the direction of the National Tsunami Hazard Mitigation Program Executive Steering Committee consisting of voting members as follows:

- NOAA (two representatives—warning and tsunami inundation mapping),
- USGS (two representatives—seismic network and geology of tsunami sources and deposits),
- FEMA (one representative),
- NSF (one representative)
- Oregon (two representatives—emergency management and tsunami hazard mapping)
- Washington (two representatives—emergency management and tsunami hazard mapping),
- California (two representatives—emergency management and tsunami hazard mapping),
- Hawaii (two representatives—emergency management and tsunami hazard mapping)
- Alaska (two representatives—emergency management and tsunami hazard mapping),
- Island Territories (two voting representatives to represent all of the territories—one for emergency management and one for tsunami hazard mapping).

Add $7.8 million to the $35 million budget to fully implement the current NTHMP goals, which include a strong education and inundation-mapping component.

Add $700,000 per state per year to fund "tsunami champions" in each vulnerable community who would organize neighborhood response and do door-to-door outreach. Only states highly vulnerable to locally generated tsunamis would receive this additional support. These are Alaska, Hawaii, Oregon, Washington, and California. The total would be an additional $3.4 million.

For example, in Oregon this would place a half-time position in every vulnerable community. For Oregon, you would need ~20 half-time positions with some travel, mailing, etc., costs. This would amount to ~19 x $30,000 x 1.18 indirect costs = $672,600/year + Oregon Emergency Management and Oregon Dept. of Geology and Mineral Industries administrative costs for the community grant program of ~$10,000 per year for a total of $685,000 for a typical state. The grand total for the five states would be ~$3.43 million per year.

Q2. Recommendations to improve the Administration's Tsunami Plan:

The following is a list of recommendations made by witnesses to improve the Administration's plan. It would be helpful to have comments on each of the recommendations.

Do you agree with the recommendation that:

- *More attention should be paid to education, especially for tsunami that are either generated close to shore or are generated by events that cannot be felt.*

A. Yes, this is the highest priority of all of the items in terms of lives saved per dollar spent.

- *Hazard mapping efforts should be expanded.*

A. Yes, education is useless unless the hazard is defined accurately in terms of where flooding can be expected and how soon the wave arrives.

- *More money should be allocated to local warning systems and research to improve them.*

A. This is of lower importance than mapping and education in terms of lives saved per dollar spent.

- *There should be a greater and more explicit commitment to operation and maintenance costs of the buoys.*

A. This is of lower importance than mapping and education in terms of lives saved per dollar spent.

- *Redundant buoys should be purchased and funds allocated to developing better buoys.*

A. This is of lower importance than mapping and education in terms of lives saved per dollar spent.

- *More work should be done on tsunami probabilities to better site the buoys.*

A. Yes, this can be done at very little cost and could yield substantial savings by maximizing the effectiveness of any buoys installed.

- *The buoys should be equipped with more instruments to be better integrated into NOAA and NSF research programs.*

A. Yes, maintenance and installation of buoys is so expensive that it is incumbent on NOAA to make sure that they give data on weather, wind waves and any other possible data that can be produced.

- *Tsunami efforts should be incorporated into the development of a broader multi-hazard warning system.*

A. Yes, any warning infrastructure should be multi-hazard.

- *The Global Seismic Network should be expanded and should include new kinds of equipment.*

A. This is of lower importance than tsunami hazard mapping and response education in terms of lives saved per dollar spent.

- *NSF funding should be provided to properly fund the operation and modernization of the Global Seismic Network.*

A. In terms of tsunami hazard mitigation for locally generated tsunamis, which pose the greatest danger, three much higher priorities for NSF research are:

1. Improvement of tsunami modeling software, including fundamental research into the numerical methods now used world-wide to simulate tsunami flooding. All current methods suffer from energy losses and inaccurate simulation of dry land inundation that generally cause underestimation of the hazard.
2. Improvement of fundamental understanding of the mechanics behind and prediction of tsunami fault and landslide sources. Uncertainty in these parameters translates to tsunami hazard mapping uncertainties on the order of 50 to 100 percent (elevation and inland penetration of the waves).
3. Ground truth tsunami simulations by improved understanding of ancient tsunami deposits. The past is the key to the present. Simulations should reproduce current velocities and water depths consistent with ancient tsunami deposits, but deriving current velocities and water depths from the deposits needs much additional research both in the field for modern tsunamis and in the laboratory.

- *The Advanced National Seismic System should be expanded.*

A. This is of lower importance than tsunami mapping and response education in terms of lives saved per dollar spent. If the seismic networks in the Cascadia region were more dense, then a better understanding of small (M 4–5) earthquakes along the fault boundary.

Q3. What are the biggest gaps in our scientific understanding of tsunami? How should the Administration address these gaps?

A3.

- Improvement of tsunami modeling software, including fundamental research into the numerical methods now used world-wide to simulate the flooding. All current methods suffer from energy losses and inaccurate simulation of dry land inundation that generally cause under-estimation of the hazard. NSF should announce a special program and proposal solicitation with dedicated funding aimed at this specific problem.
- Improvement of fundamental understanding of the mechanics behind and prediction of tsunami fault and landslide sources. Uncertainty in these param-

eters translates to tsunami hazard mapping uncertainties on the order of 50 to 100 percent (elevation and inland penetration of the waves). NSF should announce a special program and proposal solicitation with dedicated funding aimed at this specific problem. USGS should fully fund research on tsunamigenic landslides and faults. Work at NSF and USGS should be coordinated through the National Tsunami Hazard Mitigation Program to focus the research on tsunami fault and landslide sources of highest priority for mapping of tsunami inundation by State geological surveys.

- Ground truth tsunami simulations by improved understanding of ancient tsunami deposits. The past is the key to the present. Simulations should reproduce current velocities and water depths consistent with ancient tsunami deposits, but deriving current velocities and water depths from the deposits needs much additional research both in the field for modern tsunamis and in the laboratory. NSF should announce a special program and proposal solicitation with dedicated funding aimed at this specific problem. USGS should fully fund paleoseismic and paleotsunami research. Work at NSF and USGS should be coordinated through the National Tsunami Hazard Mitigation Program to focus the research on tsunami deposits of highest priority to ground-truth tsunami inundation simulations used by State geological surveys for hazard mapping.

Questions submitted by Representative Bart Gordon

Q1. What is the estimated cost for a local community to become Tsunami Ready? What is the average annual cost of operation and maintenance to local communities to sustain the program? How often do your Tsunami Ready communities conduct drills?

A1. We estimate for an average coastal community at least $10K to start and $5K per year afterward for maintenance. The contributions in staff time for Lincoln City Oregon added up to $15,000 over the past two years for certification. Annual costs/in-kind contributions from Lincoln City include:

- Staff time (Public Works—800 hours, Emergency Manager—400 hours, clerical—156 hours, and not including the City Manager's time)
- Administrative costs (travel, Internet services, and training)
- Satellite fees
- Printing fees for publications
- NOAA Weather Radios from Radio Shack
- And State expenses (mapping, evacuations brochures, tsunami signs and staff time)

Tsunami evacuation drills for schools in inundation zones are mandated at least once per year by State law. For other facilities or businesses it happen once per 2–3 years for the most active communities.

Q2. How are your Tsunami Ready and Earthquake preparedness programs connected? If a large earthquake occurred close to shore would the earthquake damage to communication equipment and shelters be likely to prevent evacuation plans from being executed? Are the Tsunami Ready communities also earthquake-hardened? Should we move to a multiple hazard-preparation program to deal comprehensively with multiple hazards that particular communities face?

A2. TsunamiReady is merely a program designed to give recognition for the base minimum level of preparedness for tsunamis, not earthquakes. It is not really adequate for full mitigation for tsunamis and does little for earthquake mitigation. A near-shore earthquake would likely damage communication equipment, but there would be little or no time to deliver an evacuation message anyway for an incoming local tsunami.

Yes, large local earthquakes have the capacity to cause damage to communication equipment and shelters if those facilities are built at locations vulnerable to liquefaction or ground amplification. Additionally, local tsunamis generated from local earthquakes will likely damage much of the communication infrastructure and many evacuation shelters where shelters are not specifically designed to withstand the earthquake. Note that in many cases bridges are the weakest links for executing evacuation plans of a few critical areas like Seaside. Bridges area major problem for long-term response and recovery, since they will isolate most coastal towns from inland areas for weeks or months.

Tsunami preparedness works well for a great many other hazards, since it relies on good education beforehand (really the only effective mitigation for a locally generated tsunami), emergency response planning (command and control), communication systems, and emergency resources (food, water, medical services, and shelter).

Q3. In the case of a tsunami generated from an earthquake far off-shore, have you experienced problems of spectators coming to vulnerable coastal areas to witness the tsunami?

A3. These problems do occur and have not to date resulted in damage or loss of life. However it does point out the need for continuing education of both full time and transient populations in coastal areas.

Q4. What role does NOAA weather radio play in the alert dissemination system of Storm Ready and Tsunami Ready?

A4. NOAA weather radio is a valuable resource for issuance of warnings and "all clear" messages for distant tsunamis and storms. The radio is not as useful for locally generated tsunamis that arrive too quickly for it to operate. It is useful for delivering guidance to local officials on the decrease of wave activity after a local tsunami.

Q5. Has it been difficult to sustain funding for your tsunami hazards programs in Oregon given that tsunami are rare occurrences and therefore the warning system may not be needed for decades?

A5. It has been virtually impossible to attract State resources other than a few one-time grants in the early years of the State mitigation effort. With State resources not able to keep schools open a full school year, mitigation of a rare catastrophic event is a low priority. The State has benefited from the National Tsunami Hazard Mitigation Program (NTHMP) from its inception several years ago. Funding for fundamental tsunami hazard mapping and education from NTHMP (contracted through NOAA) is the reason we have been able to make the progress we have. Funding has been forthcoming because of the excellent federal-State partnership powered by the five Pacific states having a majority vote in the Executive Steering Committee of the NTHMP. When states have ownership and control of some substantial portion of the funding, the resources are more likely to be targeted efficiently to the needs of local government where all really effective mitigation occurs.

The NOAA–NWS tsunami warning system, from critiques given by the State membership of the NTHMP, has become much more reliable. States insisted on elimination of false warnings for distant tsunamis and that has largely occurred mainly by some structural changes in the way warnings are issued and to a lesser extent by implementation of the new buoy sensing technology.

Q6. How far along is Oregon in producing a full set of inundation maps for the Oregon coast? How often do you need to update these maps?

A6. Oregon is about 80 percent of the way to finishing inundation maps with software that was developed over a decade ago. Tsunami modelers have suspected for some time that the prevalent software under predicts the flooding danger. The technology is poised for major advance as a result of knowledge gained from the Sumatra tsunami, but continued support will be needed for a number of different models and centers of modeling excellence to advance the techniques.

Most of the current maps of complex areas like bays and estuaries should be redone in the next decade, as the simulation software becomes more robust. Once this new generation of maps is complete, little updating will be necessary. Some areas with relatively simple terrain (cliffs next to one flat area close to the shoreline) will not need to be redone even with the improved software.

Q7. You recommended a sustained annual allocation of $7.8 million dollars for the NTHMP. This figure is higher than the figure in the new proposal and higher than current expenditures. How did you arrive at this figure? What activities would be increased with the additional funding? Would this allow states to allocate more funding to local communities to become Tsunami Ready?

A7. NOAA arrived at this figure after consultation with reviewers of the NTHMP and in consultation with the Executive Steering Committee of the NTHMP in 2002. It achieves a modest increasing in the base level funding for ongoing tsunami inundation mapping, public education, publication of products from the five Pacific states, and maintenance of currently installed buoys and seismographs. The budget also adds base level support for tsunami mapping and mitigation of Caribbean and Pacific island territories. The budget does not support large expansion of the seismograph or tsunami buoy network.

The budget would accelerate inundation mapping and education plus allow additional improvement of the warning system so NOAA could predict actual flooding impact of distant tsunamis rather than just issuing a generalized warning.

There would be funding to local communities to become recognized as TsunamiReady, since there would be increased support of evacuation map brochure production and installation of evacuation signs. There would not be adequate funding in local communities to completely achieve the more difficult mitigation goal: creation of a "culture of response" so people would know instinctively that an earthquake is the warning to get to high ground. That goal requires an ongoing commitment to public education and neighborhood emergency response. TsunamiReady, as currently defined, does not achieve this.

Funding of a "tsunami champion" in every community to do the hard work of organizing for evacuation and reaching out door-to-door and neighborhood-by-neighborhood would, in conjunction with school curricula, achieve the goal. This "tsunami champion" would be at least a half-time position for every vulnerable community and cost approximately an additional $700,000 for each of the five Pacific states.

Additionally, participants in a recent Oregon Tsunami Workshop with over 90 representatives from seven coastal counties and State agencies, acknowledged the need for a State administered grant program to oversee funding of local emergency infrastructure (sirens, emergency caches of food, medical supplies and shelter, and satellite phones). We propose $1.3 million for the first year with a similar grant amount for the next nine years to invest in coastal emergency communications that would serve, not only tsunami, but also multiple hazard warnings. Over this 10-year period we would be able to meet the requests of virtually everything on the workshop list.

Appendix 2:

Additional Material for the Record

STATEMENT IN SUPPORT OF IMPROVED EARTHQUAKE AND TSUNAMI HAZARD MITIGATION BY STEVE MALONE, PRESIDENT, THE SEISMOLOGICAL SOCIETY OF AMERICA

As compassionate people we are all saddened by the death and destruction caused by the Sumatra earthquake and resulting tsunami, but as seismologists we are additionally dismayed by the needless deaths since tsunami warning systems are scientifically and technologically possible. Indeed, many seismologists are reflecting on our discipline's responsibility for the extent of the human suffering. However, this reflection is rarely on what more we could have done scientifically and more often on our inability to translate and disseminate our knowledge in a way that might have made a difference. We have the understanding and technology to rapidly issue warnings for tsunamis based on seismic and oceanographic data (and already issue warnings for the Pacific Basin). We publish scientific papers about our understanding of past events and the way geology works, often with an eye to anticipating future hazardous events. With all of this knowledge and technology how could this disaster have occurred? Unfortunately too often the connection between scientific understanding and practical, applied use of that understanding is lacking or comes too late.

The Administration's proposed tsunami hazard reduction plan combines the capabilities of two agencies to help address the tsunami problem of the future. This is a good idea and will not only help protect U.S. coastal areas but help protect those of neighboring countries as well. However, this technological solution is just a small part of an effective real solution. There is a real danger that in our haste to fix what was broken in the recent disaster, we will fix the wrong thing for next time. Not only is this plan embarrassingly U.S.-centric, it doesn't clearly address the whole problem, even for the U.S. Detecting the earthquake and generating a warning is one thing but distributing the warning to all at-risk populations who have been educated about what to do is the bigger, more critical mitigation effort. Indeed, education alone, even without a warning system, could save large parts of a coastal population. Effective information could be as simple as, " If you feel a strong earthquake and/or see the ocean level behave in an unusual way, get off the coast as fast, far and high as possible." This plan should contain a much stronger educational component.

There are other dangers of the quick fix. While this is an opportunity to significantly improve mitigation efforts for the very serious yet rare tsunami hazard it is critical that the enormity of the recent tragic event not sidetrack us from other equally dangerous and more common hazards. Earthquakes without tsunamis are still the biggest geologic hazard worldwide. Unfortunately, even a moderate earthquake directly under one of the world's very large but unprepared cities will result in many more deaths than resulted from the Indian Ocean tsunami. Improved hazard mapping and building construction practices can make a huge difference in this case. Science and engineering show both where the hazards are high and propose techniques to significantly mitigate those hazards. U.S. science funding has made great advances; however, putting the results into practical action is too often forgotten. As one example, while on this committee's recommendation Congress authorized the Advanced National Seismic System to take a lead role in improving earthquake hazard mitigation Congress has only appropriated 10 percent of the needed and authorized funding. It would be truly unfortunate if in our rush to fix the tsunami problem we forget about other, even more hazardous situations and wait until after one of those occurs to make serious advances.