Lamont-Doherty Earth Observatory, Earth Institute, Columbia University
University Corporation for Atmospheric Research
National Association of Marine Laboratories
Consortium for Ocean Leadership
Incorporated Research Institutions for Seismology
American Geophysical Union
American Meteorological Society
Association of Public and Land-grant Universities
Aerospace Industries Association
The Weather Company, an IBM Business
Vaisala, Inc.
Atmospheric and Environmental Research, Inc.
Cleantech San Diego
Aquaai Corporation
Highwave Ocean Energy
MRV SYSTEMS LLC (Marine Robotic Vehicles)
Ocean Innovations
RBR USA
American Wave Machines, Inc.
Reinsurance Association of America
American Energy Society
Catalina Offshore Products Inc.
Analytics Ventures
Grassy Bar Oyster Company, Inc.
Teledyne RDI Instruments
Assure Controls, Inc.
BMT Group
Deep Ocean Engineering, Inc
OceanGate, Inc.
FlyWire Cameras
National Instruments
Ocean Aero, Inc.
Del Mar Oceanographic
Woods Hole Oceanographic Institution
UC San Diego's Scripps Institution of Oceanography
The Geological Society of America
American Geosciences Institute
University of California System
Penn State University
University of Oklahoma
University of Wisconsin-Madison
University of Massachusetts Dartmouth
University of California, Irvine
University of Georgia
University of Arizona
University of Washington
The University of Texas at Austin
Texas A&M University
University of Colorado Boulder
Oregon State University
University of New Hampshire
University of Delaware
Colorado School of Mines
University of California, Davis
Iowa State University
Michigan Technological University
School of Ocean and Earth Science and Technology, University of Hawaii at Manoa
Rutgers University–New Brunswick
Hubbs-SeaWorld Research Institute
Institute at Brown for Environment and Society, Brown University
The University of Texas at Austin Marine Science Institute
Annis Water Resources Institute, Grand Valley State University
National Snow and Ice Data Center, University of Colorado
The School for Marine Science and Technology at the University of Massachusetts Dartmouth
Sitka Sound Science Center, Alaska
Large Lakes Observatory, University of Minnesota Duluth
Savannah State University
Grice Marine Laboratory, College of Charleston
Belle W. Baruch Institute for Marine and Coastal Sciences, University of South Carolina
Patuxent Environmental and Aquatic Research Laboratory, Morgan State University
National Ground Water Association
National Estuarine Research Reserve Association

Testimony Regarding Fiscal Year 2018 Funding for
NSF, NASA, and NOAA
Submitted to the
Subcommittee on Commerce, Justice, Science and Related Agencies
Committee on Appropriations,
House of Representatives
April 28, 2017

Dear Mr. Chairman and Members of the Subcommittee: Thank you for the opportunity to present testimony from the organizations and institutions listed in the left-hand margins recommending strong and balanced funding for the research programs of NSF, NASA, and NOAA. A strong and balanced research portfolio should include support for the geosciences – by which we mean the earth sciences, the ocean sciences, and the atmospheric sciences.

These disciplines are vital contributors to this Nation's national security, economic competitiveness, and public safety.

While an estimated $60 billion in losses were attributed to Superstorm Sandy, the accurate forecast enabled evacuations and other actions that saved an enormous number of lives. Hundreds of thousands of people lived on land flooded catastrophically by the storm, but the total number of deaths was less than 150, due to timely warnings and evacuations. The impact would have been much worse if Sandy had hit just fifteen years ago, when hurricane forecasts extended only three days into the future, as opposed to five days in 2012. Over the last several decades, forecasts have improved steadily in accuracy, due to continuous improvements in both observations from satellites and aircraft, in the weather prediction models, and in the data assimilation methods used to combine models and observations to produce forecasts. Without these advances – all built on the foundation of broad and deep research programs at NOAA, NASA, and NSF - forecasters would never have seen Sandy's last minute westward turn into New Jersey, but with them they were able to see it five days ahead of time. The resulting accurate and timely forecasts by our academic-government-commercial weather enterprise allowed nearly a week of preparations by governments (local, state, and federal), businesses, institutions, and families, and undoubtedly made a life or death difference for many thousands of people?

How did we acquire this life-saving weather forecasting system? The short answer is that consistent funding for research, observations, infrastructure, and training by the Federal research agencies, thanks to this Subcommittee, the Congress, and ultimately the taxpayers – in science, technology, engineering, mathematics, and education – produced that capability. These investments supported everything from basic research in mathematics and the physical sciences, the computer sciences, and the geosciences to the development of

North Carolina A&T State University Division **of** Research and Economic Development
Metropolitan State University of Denver
Earth & Planetary Sciences, The Johns Hopkins University
Romberg Tiburon Center for Environmental Studies, San Francisco State University
National Weather Service Employees Organization
Institute for Global Environmental Strategies
School of the Earth, Ocean, and Environment, University of South Carolina, Columbia
Bermuda Institute of Ocean Sciences (Bermuda and New York)
The Oceanography Society
Jacksonville University Marine Science Research Institute
The Ocean Foundation
Council on Undergraduate Research
UNAVCO, Inc.
The Coastal and Estuarine Research Federation
Jacques Cousteau National Estuarine Research Reserve
Department of Marine Outreach, Rutgers University
University of Maryland Center for Environmental Science
Skidaway Institute of Oceanography, University of Georgia
School of Freshwater Sciences, University of Wisconsin-Milwaukee
National Association of Geoscience Teachers
American Association of Geographers
Soil Science Society of America
Hatfield Marine Science Center, Newport Oregon
University of California Santa Cruz
College of Fisheries and Ocean Sciences at the University of Alaska Fairbanks
North Carolina State University, Center for Marine Sciences & Technology
Institute for Water and Environment, Florida International University
Association of Ecosystem Research Centers
Stony Brook University
Desert Research Institute
George Mason University
University of South Florida – College of Marine Science
Utah State University
The Weather Coalition
Boston University
Florida State University
San Francisco State University
The University of North Carolina at Chapel Hill, Institute of Marine Sciences
University of Miami
Washington State University
University of Denver
St. Cloud State University
Earth2Ocean, Inc.
Virginia Institute of Marine Science
School of Earth, Energy, and Environmental Sciences at Stanford University
Lyndon State College
Department of Atmospheric Sciences, University of Utah
University of Oregon
Oregon Institute of Marine Biology
University of Connecticut
The University of Alaska Fairbanks
University of Maine Darling Marine Center
University of Louisiana at Lafayette and the Louisiana Immersive Technologies Enterprise
University of Pittsburgh
FAU Harbor Branch Oceanographic Institute
Bigelow Laboratory for Ocean Sciences
Duke University Marine Laboratory
California State University Council on Ocean Affairs, Science & Technology

sophisticated models, satellites, radar, and parachute-borne instrument packages that could make the key observations. Those investments also allowed us to develop an understanding of how the Earth, the oceans, and the atmosphere collectively impact our weather and the environmental conditions that ensued. They enabled us to develop and run forecast models on advanced computing systems that turned huge amounts of raw observations into "actionable advice" for businesses, local and state governments, and our citizens. These advances were coupled with investments in education and training that created the talented and dedicated workforce needed to put it all together. Finally, a host of innovative technologies and the application of social science-informed best practices in communications allowed all this information to be presented in a manner that people could understand and on which they could act.

The Geosciences and National Security

In September 2016, the Center for Climate and Security released a report entitled, *Military Expert Panel Report – Sea Level Rise and the U.S. Military's Mission.* The panel included retired flag officers from all the Armed Services: General Ronald Keys, USAF (ret); Lieutenant General John Castellaw, USMC (ret); Vice Admiral Robert Parker, USCG (ret); Rear Admiral Jonathan White, USN (ret); and Brigadier General Gerald Galloway, USA (ret). The expert panel concluded that risks of sea level rise to coastal military installations and supporting civil infrastructure will present serious threats to military readiness, operations, and strategy. The panel concluded that policies and plans for addressing climate change risks must go beyond infrastructure resilience, and into the realm of operations and strategy.

The authors recommend that policy-makers support comprehensive and preventive measures to address increasing risks from sea level rise. Recommendations included: building capacity to address infrastructural, operational, and strategic risks; gaming out catastrophic climate scenarios in planning; tracking trends in climate impacts; and collaborating with adjacent civilian communities. To get ahead of the risks, policy makers will need the research and the educated and trained workforce that comes from the geosciences community. They will need the basic research, computing, and modeling that comes from the support NSF provides the academic research community. They will also need the data, observational capabilities, computing, and modeling that NASA and NOAA can provide.

The Geosciences – Producing a Workforce for U.S. Industry

The geosciences research that NSF, NASA, and NOAA fund helps educate and train the next generation of geoscientists. Using data provided by the Bureau of Labor Statistics, the American Geosciences

Institute calculated a total of 324,411 geoscience jobs in 2014, and this number is expected to increase by 10% by 2024 to a total of 355,862 jobs. Approximately 156,000 geoscientists are expected to retire by 2024, but over the next decade, approximately 58,000 students will be graduating with their bachelor's, master's, or doctoral degrees in the geosciences. According to the American Geosciences Institute's (AGI) *Status of the Geoscience Workforce 2016*, given minimal non-retirement attrition from the geoscience workforce, there is expected to be a deficit of approximately 90,000 geoscientists by 2024.

Industry hiring of geoscience graduates fluctuates between sectors, with the oil and gas sector taking on some 60 percent of recent Master's graduates who gained employment in the geosciences, and the environmental services sector hiring the largest share (31 percent) of recent Bachelors graduates who stayed in the geosciences, according to the American Geosciences Institute's *Status of Recent Geoscience Graduates 2016* report. Other industries hiring geoscientists include mining, construction, agriculture, transportation, and information technology services, all of which contribute to our national infrastructure. NSF, NASA, and NOAA support for the geosciences contributes significantly to the education and training of these individuals via programs in research, graduate and undergraduate student support.

The Geosciences and Economic Competitiveness – Research Yielding Economic Benefits

The Federal investment in the geosciences provided the fundamental understanding of geologic structures and processes necessary to utilize hydraulic fracturing (fracking) processes to release oil from shale formations. The ability of U.S. companies to develop these natural resources is built upon decades of fundamental research and technology development in the earth sciences. According to a 2013 report from U.S. Chamber of Commerce's 21st Century Energy Institute, fracking has created a job boom even in states that don't have shale deposits, with 1.7 million jobs already created and a total of 3.5 million projected by 2035.

Research on hot-spring-dwelling microbes in Yellowstone National Park resulted in development of the polymerase chain reaction (PCR), a technology that made the molecular biology revolution possible. Scientists discovered that hot spring microbes utilize enzymes that are resistant to the high temperatures required for PCR. PCR is the process by which scientists can generate copies of a single strand or piece of DNA and is indispensable for the multi-billion-dollar biotechnology industry.

Moreover, private enterprise – ranging from insurance companies and large engineering firms to the marine and overland shipping sectors and to small farmers – increasingly relies on the results of the long-term weather, climate, and other natural hazards research enabled by government and university scientists to make strategic management decisions. The Nation's private sector needs to incorporate weather and climate risks into its risk-management portfolios to remain globally competitive. Industries that rely on global supply chains and distribution centers, such as the major overnight shipping companies, are beginning to use the results of fundamental geoscience research in their day-to-day decision making as well as long-term strategic planning.

The Geosciences and Public Safety

The benefit of the investment in public weather forecasts and warnings is substantial: the estimated annualized benefit is about $31.5 billion, compared with the $5.1 billion cost of generating the information (Lazo et al., 2009). In 2016, there were 15 weather and climate disaster events with losses exceeding $1 billion each across the United States. These events included a drought event,

four flooding events, eight severe storm events, a tropical cyclone event, and a wildfire event. Overall, these events resulted in the deaths of 138 people and had significant economic effects on the areas impacted.

We continue to experience extreme weather events in nearly every region of the country. Tornadoes in Oklahoma, Kansas, and Missouri; floods in Louisiana; droughts in Texas; and blizzards in New England. According to the NAS Report, *When Weather Matters*, the annual impacts of adverse weather on the national highway system and roads are staggering: 1.5 million weather-related crashes with 7,400 deaths, more than 700,000 injuries, and $42 billion in economic losses (BTS, 2007) and $4.2 billion is lost each year because of weather-related air traffic delays (NOAA, 2010). The death, destruction, and economic harm communities and businesses experience from these and other weather events could be further reduced with continued research and training in the geosciences.

Technologies and observing systems developed to examine the fundamental earth structure have also provided data and enabled models necessary for forecasting and estimating the impact resulting from major earthquakes, tsunamis, volcanic eruptions, and landslides. Understanding of disaster events enables business and government to engage in informed risk management and mitigation and to develop response strategies. When an event does occur, early warnings for evacuation based on timely forecasts and characterization of these disasters has the potential to save billions of dollars and countless lives. For example, EarthScope is a NSF program that has deployed thousands of seismic, GPS, and other geophysical techniques to explore the structure and evolution of the North American continent and to understand the processes controlling earthquakes and volcanoes. Thousands of geophysical instruments create a dense grid covering the continental United States. Scientists from multiple disciplines have joined together to conduct research using the large influx of freely accessible data being produced. The data collected through EarthScope and other NSF research investments are critical for the development of an earthquake early warning system. As the data is collected and disseminated in real-time, computers, communications technology, and alarms are devised to notify the public when an earthquake is in progress. Just ten seconds of warning that an earthquake is occurring is enough to halt trains, shut off gas lines, and open emergency bay doors for first responders.

Concluding Thoughts

We appreciate the difficult decisions Congress must make within the constraints of the budget environment. We have provided several examples where the geosciences contribute to the Nation's national security, economic competitiveness, and public safety. We believe that the future of this Nation is well served by a strong and sustained investment in the full scope of our research enterprise – including the geosciences programs sponsored by NSF, NASA, and NOAA. This Subcommittee has consistently been a strong champion for the Nation's research enterprise and, despite the budget challenges that it must confront, we urge you to maintain the high priority the Subcommittee has long placed on research and training in all fields of science and engineering.