The Indian Ocean Tsunami Disaster:
Implications for U.S. and Global Disaster Reduction and Preparedness

Summary of the June 21, 2005 Workshop of the Disasters Roundtable

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FOREWORD

The Disasters Roundtable (DR) seeks to facilitate and enhance communication and the exchange of ideas among scientists, practitioners, and policymakers concerned with urgent and important issues related to natural, technological, and other disasters. Roundtable workshops are held three times a year in Washington, D.C. Each workshop is an open forum focused on a specific topic or issue selected by the DR Steering Committee. For upcoming meetings, please visit http://www.nationalacademies.org/disasters.

The Disasters Roundtable Steering Committee is composed of five appointed members and sponsoring ex-officio members. The appointed members at the time of the workshop were William H. Hooke, chair, American Meteorological Society; Ronald T. Eguchi, ImageCat, Inc; John R. Harrald, The George Washington University; Juan M. Ortiz, Tarrant County Office of Emergency Management; Havidán Rodríguez, University of Delaware; Monica Schoch-Spana, University of Pittsburgh Medical Center; and David Simpson, University of Louisville. The ex-officio members were Stephen Ambrose, National Aeronautics and Space Administration; Frank Best, PB Alltech, Inc.; Lloyd Cluff, Pacific Gas & Electric; Timothy A. Cohn, U.S. Geological Survey; Elizabeth Lemersal, Federal Emergency Management Agency; James Russell, Institute for Business and Home Safety; Dennis Wenger, National Science Foundation; and Helen Wood, National Oceanic and Atmospheric Administration. The DR staff includes William A. Anderson, director, and Byron Mason, program associate.

This document presents the rapporteur's summary of the forum discussions and does not necessarily reflect the views of the roundtable members or other participants. For more information on the roundtable visit our website: http://dels.nas.edu/dr or contact us at the address below.

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This summary has been reviewed in draft form by individuals chosen for their diverse perspectives and technical expertise, in accordance with procedures approved by the NRC's Report Review Committee. The purpose of this independent review is to provide candid and critical comments that will assist the institution in making its published summary as sound as possible and to ensure that the summary meets institutional standards for objectivity, evidence, and responsiveness to the study charge. The review comments and draft manuscript remain confidential to protect the integrity of the deliberative process. We wish to thank the following individuals for their review of this summary: Kay Goss, Electronic Data Systems Corporation, and James M. Kendra, University of North Texas.

Responsibility for the final content of this summary rests entirely with the authors and the institution.

Introduction

In the early hours of December 26, 2004 a 9.0 magnitude earthquake occurred underneath the Indian Ocean approximately 100 miles from the western coast of northern Sumatra, triggering a massive tsunami that caused extensive damage in 12 countries. While Indonesia, Sri Lanka, Thailand and India suffered the greatest losses in terms of casualties and structural damage, the impacts of the catastrophe resound globally. Scores of foreign nationals and tourists were among the dead, missing, and injured. Moreover, the scale of the response was unprecedented, as government and nongovernmental disaster relief and recovery efforts were mounted internationally.

As the hazard scholar Dennis Mileti has noted, we "design our own disasters," often unknowingly (Mileti 1999). Disasters like the 2004 Indian Ocean tsunami are a function of societal decisions to develop and settle in increasingly vulnerable coastal areas. These decisions are also a reflection of a nation's financial commitment, in relation to science and technology, to disaster mitigation and preparation. There are significant disparities between industrial and developing nations in this regard. The economic and structural damage caused by the Indian Ocean tsunami highlight the acute vulnerability of poorer communities in developing nations to natural hazards. It is important for all societies to address issues of social inequity to ensure that disadvantaged groups are not exposed to greater environmental risks than others, as is too often the case in many nations.

On June 21, 2005 six months after the disaster, the Disasters Roundtable of the National Academies convened a workshop on the *Indian Ocean Tsunami Disaster: Implications for U.S. and Global Disaster Reduction and Preparedness* in Washington, D.C. Workshop speakers and participants examined:

1. The initial findings gained by researchers that investigated various aspects of the disaster and the implications of this information for developing effective tsunami mitigation, detection, warning, and emergency response systems;

2. The integration of emerging U.S. initiatives into regional and global efforts to reduce the impacts of such disasters; and

3. The implications of the Indian Ocean tsunami disaster for multi-hazards mitigation and preparedness at the national and international levels.

The workshop was opened by the chair of the Disasters Roundtable, William H. Hooke, director of the Atmospheric Policy Program at the American Meteorological Society. The format of the workshop involved presentations by individual speakers and panelists, followed by open discussion.

Session I: Initial Scientific Investigations of the Disaster

The term tsunami was originally used to describe "harbor waves" that cause extensive damage to low-lying Japanese coastal communities. In general parlance, a tsunami consists of a series of large ocean waves generated by a large-scale undersea disturbance like an earthquake, volcanic eruption or landslide (National Oceanic and Atmospheric Administration [NOAA], 2004). An earthquake that occurs in the subduction zone of the ocean floor, where tectonic plates collide, has the potential to generate destructive tsunami waves (International Tsunami Information Center [ITIC], 2005) that can move at speeds averaging 450 (and up to 600) miles per hour (201.168 to 268.22 meters per second) and travel thousands of miles with the capability of inundating large land masses (U.S. Geological Survey [USGS], 1999). Earthquakes in the subduction zone of the Indian Ocean trigger tsunamis every few hundred years, according to Lloyd Cluff, director of the Geosciences Department at Pacific Gas and Electric (PG&E).

On December 26, 2004, off the west coast of northern Sumatra, the fourth largest earthquake since 1900 occurred underneath the Indian Ocean and produced tsunami waves that caused extensive damages throughout south Asia. Sri Lanka and the Indonesian island of Sumatra were the most heavily damaged countries, but the devastation was widespread throughout the region.

Physical Impacts

Patrick Lynett, assistant professor of civil engineering at Texas A&M University, visited Sri Lanka two weeks after the disaster as a member of one of the first U.S. research teams in the affected region. He reported that the northern Sumatra province Bande Aceh suffered the brunt of the tsunami's tremendous power. According to Lynett, Sumatra received little advance warning of the oncoming tsunami; ground tremors were quickly followed 15 minutes later by tsunami waves that exceeded 30 meters in height. He reported that following the initial landfall in Sumatra, Thailand and Sri Lanka had only 90- and 120-minute lead times, respectively, before the arrival of the tsunami's waves.

The tsunami's height and force were determined by examining flow indicators. For example, tsunami waves ripped away bark as they moved over the island of Sri Lanka, and Lynett and his team were able to determine the tsunami's height by analyzing the subsequent bark lines. Mud lines along residences and other structures were also indicators of the tsunami's height (see Figure 1). Bark and mud lines are perishable forms of data that may be missed if researchers are unable to examine damaged areas shortly after a disaster event. In addition to field observations, Lynett noted that the team also used eye witness accounts to add to its knowledge about the disaster.

Lynett noted that the disaster reinforces the importance of education in preparing the public to respond to such events. He cited an example of one resident who understood the warning signs of an approaching tsunami and thus was able to warn residents of the danger. He also stressed the importance of having sound construction standards and designing load-resistant structures, noting cases where buildings that met high construction standards in Sri Lanka survived the impact of the tsunami. Lynett also indicated that mangrove forests and other forms of vegetation can provide natural protection in some locations at risk to tsunamis.

Figure 1. Mud lines on a destroyed Sumatran building. Photograph by Patrick Lynett, Texas A&M University

According to Lloyd Cluff, who surveyed impacted areas in Sumatra, the quality of construction was the most important factor in determining which facilities withstood the tsunami. Damage was widespread, but some structures, like local mosques, that were reinforced with concrete withstood the force of the tsunami's waves. He reported that residences are not generally reinforced with concrete. Cluff noted that Sumatra supplies 40 percent of Japan's natural gas. While some gas facilities were damaged by the tsunami, Japan's supply was not interrupted. These reinforced buildings withstood waves 9 to 13 feet (3 to 4 meters) in height. Cluff stated that his company, PG&E, plans to rely on Sumatra's experience when planning and building new facilities in coastal areas.

As noted earlier, a near-shore tsunami occurs too quickly for advanced warning; thus public education is imperative to save lives. Sumatrans experienced the earthquake's tremors for five minutes, and individuals that understood the implications of the earthquake sought higher ground for safety. According to Cluff, most of the residents had just finished their early prayers at the mosque and were at home when the tsunami arrived. Cluff recounted a story told to him by a local man who had been hosting a post prayer gathering at his house when the first wave hit. As the water rushed in, the man and his guests sought shelter on the second story of his house and prayed for their safety. The rising water lifted a boat onto the garage of the house, enabling the group to survive the disaster. Cluff noted that there were many of these survival stories of "miraculous emergency response."

Social and Behavioral Aspects

Staff members of the University of North Texas and the University of Delaware's Disaster Research Center (DRC), including assistant professor of sociology Tricia Wachtendorf, were part of a team of social science researchers that traveled to India and Sri Lanka to collect perishable data—that would be difficult or impossible to gather after significant time had passed—on the social impacts of the tsunami disaster. The team collected information through interviews and field observations, identified priority areas for future social

science research, and developed ties for possible future research visits. Wachtendorf stated that she and her colleagues noted a general sense of uncertainty among the victims of the disaster. Many of the disaster victims expressed concerns about the likelihood that they would be able to return to their homes and jobs, and they worried that they would have to relocate far from the coast and learn new trades. Some of the fishermen interviewed by Wachtendorf and her team acknowledged that their perception of the water had also changed; many now feared the ocean, particularly since the familiar landscape of the shore had changed. Wachtendorf noted that others were not certain that they would receive government assistance to rebuild because initial compensation programs were designed to compensate landowners and not their tenants. She stated that the uncertainty in the victims' lives disrupted sleep patterns, increased stress levels, and interrupted their daily activities.

Wachtendorf reported that many of the initial temporary shelters were inappropriate. She noted that some of the tents donated in India and Sri Lanka by relief agencies retained heat and were not expandable. As a result, disaster victims slept in makeshift shelters and used the donated tents for storage. According to Wachtendorf, similar usage concerns arose as some villagers shifted from temporary shelters to temporary housing. Fearing potential fires, the Indian and Sri Lankan governments wanted villagers to occupy housing constructed with metal roofs and siding rather than thatched roofing. Wachtendorf reported that the Disaster Mitigation Institute, a mitigation and relief organization in the region, brokered a compromise to build structures with metal siding and thatched roofing to allow heat to escape the dwellings without posing a huge fire risk. She noted that these structures were used by the villagers, highlighting the importance of stakeholder involvement in relief and recovery efforts. Wachtendorf also stressed the importance of balancing the tension between hazard mitigation efforts and the desires of citizens to resume routine economic and residential activity as the region rebuilds.

During the discussions that followed the panel presentations, several participants raised concerns that impacted communities are rebuilding using construction standards that predate the 2004 tsunami. Participants noted that engineers are continuing to build seismically inappropriate structures because of the "rarity" of tsunami events.

Session II: Disaster Response and Recovery Activities

Gregory Gottlieb, director of the Office of Foreign Disaster Assistance (OFDA) of the U.S. Agency for International Development (USAID), stated that OFDA is a self-contained unit consisting of a cadre of staff in the United States and abroad that can be mobilized quickly to respond to international disasters. OFDA has six offices worldwide, two of which are in Asia—one in Nepal and one in Bangkok. According to Gottlieb, the OFDA has a budget of $235 million appropriated by Congress. Additional special appropriations may be provided for extreme disasters. In the case of the Indian Ocean tsunami disaster, OFDA spent $110 million in two months.

Gottlieb stated that OFDA operates as an assessor of need rather than a program implementer, and therefore relies on partnerships with other organizations. In response to the Indian Ocean tsunami, OFDA partnered with the U.S. Department of Defense (DOD), which gave them access to DOD helicopters to survey damaged areas and deliver emergency aid and healthcare. OFDA also collaborated with the military units of Japan, Australia, and Singapore.

Following an international disaster, OFDA receives many calls from U.S. citizens who want to donate items. Gottlieb stressed that, although this is generous, money is preferred because of the convenience and flexibility that it allows for victims and assistance providers. He stated that it is much better to donate money

and allow organizations that are familiar with disaster aid and recovery to dispense services and aid to victims.

In the discussions that followed, participants raised concerns about the safety of relief workers in areas experiencing political turmoil and the possibility of establishing a "bank" of international organizations and professional societies charged with stockpiling medical supplies in advance of a disaster, allowing for quicker responses.

Session III: Facing the Tsunami Risk in the United States and Abroad

The United States has traditionally responded to tsunami events in the Pacific Ocean by creating warning centers, as evidenced by the establishment of the Pacific Tsunami Warning Center following the tsunami of 1946 that damaged Hilo, Hawaii, and the creation of the Alaska Tsunami Warning Center in 1965 following the 1964 earthquake. Eddie Bernard, director of NOAA's Pacific Marine Environmental Laboratory, described tsunamis as low-probability, high-impact events. He noted that the perception of tsunamis as rare events has resulted in modest funding of research by agencies. However, Bernard reported that during the six month interval of January–June 2005, eight tsunami warnings were issued for the Pacific Ocean region. States along the Cascadia subduction zone, which lies north of the San Andreas Fault and extends north to Vancouver Island, are particularly at risk from tsunami threats, highlighting the importance of tsunami research in the United States. The NOAA National Geophysical Data Center's historical tsunami database contains data about past tsunami events, including sources, land run-up locations of tsunami waves, water heights, damage, and deaths. This data is valuable for studying the physical and economic impacts of tsunami events; it is also used to assess the relative risk of tsunamis. Bernard noted that U.S. tsunami research generally lacks an economic context and would benefit from the inclusion of a social science component. He stated that tsunamis impact the economy in terms of productivity, and tsunami warnings trigger behavioral patterns associated with emergency evacuations. Bernard suggested that policies should be made with the recognition that there is a baseline risk for tsunamis everywhere but that there are certain areas that are more vulnerable than others.

In the discussion that followed, participants addressed the possibility that a potential landslide and earthquake in Palos Verdes, California could result in a tsunami with waves reaching 30 feet in height, impacting the ports of Los Angeles and Long Beach. While the length of the needed recovery time was debated, participants agreed that such an event would have an economic ripple effect across the United States.

Local and State Preparedness Programs

Richard Eisner, coastal regional administrator for the California Office of Emergency Services (OES), stressed the importance of reliable warning systems and the need to provide accurate information to the general public. He reported that following the June 15, 2005 7.2 magnitude earthquake 90 miles from the northern California coast, the California OES received contradictory information from the tsunami warning centers. The Alaska Tsunami Warning Center issued a tsunami warning within five minutes of the earthquake. Shortly thereafter, the Pacific Warning Center reported that the Pacific region did not face an evident tsunami threat. The warning was cancelled, but the contradictory information had already been disseminated to the public via the media, prompting unnecessary evacuations.

According to Eisner, many of the methods and technologies used to warn the populations of the Pacific United States are outdated, resulting in information that is difficult to interpret; additional challenges are created by the inconsistencies that exist between the two tsunami warning centers. Eisner suggested that the centers need to use consistent warning formats and protocols; and should be staffed 24 hours a day, rather than their current 8-hour staffing. Eisner also called for better understanding of the process of information distribution for near source tsunamis. Because advanced warning time is limited in the advent of a tsunami, efforts to educate the public to recognize the signs and respond quickly are vital. The tsunami warning centers would benefit from the assistance of social scientists in formatting and distributing their messages in an effective manner, according to Eisner.

National Initiatives

NOAA and USGS are the primary agencies involved in tsunami research and development in the United States. As a result of the December 26, 2004 tsunami, NOAA and USGS are working to strengthen the U.S. tsunami program. Both agencies received supplemental appropriations in FY 2005 for tsunami-related work, and they expect to receive additional funding for tsunami research in FY 2006. USGS is responsible for earthquake detection and prediction. Its role in the tsunami program is to provide seismic data to NOAA quickly in a format that can be readily understood. NOAA, which has primary responsibility for providing tsunami warnings to the nation and assumes a leadership role in tsunami observations and research, monitors the oceanographic warning systems or Deep Ocean Assessment and Reporting of Tsunamis Stations (DARTs), an integral part of NOAA's tsunami warning system. DART station building and ship deployment are the biggest element in NOAA's tsunami program at present according to John McNulty, director of NOAA's Office of Operational Systems. NOAA plans to spend additional funds to expand their existing network of buoys.

Eight elements make up NOAA's tsunami program:

1. Deep Ocean Assessment and Reporting of Tsunamis Stations (DARTs);
2. National Water Level Observation Network (NWLON) Stations;
3. expansion and upgrade of Seismic Network in the Pacific and Caribbean;
4. inundation mapping, modeling, and forecasting;
5. expanded tsunami warning center operations in West Coast/Alaska Tsunami Warning Center and Pacific Tsunami Warning Center (PTWC);
6. expanded facilities at the PTWC and National Data Buoy Center (NDBC);
7. provide incentives for communities at risk to participate in the TsunamiReady program; and
8. design, create, and populate and maintain Tsunami Data Long Term Archive.

James Devine, senior advisor to the director of USGS on science applications, outlined plans for USGS' supplemental and future tsunami funding. The funding will be used to:

1. update the Global Seismic Network computing capabilities. The equipment used at the National Earthquake Information Center in Golden, Colorado will be updated to increase its processing capacity;

2. strengthen the Prompt Assessment of Global Earthquakes for Response program (PAGER), which assesses the impacts of an earthquake;

3. expand the National Earthquake Information Center (NEIC) to a 24-hour operation. The NEIC is charged with determining the location and size of destructive earthquakes globally and disseminating this information to pertinent agencies. In the past the center shut down in the evening hours with a geophysicist available on an on-call basis. Keeping the center open around the clock will increase its response time by 10 minutes or better. This is difficult but critical for predicting potential fast-moving tsunamis, according to Devine;

4. upgrade key global seismic network stations to allow real time information into the earthquake information center for more rapid determination of earthquake characteristics so that they can better advise NOAA on the potential for a tsunami; and

5. create 13 new stations in the Caribbean. The eastern United States and the Caribbean currently have few seismic network stations. Increasing the number of stations will aid in tsunami warnings in the two regions.

A tsunami working group was formed under the auspices of the Office of Science and Technology Policy, the Subcommittee on Environment and Natural Resources, the Subcommittee on Disaster Reduction, and the U.S. Group on Earth Observations. This working group is co-chaired by Devine and John Jones, of the National Weather Service, and is charged with developing a plan to sustain the tsunami effort into the future. The current title for the plan is "Tsunami Risk Reduction in the United States: A Plan for Action." Attempting to establish general resiliency to all hazards will be an overarching theme of the plan. The plan will examine the need for consistent protocols among and within agencies in order to create a warning system that is easily understood by all. Research, response planning, and public awareness will also be covered in the plan.

In the discussion that followed the panel, participants addressed the need to educate the public about the potential risks of tsunamis. Some suggested that cable and satellite networks could make better use of the Emergency Alert System (EAS) and the NOAA weather radio, which are available to subscribers for free. It was noted that the Federal Communications Commission (FCC) does not require stations to use EAS; participation is voluntary.

Session IV: Implications for Multi-Hazard Mitigation and Preparedness

State and Local Level

The unpredictability of hazards and the uncertainty of state and local funding and programs make it difficult to prioritize investments for mitigation according to Richard Eisner of the California Office of Emergency Services (OES). For tsunami hazards in California, there are limited mitigation options to reduce exposure because most of the coastline is developed. Although mitigation should be a priority, according to Eisner, changing land use patterns in an already developed area seems impossible. Currently there are no additional construction standards for buildings in the tsunami inundation zone. Eisner noted that the Federal

Emergency Management Agency (FEMA)'s 2000 Coastal Construction Manual does not address tsunamis. The expenditures of California's OES are guided by a state steering committee charged with defining the priorities for program spending and activities. Although, as Eisner reported, California is completely dependent on federal funding for its tsunami programs.

Local governments are integral in ensuring the success of an emergency operations plan because they decide land use patterns and manage local emergency responses. Eisner noted that states can provide maps and other sources of information, but the decision to utilize and implement these tools lies with local governments. California has mapped nine of its counties and has published emergency planning and land use guidance tools. These tools can be used to develop evacuation routes, identify high-risk populations, and make educational materials available to communities. Tsunamis have also been included in California's Catastrophic Disaster Response Plan, according to Eisner.

National Level

FEMA, an agency within the Department of Homeland Security, is responsible for hazard mitigation and preparedness activities at the national level. FEMA administers several programs related to earthquake and flood hazard mitigation that incorporate tsunamis. The National Earthquake Hazards Reduction Program (NEHRP), the National Flood Insurance Program, the Hazard Mitigation Grant Program, and flood mapping programs all have relevance to tsunami mitigation, noted Michael Buckley, acting deputy director of FEMA's Mitigation division.

FEMA is involved in many specific projects dealing with tsunamis, according to Buckley. FEMA, partnering with NOAA and the USGS, is working with the city of Seaside, Oregon to develop more accurate tsunami data and to incorporate that data in new flood maps. FEMA initiated a project in the fall of 2004 to develop tsunami design and construction criteria for shelters capable of withstanding specific loads that would allow for vertical evacuation. This program will work with the Oregon State University's updated tsunami research program, which was funded by the National Science Foundation.

The Disaster Mitigation Act of 2000 requires states and localities to develop and submit hazard mitigation plans to FEMA in order to be eligible for FEMA grant funding. Buckley stated that all of the Pacific states including Hawaii address tsunamis in their mitigation plans.

International Level

The World Bank is an international development financial institution that loans money and awards grants to developing countries for social and economic development. The Hazard Management Unit (HMU) of the World Bank concentrates on furthering poverty reduction through effective hazard risk management. During her tenure with HMU, Margaret Arnold has worked to document the links between poverty and disasters. She stated that developing countries suffer the most from disasters. Developed countries often experience higher economic losses, but many of these losses are insured, and lives are better protected. The HMU has been working to improve the World Bank's response to emergencies by training staff to assess damages and impacts of disasters on local and national economies and to facilitate a more developmental approach to recovery. Arnold noted that the HMU has also been developing country case studies to demonstrate the value of investments in disaster risk management. She indicated that the HMU needs to develop these studies in order to generate a demand among borrowers for investments that involve prevention and mitigation in addition to rebuilding.

A challenge to disaster management lending at the World Bank is that, unlike more clearly delineated water or transportation sectors, disaster management efforts span across all of the program areas in which the World Bank works, according to Arnold. As a result, disaster issues have sometimes fallen through the cracks. In order to avoid this oversight, the HMU is developing tools that will allow each development project to include disaster mitigation efforts. Providing incentives for better management of disaster risk at the country and local levels is an important way for the World Bank to encourage resilience. Arnold noted that the World Bank is supporting an innovative compulsory disaster insurance program for homeowners in Turkey. By engaging the private sector in this way the potential for corruption and a lack of building code enforcement is reduced. People living in poor countries do not think that they are entitled to live in safe communities, according to Arnold. Often, they believe that managing many risks on a daily basis is their plight. Arnold added that the World Bank can have a greater impact if it better integrates disaster risk management as an integral part of all its development efforts.

In the discussions that followed the panel, participants raised concerns about conducting disaster response efforts in areas in political turmoil. Participants stressed that it is important for relief organizations and agencies to be sensitive to group conflict and push for greater transparency, accountability, and grievance mechanisms in response efforts.

Session V: Raising Questions about Reconstruction and Recovery

Frederick Krimgold, director of technology assistance and development at Virginia Polytechnic Institute and State University, visited Sri Lanka in April 2005. Much of the tsunami damage had been cleaned up by the time he arrived, but pressing issues, like the quality of the water supply following an infusion of saltwater in coastal wells, remained. According to Krimgold, two days after the tsunami hit, the president of Sri Lanka announced the creation of a new center for national operations. Krimgold reported that the center initially had neither staff nor building, but was charged with coordinating response efforts. The Sri Lankan president also acknowledged that development in the coastal zone had been unsafe and inappropriate and rebuilding should be done to ensure safety. As a result, a buffer zone was created, but Krimgold noted that its construction was not consistent around the island country. On the west side of the island the buffer zone was 100 meters, and on the eastern side of the island, where the fishermen generally reside and work, the buffer zone was 200 meters; situating fishermen at a greater distance from the coast. Moreover, the new buffer zone does not comply with a preexisting law, passed in 1981, which established a buffer zone of 300 meters around the entire island. Hence there should not have been any development along the coast prior to the tsunami, according to Krimgold. He noted that the ongoing instability of the Sri Lankan government has made law enforcement and implementation of land use management very challenging. Krimgold stated that the fundamental question is: How do we address questions of equity and how effective are we at dealing with fairness as an issue in recovery?

William Hooke, director of the Atmospheric Policy Program at the American Meteorological Society and chair of the Disasters Roundtable, concluded the workshop and thanked speakers and participants for their contributions.

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