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DEEP SEA CHALLENGE: INNOVATIVE PARTNERSHIPS IN OCEAN OBSERVATION

HEARING

BEFORE THE

SUBCOMMITTEE ON OCEANS, ATMOSPHERE, FISHERIES, AND COAST GUARD

OF THE

COMMITTEE ON COMMERCE, SCIENCE, AND TRANSPORTATION
UNITED STATES SENATE

ONE HUNDRED THIRTEENTH CONGRESS

FIRST SESSION

JUNE 11, 2013

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SENATE COMMITTEE ON COMMERCE, SCIENCE, AND TRANSPORTATION

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FIRST SESSION

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DEEP SEA CHALLENGE: INNOVATIVE PARTNERSHIPS IN OCEAN OBSERVATION

TUESDAY, JUNE 11, 2013

U.S. SENATE,
SUBCOMMITTEE ON OCEANS, ATMOSPHERE, FISHERIES, AND COAST GUARD,
COMMITTEE ON COMMERCE, SCIENCE, AND TRANSPORTATION,
Washington, DC.

The Subcommittee met, pursuant to notice, at 3 p.m. in room SR–253, Russell Senate Office Building, Hon. Mark Begich, presiding.

OPENING STATEMENT OF HON. MARK BEGICH, U.S. SENATOR FROM ALASKA

Senator BEGICH. Thank you all for being here this afternoon. Appreciate it.

This hearing will come to order. This is the Oceans Subcommittee hearing on "Deep Sea Challenge: Innovative Partnerships in Ocean Observation." So, again, thank you all very much for being here.

I will make a few opening comments, I will turn to Senator Wicker, and then we will start with the panel. But, again, we really appreciate you taking the time.

I was joking just a minute ago that it was like, when I walked in, I saw the big line out there, I am glad I bought my advance movie ticket to be here today.

[Laughter.]

Senator BEGICH. Otherwise, I am not sure I would have got in. But I am glad I am here.

Again, I want to thank the witnesses for being here, especially James Cameron.

Film director James Cameron is most widely known for taking audiences truly out of this world in blockbuster hits like "Aliens" and "Avatar," but it is his nonfiction endeavors here on Earth that may be actually most alien to us. Last year, in a partnership with the National Geographic Society and Rolex, Mr. Cameron undertook the most difficult ocean dive possible, descending to the Challenger Deep in the Pacific Ocean's Mariana Trench.

The Challenger Deep is the deepest known part of the Earth's oceans, more than 6.8 miles underwater. Mr. Cameron is the first person to have undertaken the dive alone and is one of the only three humans to ever reach that depth. By contrast, more than 500 people have traveled into outer space.

It is astounding that, in many ways, we know more about the final frontier than about our own oceans. Ninety percent of the ocean floor remains uncharted, and recent estimates suggest that we have only identified 20 to 25 percent of the marine life in existence.

To further understanding of our oceans, Mr. Cameron recently donated the submersible system and science platform used in the dive, the *DEEPSEA CHALLENGER,* to the Woods Hole Oceanographic Institution.

Woods Hole, which I have been to more than once, is an incredible facility. The President and Director, Susan Avery, is here today, as well, and I look forward to hearing about the institute's plan to use the *DEEPSEA CHALLENGER* to support ocean science.

But we cannot rely solely on the graciousness of individuals to advance science. And the need for greater ocean research and monitoring has never been clearer. Whether it is ocean acidification, sea level rise, warming water temperatures, or shifting fish populations, our oceans are changing.

This is something felt most acutely in the Arctic and in my state of Alaska, where the average temperature rises are rising twice as fast than anywhere else and the sea ice is thawing at unprecedented rates.

If we are to prepare for these changes, we have to better our understanding of the oceans. In 2009, Congress enacted several pieces of legislation aimed at improving our oceans research and observing capabilities.

The Integrated Coastal and Ocean Observation System Act provided for the development of an integrated system of coastal and ocean observations for the Nation's coasts, oceans, and Great Lakes. Development of the Integrated Ocean Observing System is ongoing but is already providing for better access to the ocean data that is critical to respond to the coastal events and changes to our oceans.

There is also the Federal Ocean Acidification Research and Monitoring Act, championed by the late Senator Lautenberg, which established a coordinated process for effectively monitoring ocean acidification and its effects on marine organizations and ecosystems.

Both Acts will be due for reauthorization at the end of the year. And I look forward to hearing from the witnesses, Dr. Jan Newton of the University of Washington and Ed Page from Alaska Ocean Observing System. They represent regional partners on how we can improve the ocean science and research coordination through changes in both these bills.

Addressing the particular needs of the Arctic science is also a top priority of mine, and I hope to hear from some of the witnesses on how we can tackle the region's unique challenges.

My bill, the Arctic Research, Monitoring, and Observing Act, is pending before this committee. It would support hydrographic surveys, mapping sensitive habitats, collecting weather data, expand ocean observational data, and other activities needed to support increased activity and changing conditions in the Arctic.

We also need to find innovative ways to develop ocean research outside the Federal Government. Given the Nation's current constraints on the budget, we should look for how we can better foster partnerships with the academic institutions as well as private entities for advancing ocean research.

There is a lot to cover in this hearing, but I really do appreciate the witnesses' being here.

Let me first turn to Senator Wicker for his opening statement. I know he has a tight schedule and will be unable to stay the whole meeting, so we just appreciate that he is here at the beginning.

Senator Wicker?

STATEMENT OF HON. ROGER F. WICKER,
U.S. SENATOR FROM MISSISSIPPI

Senator WICKER. Thank you, Senator Begich, for scheduling this hearing on the importance of partnerships in ocean observation.

And, Mr. Chairman, I want to thank you personally for holding this hearing today in 3-D. It means a lot.

[Laughter.]

Senator WICKER. I hope today's discussion facilitates a constructive dialogue among ocean explorers, scientists, and policymakers about the future of ocean observation infrastructure, research, and education.

The ocean covers 71 percent of the Earth and contains more than 97 percent of the world's water, and yet only a small fraction of this vast and integral resource has been explored. High rates of mandatory spending often limit the ability of the Federal Government to invest in discretionary funding such as ocean research.

So one way to optimize Federal investment in ocean exploration and research is through the expansion and leveraging of public and private partnerships. These partnerships allow for privately funded groups to work with the government and with academic partners to advance research and development.

The United States is home to many of the world's best ocean scientists and explorers, and it is important for them to remain in the forefront of research and development. As a member of the Senate Oceans Caucus and as a senator from the coastal state of Mississippi, I recognize the importance of understanding and exploring our oceans.

I am proud to say that my home state is actively involved in ocean research. The National Institute for Undersea Science and Technology, which was created as a partnership between the University of Southern Mississippi and NOAA, aims to discover and apply new technologies toward our understanding of the oceans. Its work includes the development of new biotechnologies and undersea vehicles.

I want to thank our witnesses for testifying today. I have had a chance already earlier to speak to Mr. Cameron and Dr. Avery. I look forward to hearing their views and the views of the other distinguished panelists on advancing ocean science.

And thank you again, Mr. Chairman, for holding the hearing.

Senator BEGICH. Thank you very much, Senator Wicker.

And what we will do is we will start with Mr. Cameron, and then we will kind of go down, Dr. Avery and so forth down, if that is OK.

And really do appreciate your time, all of you, for coming to Washington and being able to share with us your views on what more we can be doing and, in some cases, what we maybe should not be doing.

So we will open it up, and we will start with Mr. Cameron.

STATEMENT OF JAMES CAMERON,
EXPLORER AND FILMMAKER

Mr. CAMERON. Thank you. Good afternoon, Chairman Begich and Senator Wicker. Thank you for allowing me to speak here.

This week, we brought to the Nation's capital a unique symbol, one that demonstrates the power of curiosity and imagination to surmount technical hurdles and explore the unknown. The *DEEPSEA CHALLENGER* is the only human-occupied vehicle that is currently able to access the deepest parts of the ocean.

On March 26, 2012, I dove it to the bottom of the Challenger Deep in the Mariana Trench and reached a depth of 35,787 feet and explored the bottom for 3 hours. This set the record for the world's deepest solo dive. In the weeks prior to that, we used the sub to explore the New Britain Trench at depths down to 5 miles, a previously completely unexplored ocean trench system. And in both trenches, we found new life forms unknown to science.

The *DEEPSEA CHALLENGER* is now the deepest-diving operational man-submersible in the world, exceeding the depth limit of the next deepest vehicle, the Chinese Jiaolong submersible, by 9,000 feet.

Now, the ocean's trenches have a combined area larger than North America, and they are the last frontier of exploration here on planet Earth. I think of it as a dark continent still unexplored because of the technical difficulty of building machines to operate at the crushing pressure of those depths.

To withstand the pressure of 16,300 pounds per square inch at the bottom of the Challenger Deep, my team needed to develop new materials and an array of technologies that didn't previously exist, including HD stereoscopic cameras, high-intensity lights, thrusters, batteries, and electronics. No commercially available products or systems were available that could withstand that pressure.

Why should we care what is happening in these deep trenches? Well, one reason is that the trenches are formed by subduction, in which one plate of the Earth's crust is dragged by tectonics underneath another, pulling it down, which is what creates the extreme depth. And this releases tremendous energy in the form of earthquakes, often generating the kinds of tsunamis that devastated Indonesia and Japan in recent years, killing hundreds of thousands of people and wrecking national economies.

We need to put instrumentation down on the sea floor to understand these forces and hopefully someday save lives through predictive modeling. And that requires machines that can operate at that depth.

DEEPSEA CHALLENGER was designed and built by a small, privately funded team of young engineers, almost all of whom had

never worked on a sub before, and this allowed out-of-the-box thinking and unbridled innovation. The sub was designed as a science platform, not as a stunt vehicle to set records. It can explore horizontally for miles over the sea floor, collecting samples with a robotic manipulator arm, recording data with a number of instruments, and gathering high-definition 3-D video with multiple cameras.

Preliminary science results from our expedition were presented by our joint team of researchers at the December gathering of the American Geophysical Union. These results included the discovery of 68 new species, including the deepest examples of gigantism in amphipods, as well as images of the deepest bacterial mats ever discovered, which may be a glimpse into how and where life originally emerged on the Earth.

I have chosen to donate the sub and its attendant technology IP to Woods Hole Oceanographic Institution, our nation's premier center for ocean science and technology. They will publish the new tech embodied in the sub, making it available to the entire research community, and the technology will be adapted to new vehicle platforms in the future, which will include AUVs and ROVs.

We are at a critical time in oceanographic research. The ocean is an engine that drives weather, including the higher precipitation and extreme weather events like Superstorm Sandy, the severe droughts, and so on that are associated with climate change.

To understand weather and climate, we must understand the oceans. And to do so, we can't just sense them from satellites. They are a vast, three-dimensional volume that is opaque from above. We need instruments and vehicles down there in the water column.

However, as we all know, Federal ocean science funding is stretching thin as budgets come under pressure. Though a private institution, Woods Hole Oceanographic is dependant for the majority of its funding on grants from NSF and NOAA and other Federal agencies.

We need to invest more in ocean research, not less, at this critical moment in history when the ocean is rapidly changing due to human impacts. Oceans are a major part of our life support system here on Earth, even as our industrial society is degrading and transforming them.

We need to understand how greenhouse heat is absorbed into the ocean, how it is mixed by currents deep in the water column, where the carbon is going, and how these changes affect the hydrological cycle that provides rainfall to farms but also devastating floods, such as those that are currently ravaging Germany.

Extreme weather events that used to happen every 100 years are now happening every 5 years. The cost to the Nation will be in the hundreds of billions. We need to understand all this.

Woods Hole's expertise in ocean science is the reason I have agreed to join its new Center for Marine Robotics, which aims to spur collaborations across government, industry, and academia to advance ocean science and exploration through the development of new marine robotic vehicles and technologies.

Over the past 10 days, the *DEEPSEA CHALLENGER* made its cross-country trek from Los Angeles to Washington on its way to its new home at Woods Hole Oceanographic Institution on Cape

Cod. Along the way, the sub stopped to give young people a chance to see and touch the sub and, more importantly, to imagine themselves exploring the unknown, inspiring them, as I was inspired as a kid by the space and ocean exploration of the 1960s.

We have to inspire children to want careers in science, technology, engineering, and math. STEM education is critical to our future. Our planet is a big, complex system, and the ocean is the most poorly understood part of it. That system is under stress, and we need to improve our sensing and monitoring of it for our own national security and economic strength. For that understanding, we need a new generation of scientists, engineers, and explorers to carry the investigation forward.

So many people think we live in a post-exploration age, that is has all been seen and mapped. We brought the *DEEPSEA CHALLENGER* to the Nation's capital to remind people of the frontiers of exploration right here on Earth and to signal the need for continued investment in ocean science and technology.

We live in a new age of exploration. We also live in an age in which the impacts of human industrial civilization on the natural world are becoming dire. Future policy regarding climate, pollution, and depletion and their impacts on human life and biodiversity must be informed by scientific fact. Institutions such as Woods Hole Oceanographic are our only pathways to a clearer understanding of the changes we see happening around us every day.

Now, I will personally continue to support ocean science, not because I need to as some sort of clever business model, but because I believe in my heart that it is important, maybe even crucial, to our way of life and the health of our world. I urge you to continue the nation's investment in ocean science, technology, and education. I believe the return on this investment will provide benefits that are critical to future generations.

Thank you.

[The prepared statement of Mr. Cameron follows:]

PREPARED STATEMENT OF JAMES CAMERON, EXPLORER AND FILMMAKER

Good afternoon Chairman Begich and Members of the Committee. My name is James Cameron, and I am an explorer and director. Thank you for the opportunity to testify today about innovative partnerships in ocean observing and exploration.

This week we brought to the Nation's Capitol a unique symbol—one that demonstrates the power of curiosity and imagination to surmount fantastic technological hurdles and explore the unknown. The *DEEPSEA CHALLENGER* is the only human-occupied vehicle currently able to access the deepest parts of the ocean. In 2012, I used it to explore the famed Challenger Deep, in the Mariana Trench, as well as exploring the previously unseen New Britain Trench. Far from being out of its element on Capitol Hill, it serves as a stark reminder of a task that has barely begun: the exploration of the deep ocean.

A dozen people have stood on the moon. Only three have made the seven-mile descent to Challenger Deep. In fact, the vast majority of the world's ocean trenches, comprising an area larger than North America, remains virtually unknown to us.

Why? Because they lie beneath five to seven miles of water. The deep ocean is a lightless, high-pressure region that, from a technological standpoint, is exceedingly challenging to see through, to get to, and to operate in.

Because we routinely travel four miles beneath the surface, the depth other exploration vehicles are capable of reaching, people think the extra three miles is not a significant challenge be a big problem. But everything changes in attempting to reach hadal depths below 6,000 meters (20,000 feet), the deepest places in the ocean. At those depths, from an engineering perspective, the performance–benefit ratio changes in terms of flotation, pressure vessels, wall thickness, and other com-

ponents. Vehicles become very heavy and unmanageable. That not only drives up the cost of hadal-depth vehicles themselves, it drives up the cost of the ships used to launch and recover them, multiplying the at-sea operational costs that have historically been prohibitive factors to exploration. There are also limits in materials science that require the creation of entirely new materials in order to build vehicles that have the same agility and cost factors as those operating higher in the water column. One goal of the *DEEPSEA CHALLENGE* Project was to demonstrate a spectrum of new technologies in a relatively small manned vehicle for full-ocean-depth science diving and at reasonable cost.

These challenges are largely responsible for the fact that hadal depths are still relatively unexplored and why so little is known about the biology and geology in hadal depths. Yet it is known that these regions are geologically dynamic. In ocean trenches, where one tectonic plate is subducting beneath another, causing a great deal of stress, friction, and fracturing that result in earthquakes and submarine landslides, which, in turn, are sources of the kinds of tsunamis that devastated Indonesia just a few years ago, and recently dealt such a horrific blow to the people and economy of Japan.

There is also intriguing evidence of a diversity of unusual and unknown life forms. These life forms have unusual biochemical and physiological adaptations to the exotic chemistry and extreme pressure in hadal regions.

I was born in 1954 and grew up during an era of exploration. In the 1960s, the Apollo program was sending men to the moon. In 1964, the deep-sea sub *Alvin,* operated by Woods Hole Oceanographic Institution, began bringing humans to the deep sea. These exploratory pursuits inspired me at an impressionable age resulting in my later pursuit of deep ocean exploration in parallel to my filmmaking work.

I assembled a team of engineers to build *DEEPSEA CHALLENGER*—to push exploration into the deep sea, further and faster. A small, private, international team of young engineers developed a vehicle that was pioneering in several ways. It was able to dive to the deepest place in the world's oceans, a feat that had only been accomplished once before, by the historic dive of the *Trieste* bathyscaphe under U.S. Navy authority in 1960. However the *DEEPSEA CHALLENGER* weighs less than one-tenth of *Trieste,* and can be deployed like a contemporary science submersible from the deck of a mid-sized research vessel, as opposed to being towed to the site. In addition, the new sub is able to explore horizontally for miles over the seafloor, collecting samples with a robotic manipulator arm, recording data with a number of instruments, and gathering high definition stereoscopic video with multiple cameras. Preliminary science results of our 2012 expedition were presented by a joint team of researchers at the December gathering of the American Geophysical Union. These results included the discovery of at least 68 new species such as the deepest examples of gigantism in amphipods, as well as images of the deepest bacterial mats ever discovered, which may lead to an understanding of the origin of life on Earth.

However, despite being a small, international, privately funded group, I want to emphasize that our team built on a monumental foundation of prior ocean research and exploration funded by Congress and a range of government agencies.

It should also be noted that *DEEPSEA CHALLENGER* was built by a joint American/Australian team, with approximately one-third of the work done in the U.S., by engineering companies in the Bay Area, and two-thirds of the work done by a start-up company in Sydney. The Australian government provides generous rebates to encourage research and development, and this was a strong driver in my choice to site the project primarily in Australia. I would strongly urge Congress to establish new incentives, as well as enhancing existing ones, to encourage R&D among small companies in the U.S., thus maintaining this Nation's critical lead in engineering and science.

Now, the scientists and engineers at Woods Hole Oceanographic Institution and ocean research centers across the Nation are poised to take the technologies developed for *DEEPSEA CHALLENGER* submersible and science platform to the next level, so that the knowledge gained in this project can help advance ocean science.

This public/private collaboration is one of many that signal a new path to supporting the R&D and education initiatives that are critical to the future of the U.S. and global economies. I believe that advances in ocean science and technology must be at the forefront of this effort, given the growing recognition of the importance of ocean processes and their influence on weather and climate and economic and national security. Woods Hole's expertise in this area is part of the reason I have agreed to join one of its new initiatives, the Center for Marine Robotics, which aims to spur collaborations across government, industry, and academia to advance ocean science and exploration through the development and integration of new marine robotic vehicles and technologies. Despite our best efforts, the ocean remains *aqua incognita* to us—much the way the ground we're sitting on now was once considered

terra incognita by early explorers. There's much more we need to know about how the ocean operates. We haven't invested nearly enough in ocean research. And I think it's gong to come back to bite us at this moment in history when we know that the ocean is rapidly changing.

The only way we can learn about this vast and crucial part of our planet is to submerge ourselves in it, using both human and remote automated technology, which requires adequate funding, given the difficulties of operating in the ocean, from the surface to the trenches.

During the past 10 days, *DEEPSEA CHALLENGER* made a cross-country trek from Los Angeles to Washington on its way to its eventual home at Woods Hole Oceanographic Institution on Cape Cod. Along the way, the sub stopped to give young people a chance to see and touch the sub and, more importantly, to imagine themselves exploring the unknown—inspiring them, as I was inspired.

We need exemplars like this for young people to see that not only is there much we haven't explored right here on our home planet, but also that there is much we need to know about how our natural world functions. Our planet is a big, complex, intricate system, and the ocean is the most poorly understood part of it. That system is under stress, and we need to improve our understanding of how it works so that we can help preserve our home.

As the next generation of scientists, engineers, teachers, business owners, and political leaders, their enthusiasm for exploration, for taking risks, for solving problems, and pursuing knowledge is vital to our continued international leadership, national security and economic growth. To that end, the STEM programs are essential to give students at impressionable ages the inspiration and skills to learn how nature and technology works. Continued Federal investment in education at all levels must remain a high priority.

So many people think we live in a post-exploration age—that it's all been seen, and all been mapped. We brought the sub to the Nation's Capitol to help dispel this myth, to communicate the need for greater investment in ocean science and the technologies that make it possible. *DEEPSEA CHALLENGER* proves that remote parts of the ocean are within our reach. We live in a new Age of Exploration. We also live in an age in which the impacts of human industrial civilization on the natural world are becoming more dire. All future policy regarding the prevention of dangerous changes to our climate and its impacts to human life and biodiversity must be informed by scientific fact. That science must include an understanding of the oceans and their role in the transfer of heat, in the hydrological cycle, the carbon cycle, and in extreme weather events.

I will continue to support ocean R&D and build on the growing number of public, private and philanthropic partnerships, and I encourage Congress to capitalize on this opportunity by expanding *its* investment in ocean science, technology and education. I believe the return on this investment will provide benefits far beyond anyone's expectations.

Thank you again for this opportunity to address the Committee.

Senator BEGICH. Thank you very much.

Dr. Avery, before I go to you, I wanted to see if Senator Cantwell had any opening comments before we continue with the panel.

STATEMENT OF HON. MARIA CANTWELL,
U.S. SENATOR FROM WASHINGTON

Senator CANTWELL. I just wanted to welcome Dr. Newton for being here, obviously a regional expert from the University of Washington. And I look forward to her testimony.

Senator BEGICH. Fantastic. Thank you.

I want you to know, Mr. Cameron, while you were speaking of the donation, I saw Dr. Avery, she had the biggest grin on her face.

[Laughter.]

Senator BEGICH. It is like a new toy. You have no idea. I mean, you have been to Woods Hole, you have seen——

Mr. CAMERON. Yes.

Senator BEGICH.—the quarters they work in are sometimes a little cramped. But their enthusiasm is unbelievable, and I was feeling it as you were talking.

[Laughter.]

Senator BEGICH. Because I think she is ready to, like, go outside now and start using it. I sense that.

[Laughter.]

Mr. CAMERON. She is going to be in it sooner or later, sir.

Senator BEGICH. I have this feeling, as well.

Dr. Avery, President and Director of Woods Hole Oceanographic Institution, thank you very much for being here. Let me turn to you for your opening.

STATEMENT OF DR. SUSAN K. AVERY, PRESIDENT AND DIRECTOR, WOODS HOLE OCEANOGRAPHIC INSTITUTION

Ms. AVERY. Thank you. Thank you, Chairman Begich and Senator Cantwell. Thank you for having this opportunity to testify in support of the Nation's community of ocean scientists and research institutions.

I would like to recognize Jim Cameron for his commitment to helping advance ocean science exploration and education and his willingness to share his team's work on the *DEEPSEA CHALLENGER* with the science community, which Woods Hole Oceanographic Institution will facilitate.

Jim is a visionary who looks beyond what we currently are able to see. This is a particularly relevant skill since looking beyond the ocean surface has always been a huge challenge. For that reason, most people's perspectives are somewhat landlocked.

Yet the ocean is Earth's most fundamental and life-sustaining feature. It touches us every day wherever we live. The ocean is the major transportation route for global trade and a significant source of food and a major source of jobs. The ocean is also our planetary reservoir and water pump. It circulates heat and water around the globe to regulate climate and weather.

There is strong evidence that the ocean has been changing. As the planet continues to warm, more heat means more water vapor and more energy going into the atmosphere. That means more extreme weather and more rainfall and flooding in some areas, less rainfall and droughts in others. With rising sea levels, it means higher probabilities of more devastating storm surges, like we saw with Hurricanes Katrina and Sandy.

Like any frontier, the ocean also holds untapped potential, including new sources of energy, minerals, and medicines. In addition to the deep ocean, there are other frontiers in the ocean. We have barely gained access to explore the ocean beneath our polar icecaps, at a time when the sea ice is rapidly disappearing. This has profound implications for Earth's climate, ocean ecosystems, and for access to new shipping routes and natural resources.

There are reasons why Russia planted its flag at the bottom of the Arctic Ocean in 2007 and why China has ramped up its investments in deep ocean exploration.

There is also the microbial frontier. There are about 300,000 times more microbes in the ocean than there are observable stars in the universe. They have evolved all sorts of chemical pathways to live in extreme environments. Ocean scientists have just begun to explore this universe of marine microbes for unknown biochemical pathways and compounds, for new antibiotics, and for

novel treatments for diseases, such as Alzheimer's and cystic fibrosis. These microbes also hold the key to the healthy functioning of the ocean ecosystem, much as our own microbiome in our body is critical to human health.

Then there is the frontier of climate. For atmosphere and ocean, they are both fluids and they are both fluid dynamical systems. The atmosphere works over days, weeks, and months. The ocean is more lumbering but larger, a flywheel that works over months, years, and decades.

The two systems, the atmosphere and the ocean, are interwoven and inseparable. But while we have long established extensive networks of meteorological instruments continually monitoring our atmosphere, we have just begun to establish a toehold of long-term observatories to understand and monitor how the ocean operates.

Toward that end, I urge this committee to support the following:

First, the reauthorization of the Integrated Coastal and Ocean Observation System Act. This legislation provides the foundation for a national ocean observing system, one that enhances those provided by states and other nongovernmental, academic, and private entities. Such a network will give us the ability to understand ocean processes and provide knowledge and forecasts for fisheries, coastal residents, and shipping.

Second, reauthorize America COMPETES legislation to bolster innovation, research and development, and STEM initiatives. This will ensure our country has a ready supply of young people with the inspiration to push the boundaries of knowledge and gain the skills that our businesses require in their employees.

And, third, support the National Science Foundation, Navy's Office of Naval Research, NOAA, NASA, and NIST, whose science and technology programs are essential to pursuing new lines of inquiry that can lead to new technologies, industries, jobs, and ways to solve societal problems. We have to be brave enough and smart enough to look beyond the next Fiscal Year and invest in what we can't already see.

I conclude my remarks by highlighting the value of partnerships to the future of R&D in this country. Jim Cameron's partnerships with Woods Hole Oceanographic Institution and also with Scripps Institution of Oceanography are welcome examples of how public and private funding can leverage each other. But I must emphasize that they are partnerships. One doesn't replace the other. Neither adequately does the job alone, and each augments and leverages the other.

In an almost poetic statement, the National Science Foundation annual report from 1952 says, "That which has never been known cannot be foretold. And herein lies the great promise of basic research. It enlarges the realm of the possible."

It takes all of us together—private citizens and foundations, academic scientists, industry, and government—to explore the unknown and enlarge the realm of the possible.

I look forward to your questions. Thank you.

[The prepared statement of Ms. Avery follows:]

PREPARED STATEMENT OF DR. SUSAN K. AVERY, PRESIDENT AND DIRECTOR, WOODS HOLE OCEANOGRAPHIC INSTITUTION

Good afternoon Chairman Begich and Members of the Committee. My name is Dr. Susan K. Avery, and I am President and Director of the Woods Hole Oceanographic Institution in Woods Hole, Massachusetts. Thank you for the opportunity to testify today on behalf of our nation's community of ocean scientists and research institutions. I'd like to recognize Jim Cameron for his commitment to helping advance ocean science, exploration, and education, and his willingness to sharing his team's work on the DEEPSEA CHALLENGER with the science community, which Woods Hole Oceanographic Institution will facilitate.

Importance of the Ocean

The ocean is the dominant feature on Earth. Removing all that water away reveals some surprising things about our planet: There are mountain ranges longer than anything on land, mountains higher than Everest, and canyons deeper and grander than the Grand Canyon. And it's all covered by a relatively thin skin of water. Despite this, the ocean most people see is the surface. A sunset over a healthy ocean looks just like one over a sick ocean. It is what happens underneath the surface that is critical to humanity.

The importance of the ocean in daily life, whether you live on the East Coast, the Great Plains, or the Mountain West, cannot be oversimplified or understated. In short, it is one of the most fundamental reasons why our planet is capable of supporting life and why we are able to sustain the economy and way of life that are among our national hallmarks. Our fate has always rested in one way or another with the ocean and its interaction with the atmosphere, land, and humanity. The ocean plays a critical role in governing Earth's climate system helping to regulate global cycles of heat, water, and carbon. The rates and regional patterns of land temperature and precipitation depend on the ocean's physical and chemical balances. It touches us every day, wherever we live through our climate and weather; rainfall, floods, droughts, hurricanes, and devastating storm surges such as what we witnessed with Hurricane Sandy.

The services the ocean provides—and that we often take for granted—range from endless inspiration and deep-seated cultural heritage to the very air we breathe and the rain that waters our crops. Roughly half of the oxygen we breathe and about 80 percent of the water vapor in our atmosphere comes from ocean processes. The ocean feeds us, processes waste, holds vast stores of mineral and petroleum reserves, and provides inexpensive transportation of goods and people. Its rich biodiversity is a potential source for new medicines and an insurance policy for our future. Many of these things it provides the planet without our intervention; other things we actively seek and extract—and we will continue to do so.

In 2010, maritime economic activities contributed an estimated $258 billion and 2.8 million jobs to the national economy.[1] In addition, roughly 41 percent of the Nation's GDP, or $6 trillion, including 44 million jobs and $2.4 trillion in wages, was generated in the marine and Great Lake shoreline counties of the U.S. and territories.[2] The key for the future of the ocean and for humanity will be to learn how to balance these economic activities with the natural functioning of the ocean.

We know that the ocean is taking up more than 80 percent of the heat that is generated by rising levels of greenhouse gases in our atmosphere.[3] Excess carbon dioxide mixed into the upper ocean is lowering the pH of seawater, making it more acidic and raising the potential for large-scale change at the base of the marine food chain and in the coral reef ecosystems that are considered the breadbasket of the tropical oceans and an important source of biodiversity and income for many regions. Excess heat is causing Arctic sea ice to retreat to levels never before seen, setting up the likelihood of still further melting driven by positive feedback loops, as well as disruptions to the Arctic ecosystems that have evolved in an environment partly reliant on ice cover for millions of years. Sea level is also rising, both as a result of increased melting of terrestrial ice caps and of thermal expansion of the seawater, resulting in higher probabilities of more frequent and more severe storm

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[1] NOAA Coastal Services Center, *NOAA Report on the Ocean and Great Lakes Economy of the United States,* 2012, *http://www.csc.noaa.gov/digitalcoast/__/pdf/econreport.pdf* (accessed February 2013).

[2] NOAA National Ocean Service, Special Projects Division, *Spatial Trends in Coastal Socioeconomics* (STICS), 2013 *http://coastalsocioeconomics.noaa.gov/* (accessed February 2013); and NOAA Office of Program Planning and Integration The Ocean and Coastal Economy: A Summary of Statistics, 2013 *http://tinyurl.com/p55na2q* (accessed June 2013).

[3] Levitus, S., J. Antonov, and T. Boyer, "Warming of the world ocean, 1955–2003," Geophys. Res. Lett. 32(2005), L02604, doi:10.1029/2004GL021592.

surges such as those associated with Hurricane Sandy. Our ability to build properly designed and appropriately scaled adaptations into cities and societies around the world is predicated on our ability to accurately predict how, when, and how much the ocean will change in the future.

For these reasons and many others, our nation must recognize that the ocean is changing almost before our eyes. Perhaps the question is, not how much can we afford to invest in research on the ocean, but rather how can we afford not to?

Despite its importance, there remain many unanswered questions about the ocean. It is far more difficult to observe than the atmosphere. Because the ocean is opaque to most forms of electromagnetic radiation, satellite observations are limited in the type and resolution of information they can gather. We are capable of monitoring many surface features, including waves, winds, temperatures, salinity, carbon, color (a measure of biological productivity), as well as some large-scale subsurface features. But satellites cannot tell us much about the diversity of life in the ocean or the many fine-scale dynamic processes at work beneath the surface, nor can they tell us much about the internal complex biogeochemistry that supports life. Satellites can't show us the bottom of the ocean, where volcanic hydrothermal vents sustain rich communities of exotic organisms—which might answer questions about the early evolution of life. To learn more about these important parts of the ocean system, we must have more and better eyes *in* the ocean and, at the same time, work to surmount the huge challenges of working in a cold, corrosive, and physically punishing environment.

Frontiers in the Ocean

Jim Cameron is a visionary who is capable of looking beyond what we are currently able to see. Let me tell you about another visionary. In the mid-1930s, a physicist from Lehigh University named Maurice Ewing sent letters to several oil companies. He asked them to support a modest research program to see whether acoustic methods used to probe buried geological structures on land could be adapted to investigate the completely unknown geology of the seafloor. Ewing later wrote: "This proposal received no support whatever. I was told that work out in the ocean could not possibly be of interest to the shareholder and could not rightfully receive one nickel of the shareholder's money."[4]

Ewing did get a $2,000 grant from the Geological Society of America, however, and he and his students came to Woods Hole Oceanographic Institution to use its new ocean-going research ship, *Atlantis.* The ship and the institution were launched by a $3 million grant from the Rockefeller Foundation. The scientists launched novel experiments using sound waves to probe the seafloor. To Ewing, the ocean was annoyingly in the way. To study the seafloor, he and his colleagues had to learn how to negotiate the intervening water medium. In the process, they unexpectedly made profound and fundamental discoveries about ocean properties and how sound propagates through seawater.

In 1940, on the eve of war, Woods Hole's director, Columbus O'Donnell Iselin, wrote a letter to government officials, suggesting the ways the institution's personnel and equipment could be better utilized for the national defense. Soon after, one of Ewing's students, Allyn Vine, began incorporating their newly gained knowledge to build instruments called bathythermographs, which measured ocean properties. Vine trained naval personnel to use them to escape detection by sonar. It was the first among many subsequent applications of this research that revolutionized submarine warfare.

Many scientists pursued the marine geophysics research initiated by Ewing. Their work culminated in the late 1960s in the unifying theory of plate tectonics. It transformed our understanding of continents, ocean basins, earthquakes, volcanoes, tsunamis, and a host of other geological phenomena—including significant oil reservoirs beneath the seafloor—where oil companies now routinely drill and make money for their shareholders.

Al Vine remained in Woods Hole and spearheaded deep-submergence technology, including the research sub *Alvin,* which was named after him. Two years after it was completed, *Alvin* was applied to a national emergency, locating a hydrogen bomb that accidentally dropped into the Mediterranean Sea. A decade later, *Alvin* found seafloor hydrothermal vents. To humanity's utter astonishment, the vents were surrounded by previously unknown organisms sustained not by photosynthesis but chemosynthesis. This discovery completely changed our conceptions of where and how life can exist on this planet and elsewhere in the universe.

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[4] Lippsett, L., "At Deepwater Horizon, basic research was applied," *Oceanus* 48(2011) *http://www.whoi.edu/oceanus/viewArticle.do?id=116709* (Accessed June 2013).

Thirty-five years later, Alvin was again called into action to help assess and monitor the Deepwater Horizon oil spill and its impacts in the Gulf of Mexico, but at the same time, the ocean science community was able to bring much more to bear in a time of national crisis. The community's unparalleled response in the Gulf was enabled by more than three decades of technological advancements related to development of remotely operated and autonomous underwater vehicles and new sensors and data assimilation techniques, and integrated networks of sensors, vehicles, and platforms that have opened the ocean to the light of new study, many of which were developed through novel partnerships with private funders.

Society has benefitted in the past from public-funded/private-funded partnerships that advance research and development, probably even before Queen Isabella financed Columbus's voyage of discovery in 1492. But I emphasize: It's a partnership. One doesn't replace the other. Each augments the other. In an unexpected bit of poetry, the NSF annual report from 1952 says: "That which has never been known cannot be foretold, and herein lies the great promise of basic research. . . . [It] enlarges the realm of the possible." The bottom line question is: How much are we willing to invest in enlarging the realm of the possible?

Jim Cameron did that with DEEPSEA CHALLENGER. He enlarged the realm of the possible by demonstrating that even the deepest part of the ocean is not beyond our physical presence. Still other advances are expanding the possible in many ways through the development and deployment of novel sensors, autonomous vehicles, and new ways for humans and machines to interact. There is a revolution in marine technology underway that is positioning us to reach many unexplored frontiers in the ocean—and the ocean has many. The deep ocean is only one.

We have barely gained access to explore the ocean beneath our polar ice caps—at a time when rapidly disappearing sea ice has profound implications for Earth's climate, for ocean ecosystems, expanded shipping, oil and mineral resource development, and national security. There is the microbial frontier, where 90 percent of the ocean biomass resides and which is invisible to the human eye. There are about 300,000 times more microbes in the ocean than there are observable stars in the universe.[5] Ocean scientists have just begun to explore this universe of marine microbes, which holds the key to healthy biological functioning of the ocean ecosystem, much as the microbiome in the human body is critical to our health. They are also searching for unknown biochemical pathways and compounds, for new antibiotics, and for novel treatments for diseases such as Alzheimer's and cystic fibrosis.

Then there is the frontier of temporal and spatial scales that must be overcome to monitor and forecast changes to the deep and open ocean. The ocean exhibits large, basin-wide patterns of variability that change over periods ranging from days and weeks to years, decades, and longer. Understanding and observing these patterns, including El Niño-Southern Oscillation (ENSO), offer potential for improved prediction of climate variability in the future. For most of my career, I have been an atmospheric scientist. The atmosphere and ocean are both fluids (one that is compressible, the other incompressible). These two systems are interwoven and inseparable.

But while we have long-established, extensive networks of meteorological instruments continually monitoring our atmosphere, we have just begun to establish a relative toehold of long-term observatories to understand, and monitor how the ocean operates. To truly comprehend Earth's dynamic behavior and to monitor how it affects us back on land, scientists must establish a long-term presence in the ocean, including platforms and suites of physical, chemical, and biological sensors from which to view how the ocean and seafloor change in fine resolution over seasons, years, and decades. This same observing capability will provide the basis for improved forecasts from models that incorporate data and observations from the ocean, atmosphere, and land and that provide the basis for decision making by national, state, and local agencies.

Variability such as weather events associated with ENSO has significant societal and economic impacts in the U.S., and a combination of a dedicated ocean-observing system in the tropical Pacific plus models that forecast ENSO impacts is now in place to help society adapt in times of increased variability. The promise of additional benefits from observing, understanding, and predicting the ocean and its impacts is real. Modeled reconstructions by Hoerling and Kumar of the 1930s drought in the Central U.S. recently linked that event to patterns of anomalies in sea-surface temperature far from the U.S.[6] The global scale of the circulation of the ocean

[5] Mincer, T., personal communication, June 6, 2013.

[6] Hoerling, M and A. Kumar, "The perfect ocean for drought," *Science* 299(2013):691–694 doi:10.1126/science.1079053.

and basin-scale patterns of ocean variability on decadal and longer time scales may present sources of improved predictive skill in future weather and climate models.

Moving forward, we need to be even more adaptive and agile, applying new technologies in ways that both make crucial observations more effectively and make coincident observations of the biology, chemistry, and physics of the ocean. At the same time we need at our modeling and prediction centers to establish the resources and mindset that will support testing and adoption of research results that lead to improved predictions.

We are on the edge of exploration of many ocean frontiers that will be using new eyes in the ocean. Public-funded/private-funded investment in those eyes is required, but will not be successful without adequate and continuing Federal commitment to ocean science. Support such as Jim's and the Schmidt Ocean Institute, which was founded by Eric Schmidt and operates the research vessel *Falkor,* help fill gaps in support for research and development or for access to the ocean. However, the fact remains that Federal funding is by far the leading driver of exploration, observation, and technical research and development that has a direct impact on the lives of people around the world and on U.S. economic growth and leadership. It also remains the bellwether by which philanthropic entrepreneurs judge the long-term viability of the impact their investment will have on the success that U.S. ocean science research will have around the globe.

Recent Model Advances

Most advancements in global oceanographic and climate modeling in the recent past have been incremental, but have proved crucial to our greater understanding of Earth's ocean and climate as internally complex and interlocking systems. Further work needs to be done to provide greater insight into the workings of the ocean, atmosphere, land, and human systems individually and as an integrated whole. At its core, this requires enhanced observational infrastructure, as well as better data assimilation and more robust statistical and dynamic models.

Over the past 30 years, one of the most visible examples of breakthrough understanding of ocean processes related to climate and weather has been the link between the El Nino-Southern Oscillation (ENSO) and extreme weather events around the world, including patterns of drought and hurricane frequency in the tropical Atlantic. Understanding phenomena such as ENSO helps forecasters better predict how Earth's climate will respond to changing conditions in the ocean over seasonal to annual time scales. But such oscillatory behavior is difficult to forecast under the changing conditions driven by increased atmospheric greenhouse gases.

There are, however, several noteworthy advancements in the recent past.

New sea ice projections [7]

Loss of nearly all Arctic sea ice in the summer is now projected to occur as early as 2050. An ice-free Arctic will have benefits for transportation and natural resource extraction, but these, in turn, will likely come at a cost. Territorial claims in the Arctic Ocean could lead to tension among regional partners, but also present opportunities for new avenues of international cooperation; and extractive activities pose risk for accidental oil spills in remote and hazardous locations. In addition, the loss of sea ice is a significant disruption to the fragile and unique ecosystem of the Arctic Ocean for which the implications, in the Arctic or beyond, are difficult to predict.

Expanded Sea-surface Temperature Forecasts [8]

It now appears possible to extend our ability to forecast some variations in sea-surface temperature which could prove to be an important tool for improving climate models. Research is focusing on patterns of decadal variability in sea surface temperatures. However, initialization data is very important to such a model, which means that a comprehensive ocean observing system remains essential to incorporating this potential advancement into future predictive capability.

Improved horizontal resolution and improved model physics [9]

Higher resolution models are better able to incorporate the physical, chemical, and biological processes. A new suite of climate models known as CMIP5 is being used to prepare the Intergovernmental Panel on Climate Change Fifth Assessment

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[7] Overland, J.E. and M. Wang, "When will the summer Arctic be ice-free?" *Geophysical Research Letters* 40(2013), doi:10.1002/grl.50316.

[8] DelSole, T., J. Liwei, and M.K. Tippett, "Decadal prediction of observed and simulated sea surface temperatures" *Geophysical Research Letters* 40(2013), doi:10.1002/grl.50185.

[9] Polade, S.J., " Natural climate variability and teleconnections to precipitation over the Pacific-North American region in CMIP3 and CMIP5 models" *Geophysical Research Letters* 40(2013), doi:10.1002/grl.50491.

Report (IPCC AR5) and, along with other developments, is helping provide better estimates of precipitation over the continental U.S. under an evolving climate. This comes at a time when evidence points to the fact that the water cycle is intensifying under global warming [10] and it is becoming increasingly important to understand and predict the accompanying intensification of droughts in dry regions and the incidence of floods in wet regions. The ocean is the major source of most rainwater and must be part of any effort to predict the future water supplies for metropolitan, agricultural, and industrial regions of the U.S.

Predicting long-term cycles [11]

Regular changes in sea-surface temperature in the tropical Pacific Ocean, such as the El Niño-La Niña cycle, influence precipitation and extreme events over a wide swath of the globe. However, many other, longer-term modes of ocean-temperature variability such as the Pacific Decadal Oscillation (PDO) exist that can impact regional climate and weather patterns far afield. Much of our understanding on these climate modes is based on the instrumental record of temperature, but this only extends back only a couple of centuries. Important new insights on past climate variability and extremes is being discovered by analyzing tree rings and other paleo-climate proxy records. Recent work also suggests the presence of centennial-scale cycles in the Pacific, and researchers are currently analyzing coral samples from remote islands of the western Pacific for signs long-term variability in ocean temperature that might confirm the presence of this and its current phase.[12]

Incorporation of biological processes into modeling and operational forecasts [13]

Advancements in predictions of harmful algal blooms (HABs) in the Gulf of Maine have reached a point where the research program will soon transfer to operational forecasting. Forecasts of HABs are already operational in the Gulf of Mexico and Lake Erie. The economic cost of HABs to recreation, fishing, public health, and coastal monitoring in the U.S. is estimated to be nearly $100 million annually. Forecasts of the severity of HABs in recent years have allowed fisheries managers and public health officials to take preemptive action that minimizes costs associated with beach and shellfish bed closures or the treatment of drinking water systems to remove cells and toxins. Recent research and modeling also provided evidence that allowed for the 2013 opening of clam harvesting on Georges Bank after being closed for 22 years.[14]

Efforts to improve hurricane intensity prediction [15]

Accurate predictions of hurricane intensity prior to landfall are significantly hampered by high-resolution observations of upper-ocean heat content and mixing immediately upstream of a storm. Data collected from NOAA "Hurricane Hunter" aircraft using airborne expendable bathythermographs (AXBTs), which cost nearly $1,000 per instrument (not including aircraft costs), are limited by the one-time nature of the probes. Funding obtained through the Hurricane Sandy Relief Bill (HR–41) will enable advancements in the technology behind the Argo profiling floats that resulted in an air-deployable version of the autonomous floats. When deployed from the same aircraft, a single float should be able to make as many as 150 vertical profiles before, during, and after the storm to provide a more complete picture of heat transfer from the ocean that fuels a tropical storm like Sandy, at a cost of roughly $40 per profile.

Observational Capability to Support Modeling

The process of expanding our understanding of the ocean system, both alone and as it relates to other planetary cycles, is driven by our ability observe marine processes near and far from shore, deep beneath the surface, over large spatial expanses, and over long periods of time. This, in turn, provides much needed data that enables comprehensive modeling efforts to forecast natural and human-driven

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[10] Durack, P.J., "Ocean salinities reveal strong global water cycle intensification during 1950 to 2000," *Science* 336(2012):455–458 doi:10.1126/science.1212222.

[11] MacDonald, G.M. and R.A. Case, "Variations in the Pacific Decadal Oscillation over the past millennium," *Geophysical Research Letters* 32(2005) doi:10.1029/2005GL022478.

[12] Karnauskas, K.B., "A Pacific Centennial Oscillation predicted by coupled GSMs" *Journal of Climate* 25(2012), doi:10.1175/JCLI–D–11–00421.1

[13] Stumpf, R.P., *et al.,* "Skill assessment for an operational algal bloom forecast system," Journal of Marine Systems 76(2009):151–61, doiI: 10.1016/j.jmarsys.2008.05.016

[14] NOAA Fisheries Northeast Regional Office, "New England offshore areas will reopen for Atlantic surfclam and ocean quahog fishing," December 18, 2012 http://tinyurl.com/nc2og8b (accessed June 2013).

[15] Owens, B. and S. Jayne, personal communication, June 6, 2013.

changes far into the future and over time frames that support a wide range of decision-making at the national, regional, and local levels.

Growth of our national modeling capability is inherently dependent upon continued research and development of new observational technologies, including autonomous tools and methods, and enhanced by new data-handling and assimilation systems, as well as development of new statistical and dynamical modeling capabilities. Four areas of increased observational capability are needed:

1. Observations that support detailed studies that help capture processes needed to improve models. To incorporate these observations, models will need spatial resolution sufficient to resolve these processes or, alternatively, the observations will help develop parameterizations of these processes to incorporate in models.
2. Ongoing broad-scale observations for initialization of modes.
3. Long-term, sustained observations that serve as reference stations for model verification and validation, as well as motivation for model improvement.
4. International collaboration on sustained observations and access to the sea that capitalize on international assets in order to enhance the collective global observation of the ocean. For example, the access to the polar ocean regions would be better achieved through operational collaboration between the U.S., Australia, Japan, and Norway—all of which are pushing observing capabilities into high latitudes. This requires member states of the Intergovernmental Ocean Commission, to continue to take on responsibilities similar to what is done in the World Meteorological Organization.

IOOS and the ICOOS Act

The networks and partnerships developed through the Integrated Ocean Observing System (IOOS) have connected academics with managers and other users of their work allowing co-development of projects and products to provide user-driven, science-based solutions to real-world problems. The reauthorization of the Integrated Coastal Ocean Observing (ICOOS) Act of 2009 is critical to ensuring this continued success.

IOOS provides core infrastructure for coastal, ocean, and Great Lakes research and discovery. Long-term, sustained observing systems are critical to understanding natural variability in U.S. waters and for rapidly detecting change that can have an impact on terrestrial and marine activities. These same observing systems can also be leveraged to allow more detailed studies, and novel sensors added to established systems, when combined with IOOS observations, are providing critical background and new insights on marine processes. Two examples in the northeast include the Pioneer Array, which is a part of the NSF-funded Ocean Observatories Initiative (OOI), and the NOAA-, NIEHS-, and NSF-funded Harmful Algal Bloom (HAB) work.

The location of the Pioneer Array is particularly important in understanding the important transports (nutrients, heat, etc.) associated with the abundant fisheries over the continental shelf and slope regions south of Georges Bank. Although a primary focus is on research, the sustained observations over five years together with partnerships with the fisheries industry will be mutually beneficial and may lead to a much wider investment in operational monitoring in this important economic area.

Coastal IOOS networks deliver key regional-scale information, both observations and models that help place local process studies at the Pioneer Array site into a regional context. Changes in regional-scale circulation and water properties detected by IOOS observing systems have proven an essential element to understanding and predicting HAB severity each year. In 2014, WHOI scientists will deploy four environmental sample processors, novel sensors capable of detecting HAB species autonomously at the molecular scale. Never before have four sensors been deployed at one time. This effort is part of an IOOS goal to accelerate the deployment and integration of new technologies.

Coastal IOOS also operate regional modeling systems that act as incubators for rapid advances in technology and methods. Through IOOS, state-of-the-art forecast systems are being developed by researchers in partnership with decision makers. Regional-and local-scale models are run every day at academic institutions and delivered to a range of agency and commercial users, including local Weather Forecast Offices of the National Weather Service (NWS). Through IOOS partnerships, near-street-level inundation forecast systems have been developed with and for NWS forecasters and town emergency managers that often push the envelope of what is capable of being modeled. At a larger scale, similar rapid progress has been made with researchers and managers through the IOOS Coastal Ocean Modeling Testbed,

which has also focused on research into how to disseminate and make accessible model output. This efficient management and communication of data is another core component of IOOS and OOI that is essential for its effective use by researchers.

For the most part, the ICOOS Act establishes an adequate structure for IOOS, but inadequate funding and other issues remain that, if solved, will help make the program more effective over the long-term. The primary issue of concern with IOOS is the continued low, flat funding of the program. The House version of the re-authorization limits the funding to appropriated amounts, or $29.6 million. At this level, the program will be forced to remove assets from the water and will not be able to address the gaps in the coastal observing network. In addition, the funding does not address the need to transition programs from research to operations, as in the case of the impending operationalization of HAB monitoring and forecasting in the Gulf of Maine. This decade-long research program made heavy use of the IOOS network. In addition, IOOS is an interagency program and many Federal agencies benefit from IOOS data and products, but these same agencies do not support the infrastructure; currently, NOAA is the only program that supports the infrastructure.

Improving Research to Operations (R2O)

In 2010, the National Research Council's Committee on Assessment of Intraseasonal to Interannual (ISI) Climate Prediction and Predictability released a final report that addressed specific ways to improve the operations and integration of the U.S. research and forecasting communities. The committee identified three general areas of improvement to advance ISI predictive capability: *best practices, building blocks of ISI forecast systems,* and *research for sources of predictability.*

The Committee's 11 recommendations are outlined below. More detail of each can be found in the Committee's final report.[16]

Suggested improvements to best practices are focused on the activities of the operational forecast centers and aim to improve the delivery and dissemination of forecast information for both decision-makers and researchers. Specifically, it is recommended that the synergy between operational ISI forecasting centers and the research community be enhanced and the public archives of data used by operational ISI forecasting centers in forecasts be established. Data includes observations, model code, hindcasts, analyses, forecasts, re-analyses, re-forecasts, verifications, and official forecast outlooks.

Improvements to the building blocks of ISI forecast systems apply to both the operational and research communities and focus on the continued development of observations, statistical and dynamical models, and data assimilation systems. Recommendations are targeted at various improvements in models and model techniques, analysis and interpretation of errors, and improved incorporation of physical processes.

Improvements to research for sources of predictability are aimed primarily toward the research community and provides a set of longer-term research priorities based on a set of criteria indicating each has an impact on ISI variability and predictability, contains gaps in knowledge that prevents them from being exploited by ISI forecast systems, and there is potential social value for gaining knowledge of each as a source of variability. Key examples of key processes that are likely to contribute to improved ISI predictions include the Madden-Julian Oscillation, ocean-atmosphere coupling, stratosphere-troposphere interactions, land-atmosphere feedback, and high impact events affecting atmospheric composition.

Underlying all of these recommendations is the challenge that the basic state of the ocean is changing on scales that are faster than our development of the understanding of those changes and how they might impact the processes that are needed to incorporate in models to advance our predictive capabilities and decision-support information.

Conclusions and Recommendations

I conclude my remarks by highlighting the value of public-funded/private-funded partnerships to the future of R&D in this country. In addition to the above, I believe my recommendations will help U.S. ocean science community be more competitive in the international research arena for decades; will help advance national priorities in the economic, security, and research arenas; and ensure future success by bolstering STEM initiatives that keep students involved, interested and inspired to push the frontiers of knowledge and exploration beyond what we can imagine today.

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[16] National Research Council of the National Academies, *Assessment of intraseasonal to Interannual Climate Prediction and Predictability,* Washington, D.C: National Academies Press, 2010.

Jim Cameron's partnerships with Woods Hole Oceanographic Institution and also with Scripps Institution of Oceanography are welcome examples of how public and private funding can leverage each other. But I must emphasize that this partnership and others like it are only one type that helps us all meet these important national objectives. At the core must be a significant public commitment by the Federal Government supporting exploration, research, and observing infrastructure about our planet and the ocean processes that have a very real and significant impact on all of us every day.

Toward that end, I urge this committee to support the following:

1. *Fully fund NSF budget requests and support ocean science research by Navy/ONR, NOAA, NASA, DOE, and NIST.* The leadership these agencies provide through their science and technology programs is essential to pursuing new lines of inquiry that can lead to new technologies, industries, and jobs, as well as novel ways to solve societal problems. Given the current 15-to-20-year timeframe for doubling the NSFs budget, and taking into account inflation, support for the premier U.S. science agency is actually in danger of significantly declining in constant dollars over that same period. Even in the face of very difficult budget constraints and sequestration, continued investment in NSF will provide the unanticipated dividends that have helped our Nation maintain its global economic competitiveness and leadership. Support for the NSF also enhances STEM initiatives, from K–12 through post-graduate, which further ensure U.S. leadership and competitiveness for decades.
2. *Reauthorize the Integrated Coastal and Ocean Observation Act.* This legislation provides the foundation for a national ocean observing system—one that enhances those provided by states and other non-governmental, academic, and private entities—to shed light on the oceans and provide knowledge and forecasts for fisheries, coastal residents, and shipping. Even with the existing and potential advances by IOOS assets, there is currently very limited capacity to understand what is happening below the surface of the ocean temporally or spatially. Broad spatial and temporal observation of the ocean will complement existing Earth-observing capacity that is currently dominated by satellite observation of terrestrial and atmospheric processes. Moreover, we are still learning about physical processes within the ocean that have a direct impact on humanity. This will require additional support for operational ocean observing systems and, support for mission-driven agencies such as NOAA, ONR, NASA, and other Federal agencies.
3. *Reauthorize America COMPETES legislation to bolster innovation, research and development, and STEM initiatives.* Support science (R&D) and education (STEM) funding in general and, increasing understanding of the importance influence of ocean processes on humanity, in particular, will ensure our country has a ready supply of technological capacity and of young people with the drive and inspiration to push the boundaries of knowledge and gain the skills that will benefit the U.S. economy, environment, and national security well into the future.
4. *Continue to support and sponsor the lead role of the U.S. and its ocean agencies on the critical international stage.* The U.S. has provided international leadership and funding in sustained ocean observations, especially for the development and operations of key networks including the tsunami observing system, the TOGA array, the Argo float network, and OceanSites array. Our declining leadership puts much of the existing ocean observation networks at risk.

Thank you again for this opportunity to address the Committee.

ADDENDUM: LIST OF SUPPORTING MATERIAL

Woods Hole Oceanographic Institution (WHOI) Overview
http://www.whoi.edu/main/about

WHOI Vessels and Vehicles
http://www.whoi.edu/main/ships-technology

Human Occupied Vehicle *Alvin*
http://www.whoi.edu/alvin/

WHOI Center for Marine Robotics (CMR) Overview
http://www.whoi.edu/marinerobotics

***Oceanus* Magazine, Volume 48, Number 3, October 2011**
Deepwater Horizon: Mustering scientific muscle during a national crisis

http://www.whoi.edu/oceanus/viewPrintedIssue.do?archives=true&sortBy=printed&o=read&id=342

News Release: Explorer and Filmmaker James Cameron Gives DEEPSEA CHALLENGER Sub to Woods Hole, March 26, 2013
http://www.whoi.edu/main/news-releases?tid=3622&cid=165229

Consortium for Ocean Leadership Ocean Priorities
http://www.oceanleadership.org/ocean-policy-legislation/ocean-leadership-policy-priorities/

Senator BEGICH. Thank you very much, Dr. Avery.

Next we have Ed Page, Executive Director of Alaska Marine Exchange.

Ed, good to see you again. Thanks for participating in our effort a few months ago in Alaska on issues of the Arctic.

STATEMENT OF CAPTAIN EDWARD PAGE, BOARD CHAIR, ALASKA OCEAN OBSERVING SYSTEM AND EXECUTIVE DIRECTOR, MARINE EXCHANGE OF ALASKA

Captain PAGE. Well, thank you, Senator, and thank you, Senator Cantwell, for allowing me the opportunity to testify today regarding the Alaska Ocean Observing System and also the Integrated Ocean Observing System.

I am providing a little different perspective than Mr. Cameron. I stay on top of the ocean——

[Laughter.]

Captain PAGE.—and I am going to stay on top so we won't have any competition down there.

For the last 45 years, I have been involved in the safety of maritime operations, both as a Coast Guard captain and chief of marine safety for the Pacific Area and captain of the port and other functions and now presently as a mariner operating commercial vessels and Executive Director of the Marine Exchange of Alaska, which is a nonprofit maritime organization providing information to aid safe, secure, efficient, and environmentally sound maritime operations, as well as the Chair of the Alaska Ocean Observing System.

I have sailed on Coast Guard vessels, tankers, container ships, fishing vessels, offshore supply vessels, landing craft, cruise ships, cargo vessels, whatever, throughout Alaska waters dating back to 1973, when I first sailed to Alaska from Boston.

I can say from experience that operating in Alaska is a very harsh, extreme environment with many challenges, environmental challenges, and with new waterways opening, thanks to the opening of the Artic or the ice between the Arctic. And all of this requires good environmental information for mariners to operate safely and to respond to emergencies.

Alaska is a huge state with 39,000 miles of shoreline, most of which is remote, and mariners and sailing explorers have limited communications. The Marine Exchange has been involved in developing a vessel tracking system throughout the state in hundreds of locations, from the Arctic out to the Aleutian Islands, down southeast, where we track vessels.

But we also, through the partnership of AOOS, have been able to bring the science to these vessel tracking systems and adding weather sensors that can provide real-time information to vessels and the National Weather Service. We are taking the science infor-

mation and providing it to mariners real-time to aid maritime safety and efficiency and also aid emergency response.

This information is valuable to the maritime industry, to the Coast Guard, to the state of Alaska, to NGOS who are doing research on the environment, as well as other agencies, Department of the Interior and others, who have a stake in environmental protection in Alaska.

This is enabled through the AOOS partnership forum. The meetings at AOOS are comprised of all these different entities who pool their resources and, through leveraging their resources, are able to provide much more capabilities in detecting ice and reporting that information and weather information. All of that is valuable to research but also the day-to-day operations of vessels operating in our waters.

As you know, AOOS, or Alaska Ocean Observing System, is 1 of 11 regional systems that have partnered with 17 Federal agencies and state agencies in the Integrated Ocean Observing System. And AOOS is uniquely equipped to leverage public and private observations, as has been done in Alaska, to meet regional needs, improving the Nation's economy, navigation safety, and ocean ecosystems.

The IOOS legislation provides a framework for building this system of systems that links and enhances our existing observing capacity. It is an innovative approach for leveraging resources, one that relies on partnerships, being cost-effective and responsive.

And it is working. Eleven regional systems, including AOOS, rely on the partnership to address the societal needs of safe commerce and navigation, climate variability, as we are experiencing in Alaska, ecology, and environmental hazards. And we do so in close partnership with the universities, private companies, government agencies, and others. And IOOS links together partners at the regional level and leverages resources nationwide. It is cost-effective, flexible, responsive, and innovative.

And, of course, the systems and information provided by IOOS have been used in the responses to Superstorm Sandy, the Deepwater Horizon spill, and in search and rescue periodically by the Coast Guard.

These are just a few examples of how IOOS is making a difference. And we, accordingly, urge the reauthorization of the ICOOS Act of 2009 to ensure that the Nation's ocean, coastal, and Great Lakes observing systems are sustained and enhanced.

I know we are here today to talk about deep sea challenges, but I also have to talk about the challenge of operating vessels on the surface of the ocean and how important IOOS is to their safe operation.

And the rapid development that is occurring in Alaska presents some unique challenges and also an opportunity for us to set in place some responsible risk-reduction measures, including observations communication products delivered from observations, such as rain forecasts.

In closing, I urge the continued and expanded risk-mitigating measures like the Arctic Research, Monitoring, and Observing Act that you are proposing, Senator, as well as the ICOOS Reauthorization Act.

Thank you for the opportunity to speak here today.

[The prepared statement of Captain Page follows:]

PREPARED STATEMENT OF CAPTAIN EDWARD PAGE, BOARD CHAIR, ALASKA OCEAN OBSERVING SYSTEM AND EXECUTIVE DIRECTOR, MARINE EXCHANGE OF ALASKA

Chairman Begich, Ranking Member Rubio and Members of the Subcommittee, thank you for inviting me here today to talk about innovative partnerships in ocean observations and the Alaska Ocean Observing System in particular. I am Ed Page, Chair of the Board of the Alaska Ocean Observing System and Executive Director of the Marine Exchange of Alaska.

During my 30+ years in the Coast Guard followed by 12 years as executive director of the Marine Exchange of Alaska, I have sailed on Coast Guard vessels, oil tankers, container ships, fishing vessels, tugs, oil exploration and support vessels, oil spill response vessels, cruise ships and cargo ships throughout Alaska. I can say from experience that operating in Alaska presents unique challenges and risks. Increases in vessel traffic, the opening of new waterways as ice impacted waters recede and changing ocean conditions will only intensify risks to all maritime operations. Today I am going to share just one innovative partnership—between my organization and the Alaska regional component of the national Integrated Ocean Observing System—that both adds value and reduces risks in a notoriously harsh environment.

Alaska is a huge state with over 39,000 miles of shoreline, most of which is remote and mariners sailing these waters are mostly outside of cell or VHF range. The Marine Exchange of Alaska was established in 2000 to bring the far-flung maritime community together to develop an extensive network of over 100 Automatic Identification System (AIS) receivers to track vessels operating in Alaska. I am proud to say that my organization has helped prevent maritime accidents, assisted emergency response efforts, and aided the maritime community to comply with state and Federal regulations for vessel tracking; but that's not why I'm here today. I am here today to tell you about what happened when my organization began working with the Alaska Ocean Observing System—or AOOS.

AOOS is the Alaska component of the national Integrated Ocean Observing System, which seeks not only to increase ocean observations to meet societal needs to improve the Nation's economy, navigation safety and ocean ecosystems, but also to integrate the plethora of observations made by multiple state, federal, local and private sector entities to aid stakeholder decisionmaking.

From the AOOS perspective, my organization is really just one stakeholder group in the region. AOOS works with everyone: with industry, state and Federal researchers to share data and observations; with the National Weather Service to integrate real-time weather and ocean observations to improve forecasts; and with the commercial maritime industry, whom I represent, who also need environmental information that aids safe, secure, efficient and environmentally sound maritime operations. Partnering with AOOS didn't just help us to do our job better; it brought us into a collaborative relationship with other groups in our region to leverage our resources and cultivate mutual benefits.

Until the Marine Exchange of Alaska partnered with the Alaska Ocean Observing System AIS communication with boats was one-way and the information was strictly geographic. Search and rescue could track a vessel in trouble, but there was no way to warn individuals at sea if conditions or forecasts changed once a vessel went out of cell or VHF Radio range. Listening to various stakeholders, AOOS identified a need for real-time weather information while at sea. They approached us to partner on a project using the AIS system to provide real-time weather conditions to mariners. AOOS staff is now working closely with mariners to deliver critical ocean and coastal information with this new technology and exploring opportunities to enhance the delivery of real time weather, ice and other environmental data as well as marine forecasts. This private-public partnership delivers a cost effective solution to a regional problem that no other government agency or contractor was set up to do. Remarkably, it is one of over a dozen similar projects this small but agile regional organization is able to support throughout the state.

Another example of the AOOS private-public partnership is their willingness to host the public access portal for all of the oil and gas industry-collected data in the Chukchi Sea that is now available to the larger scientific community as a result of the NOAA data sharing agreement with Shell, ConocoPhillips and Statoil. The industry data, valued at approximately $80 million, will be of tremendous value as Federal and state managers make decisions about how best to manage oil and gas development in the Alaska Arctic.

The Alaska Ocean Observing System model of regional collaboration is one that should be replicated as the U.S. Arctic continues to open up. I commend Senator Begich's Arctic Research, Monitoring and Observing Act, which offers a roadmap to improve maritime safety and advance marine science. For those of you who may be less familiar with Senate Bill 272, this bill recognizes that the Arctic is undergoing profound changes. The region is warming at twice the rate of the global average and seasonal sea ice is diminishing both in area and volume. Growing interest in oil and gas, commercial fishing, marine shipping and tourism are also driving changes now and down the road. This legislation would provide sustained support for long-term research, monitoring and ocean observing programs in the Arctic Ocean, Bering Sea and North Pacific. Long-term observations in particular are difficult to fund; but they provide the backbone of most of the products—like sea ice and weather forecasts and emergency response plans that so many mariners and coastal residents rely on. We are especially supportive of providing sustained funding for the Alaska Ocean Observing System to provide the critical observations needed to sustain a healthy Arctic.

The Alaska Ocean Observing System is one of the 11 regional systems that have partnered with 17 Federal agencies as part of the Integrated Ocean Observing System—IOOS—to provide services to the entire coastline of the U.S., including the Great Lakes. Regional systems like AOOS are uniquely equipped to leverage public and private observations to meet regional needs improving the Nation's economy, navigation safety and ocean ecosystems. For that reason, we also are in support of reauthorizing of the Integrated Coastal and Ocean Observing System Act of 2009 (ICOOS) that provides the foundation for our work in the Arctic.

The Act provides the framework for building a "system of systems" that links and enhances our existing observing capacity. It is an innovative approach for government, one that relies on partnerships to be cost-effective and responsive. And, it is working. The 11 regional systems, including AOOS, rely on partnerships to address the societal needs of safe commerce and navigation, climate variability, ecology and hazards. They do so in close partnership with universities, private companies, government agencies and others. IOOS links together partners at the regional level and leverages resources. IOOS is a cost-effective, flexible, responsive and innovative.

These partnerships work:

- *Superstorm Sandy.* During Superstorm Sandy, the marine transportation industry in the New York/New Jersey area made preparations based on forecast products derived from IOOS observations. In the Port of NY and NJ, all vessels were moved from anchorages in the Harbor. Over 6,700 containers were diverted from the New York/New Jersey area to Virginia. The cost estimate for these containers is approximately $1 Billion (Marine Technology Society TechSurge Event 2012);
- *Deep Water Horizon Spill.* The IOOS data management system allowed for the seamless integration of data from non-federal sources for use by the Unified Area Command. Prior to this, valuable non-Federal information collected by universities, state agencies or private companies was not accessible to Federal responders. The IOOS data management system, based on interoperable standards and services, now allows for the integration of data from all relevant sources. In fact, approximately 75 percent of the data now served by NOAA's National Weather Service through the National Data Buoy Center is from non-federal sources, most of which is directly attributable to the work being done and supported by the Regional Associations.
- Much of the oil from the spill remained subsurface where, despite the availability of technology, we lacked the ability to readily monitor the flow of oil. IOOS, through its regional network, redeployed several underwater gliders from around the country to assist with subsurface monitoring efforts. This unique and flexible capability is one of the hallmarks of the IOOS system.
- *Search and Rescue.* The U.S. Coast Guard estimates that with the use of IOOS data on real-time surface currents they can reduce the search area for a distress call by two-thirds, increasing the chances of safe recovery.

These are just a few of the many examples of how IOOS is making a difference. We urge the reauthorization of the ICOOS Act of 2009 to ensure that the Nation's ocean, coastal and Great Lakes observing systems are sustained and enhanced.

We're here today to talk about Deep Sea Challenges, and the rapid development that is occurring in Alaska does present challenges and also an opportunity to set in place responsible risk reduction measures, including both observations and communication of products derived from observations, like marine forecasts.

I hope that my experience with the Alaska Ocean Observing System illustrates the potential and the proven success of this innovative approach and I hope that the folks in this room leave here today feeling at least a fraction of the urgency that I feel about the need to implement risk mitigating measures like the Arctic Research, Monitoring and Observing Act and the ICOOS Act Reauthorization now.

Senator BEGICH. Thank you very much.

And next we have Dr. Newton, Senior Principal Oceanographer, Applied Physics Laboratory, University of Washington.

Thank you for being here.

STATEMENT OF JAN NEWTON, PH.D., EXECUTIVE DIRECTOR, NORTHWEST ASSOCIATION OF NETWORKED OCEAN OBSERVING SYSTEMS; PRINCIPAL OCEANOGRAPHER, UNIVERSITY OF WASHINGTON APPLIED PHYSICS LABORATORY; AND AFFILIATE ASSISTANT PROFESSOR, UNIVERSITY OF WASHINGTON SCHOOL OF OCEANOGRAPHY

Ms. NEWTON. Thank you, Chairman Begich, and thank you, Senator Cantwell, for this opportunity to testify with you here today and to talk about innovative partnerships in ocean observations, specifically the Northwest Association of Networked Ocean Observing Systems, or NANOOS, which is part of the United States Integrated Ocean Observing Systems, or U.S. IOOS, program.

My name is Jan Newton, and I am a Principal Oceanographer at the University of Washington, the Executive Director of NANOOS, and also a University of Washington faculty member.

As a graduate student starting out studying ocean processes on ships, I found so many of the research cruises, which are conducted over the span of a few weeks, encountered what folks said were anomalous conditions. And this repeated situation spoke volumes to me that if so many cruises revealed the unexpected, then maybe we really don't know that much about the state of the oceans.

So it has been a logical passion for me to be one of the many implementing IOOS and leading those efforts in the Pacific Northwest via NANOOS.

I think the genius of IOOS is that it goes beyond just the science, to bring ocean observations to all sectors of society for diverse and compelling needs, such as safe maritime transport, sustained health of natural resources, response to extreme weather or tsunami events.

IOOS is a congressionally established, stakeholder-driven, and science-based ocean analog of the National Weather Service. It provides and enhances our nation's access to data from oceans, coasts, estuaries, and Great Lakes. It was designed and is implemented with both a Federal and a regional footprint, allowing IOOS to connect with regional stakeholders while still maintaining national consistency. IOOS is the essence of an innovative partnership.

NANOOS is the regional association for the Pacific Northwest, just as AOOS is for Alaska. We work with diverse stakeholders in Washington and Oregon to understand their information needs and to coordinate and support development, implementation, and operation of a regional coastal ocean observing system, the buoys, radars, models, and data management capacity to provide data and data products on the spatial and time scales that meet their needs.

Established in 2003, NANOOS is a growing partnership of almost 50 entities, and that is industry, tribes, state, local, Federal

agencies, nongovernmental organizations, education and research institutions, who form our governing council. We work with IOOS to implement national priorities on a regional scale and to understand regional Pacific needs.

To build NANOOS, we integrated existing regional assets, not only the technologies but also the people, in a sustained way to build a network system, whereby at this very moment, from our NANOOS data portal, I can click on buttons that tell me the sea temperature 13 miles off La Push, Washington, the pH in the seawater intake at Taylor Shellfish and Hatchery, the oxygen at the bottom of Hood Canal, the sediment load in the Columbia River, the offshore currents along the coast of Oregon, and the predicted temperature of the coastal waters off Newport.

Those may sound like disparate and esoteric things to know, but to shellfish growers who want to know whether to spawn their oyster larvae, to the fisheries manager who wants to know if fish are subject to additional stress from reduced oxygen before setting fisheries catch limits, to the Columbia River Bar pilot who wants to navigate the entrance channel safely, to the true heroes of the Coast Guard who need to optimize the effectiveness of their search and rescue operations, and to the recreational tuna fishing captains who want to optimize their safety and profitable local businesses, all of those data inform decision points that NANOOS currently delivers to the users. And each one of those is a real example I mention where NANOOS is making a difference.

By building NANOOS, we have dramatically increased the efficiency in how taxpayer-purchased ocean data, as well as privately funded ocean data, reaches the hands of the public, both regionally and nationally.

The Federal investment in NANOOS reaps substantial return. For example, we partially support 19 data streams, yet through partnerships we serve 176. And those additional ones are from other Federal programs, as well as from state, tribal, and industry data providers who want their data served in this fashion. And, together, we have a better integrated picture of the conditions.

IOOS builds communities of practice, and those are communities of practice from disparate groups. So our data management system was designed and implemented by a team from three regional universities working with The Boeing Company. The national high-frequency radars that the U.S. IOOS team has over 10 years consolidated has gone from a handful of radars to 130, all operated as a single network with nationally compatible data, operated by academic and industry partners, led by IOOS.

The Federal investment in sustaining ocean observations makes a difference and provides a significant return on investment. Prior to 2010, we had no sustained observations of subsurface water properties, like oxygen, nutrients, pH, off the coast of Washington. Because IOOS investments in NANOOS are used for jobs to sustain those regional observations, we were able to obtain a $500,000 grant from the Murdock Charitable Trust to build a state-of-the-art buoy and glider system, yielding yet unprecedented data series with new scientific discoveries like 40-meter internal waves and key data to assess hypoxia and ocean acidification.

The IOOS observing system, including this buoy at La Push, is being utilized to provide an early-warning system for ocean acidification to support local shellfish growers and hatchery owners, helping them to save over $35 million in 2011 alone. And I would say that is a great return on investment for the $2 million budget awarded to NANOOS for the entirety of our system.

A local shellfish grower, Mark Wiegardt, co-owner of Whiskey Creek Shellfish Hatchery, said it this way: "Putting an IOOS buoy in the water is like putting headlights in a car. It lets us see changing water conditions in real-time."

We also interact with the Columbia River Bar pilots, like Captain Dan Jordan, with now the ability to provide real-time wave conditions and forecasts for the Columbia River system that, alone, handles 300 million tons of foreign trade worth $16 billion a year.

IOOS stimulates government efficiency, stimulates the economy, provides jobs, and increases quality of life for the nation. In short, IOOS works.

And I am grateful to our Washington State Senator, Maria Cantwell, for her leadership in supporting IOOS and promoting reauthorization of the ICOOS Act. The ICOOS Act of 2009, as you heard, enables IOOS to be a Federal-regional partnership. And I request the Committee's support for this.

You also asked for my input on the implications of climate change on ocean waters, such as warming, altered productivity, and ocean acidification. And I ask that we all take a breath and then, after you do that, take another. Please understand that the oxygen for every other breath that you take was supplied by the ocean, the phytoplankton in the ocean, the other being supplied by terrestrial plants. So the oceans are critical to every other breath that we take.

Only 33 percent of the surface of the Earth is the part that we live in—definitely the minority. I often reflect that the sight of sea surface without any land visible is a foreign sight to most of the population of our planet, yet truly that is the most common sight of the Earth.

So, as we have changed the composition of our atmosphere, these alterations have indeed heated the planet and increased the concentrations of CO_2 that diffuses into the oceans. These have strong implications for the food web. And as increased CO_2 changes the pH, it shifts the ocean waters toward a more acidified state. Species such as oysters, pteropods, which are food for salmon, and of course ecosystems such as coral reefs have less capacity to be formed or to be competitive. And this effect is certainly being felt in the Pacific Northwest.

It has been my honor to work with Dr. Richard Feely of NOAA's Pacific Marine Environmental Lab researching OA in Washington State. And, as a partner, NANOOS is making high-quality measurements for assessing, modeling, and communicating the regional status of ocean acidification. Via IOOS, NANOOS works with the NOAA Ocean Acidification Program. And these synergies assure the most effective use of limited ocean observing resources.

I was one of seven scientists appointed to then-Governor Christine Gregoire's Blue Ribbon Panel on Ocean Acidification to develop recommendations and actions needed to ensure the health and

economy of Washington State. It appears that some of these recommendations may be funded at limited levels in the next biennium through the Washington State legislature, actions such as monitoring, forecasting, and food web impact assessment. But I want you to know that these actions dovetail extremely well with the Federal investments from NOAA's Ocean Acidification Program and from U.S. IOOS in NANOOS.

So national leadership that can be implemented regionally can only succeed when there is a strong community of practice that builds an allegiance and the human network required to assure that common methods and calibrations are implemented. The reauthorization of both the Federal Ocean Acidification Research and Monitoring, or FOARAM Act and the ICOOS Act will assure that this will continue and in a cost-effective manner. And I urge your actions on these both.

And I thank you for my time.

[The prepared statement of Ms. Newton follows:]

PREPARED STATEMENT OF JAN NEWTON, PH.D., EXECUTIVE DIRECTOR, NORTHWEST ASSOCIATION OF NETWORKED OCEAN OBSERVING SYSTEMS; PRINCIPAL OCEANOGRAPHER, UNIVERSITY OF WASHINGTON APPLIED PHYSICS LABORATORY; AND AFFILIATE ASSISTANT PROFESSOR, UNIVERSITY OF WASHINGTON SCHOOL OF OCEANOGRAPHY

Good Afternoon Chairman Begich, Ranking Member Rubio, and members of the Subcommittee. I want to thank you sincerely for inviting me here to talk about innovative partnerships in ocean observations and specifically, the Northwest Association of Networked Ocean Observing Systems, NANOOS, part of the United States Integrated Ocean Observing System (U.S. IOOS) Program. My name is Jan Newton. I am a Principal Oceanographer at the University of Washington Applied Physics Laboratory and the Executive Director of NANOOS. I am also faculty in the University of Washington's College of the Environment.

Introduction: U.S. IOOS and NANOOS

To give you context, as a scientist who trained to be an oceanographer, I certainly did not set out to be an Executive Director of anything. My path has evolved in a very logical way actually. As a graduate student studying ocean processes via ships, I soon found that so many of our research cruises, which are conducted over the span of a few weeks, encountered what folks said were "anomalous" conditions. This repeated situation spoke volumes to me that if every cruise seemed to reveal the unexpected, then maybe we really don't know that much about the state of the oceans. So, as a scientist wanting to understand nature, it has been a logical passion for me to be one of the many involved with implementing IOOS, helping to bring this system on-line, and to lead those efforts in the Pacific Northwest via our NANOOS.

The genius of IOOS is that it goes beyond "just the science" to bring ocean observations to all sectors of society for diverse but compelling needs, such as safe maritime transport, sustained health of natural resources, and response to extreme events. IOOS is a congressionally-established, stakeholder-driven, and science-based "ocean analog" of the National Weather Service. It provides and enhances our Nation's access to data from the oceans, coasts, estuaries and Great Lakes. Because it is implemented with both a Federal and regional footprint, this allows IOOS to connect with regional stakeholders while maintaining national consistency. IOOS is the essence of an innovative partnership. The U.S. IOOS Program Office while housed at NOAA interacts with a broad Federal agency family, as well as with a network of eleven non-federal Regional Associations. I want to tell you more about how we implement IOOS through one of those Regional Associations, NANOOS, in the Pacific Northwest.

For the states of Washington and Oregon, we at NANOOS work with diverse stakeholders to understand their needs and to coordinate and support the development, implementation, and operation of a regional coastal ocean observing system–the buoys, radars, models and data management capacity—to provide ocean data and data products to diverse end users on the spatial and temporal scales that meet

their needs. While I say "oceans" . . . in the context of IOOS and NANOOS this means the coastal ocean, which includes our estuaries, bays, and shorelines.

How did NANOOS build its ocean observing system?

We formed a partnership of Pacific Northwest industry, tribes, local, state, and Federal agencies, non-government organizations, and educational and research institutions. Established in 2003, NANOOS is a growing partnership of almost 50 entities now. The NANOOS system encompasses not only ocean observations, but also data management, modeling and analysis, generating useful information products, providing outreach to various audiences to connect them with the information they need, and increasing the region's ocean literacy. To do this, we had two very simple yet compelling strategies for building the system: 1) integrate the assets we had in the region and 2) prioritize what we needed. With NOAA funds, NANOOS implements IOOS regionally through its partnerships.

How does NANOOS decide where to make our investments?

The nearly 50 NANOOS member partners who have signed our Memorandum of Agreement (MOA) appoint a person to our Governing Council and annually establish NANOOS' regional priorities. Using the input from our Governing Council, we have harnessed our infrastructure, the technological observing capacity as well as the skilled workforce, to build a networked system whereby at this very moment from our NANOOS data portal I can click on buttons that tell me the sea temperature 13 miles off La Push Washington, the pH in the seawater intake at Taylor Shellfish hatchery, the oxygen at the bottom of Hood Canal, the sediment load in the Columbia River, the offshore currents along the coast of Oregon, and the predicted temperature of the coastal waters off Newport. These may sound like disparate and esoteric things to know, but to the shellfish growers who wants to know whether to spawn their oyster larvae, to the fisheries manager who wants to know if fish are subject to stress from reduced oxygen before setting fisheries catch limits, to the Columbia River bar pilot who wants to navigate the entrance channel safely, to the true heroes of the Coast Guard who need to optimize the effectiveness of their search and rescue operations, and to the recreational tuna fishing captains who want to optimize their safety and profitable local businesses, these data all inform decision points that NANOOS currently delivers to these users. Each one of those examples I mentioned is a real case showing how NANOOS is making a difference through our partnerships.

What does NANOOS achieve for the Nation and the region?

By building NANOOS, we have dramatically increased the efficiency in how taxpayer purchased ocean data as well as privately-funded ocean data reaches the hands of the public, both regionally and nationally. My two favorite words to describe IOOS and NANOOS are "leverage" and "link," which we do in spades. The Federal investment in NANOOS reaps substantial return, for example, we use our Federal dollars received from the U.S. IOOS Program Office to partially, yes partially, support 19 data streams throughout Washington and Oregon. Yet because of the partnerships we have made, our data portal makes 176 data streams available to the public . . . nearly an order of magnitude more. The balance are Federal assets (funded by other Federal programs) collected throughout our region as well as private, state, tribal, or other data providers who want the data services that NANOOS offers. As we collect and integrate these disparate data streams, we are able to use them to provide information products like the types I mentioned above.

There is a second efficiency in IOOS, and that is that we have built a community of practice. We have integrated the people. This is another aspect of innovative partnership that has paid off substantially.

- Our data management system was designed and implemented by a team from three regional universities, UW, OSU, and OHSU, working the Boeing Company, an industry with a wide footprint in our region. Each member organization came with a unique perspective and capability, but together as a team they built a system that has seen great success and has been shared with other IOOS Regional Associations. The innovation that happens at the regional level is shared with the national level and vice versa; regional data systems are linked through standards and protocols to the national system.
- Our observational effort on water quality has integrated university, federal, tribal, state, and industry scientists and practitioners, to share practices and increase data quality. Also, when a new and better sensor comes along, NANOOS can take advantage of letting this network know about it, and if adequately funded, NANOOS could provide the new sensors to our partners to implement on their existing platforms.

- NANOOS and the IOOS Regional Associations in California have a Memorandum of Understanding with the West Coast Governors Alliance to work collectively together and optimize efforts on marine spatial planning, ocean acidification, marine debris, and other priorities.
- The NANOOS observing system sustains high-frequency radars that measure surface currents off Oregon; NANOOS serves these data directly to the U.S. Coast Guard to assist with search and rescue. Our new NANOOS "Maritime Operations" portal, developed with input from mariners, like the Marine Exchange of Puget Sound, provides real-time wave observations offshore the coast, high-resolution wave forecasts out to 84 hours in the future, virtual wave stations showing changes in wave height and where the waves are coming from, and high-frequency radar surface maps of ocean currents. This is part of the national HF Radar network, a direct result of U.S. IOOS. In 2002 there were only a handful of radars; this has now grown to 130, all operated as a single network with nationally compatible data. Operation by 30 academic institutions nationwide in partnership with a U.S. company (CODAR Ocean Sensors), all led by the U.S. IOOS program is the kind of innovative partnering that epitomizes U.S. IOOS.

NANOOS Successes from Innovative Partnering

The Federal investment in sustaining ocean observations makes a difference and provides a significant return on investment. For example, prior to 2010 there were no sustained observations of subsurface water properties, like oxygen, nutrients, pH and chlorophyll off the coast of Washington. We were able to obtain a $500K grant from the Murdock Charitable Trust to build a state-of-the-art observation system, with surface and profiling buoys and an autonomous Seaglider, to yield 3-dimensional data through time. Our successful competition for this award was in part because IOOS represented anticipated funds for sustaining the operation of these assets well into the future. Now three years in, we have an unprecedented data series, new scientific discoveries such as 40 m high internal waves, as well as key data to assess hypoxia and ocean acidification. It was obvious to the Murdock Charitable Trust that NANOOS was well-networked within our region and the payoff from the data would be shared, not only to regional scientists but also so many others across society. We have partnered with NOAA's Olympic Coast National Marine Sanctuary to add a current meter they had onto our buoy, with the Quileute Tribe to optimize the buoy's weather sensing, and with NOAA's Ocean Acidification Program and NOAA's Pacific Marine Environmental Laboratory to work together measuring variables to assess ocean acidification on this buoy, now part of the NOAA Ocean Acidification Buoy Network. *The IOOS observing system, including this buoy, is being utilized to provide an early warning system for ocean acidification to support local shellfish growers and hatchery owners, helping them to save over $35M in 2011 alone.* A local shellfish grower, Mark Weigardt, co-owner of Whiskey Creek Shellfish Hatchery said it this way: *"Putting an IOOS buoy in the water is like putting headlights on a car. It lets us see changing water conditions in real time."*

Some of our other successes:

- NANOOS assisted Oregon and Washington state agencies with the development of a Pacific Northwest tsunami evacuation portal and mobile app; a visual representation of the expected inundation of coastal areas and communities from a worst-case locally generated tsunami (similar magnitude to the 2011 Japan earthquake), as well as from a distant event adjacent to the Aleutian Islands. Users search by street address to determine if they are in the tsunami hazard zone, and plan an escape route accordingly. The portal also provides direct links to the West Coast Alaska Tsunami warning center, notifying users of a tsunami watch or warning.
- NANOOS supports the collection of beach information—flooding, erosion, and seasonal sand changes—along the Oregon and Washington coasts. These data are being used by engineers and resource managers to assist with the design and permitting of coastal engineering structures, to understanding the rates and patterns of coastal change, and to support FEMA.
- Now Columbia River bar pilots, like Captain Dan Jordan, a NANOOS advisor, can access real-time wave conditions directly offshore of the Columbia River's mouth—a busy port of entry with hazardous currents and large waves—to assist with the safe passage of vessels. The Pacific Northwest, home to more than 20 ports supporting commercial, fishing, transportation, security, and recreational activities, benefits from this information service. The ports connect the U.S. with foreign markets and with a fishing industry worth about $800 million

in personal income annually. The Columbia River system handles 30 million tons of foreign trade and $16 billion in value each year.

I think these examples show how IOOS and NANOOS are good government, implement national priorities on a regional scale, stimulate the economy, provide jobs, and increase quality of life for the Nation.

While there are many successes, we could do much more. For example, you will notice I said "NANOOS observing system sustains high-frequency radars that measure surface currents *off Oregon.*" NANOOS sustains these systems, originally purchased through research grants through the National Science Foundation. NANOOS has proposed to build similar capacity in Washington, but funding allocated to the IOOS program has not been sufficient to allow us to do so. Elsewhere such surface current data are used in combination with computer-run models to predict the movement of water, tracking associated items such as marine debris and harmful algal blooms. We do not have this capability in Washington state, and I know many of the other IOOS Regional Associations face similar inequities in their regions. Our nation deserves a contiguous capacity along all its coasts for measuring surface currents through this proven technology.

The Future for IOOS and the ICOOS Act Re-authorization

The IOOS Program stands on the shoulders of great visionaries, such as Admiral Watkins. U.S. IOOS was recommended by both the Ocean Commission established by former President Bush, the Pew Commission which stills calls for its full implementation, and the importance of sustained observations is called out in President Obama's National Ocean Policy. The Integrated Coastal and Ocean Observing System (ICOOS) Act passed by you and signed into law by President Obama has been a strong tool to advance U.S. IOOS. Administered by NOAA as the lead Federal agency, the U.S. IOOS Program has been well conceived and, I believe, very well implemented. The success stories I shared here are repeated many times over within NANOOS, but also within the other ten Regional Associations of IOOS, comprising the entirety of the United States, including its Great Lakes, Caribbean and Pacific Islands, and three continental coastlines, Atlantic, Gulf and Pacific. IOOS has stimulated green U.S. jobs and technology innovation. In short, IOOS works.

The ICOOS Act of 2009 enables IOOS to be a federal-regional partnership that connects with regional stakeholders while maintaining national consistency and addressing national priorities at the regional level. *I strongly urge you to re-authorize the ICOOS Act so that this successful example of governmental efficiency and innovative federal-non-federal partnership can continue and grow.* The IOOS distributed system, as witnessed by the diverse membership of its 11 Regional Associations, by its NOAA leadership and the U.S. IOOS Program Office, the Interagency Ocean Observing Systems Committee, and by the nearly 200 individuals who attended the IOOS Summit held in Reston VA in November 2012 and signed its Declaration from which I quote: "Now, more than ever, the United States requires a sustained and integrated ocean observing system." I am grateful to our Washington State Senator Maria Cantwell for her leadership in supporting IOOS and promoting the re-authorization of the ICOOS Act.

I want to underscore the importance of Congress' funding of IOOS at levels that do not jeopardize the sustained operation and expansion of IOOS. I applaud the Senate for your leadership on this to date. Without your action in 2012 and 2013, I potentially faced having to cut the program by $250K. With a program so highly leveraged already, my decision for a cut of that magnitude was to either eliminate support for our data delivery system, *or* estuarine observations in Puget Sound and the Columbia River, *or* observations on the WA and OR outer coast, *or* observations of the shorelines. Given the input from our Governing Council I honestly did not know how to make that decision. I thank you for preventing me having to face that.

Climate Change and the Oceans

You have also requested my input on the implications of climate change on ocean waters, such as warming, altered productivity, and ocean acidification. As a teacher, it is my honor to comment on the importance of these ocean issues. First I ask that we all take a breath . . . and after you do that take another. Please understand that the oxygen for every other breath you take is supplied by algae, phytoplankton, in the worlds' oceans, with the other breath from terrestrial plants, trees and grasses. With Earth's land masses being productive, yet in the minority . . . only 33 percent of the surface of the earth . . . we absolutely depend on the oceans for our very life. I often reflect that sight of the sea surface without any land visible is a foreign sight to most of the population of our planet, yet it truly is the most common sight on planet Earth.

As humans have changed the composition of our atmosphere, these alterations have indeed heated the planet and increased the concentration of CO_2 that diffuses into the oceans. These changes have very strong implications for the plankton at the base of the ocean food web and all that depend on these organisms. As the heating changes the temperature of seawater and its density layering, this inhibits the ability of the ocean to supply nutrients upward and to ventilate its deep waters with oxygen; these changes have implications to select for an ocean that does not support the same life in exactly the same way we are accustomed to. While there will undoubtedly be as yet unpredicted consequences there are some things we do know that are well established scientifically. As the increased CO_2 changes the pH of the ocean waters towards a more acidified state, this selects for what life forms can thrive. Species such as oysters, pteropods (food for salmon) and of course ecosystems such as coral reefs have less capacity to be formed or be competitive.

Ocean Acidification

It has been my professional honor to work with Dr. Richard Feely of NOAA's Pacific Marine Environmental Laboratory and his group researching ocean acidification in the local waters of Washington State. It has also been my responsibility to direct the capacity of NANOOS to participate in making high quality measurements for assessing, modeling, and communicating the status of ocean acidification in the Pacific Northwest. NANOOS works via IOOS with the NOAA Ocean Acidification Program (OAP), whose mandate is to provide the Nation with high quality data and leadership on this issue. Two of NANOOS' offshore buoys, one off Newport and one off La Push, receive OAP funding to be part of our Nation's Ocean Acidification Buoy Network. The synergies between these Federal programs and NANOOS have assured the most effective use of limited ocean observing resources and also provide free data access to our regional citizenry via the NANOOS data portal. *While local data access is important, another true wisdom of IOOS is its nested design, such that any data stream NANOOS serves, such as Taylor Shellfish pH data from Puget Sound, immediately is available through the national IOOS data portal and available to the global community as well.*

The issue of ocean acidification is not only central to the vitality of our thriving shellfish industry, but also to the tribes who have treaty rights to sustained natural resources that have fed their culture for thousands of years. Additionally, seafood such as oysters and salmon are healthful foods that support our populace not only regionally but also, via export, nationally and internationally.

I was one of seven scientists appointed to Governor Christine Gregoire's Blue Ribbon Panel on Ocean Acidification. Our panel consolidated and reported what was known in our region regarding ocean acidification, what information was missing, and what recommendations and actions were needed to insure the health and economy of Washington State. It appears that some of these recommendations will be funded through the Washington State legislature, actions such as monitoring, forecasting, and food-web impact assessment. These actions dovetail extremely well with the Federal investments from NOAA's OAP and from U.S. IOOS in NANOOS. *National leadership that can be implemented regionally can only succeed when there is a strong community of practice that builds an allegiance and the human network required to assure that common methods and calibrations are implemented.* The NOAA OAP has been adept at partnering with IOOS Regional Associations throughout our Nation to expand their network several-fold in a highly cost effective manner, yet with consistent methodology. NOAA's leadership on this is to be commended. *The re-authorization of the Federal Ocean Acidification Research and Monitoring (FOARAM) Act will assure this will continue and I urge your action to make this so.*

Summary

I hope my testimony has illustrated the critical importance of the oceans to so many of our daily practices, from breathing to shipping cargo, and the great successes IOOS has already realized in serving to bring ocean information to the public. I hope you share my view that this system has an even greater potential to build on the innovative partnerships we have established, if adequately funded, but that the reauthorization of the ICOOS Act is essential. I hope I have underscored in your minds the importance of the oceans' health. The 30 percent increase in ocean acidity we have achieved to date is not the direction our children will appreciate from us. The reauthorization of the FOARAM Act is imperative to guide the legacy we will want to leave. I thank you for your leadership to our country and for this opportunity to convey how urgent I think these two Acts are for our nation.

Senator BEGICH. Thank you very much.

Let me turn to Senator Cantwell, and I want to—Senator Cantwell, we have been notified of 4 o'clock votes, so we will have about 20 minutes here.

So let me turn to Senator Cantwell. We will start with 5 minutes. We may be a little flexible because——

Senator CANTWELL. OK.

Senator BEGICH.—we are both here.

Senator CANTWELL. Well, thank you, Mr. Chairman. And thanks for holding this important hearing.

And from our part of the country, definitely these are very, very important issues. So thank you to all the witnesses today.

And, Dr. Newton, thank you for bringing up that quote. That was actually, I think, Bill Taylor—maybe you said that—from Taylor Shellfish, about putting headlights on the cars.

And, certainly, to me, this is about information that we now can acquire about the oceans. In fact, my staff was just showing me this particular app that has a link to every buoy that the fishermen then can link to and see wave, temperature, all of these various things. So not only are we collecting the information, we are making it available to people.

So my first question is, what do we need to do—I mean, in the case of shellfish, that was real information on ocean acidification that allowed them to do seeding at a different time to be successful.

How many ocean acidification sensors are deployed today? And what else do we need to do to build that network?

Ms. NEWTON. So I would say, nationally, I actually don't know the number. I know that NOAA's Ocean Acidification Program probably has on the order of, I am going to guess, 20 nationwide, but I will get back to you on that. But, in our region, we really only have two. And I think that this is very much underestimating the situation.

We have been very successful with those two offshore buoys, one off La Push that I mentioned and one off Newport, because it tells the nearest shore growers when ocean acidification events are coming. But when you look at the inland waters, such as Puget Sound or the Columbia River, we know that very different conditions exist.

And so my examples are all from the Pacific Northwest, but this is certainly true for Alaska, certainly true for the Caribbean and the Northeast and all of the areas around our nation.

So I see that we need a significant investment in expanding these observations, but the great thing about IOOS is that the platforms are there. It is not like we need to be putting a whole bunch of new buoys in the water, because we have a lot of buoys which could be adapted to be ocean acidification monitoring buoys. And we have the human infrastructure, and we have the data delivery systems. The app that you saw that NANOOS produced is also mirrored by other regional associations and by IOOS.

So I think we have some of the picture, but we need the sustained support and the way to grow it.

Senator CANTWELL. I have been a big fan of using our new high-tech Doppler radar system to get a better weather-ready nation, in the context that so much can be known about these storms now. There are all sorts of algorithms that if people would just put high-

power computing time behind, they would tell us some of the potential damage that we are looking at coming at us and give us better preparation.

Do you think using high-frequency radar with the buoy system and combining all this data under NOAA in a forecasting situation would be good for us as it relates to hurricanes and some of the events that we are seeing, maybe some that we see in the Northwest but certainly other parts of the country see way more frequently than we do?

Ms. NEWTON. I absolutely do. And I know that during Superstorm Sandy that was actually put to test. And the HF radar measurements that were made by MACOORA on the middle Atlantic helped the weather forecasting capacities.

I think these are critical. As Dr. Avery mentioned, the oceans and the atmosphere intimately work together. And if we have better weather-over-water measurements, those can aid the forecasts. The HF radar that measure the surface currents can be used to improve ocean circulation models. And so that is really critical for getting the weather right.

So, absolutely, I believe that what you said is critical for a better weather-ready nation. And I think we have pieces there. We have HF radars in Oregon; we don't have them in Washington. And I know that is true around the nation. There are places that have it and places that don't. I think we need to fill in that system. I think the system is already integrated with modeling efforts. I think we need to sustain and expand those efforts.

Senator CANTWELL. But it is a resource issue, right, not a technology issue? The technology exists.

Ms. NEWTON. Absolutely.

Senator CANTWELL. It is about measuring——

Ms. NEWTON. Technology is being used today successfully.

Senator CANTWELL. Mr. Cameron, what about this issue, the larger issue of ocean acidification? And, you know, I know there is an XPRIZE that has been announced to try to tackle this problem.

I mean, should we be looking to the private sector—you have done a lot, but should we be looking to the private sector to try to stimulate more investment here as it relates to solving some of these problems?

Mr. CAMERON. I think we can. I think the prize model is a good model, but somebody has to put up the prize money, so, you know, this is still going to come back down to the bottom line.

I think there are incentives that you might consider for innovation and for partnership. A good example is the Center for Marine Robotics at Woods Hole Oceanographic. This is a place where we are hoping to have the oil and gas industry, especially offshore, and other extraction industries come to a common development place with academia, including Woods Hole but also some other academic partners that specialize in robotics but not necessarily ocean robotics. So, putting a group together where money can be brought into it that doesn't necessarily have to come from the Federal Government.

But, on the other hand, we need to stimulate the, let's say, offshore oil and gas industry to want to come to do this and develop

common-platform technology that could be used both for research and for commercial survey work, for example.

And this would apply, Senator Begich, to your issues in Alaska working underneath the ice, looking forward 10, 15, 20 years to the leases on the continental shelf and so on. To be able to do those surveys currently, we have to work under ice that is seasonal that will continue to retreat over time.

And so this is an area where we need new oceanographic tools, advanced robotics, abilities to communicate over long distance under water, artificial intelligence to be able to home those robots back to their base stations to work autonomously, and so on.

And, you know, we believe that we can create some common technology that can be used by industry commercially, can be used by the science community. The science community doesn't have the resources always to create these new toolsets, so this is a way to do that. If there is a way that you guys can imagine that can stimulate that so that it is, you know, private-sector money moving into essentially the research community, with some kind of rebate system or something like that, that would be, I think, very helpful.

For example, I built the *DEEPSEA CHALLENGER* submersible in Australia. We had an American component to the team; they provided about a third of the sub. But the assembly and most of the R&D work was done in Australia because Australia has a rebate system there for pure R&D.

So entrepreneurs who want to create new technology can create that technology and they can receive a rebate from the government. That was significant to me, to the tune of about half a million dollars. And on a small project like that, that made a difference.

So that type of thing should be considered, as well. And it might play hand-in-glove with the kinds of things we are proposing with the Center for Marine Robotics.

Senator CANTWELL. Thank you. That is very interesting.

I see my time has expired, and unfortunately I have to go. But, Mr. Chairman, I think this is a very important issue, in the sense of I think we need to identify the issues.

Mr. Cameron brought up this notion of the technology and getting a consensus between the public and private sector. You know, when we had our big Gulf oil spill, we realized we didn't even have, you know, the way the Coast Guard was on cleanup, we didn't even have an agreed-upon list of technology that we really were pursuing as the next great thing. So then there was a whole big debate about, well, what level of technology should we be adhering to?

So I think oceans, among many things, where it suffers because it is, you know, out of a lot of people's view sight, is the issue of how much technology really could give us information and data that could be so critical to our ocean, economy, and the fishermen, to science, to safety, to all of these things.

But it just, like so many things with the oceans, falls between the cracks of various organizations and agencies, and there is no prioritization of that next step in technology. So I certainly want to work with you, and I applaud you for having this hearing.

Senator BEGICH. Thank you, Senator Cantwell.

You know, I was talking to a group of fishermen in Alaska on Friday and it is always the case that when it comes to the oceans

or what comes out of the oceans—for example, we debated the Farm bill for 2½ weeks, very little about fish is in there. But if we would take that bill and call it the fish bill and have those same things——

[Laughter.]

Senator BEGICH.—it would be an incredible opportunity for our fishermen. But it is created kind of as a secondary thought, even though the only difference is the farm bill you harvest from the land, fisheries harvest from the oceans. That is the only difference.

And it is an amazing way the oceans are treated in our overall view and economy. And kind of to your point, it is always kind of the second-class citizen. Can you imagine if we were to spend half as much as we spend on exploring space, if we spent on oceans, where we would be today?

I noted your comment, when you were a young boy you saw NASA, you saw that, but you also got intrigued by the oceans. I mean, just imagine what that difference would be today. Acidification wouldn't be starting to be studied; we would know a lot about it today. Not worrying about two buoys; we would have plenty out there.

I mean, that is how I visualize this. So your point is well-taken. This is going to be one of many kind of discussions we have through this committee.

Mr. Cameron, I want to follow up on that thought you had. And maybe all of you could comment on it since you feel comfortable.

How do we inspire that next generation to really—I mean, you got inspired through a variety of reasons, and you were intrigued by the oceans, and now you have taken it to a whole new level. But how do we get young people to see the oceans, as we see the Arctic, for example, as the last frontier?

I joked when I go back home that I think most people around Washington have discovered we have an ocean in the Arctic now.

[Laughter.]

Senator BEGICH. And it is not because they were looking it for it. It is because we are talking about it.

Mr. CAMERON. Right.

Senator BEGICH. Which is amazing to me, when you think about the size and vastness of just that component of our oceans.

And maybe others might have some thoughts on this. But, to me, how do we really get young people to think this is an incredible field to go into? Obviously, some of the work you are doing now is intriguing in itself.

So I don't know if you have any comment on that, but——

Mr. CAMERON. Well, thank you.

You know, obviously the *DEEPSEA CHALLENGER* was designed as a science platform and it had a significant science yield, but I think its biggest long-term effect will be what I call the inspiration dividend. Because what I have found is that when young kids get a chance to see this up in person and ask members of the expedition how it was done and so on, they get very, very excited. It really unleashes their curiosity and natural inventiveness.

And we just came here from showing the sub publicly to a couple of hundred kids from schools around D.C., and they were so engaged. And they came up to me, and their questions, even the

younger ones, 7, 8, 9 years old, were so perceptive. And you could see their minds working. You know, they all want to build subs.

[Laughter.]

Mr. CAMERON. And that is OK, that is good. That is when you get them. That is when you inspire them. And that will last a lifetime. Whether they actually become explorers or they become engineers or scientists and so on and go to work at places like Woods Hole Oceanographic Institution or whether they are simply trained there and go into other jobs, this is such an important thing.

It is difficult, inspiring people into STEM-type careers these days. As somebody who works in media myself, even when I am making a fictional film like "Avatar," I put in a sympathetic character who is a scientist. And my thinking there is to show an aspirational role model for kids and high school students, even college students; say, oh, scientists aren't stuffy, they are not some kind of strange elite, they are not evil mustache-twirlers.

Senator BEGICH. They can be cool.

Mr. CAMERON. They can be cool. Exactly.

[Laughter.]

Mr. CAMERON. That is absolutely critical.

And so it is partly how kids perceive that role model and partly how they perceive themselves and feel empowered to do it.

And I think the idea of reinforcing to them through media and the messaging they get through education that exploration is not done. Even if that is in the abstract of exploration as a metaphor, if you are, you know, looking through a microscope or you are in a lab someplace. But there is so much to know and understand.

So capturing and bottling that curiosity early on is critical for us in the science community and in the educational community.

Senator BEGICH. Let me ask Dr. Avery, you mentioned STEM in your testimony. One of the things that I know we are looking at, obviously, is the budget for 2014. And the President has cut out the ocean science education in NOAA, which, of course, we are very—as you can imagine, the Oceans Subcommittee is concerned about the impact of that.

But when you look at the data points of where we are internationally when it comes to STEM education—science, technology, engineering, and math—we are so far down on the scale of where we could be. And as I was hearing the description of some of the equipment utilized in the facility going to the bottom of the ocean, all that new technology, it seems like this is a huge opportunity for us.

But give me your thoughts. I mean, honestly, I am concerned about some of these cuts and what they may impact, marine science in the future. Because STEM is not something you do in 12th grade. It is an educational process throughout your years of K through 12, that when you get to 12th grade, you might be doing not only a high school course but a college course in conjuction, together, to become that next scientists or marine biologist or whatever it might be.

What can we do here, I guess, what should be our role to ensure that this is not lost in the long picture of our budget fights that we have around here?

There we go. Is it not working?

Like I said, technology. We need——

[Laughter.]

Ms. AVERY. This is technology at work here.

[Laughter.]

Senator BEGICH. Yes. If it wasn't working, I would call my 11-year-old and he would fix it like that.

[Laughter.]

Ms. AVERY. Fix it like that, yes.

No, thank you, Senator Begich.

I think that, you know, when you look at STEM careers and STEM in general, there is the inspirational component at a very young age. You know, young kids are really excited about science. They are excited about their natural world. They can see things, they can touch things.

And we have, you know, most of our institutions, I am sure, around here have outreach programs where children are just so much fun to work with. And our scientists love engaging with them. Our scientists work on science fair projects. There is a real sort of mentorship role there that I think one should not underestimate in terms of enhancing the STEM pipeline.

But you are right; you have to constantly reinforce this. You know, you start it at the younger age, but it has to be throughout that whole K through 12 system and then through the college experience, as well. So that whole pipeline is really very critical.

And I guess I would say, and I think a number of us in the scientific community are concerned a little bit about what has been proposed in terms of eliminating some of these STEM programs from the mission agencies, in particular, and consolidating certain parts of that educational pipeline in certain parts of the agency.

Because I think that, in general, a lot of us in research and science organizations have been spending a lot of time really taking a look at what we can do, how we can be engaged. And when you take that away from us, I worry about a little crack in that pipeline.

These are long-term issues that you are looking at. They are hard issues to deal with. But, yes, I would be concerned.

Senator BEGICH. Do you—and I don't know the answer to this, and that is: Is there a research or document or information that is available that you utilize to talk about—one of the things that I have done a couple times is had hearings and discussions on the economics of our oceans.

Ms. AVERY. Yes.

Senator BEGICH. Because I think people, we talk about the environment of our ocean, which is important, but there is a whole piece to this—and I think of Ed's work and, you know, all the work there.

The economics of oceans are so impactful, but there is very little data that you could say—you know, I could tell you all about, you know, wheat and the impact. I can tell you all about oil and gas. I can tell you about copper. But when it comes to the oceans, we can tell you a segment of it, fisheries to a certain extent, but all the science and all the other pieces that come from it and what that means.

Is there really reliable or enough data out there that we can point to and say, this is the kind of investment we need to make?

And, Mr. Cameron, I appreciate your words at the end of your opening comments, because it is an investment. It is not an expenditure, it is an investment.

Ms. AVERY. Yes.

Senator BEGICH. Because if you do this right, the multiplier effect may be in science, may be in better understanding of the oceans for our own health, may be better understanding for extraction, as we are dealing with in the Arctic.

Do you think that—and maybe it is just me not seeing all the information. It just seems like that is a gap, the economic understanding of our oceans. I don't know, Dr. Avery and Ed and others may want to comment on this.

Ms. AVERY. Sure. I think there is a really good strategy, as we look at the numbers of ocean ecosystem services that the ocean provides us, how you actually quantify that in terms of an economic value. And there have been studies that have looked at it. There has been some work done in terms of looking at the recreation and tourism industry, on the economic value of that. Certainly, the fisheries industry is another one, the aquaculture industry that derives from that.

It is hard to put a price tag on every second breath you take, but——

[Laughter.]

Ms. AVERY.—it should be a pretty high price, actually.

Senator BEGICH. It is half the value.

Ms. AVERY. There is some extra value there.

[Laughter.]

Ms. AVERY. But I think that, you know, one can always look at a need for more data. I think we have had a discussion amongst ourselves just recently about how this committee might take a moment to think more globally, more about what is the investment that has been made in the ocean, what is the return on that of ocean, how do you get to a certain value, both economically and some of the intrinsic values of the ocean. It certainly would be a very good discussion to have.

Do we have good data? We always could have more, you know.

Senator BEGICH. From a scientist——

Ms. AVERY. You never ask a scientist——

[Laughter.]

Senator BEGICH. I know, I know.

Ms. AVERY.—do you need more data? We will say we need more data.

Laughter.]

Senator BEGICH. I know. I actually, when I started to say that, I already——

Ms. AVERY. The wrong person to ask.

Senator BEGICH. I knew I was going to open that up to a scientist and say we have enough.

Ms. AVERY. Yes.

Senator BEGICH. There is never enough.

Others who have maybe a comment on that?

Mr. Cameron?

Mr. CAMERON. I would comment briefly on that if——

Senator BEGICH. Sure. And then I will go to Dr. Newton.

Mr. CAMERON. I think you identified a specific gap, and it also reflects a perceptual gap, as well. Because, certainly, in government and the public's attention, we think of ocean problems in terms of specifics, whether it is shark finning or fishing nets or oil spills and that sort of thing, and we always picture the ocean.

And that, in a way, allows all the states that don't have coastlines to just kind of shrug off the concern, when, in fact, what we need to do is look at major economic drivers, whether it is food prices and that sort of thing because crop yields are down because ocean precipitation is not what it was because ocean currents have changed because the heat flux in the ocean has changed as climate changes cause these effects.

We need to think of the ocean as this engine that is actually driving back into the economy and creating big fluctuations in the bottom line, you know, billions of dollars, vast multiples of the amount of money it takes us to study the ocean and understand it.

So I think it is this perceptual gap that needs to be closed, both, I think, in the public and amongst policymakers. It is a question of looking at all of these, let's say, you know, economic problems through a lens of ocean." And that might be something that this forum is best to address.

Senator BEGICH. Very good. Thank you.

Let me go to Dr. Newton, then I will go to Ed. And I apologize; they have indicated that we have vote that has started, and I don't want to—but this is interesting and one that we are going to continue on.

But Dr. Newton?

Ms. NEWTON. Thank you. I just wanted to agree with the issue of perception that Mr. Cameron brought up. I think in terms of—and you said it yourself, Chairman Begich, that the exploration and the observation of the ocean pales in comparison to space. And so, when you were talking about how to inspire kids, I think if there is more funding directed toward ocean exploration, there will be more activity around that.

And I can tell you that, from my experience in academia, there is a perceived notion of lack of opportunity in ocean-related jobs. But one of the things I am very proud about with the Ocean Observing System is there are jobs to maintain that, to provide the data for that.

There is a whole host—not everybody is going to be a Ph.D. scientist at an academic university, but this system invests in people, and the more people looking at the oceans and having jobs in the oceans, the more kids will be inspired.

And the second thing, really quickly, is that these systems provide near-real-time data over the Web. And so, classrooms—it is one thing to teach students about phytoplankton blooms, and it is another thing for them to say, go on to your computer and look at this station and this station and this station and tell me if the bloom is happening. People get excited. So they can explore right there in their classroom.

Senator BEGICH. And with kids today, it is more valuable, that—when I was growing up, you could do it in the book and it was fine.

Ms. NEWTON. Right.

Senator BEGICH. But today kids have a much higher demand of real-time.

Ms. NEWTON. Right.

Senator BEGICH. It is very interesting.

Ed, if you have any—because you are on top of the oceans, but——

Captain PAGE. I am on top. I am staying there.

[Laughter.]

Senator BEGICH. But they are connected. Without you on top, without them on the bottom, nothing works, you know.

Captain PAGE. Right.

Senator BEGICH. So any thought, Ed, you have on this? And then I apologize——

Captain PAGE. I think you have a good point there that is worth exploring further—more data——

[Laughter.]

Captain PAGE.—is this holistic approach which is not taken right now as far as the value of the ocean, if it is transportation.

And certainly in Alaska, we know for sure that Kivalina would not exist if there wasn't an ocean means of transporting those raw materials around the world, or Valdez would not exist if he didn't have a means of shipping it by vessel. It would be just too expensive to ship it out. Or the fishing wouldn't exist, or very nominally. We would have to wait until they came to our shores or into our rivers, which they don't do all the time.

And so, if you start looking at if you had to do everything by another means of transportation, every other means of transportation is more expensive than going via the ocean. It is the most efficient way of moving goods. If you just displace that and said, we can't do that, it is truck or plane or train, suddenly you realize the economic value of just the transportation system.

All those containers in L.A.-Long Beach when I was captain of the port, those containers would have wrapped the world several times over in 1 year, just coming to L.A.-Long Beach. If you didn't have the ships to do that, how could you possibly engage in international commerce? And it would change our whole world.

But I don't think people understand that, because if we look at the value of fishery, we are all independent, but we never take them all together——

Senator BEGICH. In a holistic way.

Captain PAGE.—cumulative. So I think is a good perspective that maybe would open some people's eyes.

Senator BEGICH. Well, let me again thank you. I have additional questions, but, because of time, I will need to submit them for the record.

You know, to me, we sometimes undervalue our oceans or our lack of understanding. Or, as I described on the farm bill, if this was the fish bill—I mean, I talk to fishermen all the time, and I say, "Imagine this," and I give them the description of the Farm bill but I just substitute "farm" with "fish," and they are very excited, because the amount of concentration and research and activity around it and investment could be so substantial to their long-

term future. And as we struggle to deal with fisheries as one element of our oceans to create sustainability, it is multifaceted.

And you are right; when you are living in Kansas, the oceans are, you know, somewhere over there. What we have to do is connect it, so when someone is sitting in a small town in Kansas and they think about the oceans, they want to be that oceanographer or they want to be that scientist or that boat captain or they want to be out on that rig making sure it is done the right way.

And that is the trick here. And this committee is focused on trying to elevate the issues of our oceans at a much different level than has been done in the past and equalize it.

And so your thoughts today are helpful, your ideas are helpful. And I am sure, as time progresses here, we will be more in contact.

And, obviously, up in Woods Hole, I have been there a couple times and always will be back. I think it is amazing because of your partnerships you have around the globe and in Alaska.

And it is always a pleasure to see all of you so adamant about the oceans. So thank you very much for being here.

The record will stay open for 10 business days for any additional questions that members who were not here, or here, may have questions they want to submit to you.

But, again, thank you very much.

At this time, the hearing is adjourned. Thank you.

[Whereupon, at 4:08 p.m., the hearing was adjourned.]

A P P E N D I X

PREPARED STATEMENT OF HON. JOHN THUNE, U.S. SENATOR FROM SOUTH DAKOTA

Thank you, Mr. Chairman, for holding this hearing. This hearing exemplifies the spirit of adventure and exploration that has made this country what it is today—and indeed, this same spirit has defined our nation's history.

From the Lewis and Clark expedition that explored the Dakota territory, including the important scientific observations they made as they traveled up the Missouri River, to more recent trips to the surface of Mars and the bottom of the ocean, this spirit of exploration is important in fostering a continued interest in science and the world outside our everyday lives.

Mr. Cameron, you were the first person to return to the ocean's deepest point in the Mariana Trench since 1960—we appreciate you being here to discuss that exploration and the amazing vessel in which you made the dive, as well as your partnership with the Woods Hole Oceanographic Institution. Dr. Avery, I am interested in learning more about the partnerships that the Institution has forged with industry to spur innovation in marine robotics and other fields. I appreciated the opportunity to meet with both of you; as we discussed, I think that public-private partnership and other innovative funding models are especially relevant in today's budget environment.

This is particularly true when you consider that data from our oceans and coasts is important for protecting lives and property at sea *and* across the country. For example, ocean observing systems provide data to inform long-term drought forecasts, which the National Integrated Drought Information System uses to provide early warnings of drought conditions on a regional scale. These forecasts and data products, in turn, help to support the livelihoods of our Nation's agriculture producers.

I also want to welcome our other witnesses. Dr. Newton, we appreciate your testimony about the integrated ocean observing system as one example of leveraging non-federal assets to improve data collection and dissemination. Mr. Page, thank you for traveling all the way from the "Last Frontier" to discuss the ways that regional ocean observing assets have supported marine transportation in and around the State of Alaska.

Again, I thank all the witnesses for their testimony about ongoing research activities and how we can better leverage public and private sector resources when it comes to oceanic monitoring and exploration.

PREPARED STATEMENT OF DR. MICHAEL HEITHAUS, ASSOCIATE DEAN, COLLEGE OF ARTS AND SCIENCES, FLORIDA INTERNATIONAL UNIVERSITY, AQUARIOUS REEF BASE AND PARTNERSHIPS IN OCEAN OBSERVATIONS

Thank you for the opportunity to provide testimony on behalf of Florida International University and our efforts to build partnerships to ensure that NOAA's Aquarius Reef Base continues to address national and global priorities for marine exploration, research, natural resource management and STEM education. The Aquarius facility is a key resource for developing tools to conserve marine resources and to support the communities that depend upon them, as well as for inspiring millions of Americans to take leadership in science and the environment.

Florida International University, a Carnegie community engaged university, is a young and rapidly expanding public research institution. FIU has 50,000 students and is the largest Hispanic Serving Institution in the Nation and among the ten largest universities nationwide. FIU is internationally known for its work in marine biology and coastal marine sciences. FIU is a significant research partner with NOAA: NOAA's national Hurricane Center is located on the FIU campus and FIU is a member of NOAA's Cooperative Institute for Marine and Atmospheric Studies (CIMAS). Recently, FIU took over operations and maintenance of NOAA's Aquarius Reef Base, the world's only underwater marine laboratory and habitat available for use to support ocean exploration, research and STEM education.

In addition to graduate and undergraduate education, FIU is deeply engaged with K–12 and community education and outreach. Its dedication to improving K–12 education is highlighted by its newly formed STEM Transformation Institute and environmental education programs.

National Needs for Ocean Science and Education

Coastal marine habitats such as coral reefs, seagrass beds and mangroves support the highest marine biodiversity in the world. More than 500 million people worldwide depend upon them for food (fisheries), storm protection, jobs and recreation. Their resources and services are worth an estimated 375 billion dollars each year to the global economy, yet they cover less than one percent of the Earth's surface. There is an urgent need to develop scientifically based tools for conserving these habitats and where feasible restoring the ecosystem services they deliver.to millions of people around the world. While the Deepwater Horizon Incident highlighted the interconnectedness and susceptibility of marine ecosystems to human activities, global threats including climate change and ocean acidification have the potential to cause even more wide-spread and profound damage. Coral reefs and other coastal ecosystems that provide huge economic benefits are particularly susceptible to climate change and other human caused stresses. The next decade will be pivotal in whether society can successfully chart a path to a sustainable ocean future with thriving ecosystems and coastal human communities.

Overcoming the threats facing ocean ecosystems while ensuring that human needs for ocean resources are met requires a multidisciplinary approach that involves coastal ocean observing systems to monitor ecosystems, in-ocean experiments to understand the nature of threats and to develop solutions, development on new technologies for ocean observing and underwater industrial activities, high-value public outreach to communicate the importance of ocean ecosystems and solutions to threats to their health, and K–12 education programs and teacher development to inspire the next generation of STEM professionals and marine scientists.

How do we move forward to ensure that we, as a country, are able to accomplish this approach? The answer lies in diverse partnerships, innovative technology, and human exploration and imagination.

Aquarius Reef Base

The Aquarius is the only operating undersea laboratory, 43 feet long by 9 feet in diameter that houses six aquanauts on the ocean floor 60 feet below the surface for 10–31 days at a time. The habitat, the world's only operational marine habitat dedicated to science and education, is a national treasure owned by NOAA. It has been sited in the Florida Keys Marine Sanctuary off Key Largo for 20 years and has proven to be instrumental in the advancement of oceanic research, engaging America's future leaders through ocean-inspired learning, and serving as a catalyst for development of the next generation of marine and extra planetary explorers and exploration technologies. Research at Aquarius has directly guided the stewardship of not just the Florida Keys National marine Sanctuary, but other coral reef ecosystems both in the U.S. and worldwide.

An ocean observatory

Aquarius provides an ideal platform for long-term monitoring of coastal oceans and coral reefs. It will serve as a permanent station, providing real-time and long-term data on the marine environment, which will serve as an early-warning system for impacts to ocean ecosystems both locally and globally. Because it can provide stable power, has a scalable IT infrastructure that facilitates innovative sensor deployment, utilizes the latest industry communication technology that offers a reliable means to transmit data and video, and is the only manned ocean observing platform that allows for data ground-truthing and sensor design and testing Aquarius will become a world-class ocean observation platform that will facilitate monitoring and experimentation on, among other issues, the impacts of ocean acidification on coral reefs, seagrass meadows and a diverse array of ocean organisms. The position of Aquarius makes it particularly well-suited for studies of ocean acidification because it sits between seagrass meadows, which remove CO_2 that causes acidification, and the coral reefs and open ocean that will be most impacted. The data generated by Aquarius will be critical for guiding policy and conservation management to preserve these critical ecosystems and potentially mitigate acidification worldwide.

Finally, Aquarius Reef Base is, quite simply, the best platform for observing the condition of the Florida Keys National Marine Sanctuary (FKNMS). The National Marine Sanctuaries Act was intended to identify, designate, and comprehensively manage marine areas of national significance. National marine sanctuaries are established for the public's long-term benefit, use, and enjoyment. As home to the

largest continental coral reef ecosystem in the U.S., upon which the economy of south Florida is based, the FKNMS was designated. Sanctuary status is designed, among other things, to:

- Enhance resource protection through comprehensive and coordinated conservation and ecosystem management that complements existing regulatory authorities.
- Support, promote, and coordinate scientific research on, and monitoring of, the marine resources of the Florida Keys to improve management decision-making
- Enhance public awareness, understanding, and the wise use of the marine environment through public interpretive, educational, and recreational programs.

Aquarius is superbly enabled to facilitate all of these goals of the FKNMS—with a special emphasis on the unique interpretive and educational programs it allows. A manned presence on the sea floor—and the ability of citizens to share in that experience through traditional media outlets as well as live over the internet, ignites the imaginations of future scientists and educators like nothing else!

Fostering innovation

Because of its well-studied and strategic location, highly-trained and competent staff, land-based and boat-based support infrastructure, stable power supply and climate-controlled conditions, Aquarius provides the ideal location for the deployment, development and testing of new technologies. This is especially true for work that requires a human presence, since inventors, engineers and technicians can have their hands on their technology 24 hours a day for as long as a month during critical R&D stages. And, these same capabilities make Aquarius the ideal place to compare competing technologies in a test-bed environment.

STEM education: inspiring the next generation

Because of its ability to capture the imagination of an entire country and world through the eyes of people living under the sea, Aquarius can play an important role in ensuring American competitiveness for generations to come. Equipped with the ability to send live video from the habitat and surrounding waters to schools, universities, aquariums, and museums around the country, Aquarius can reach millions of students and citizens every year while actual scientific and training missions are underway. They can watch science while it is happening and experience it through the eyes of scientists, students, and teachers living and working underwater! They can even interact with the aquanauts! Watching people living and exploring the ocean captivates and inspires people, especially young students, in ways that remote sensing cannot. The personal connection to ocean exploration, coupled with high-quality curriculum, will inspire a generation of students and motivate understanding, achievement and career choices.

Funding Aquarius: a model of Public-Private Partnerships

Florida International University took over operation of Aquarius Reef Base in 2013 and has undertaken a transformation of its business model. Aquarius is transitioning to being supported by a blend of partnerships with private industry, user fees, private philanthropic donations, and state and Federal research and education grants. This new business model will ensure that Aquarius will be available and providing significant benefits to American taxpayers for years to come while lessening the tax dollars invested in its continuation. FIU is partnering with the Aquarius Foundation, a not for profit dedicated to the support of the Aquarius project.

There has been a public outpouring of support for Aquarius when NOAA signaled a desire to close the lab. One of the first groups to step in in to support was the Diver's Alert Network (DAN). Stephen Frink, of DAN, agreed to serve on the board of the Aquarius Foundation—which formed to save Aquarius. DAN has accepted donations for Aquarius and sponsored an end-of mission fundraising event after a mission led by Dr. Sylvia Earle, who also sits on the board of Aquarius Foundation.

Since FIU took over the operation of Aquarius Reef Base, we have been approached by companies interested in testing equipment for the oceanographic, maritime industry, oils and gas exploration, extraction and delivery, and aerospace applications. We have also had contact with private aerospace companies—as well as NASA—since Aquarius provides the only facility of its kind for training astronauts in an extreme, high-stakes, environment. We also have received considerable interest from media companies and are developing partnerships with the local dive operators in the Florida Keys to enhance their business while providing funding for Aquarius.

Recognizing its incredible value for marine sciences and education, we have begun to build important partnerships with groups and individuals interested in helping provide financial support for FIU and Aquarius. One individual has pledged $1.25 million, and assistance raising further funds, pending a long-term agreement with NOAA on the future of the base. We have been partnering with Edeavorist.org to assist with the optimization of this crowd funding platform, which will feature Aquarius's Teacher-Under-the-Sea program for the platform's launch in July 2013. Also, FIU and Guy Harvey Foundation are working on a partnership to enhance marine education for K–12 students.

A Need for Continued Federal Support

Key, however, to realizing the potential of the growing public private partnerships for operating Aquarius is continued support from the Federal Government. The investment need not be considerable. FIU and its private partners needs NOAA to agree to a three-year plan that will transition the base from its previous position of complete Federal support to the new mix of industry, governmental and philanthropic support. This three-year plan must deal with issues remaining about the liability for operation and eventual decommissioning of the facility.

WRITTEN TESTIMONY FROM JULIE THOMAS, PRESIDENT, THE IOOS ASSOCIATION

Chairman Begich, Ranking Member Rubio, and members of the Subcommittee.

I am writing on behalf of the Board of Directors of the Integrated Ocean Observing System (IOOS) Association to urge reauthorize the Integrated Coastal Ocean Observing Act of 2009" (ICOOS Act). The IOOS Association is a non-profit organization dedicated to improving the Nation's ability to observe our oceans, coasts and Great Lakes and to making that information available to a wide variety of users in a timely manner. The ICOOS Act provides the legal and institutional framework for the federal-regional partnership that comprises the Integrated Ocean Observing System (IOOS). Reauthorization of the Act will ensure this capability is sustained and enhanced.

Background

Our nation's health, prosperity and security are directly linked to the Nation's oceans, coasts and Great Lakes. Over 50 percent of our nation's residents live in coastal areas, and the ocean and Great Lakes economies contribute more than $223 billion to the Gross Domestic Product and support in excess of 2.6 million jobs.[1] These trends are expected to grow in the future.

The U.S. IOOS provides a unique national capability that is necessary to meet our nation's current and future needs for sustained ocean observations and products. Sustained observations from buoys, gliders, shore stations and other platforms are integrated, analyzed and transformed into actionable information through models and data management systems. Data and information from U.S. IOOS aids:

- the safe passage of large, ocean-going tankers to enter U.S. ports;
- the U.S. Coast Guard in their search and rescue efforts by providing, in real time, information on the speed and direction of ocean currents;
- shellfish growers in the Pacific Northwest so they can protect young larvae from lethal, acidic ocean water masses;
- emergency managers preparing for extreme events such as hurricanes by providing them information related to storm surge; and
- resource managers concerned with how ocean conditions affect living marine resources, hypoxia and harmful algal blooms.

The Integrated Ocean Observing System (IOOS) is a partnership between 17 Federal agencies and a network of 11 regional systems that provide services to the entire coastline of the U.S., including the Great Lakes. The ICOOS Act provides the framework for building a "system of systems" that links and enhances our existing observing capacity. It is an innovative approach for government, one that relies on partnerships to be cost-effective and responsive. And, it is working.

Sometimes called the ocean analog of the National Weather Service, IOOS is a novel approach to addressing the critical gaps in the Nation's ocean, coasts and Great Lake observing systems. It brings together national and regional observing systems to address critical societal needs, fill gaps and harness innovation for system improvement and cost-effectiveness.

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[1] NOAA. 2013. National Coastal Population Report. Population Trends from 1970 to 2020.

IOOS is good government. One of the goals of IOOS is to create a single system that can serve multiple national and regional missions. Instead of each mission agency or regional program creating its own issue-specific ocean and coastal observing system, IOOS strives to be one system that can be used by many agencies, programs and individuals. For example, real-time information on the speed and direction of surface currents is used by the U.S. Coast Guard in search and rescue operations, by fisheries managers to model the transport of fish larvae, by regional scientists to forecast harmful algal blooms and by public health officials to understand beach water quality. Measure once, use multiple times is the IOOS mantra.

The IOOS data management system is based on standards and protocols and allows for the seamless integration of data between the regional systems and the Federal agencies. Data from regional systems are now available to Federal agencies and have proven to be extremely valuable. Today, over 50 percent of the data provide to the Global Telecommunication System by NOAA's National Data Buoy Center (NDBC) now comes from non-federal sources, most of which is directly attributable the IOOS data management system and the work being done and supported by the Regional Associations.

IOOS Is Making a Difference

Examples of how IOOS is making a difference are numerous. Here are a few highlights of the program's accomplishments over the last ten years:

- *Superstorm Sandy.* During this extreme event, the marine transportation industry in the New York/New Jersey area made preparations based on forecast products derived from IOOS observations. In the Port of New York and New Jersey, all vessels were moved from anchorages in the Harbor. Over 6,700 containers—valued at approximately $1 Billion[2]—were diverted from the New York/New Jersey area to Virginia.
- *Deepwater Horizon Spill.* During the response effort following the 2010 oil spill, the Unified Area Command was able to access data and model output from universities, state agencies and private companies, increasing their understanding of the ocean conditions affecting the path of the oil. This was the first time that Federal responders had routine access to non-federal information and was enabled by the protocols developed by the IOOS data management system.

  Much of the oil from the spill remained subsurface where, despite technological advances, we still lacked the ability to readily monitor the flow of oil. IOOS, through its regional network, accessed several underwater gliders from around the country and redeployed them in the gulf to assist with subsurface monitoring efforts. This unique and flexible capability is one of the hallmarks of the IOOS system.
- *Search and Rescue.* IOOS supported the development of the "National Surface Current Mapping Plan" that calls for a network of shore-based radars to detect surface currents in real time. While only a quarter of the national plan has been built to date, it is proving to be a powerful tool. Real-time information from the network feeds directly to the U.S. Coast Guard for use in search and rescue efforts. The Coast Guard estimates that the information can reduce their search areas by two-thirds, thereby greatly increasing the chances of safe recovery.

IOOS Leads to Innovative Solutions

In tight fiscal times, IOOS provides a pathway for bringing forward new solutions to challenges faced in sustainably using and managing our nation's oceans, coasts and Great Lakes, and will play an ever-increasing role in meeting our nation's need for coastal ocean data and information. IOOS is a flexible system that can facilitate the transition from research and development to operations. IOOS's capability to move vital observing assets from research institutions into operations in support of Federal response missions has been demonstrated, and will continue to be deployed to address unexpected events around the country. Regional observations are efficiently filling critical gaps not currently being met by our Federal partners. IOOS is harnessing the flexibility and innovation of private and academic research and development capability.

The networked capability represented by IOOS works, and has repeatedly demonstrated its value. In short, IOOS is unique; IOOS is efficient; and IOOS is the future.

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[2] Marine Technology Society. 2012 TechSurge Event.

Specific comments on reauthorization

The ICOOS Act of 2009 provides the solid foundation for U.S. IOOS that allows for innovation, leveraging of resources, and the creation of partnerships and for the standards and protocols that allow for seamless transition of data and information between the regional and Federal programs.

Authorization Levels

We are extremely concerned about the authorization levels for the program and its ability to meet societal needs or to respond to the next hurricane, severe flooding, storm surge or oil spill. The regional IOOS systems have been operating for over a decade and are in need of repairs and upgrades. Measured, reasonable growth ensures that assets would not be removed from the water, the quality of data would not be deteriorate because of delayed maintenance and upgrades, and information products would not become outdated without adequate staff to ensure quality.

The buoy network in the Northeast U.S. illustrates the impact of such delayed maintenance. The array has successfully operated for over ten years, reliably transmitting hourly data to users dependent on that information. However, maintenance and repair trips have been reduced from twice a year to just once a year. Buoys that have withstood extreme waves and winds are now breaking free. Data modems that transmit the data in real time are failing, causing great concern to many including scientists charged with providing forecasts of red tides, the harmful algae that is so toxic to clams and other shellfish. The Northeast system needs to be repaired and upgraded so that it can be fully functional when the next hurricane or nor'easter happens. This regional system is not the only one that needs such repairs and upgrades. The other ten regional IOOS systems are also facing similar issues.

We encourage the Committee to use the Congressionally-mandated "Independent Cost Estimate (ICE) for U.S. IOOS"[3] as a resource for determining the authorization levels to include in the ICOOS Reauthorization Act. NASA's Jet Propulsion Laboratory completed the cost estimate in 2012 based on regional and Federal plans for addressing critical societal needs. The ICE estimates that the IOOS system would cost $591 million per year once it is fully built ($534 million for the regional systems, $57 million for the central functions of the U.S. IOOS Program Office). Full build out of the system would take 10 years to achieve.

A phased approach for building the system over the next five years would allow for reasonable and measured growth of the program. The following chart is based on the ICE, beginning with the President's Budget Request for IOOS in the Fiscal Year 2014.

Fiscal Year	Regional Line	National Line	Total
2014	$34.5 m	$ 6.5m	$ 41 m
2015	$ 39 m	$ 10 m	$ 49 m
2016	$ 44 m	$ 15 m	$ 59 m
2017	$ 55m	$ 20 m	$ 75 m
2018	$ 66 m	$ 25 m	$ 91 m

The ICOOS Act must allow for the reasonable and justifiable growth of the program. The authorization level should be commensurate with the critical importance of IOOS to jobs and the economy, safety and quality of life.

Clarifying the role of the regions. The Act refers to the regional IOOS partners as "Regional Information Coordinating Entities" and notes that this includes the existing Regional Associations, the term that is widely used for the regional IOOS systems. The wording is confusing and has raised questions as to whether the Regional Associations are the RICEs or if there is a difference between the regional coordinating entities and the Regional Associations. The existing regional framework of IOOS welcomes the participation by all concerned parties, allows for open competition to serve regions every five years and actively encourages the involvement of data providers. This framework is based on consideration of marine ecosystems, geography, and political and economic issues. The delineations are similar to many other regional approaches adopted by Federal agencies. Existing Regional Associations foster integration and partnerships across the regions, and we encourage the use of the term Regional Associations in the Act.

Interagency Financing. IOOS is an interagency program intended to foster partnerships among Federal agencies and regional partnerships. The transfer of funds

[3] Interagency Ocean Observing Committee. 2012. Independent Cost Estimate for the U.S. Integrated Ocean Observing System. Prepared by NASA's Jet Propulsion Laboratory Earth Science and Technology Directorate.

among agencies is an important part of this partnership. Unfortunately, agency lawyers have found that the existing language in the Act is not sufficient to allow to enable efficient transfer of funds between Federal agency partners.

Certification. The Act requires that the Regional Associations be certified to ensure regional systems have the capacity to fulfill their obligations. In addition, data management certification standards are to be developed to ensure the quality of IOOS data. The IOOS Program Office has been working on these requirements over the last five years and is expected to soon release a draft of the certification standards for public comment. We understand that NOAA is proposing to separate the regional association certification standards and the data quality certification standards in their proposed rule since the two sets of standards are very different. We support that approach, and it should be adopted in the ICOOS Act.

Liability. The ICOOS Act currently extends liability coverage to the regions operating. This is a critical issues for the program, allowing IOOS to serve data and, information in real time. NOAA lawyers are proposing to limit this coverage to just 3 regional employees. Liability coverage should not be predetermined by an arbitrary number but rather by the circumstances of the situation. The Act should clarify this provision.

Thank you for your consideration of these comments. Please let us know if you have questions or require additional information.

Sincerely,

JULIE THOMAS,
Chair,
IOOS Association,
c/o University of California, San Diego,
Scripps Institution of Oceanography.

PORT TOWNSEND MARINE SCIENCE CENTER
Port Towsend, WA, June 18, 2013

Dear Chairman Begich, Ranking Member Rubio, and members of the Subcommittee,

I am writing to support the re-authorization of the Integrated Coastal and Ocean Observing System (ICOOS) Act and the Federal Ocean Acidification Research and Monitoring (FOARAM) Act. These were recently discussed at a hearing called "Deep Sea Challenge: Innovative Partnerships in Ocean Observation" held before the U.S. Senate Committee on Commerce, Science and Transportation, Subcommittee on Oceans, Atmosphere, Fisheries and Coast Guard on June 11, 2013.

At this time of rapid climate change and ocean acidification, both of these Acts enable monitoring and collection of data essential to evaluate and respond to changes in ocean systems. This data informs everything from meteorology to fisheries, shellfish growing to modeling of changes in climate and sea level. Through these Acts, resource managers and scientists will have near real-time data essential to understanding ocean acidification, drivers and effects.

Because of the ICOOS Act, IOOS and NANOOS, its regional entity in the Pacific NW, have been able to bring together regional Federal and non-federal partners to create a system of observing platforms, data delivery, modeling, and outreach that leverages existing assets, non-federal investments, and communities of practice. Of special note, NANOOS has reached out to engage the public in understanding the value of ongoing ocean observation. Because of the FOARAM Act, NOAA's OAP has been able to further assessment of ocean acidification nation-wide. The OAP has been adept at working with the IOOS regional associations, such as NANOOS, to maximize their investment.

Re-authorization of these two Acts will serve our nation's economy, environmental quality, and quality of life. Please lend your full support to these critical efforts.

Sincerely,

JEAN WALAT,
Program Director,
Port Townsend Marine Science Center.

PUGET SOUND PARTNERSHIP
Takoma, WA, June 18, 2013

Hon. MARK BEGICH,
Chair,
Subcommittee on Oceans, Atmosphere, Fisheries, and Coast Guard,
Committee on Commerce,
United States Senate,
Washington, DC.

Hon. MARCO RUBIO,
Ranking Member,
Subcommittee on Oceans, Atmosphere, Fisheries, and Coast Guard,
Committee on Commerce,
United States Senate,
Washington, DC.

Re: Re-authorization of the Integrated Coastal and Ocean Observing System Act and the Federal Ocean Acidification Research and Monitoring Act

Dear Chairman Begich and Ranking Member Rubio:

Thank you for holding the recent hearing regarding the "Deep Sea Challenge: Innovative Partnerships in Ocean Observation." As the Chair of the Puget Sound Partnership Leadership Council, I am writing in strong support for the re-authorization of the Integrated Coastal and Ocean Observing System (ICOOS) Act and the Federal Ocean Acidification Research and Monitoring (FOARAM) Act. Both of these Acts support monitoring and assessment of coastal ocean and inland waters that are needed globally, and that are essential in managing the effectiveness of ecosystem recovery efforts in Washington State's Puget Sound.

The U.S. Environmental Protection Agency's approved Comprehensive Conservation and Management Plan for Puget Sound, called the Action Agenda, has prioritized three strategic initiatives for restoring water quality: restoration and protection of habitat, recovery of shellfish beds and abating pollution from stormwater runoff. Scientific monitoring of the effectiveness of the strategies employed is critical for adaptively managing recovery work and ensuring efficient use of public and private investments.

Through the NOAA Ocean Acidification Program (OAP), the U.S. Integrated Ocean Observing System (IOOS), its regional association, the Northwest Association of Networked Ocean Observing Systems (NANOOS) and others, these Acts result in near real time data shared with affected parties (*e.g.,* shellfish growers, tribes, and landowners) and scientific quality data for researchers and agencies. In Puget Sound, over six marine water profiling monitoring buoys are providing data that directly support Sections 303(d) and 305(b) of the Clean Water Act. These data feed the environmental indicators and 2020 recovery targets that allow our partners to assess ocean acidification, salmon recovery, dissolved oxygen and other environmental concerns.

Washington State is poised to implement the recommended actions from Governor Gregoire's Blue Ribbon Panel on Ocean Acidification. In doing so, our state recognizes the value that Federal investments in IOOS, NANOOS, and NOAA's OAP have for our ability to implement these recommendations. Because of the ICOOS Act, IOOS/NANOOS have been able to bring together regional Federal and non-federal partners to create a system of observing platforms, data delivery, modeling, and outreach that leverages existing assets and non-federal investments.

Re-authorization of the ICOOS Act and FOARAM Act will serve our nation well by providing high quality and timely data that guides economic decisions and benefits the environment and our quality of life. I respectfully request your leadership in re-authorizing these Acts.

Thank you for your consideration of this request.

Sincerely,

MARTHA KONGSGAARD,
Leadership Council Chair.

cc: The Honorable Maria Cantwell, U.S. Senate
Jan Newton, Ph.D., University of Washington

RESPONSE TO WRITTEN QUESTIONS SUBMITTED BY HON. AMY KLOBUCHAR TO DR. SUSAN K. AVERY

Discover of New Medicines

Question 1. The Mayo Clinic in Minnesota is known for pioneering research to discover new treatments and medicines. You mentioned that when it comes to exploration of the ocean we have untapped potential, which includes new medicines. What technology is currently being used to collect data for discovery of new medicines when it comes to ocean research?

Answer. Scientists at Woods Hole Oceanographic Institution explores microbial chemical ecology and the interplay of applications in biomedicine to discover chemotherapies for human betterment. One specific research project area has to do with microbially-derived molecules that could aid in the problem of antibiotic resistant pathogens.

Antibiotics have been one of the greatest contributions to human health, however, the discovery of new antibiotics has not kept pace with the growing threat of bacterial antibiotic resistance. With the lack of new antibiotics in the drug discovery pipeline, especially for Gram-negative infections, a new strategy needs to be implemented to both preserve the clinical effectiveness of existing antibiotics and block the progression of antibiotic resistance. Multidrug transporters have been determined to be a key target in these efforts.

The search for molecules of pharmacological significance to reverse drug resistance has benefited enormously from understanding the natural history of chemical interactions among marine microorganisms. For instance, some recent findings in have led scientists to suspect that microbes in certain marine habitats produce diverse molecules that inhibit these multidrug transporters of various types.

A powerful aspect of the WHOI culture collection is that it has a high degree of associated phylogenetic and ecological metadata that can be mined. For example, nearly all of our cultures have been characterized by small-subunit Ribosomal RNA gene sequence (a gene common to all cellular life that can be used as a type of identification "barcode"). In addition, copious metadata are obtained during collection of our isolates, including GPS coordinates, salinity, temperature, depth, nutrients, oxygen saturation, light regime and so on. The substrate or host information that the microbes were cultivated from is also recorded. All of these data enable us to have a deeper understanding of the microbial habitat that the organisms naturally resided. For example, if a specific bacterium within the *Vibrio* clade that was collected from the surface of a diatom (phytoplankton) produced a low-level hit in our screening, we can go back to our collection database and search all vibrios of that ancestry (phylotype) or ecotype (or both). Those isolates can then be re-screened, prioritized for re-growing under different conditions and chemically derivitized. This type of phylotype/ecotype bioprospecting is an added rational dimension provided by our approach. A far cry from the purely discovery-based old days of "find 'em and grind 'em."

As this work proceeds WHOI researchers will be seeking a biomedical partner, likely in the private sector, to develop our drug leads into actual approved drugs. Although there are some NIH sponsored programs for pre-clinical drug development that we will explore as well.

Question 2. Are there opportunities for partnership between private sector companies and researchers to utilize existing infrastructure, such as telecommunications cables on ocean floor beds, to collect data which could lead to a better understanding of new species and/or medicines?

Answer. Two obvious private sector infrastructure opportunities to support basic ocean research include telecommunication cables and commercial shipping. Both of these sources offer considerable opportunity to provide a much more comprehensive picture of many physical, geological and some biogeochemical processes in the oceans. Placing sensors at regular intervals on telecommunication cables could greatly increase our awareness of changes in ocean physical processes that are important for understanding how the ocean is responding to climate warming, including changes in physical and biological processes. There is currently an effort to use the extensive telecomm cable network supporting the oil and gas platforms throughout the Gulf of Mexico to support elements of a regional ocean observing system. Another suggestions include the placement of pressure sensors on cables to support a tsunami network and the inclusion of listening posts for marine mammals and fish that have been outfitted with acoustic tags.

Similarly, commercial shipping traffic that operate on regularly scheduled routes are being outfitted with sensors and sounders to supplement data collected in the EEZ and international waters during research cruises and by the vast network of ARGO floats. As sensor technology advances these devices will expand to include

the capacity to monitor biological activity, increasing our awareness of changes in biological productivity below the surface in the open ocean, where satellites are unable to penetrate.

However, there are considerable financial and legal issues that complicate the implementation of these strategies. From the financial perspective, the operators of commercial systems and infrastructure can expect some level of financial support for the use of their assets. Submarine cable operators in particular consider their capacity to provide both power and data transmission capabilities a potentially valuable commodity that can help offset infrastructure construction and maintenance costs.

The other major difficulty is the unsettled legal environment surrounding the collection of scientific data from the EEZ of nations. Uncertainty and disputes over treaty interpretation and national regulation of marine data collection create potential regulatory burdens and risks, though particulars vary with each coastal state. There are also sovereignty concerns, rightly or wrongly, with some coastal states worrying that dual telecomscience cables will be used for covert energy exploration or surveillance of military activities. Difficulties surrounding what constitutes marine scientific research will hamper the potential to fully exploit the scientific benefits of existing marine infrastructure, a situation that would be improved, but far from solved, if the U.S. eventually accedes to UN Convention on the Law of the Sea.

RESPONSE TO WRITTEN QUESTION SUBMITTED BY HON. AMY KLOBUCHAR TO JAMES CAMERON

Need for STEM Education

You mentioned in your testimony that STEM education is critical to our future, in relation to understanding the ocean for a number of purposes. You say that we need to inspire children to want careers in Science, Technology, Engineering and Math.

Question. Because innovative technologies are needed to further explore the deep ocean, how vital is STEM focused education for deep sea exploration? We know there are partnership programs to entice students and companies to pursue investing in STEM education, and more specifically ocean exploration technologies, what do you feel makes these partnerships successful, and what more needs to be done?

Answer. The issue of the importance of STEM education to ocean exploration goes in both directions; the ocean science community is dependent upon a highly trained scientific and technology savvy workforce, but it is also provides an attractive and effective mechanism to interest and engage students in STEM disciplines. One example is growing student interest in robotics in general while underwater robotics provides the increased attraction of applying this interest to ocean exploration. The ocean science community remains fully committed to supporting the STEM education initiative, which includes direct interaction with students at all levels of the academic spectrum, from K–12 through post-doctoral students.

What has helped make many marine education partnership successful, perhaps first and foremost, is the hands-on engagement of students with scientist, in the field, in the lab, and for post-graduate level, in the agencies, where particpants gain a better understanding of the context within and drivers behind the work is being done. It is difficult to overstate the importance of establishing a direct relationship between students and scientists, since these interactions provide much of the intellectual stimulus that rewards the participants and provides the foundation for the continuation of these efforts with the encouragement and support of the participants.

As for what is needed to improve the success of these efforts, there are multiple suggestions. One of the biggest growth areas in ocean studies at present is the huge expansion in data volumes associated with all aspects of the research. This means that the next generation of ocean scientists and engineers will need to be far more numerate and computer literate that ever before. Researcher today must deal with immense volumes of data, which has resulted in the growth of the field of ocean informatics, which represents the union of oceanography, information science and social science domains. Infomatics' focus is to design a thick infrastructure that enables interoperability and facilitates collaborative science and scientists. The term is used simultaneously today in a variety of ways, emphasizing applications of information technology, representing natural or human systems, and exploring multifaceted sociotechnical issues. Thus, one of the key ingredients to future success will be the ability to transfer, store and manipulate these large data sets more effectively and more efficiently. Important in this regard will be:

- The use of telepresence to engage a wider number of researchers, educators and their students than can participate in deep ocean research directly using the traditional approach of restricting participation to those at sea on research ships.
- Improved algorithms to maximize efficiency searching larger and more disbursed databases to select the most relevant data.
- Improved forward and backward modeling of processes to help anticipate where important data may arise and to help prioritize where future studies should be focused to maximize returns on investment.

To date, programs such as NOAA's Ocean Exploration program, the Ocean Exploration Trust and the newly established Schmidt Ocean Institute have made great advances in bringing research and exploration ashore, in real time via telepresence, so that members of the public of all ages and abilities can follow along, in the moment. The next step is to move this a one-way data-stream—which is already very effective for outreach purposes—and provide a more engaging two-way form of communication. Using the same data-pipelines to harness these capabilities, just as has already been done for Space-based research, will allow for meaningful oceanographic research and education to be pursued without the need for all such researchers and educators to be aboard ship. Moving beyond the role of a distant observer, to having students become actively participating in authentic research in real-time, provides for a much more engaging experience.

Finally, there is also need for extra-curricular activities, either after-school or during STEM summer camps, which feature ocean exploration and robotics. Industry sponsorship is essential if we are to make after-school and summer opportunities available for all children, not just those whose parents can afford camp tuition. Greater emphasis can be placed on developing partnership programs to entice students and companies to pursue investing in STEM education.

RESPONSE TO WRITTEN QUESTIONS SUBMITTED BY HON. JOHN THUNE TO JAMES CAMERON

Question 1. With respect to its ability to inspire the next generation of scientists and explorers, what kinds of responses have you gotten as the *DEEPSEA CHALLENGER* has traveled across the country?

Answer. The *DEEPSEA CHALLENGE* Tour Across America made five stops in the following U.S. cities between June 1 and 14, 2013: Los Angeles, Dallas, Atlanta, Washington, D.C., and Woods Hole, MA.

In each of these cities, the *DEEPSEA CHALLENGE* team and its education partner, the MUSE School, coordinated with local museums and schools to host outreach events for student audiences with the goal of inspiring future generations of scientists, engineers and explorers.

In addition to its scheduled tour stops, the *DEEPSEA CHALLENGER* and its team made numerous unscheduled stops driving across the country in both large and small cities including, but not limited to, El Paso and Odessa, Texas and Shreveport and Monroe, Louisiana. Several of these stops were covered by local news stations and generated significant community interest. A partial list of links to the coverage these informal stops generated is attached.

In Washington, D.C., Mr. Cameron and the *DEEPSEA CHALLENGER* appeared at an education event that was attended by approximately 480 students representing 18 schools spanning K–12 grade levels (a complete list of participating schools is attached). The following testimonials represent a sampling of feedback from teachers and students regarding their experience at this event.

- *"Thanks again for a great day; the kids had a fabulous time. We appreciate your hard work!"*—Ellen Ring, Anacostia High School
- *"My students really enjoyed the event today! They especially liked seeing the sub and building their own."*—Trilby Hillenbrand, MacFarland Middle School
- *"All the kids had a great time at the DEEPSEA CHALLENGE Expedition. Even though they had [had] a crash course about the expedition, I was SO proud of their fantastic questions to the engineers and scientists."*—Monica Davis, Harriet Tubman Elementary School
- *"I am going to work on my own sub over the summer. I think that it should be operated by an android."*—Anonymous 4th grader
- *"Our students appreciate this opportunity. They have completed oceanic internships, and have followed Mr. Cameron's ocean research. We would like to col-*

laborate with the Muse school, as well as other local schools."—Science Director, Thomas Jefferson High School

In Dallas, the expedition team partnered with the Perot Museum of Nature & Science to provide special programming—including a video conference with Mr. Cameron to which school classrooms across the country could link—on the subject of deep ocean science and exploration. In the words of the Perot Museum's Vice President for Programs, Steve Hinkley, "During Jim's question and answer session . . . literally every question came from someone under the age of 14; it was one of the most impressive and encouraging things I have ever seen in my 17 years in education. We didn't place an age restriction on the audience participation, it was just the nature of the day, and the kids were energized."

The following links connect to footage of this video conference from within the Perot Museum's auditorium and documents the student audience's interactions with Mr. Cameron as they learn about the *DEEPSEA CHALLENGER* and expedition.

http://www.youtube.com/watch?v=ores5avIVwk
http://www.deepseaamerica.com/videos

***DEEPSEA CHALLENGE* Across America Tour—News Coverage**

The following list represents a sampling of international, national and local news coverage of the submersible's journey across the U.S. and the public's reactions to seeing it.

Editorial by James Cameron and Susan K. Avery of WHOI

http://www.huffingtonpost.com/james-cameron/a-new-age-of-discovery__b__3421979.html?utm__hp__ref=politics

National and International Press

Iniziato il tour da costa a costa del sottomarino Deepsea Challenger ideato da James Cameron

http://blog.screenweek.it/2013/06/iniziato-il-tour-da-costa-a-costa-del-sottomarino-deepsea-challenger-ideato-da-james-cameron-269761.php

'Deepsea Challenger'—Gulf Times

http://www.gulf-times.com/us-latin%20america/182/details/355953/'deepsea-challenger'

James Cameron recorre EEUU con el minisubmarino "Deepsea Challenger"

http://www.latercera.com/noticia/tendencias/2013/06/659-527899-9-james-cameron-recorre-eeuu-con-el-minisubmarino-deepsea-challenger.shtml

James Cameron Puts Sea Exploration Work on Hold (Arab Emirates)

http://topnews.ae/content/216537-james-cameron-puts-sea-exploration-work-hold

James Cameron llega con su minisubmarino "Deepsea Challenger" a Washington

http://noticias.terra.cl/ciencia/james-cameron-llega-con-su-minisubmarino-deepsea-challenger-a-washington,f0053de2b4c2f310VgnCLD2000000ec6eb0aRCRD.html

Début de la mission Deepsea Challenge de James Cameron

http://www.nationalgeographic.fr/1519-mission-deepsea-challenge-james-cameron/

Hollywood Director James Cameroon tells Senate Panel to Boost Ocean Research

http://frenchtribune.com/teneur/1318598-hollywood-director-james-cameroon-tells-senate-panel-boost-ocean-research

James Cameron llega con su minisubmarino "Deepsea Challenger" a Washington

http://www.noticias24.com/gente/noticia/101679/james-cameron-llega-con-su-minisubmarino-deepsea-challenger-a-washington/

James Cameron: We're still living in an age of exploration

http://www.salon.com/2013/05/31/james__cameron__were__still__living__in__an__age__of__exploration__partner/

James Cameron: 'Deep sea exploration could help predict tsunamis'

http://www.cnn.com/2013/06/06/tech/james-cameron-deep-sea-exploration/index.html

Deep Thoughts: James Cameron on the New Age of Exploration and His 11-Kilometer Dive to the Challenger Deep, Part 1
http://news.yahoo.com/deep-thoughts-james-cameron-age-exploration-11-kilometer-103000662.html

Special Rolex Deepsea Challenge Exhibition in Aventura
http://www.hauteliving.com/2013/06/special-rolex-deepsea-challenge-exhibition-in-aventura/364382/

James Cameron Puts Sea Exploration Work on Hold
http://topnews.ae/content/216537-james-cameron-puts-sea-exploration-work-hold

NG Kids Reporter Visits the Deepsea Challenger Sub
http://www.heralddeparis.com/ng-kids-reporter-visits-the-deepsea-challenger-sub/209843

Los Angeles, CA

Submarine piloted by James Cameron to begin cross-country journey
http://www.latimes.com/local/lanow/la-me-ln-james-cameron-sub-20130601,0,3530910.story

James Cameron's DeepSea Challenger Begins Its Final Journey
http://www.looktothestars.org/news/10269-james-camerons-deepsea-challenger-begins-its-final-journey

Deep Sea Exploration Will Have to Wait for 'Avatar' Pics, Says Cameron
http://variety.com/2013/film/news/james-cameron-avatar-comes-before-deepsea-challenger-1200491027/

El Paso, TX

'Deepsea Challenger' passes through El Paso
http://www.kvia.com/video/-Deepsea-Challenger-passes-through-El-Paso/-/421452/20417798/-/gr89gz/-/index.html

Shreveport, Louisiana

KSLA
Record breaking submarine passes through Shreveport
http://www.ksla.com/story/22503728/record-breaking-submarine-passes-through-shreveport

Monroe, Louisianna

KTVE
James Cameron's Submarine Stops in West Monroe
http://myarklamiss.com/fulltext/?nxd__id=221492

KNOE
Movie Director James Cameron's submarine makes a stop in the Twin Cities
http://www.knoe.com/story/22504438/movie-director-james-camerons-submarine-makes-a-stop-in-the-twin-cities

Atlanta, Georgia

Sub from Cameron solo dive to stop in Atlanta
http://www.wsav.com/story/22517087/sub-from-cameron-solo-dive-to-stop-in-atlanta

Deepsea Challenger makes stop at Georgia Aquarium
http://www.mnn.com/earth-matters/wilderness-resources/stories/deepsea-challenger-makes-stop-at-georgia-aquarium

For World Oceans Day: the Deepsea Challenger
http://deepseanews.com/2013/06/for-world-oceans-day-the-deepsea-challenger/

Sub from Cameron solo dive to stop in Atlanta
http://romenews-tribune.com/view/full__story/22818514/article-Sub-from-Cameron-solo-dive-to-stop-in-Atlanta?instance=home__news__lead__story

Washington, D.C.

The week ahead: Moniz testifies; senators dive deep
http://thehill.com/blogs/e2-wire/e2-wire/304431-the-week-ahead-moniz-testifies-senators-dive-deep

OVERNIGHT ENERGY: Senate dives into ocean research—a James Cameron production
http://thehill.com/blogs/e2-wire/e2-wire/304559-overnight-energy-senate-dives-into-ocean-research-a-james-cameron-production#ixzz2W1UNfHOZ

James Cameron brings his sub to D.C.
http://washingtonexaminer.com/james-cameron-brings-his-sub-to-d.c./article/2531540

James Cameron to Show Off His Submarine Tomorrow
http://dcist.com/2013/06/james__cameron__to__show__off__his__subma.php

Woods Hole Oceanographic Institution president, "Titanic" director head to Capitol Hill
http://www.capecodtoday.com/article/2013/06/11/19779-woods-hole-oceanographic-institution-president-titanic-director-head-capito

James Cameron's Next Deepsea Mission: Get Congress to Pay Attention to the Ocean
http://www.usnews.com/news/articles/2013/06/11/james-camerons-next-deepsea-mission-get-congress-to-pay-attention-to-the-ocean

James Cameron and submarine stop in DC
http://www.washingtonpost.com/blogs/style-blog/wp/2013/06/11/james-cameron-and-submarine-stop-in-dc/

Hollywood director James Cameron urges boost in oceans research
http://www.mcclatchydc.com/2013/06/11/193653/hollywood-director-james-cameron.html

James Cameron directs Congress: fund deep sea exploration
http://washingtonexaminer.com/james-cameron-directs-congress-fund-deep-sea-exploration/article/2531633

James Cameron takes Deepsea Challenger to Capitol Hill; pushes for boost in oceans research
http://washingtonexaminer.com/james-cameron-directs-congress-fund-deep-sea-exploration/article/2531633

Washington, D.C. Education and Outreach Event—List of Schools in Attendance

School Name	Grade Range	# of Students
Stokes	K–6	45
Capital City	K–8	30
Cesar Chavez Parkside	6–8	25
Cardozo	9–12	30
Hart	6–8	30
Roots	K–8	25
EL Haynes	6–8	25
Thomas Jefferson (VA)	9–12	4
Perry St. Prep	preK–12	25
Ideal Academy	preK–5	25
William E. Doar	6–8	25
Friendship Tech Prep	6–11	20
Imagine	preK–5	20
Stuart Hobson	6–8	30
MacFarland	6–8	20
Anacostia HS	9–12	44
DC Prep	K–8	11
Harriet Tubman ES	K–5	50
18 Schools		484 Students

Question 2. You mentioned that government incentives influenced your decision to build some of the *DEEPSEA CHALLENGER* sub in Australia. In addition to government rebates to entrepreneurs, what are some other policies that can effectively spur private-sector research and development that you think might work in the U.S.?

Answer. I could not provide a substantive response to the question to meet the deadline.

RESPONSE TO WRITTEN QUESTIONS SUBMITTED BY HON. JOHN THUNE TO DR. SUSAN K. AVERY

Question 1. I am a cosponsor of a bill that would reauthorize the National Integrated Drought Information System (NIDIS). NIDIS seeks, in part, to integrate multiple sources of data in order to provide useful information about drought conditions to end users including those in the private sector and at the local level. Are there any lessons learned from the Integrated Ocean Observing System (IOOS) experience that you think could apply to the model used by NIDIS? How has data from IOOS assets been applied to our understanding of weather patterns, like droughts, and how might these assets be better leveraged in the future?

Answer. First, it is necessary to clearly define the Integrated Ocean Observing System (IOOS) as a comprehensive open ocean and coastal observing system, as envisioned by the visionary ocean scientists who have advocated for such a system for the past two decades or more. Unfortunately, such an operational system does not exist, at least on the scale required to fully observe ocean processes from the shoreline out through international waters, and from the surface down to the ocean bottom. Elements of this system are operating, including the IOOS program in NOAA's National Ocean Service and the global ocean reference stations supported by the NOAA Office of Research (OAR), the National Science Foundation's research-based Ocean Observatories Initiative, and additional observing systems supported by the U.S. Navy. However the Nation and Federal agencies are still lacking a coherent governance system and funding to support a truly operational integrated ocean observing system.

This is not for lack of effort or attention given it was arguably the highest science priority of the congressionally-mandate U.S. Commission on Ocean Policy (USCOP) and the Joint Ocean Commission Initiative, which was co-chaired by Admiral James Watkins and the Honorable Leon Panetta. A key element to the success of IOOS is stable sustained funding. The only way to understand ocean processes, and changes in these processes and their influence on weather and climate patterns, is to establish long-term data collection systems that provide crucial baseline data. This baseline data provides the foundation for modeling and forecasting, as well as hind-casting, to validate and refine model accuracy. The cost of ocean and coastal data collection is high, given the size of the area, the harsh environment and cost

of deploying and retrieving data collection instruments. The lack of a dedicated and centrally coordinated coastal and ocean observation and data collection program has resulted in a balkanized system that been receive less funding in recent years, despite increased recognition of the role ocean plays in climate and weather forecasting, including droughts.

These same data collection systems are also necessary to validate and calibrate data collected by remote sensors on satellite systems, which cannot "see" below the surface of the ocean. This last point is significant, since the mixing of water below the ocean surface drives much of the heat exchange at the water/atmosphere interface, which is a key factor in many weather models.

The other major lesson learned from efforts to implement an operational IOOS is the need for dedicated support for pragmatic, functional data management. Priority should be given to the easy submission, easy retrieval of data, over higher level functionality and specialized configurations that limit access to and the usability of data collected by various systems. Additional effort must focus on simplifying the data management system to ensure that data collected can be fully exploited by researchers across scientific disciplines.

Despite the fractured state of current ocean and coastal observations, IOOS assets and related data are key to better prediction of improved weather, climate, and their extremes. The ocean covers 70 percent of the land surface. It's a key source of heat and moisture that drive the atmosphere. Changes in the amount and location of moisture leaving the ocean, even at distant locations, will impact rainfall and drought over land. Getting sea surface temperature, upper ocean heat content, and the air-sea fluxes of heat, freshwater, and momentum correct and accurate—both from observations and how they are predicted/used in models is an essential part of a national strategy to better understand and predict drought.

The ocean at remote global locations as well as along our coasts modifies the weather and climate over the U.S. Moisture flows from the oceans are key to understanding and predicting floods (*i.e.,* atmospheric "rivers" pour onto the west coast, monsoonal moisture flows over southwest and central U.S.). Similarly, large scale ocean conditions and cyclic patterns, (such as El Niño and La Niña) play a key factor in prolonged droughts. Going forward in the future it is essential for the Federal Government to support more comprehensive and sustained coastal and global ocean observations. This effort must not be limited to just the collection of observations, but support the continuum through data management and modeling, and facilitate the interaction of the observing and modeling communities to maximize the value of the data collected and guide the evolution of observing systems.

Question 2. Adequate funding to support research is one factor in maintaining our nation's competitiveness in science. What other factors have contributed to your success in facilitating partnerships with the private sector? What barriers have you encountered?

Answer. Academic and independent research institutions have become a critical part of science enterprise of the U.S. economy, performing more of the basic research. Private sector business funding is disproportionately directed to applied research and development, moving promising basic research results through the development stages towards commercially viable products and services. This shift in focus has increased industry's recognition of the importance of Federal funding support for basic research and basic research institutions, such as WHOI and the academic research community.

Beyond the increasing split in academic and private sector responsibility for R&D activities, WHOI is unique as an independent research institution with a scientific and engineering workforce that is fully dedicated to R&D. This is different from most other ocean research entities that are affiliated with formal academic research institutions, where the majority of a scientist's responsibility is associated with his or her education responsibilities. (FYI: WHOI has a long-standing partnership with the Massachusetts Institute of Technology supporting graduate and PhD level training). WHOI's 24/7 research focus is supported by a diverse workforce of roughly equal number of scientists and engineers from across the spectrum of scientific disciplines. These individuals are supported by highly trained full-time technicians whose continuous training and extensive knowledge greatly enhances the capacity of the Institution.

This workforce foundation and dedicated research focus is further enhanced by the applied focus of the resident engineers. As basic research transitions to applied research, supporting technology is refined to meet operational demands. It is at this nexus of basic and applied stages of research where opportunities for partnerships with the private sector ripen. This is made evident by the 15 companies that he been spun-off from WHOI licensed technology and knowledge.

One of the challenges to developing partnerships with private industry is the issue of intellectual property rights. Private industry investment in basic research with external partners comes with the expectation that promising knowledge and technological advances resulting from this work, which it has subsidized, should provide them with some degree of preferential rights to capitalize on this information in the market place. Establishing the balance of interest among the partners supporting basic research and technology development requires careful communication among the participants and a well-designed legal agreement. Even with these tools the challenge of soliciting private industry support for basic research with the understanding that the long-term objective is to share this information for the betterment of society, particularly when these funds are leveraged by Federal funding support for research and research infrastructure, is still in the process of being resolved.

WHOI is currently in the process of working through theses negotiations with partners is has solicited in support of its Center for Marine Robotics (CMR). The CMR is a partnership between WHOI, six academic partners (MIT, John Hopkins, Carnegie Mellon, Georgia Tech Research Institute, University of Rhode Island and Draper Laboratory. The goal of the Center is to collaborate with industry sponsors, academic partners, private philanthropy and key government agencies to change the way people and machines work together in the marine environment. Recent advances in robotic technology hold vast potential to improve or expand exploration, monitoring, and intervention from coastal waters to full ocean depth, and from ice-covered open ocean to complex underwater infrastructure. This effort has the potential revolutionize how humans and machines work in the ocean, providing industry and the Federal Government with more efficient and effective tools to support U.S. competitiveness and ensure the ecological integrity our the ocean and its resources.

Finally, there is a clear role for Federal incentives to support public/private R&D partnerships. James Cameron built the *DEEPSEA CHALLENER* in Australia in large part because of the tax incentive they provided—which emphasize support for small and medium sized firms—allowing him to draw heavily on technology and engineering expertise from multiple private companies in Australia. The submersible contains over 180 onboard systems, including batteries, thrusters, life support, 3D cameras, and LED lighting, supported by a specially engineered backbone and pilot sphere. Remarkably, this investment has been further leveraged by Jim's decision to share this advanced technology with the ocean science community by subsidizing its integration on to the current fleet of HOVs, ROVs and AUVs, significantly expanding our capacity to see and work beneath the surface of the ocean.

Question 3. In a budget environment where there is little to no new money available for science, how would you prioritize the kind of science that gets funded? For example, some testimony for this hearing discussed the benefits of leveraging Federal assets, but others pointed out that highly-leveraged funding can also be problematic when budgets decrease. How do we best balance "basic" science and applied research portfolios in the ocean sciences? In your opinion, are certain kinds of research better suited to funding by public institutions or by the private sector?

Answer. Regarding prioritization of ocean science, it's important to distinguish between science for which the hypothesis or theme is provided by mission-driven agencies or other societal demands, versus projects for which practicing scientists pursue discovery-driven hypotheses based research pursuing knowledge within their respective fields guided by the peer review process. NSF and NASA are the two primary Federal agencies that support basic ocean research. The priority for these two agencies should thus be the science for which the hypotheses or themes are developed by the scientists.

In acknowledgement of the breadth of scientific disciplines supporting ocean science, NSF recently sponsored the National Academies to develop "A Decadal Survey of Ocean Sciences: Guidance for NSF on National Ocean Research Priorities" (*http://dels.nas.edu/Study-In-Progress/Decadal-Survey-Ocean-Sciences/DELS-OSB-12-03*). This Ocean Decadal Study, which is modeled after NASA's Earth Science and Applications from Space decadal study, will develop a list of the top ocean science priorities for the next decade in the context of the current state of knowledge, ongoing research activities, and resource availability. It is scheduled to be released early in 2015 and should help ensure a balance in hypotheses driven research within NSF.

Mission-driven or applied research is guided by societal demands for information, with the National Oceanic and Atmospheric Administration (NOAA) and DOD's Office of Naval Research (ONR) as the primary funders. Whether it is environmental data to support NOAA stewardship, climate and weather forecasting responsibilities, or DOD and the Navy's national security interests and information requirements to ensure battlespace superiority, one of the great concerns within the ocean

science community is the need for sustained funding to support baseline observations and monitoring. Continuous baseline datasets are critical to research to understand drivers underlying changes in physical, biological, chemical and geological processes. These same observations are also essential to building and refining models supporting forecast and prediction that guide civilian and defense decision-making.

In reality science is a continuum from basic through applied research and the integration of this information into modeling and decision-making processes as well as technology development. This is readily apparent in ongoing efforts to improve the translation of research to operations, or "R20." A key element to extracting the greatest value from investments in basic and applied research is ensuring the continuity of data, implicit in which is funding support for the collection, synthesis, analysis and delivery of this data in a useable form. The benefits of discovery driven research and databases supporting this work often take years, or decades to be fully recognized and exploited for the benefit of society. Maintaining the infrastructure responsible for the collection of scientific data has proven to be a huge challenge, particularly in the ocean sciences where infrastructure construction and operation and maintenance costs are high due to the harsh working environment and cost of accessing the ocean.

Public funding of basic research is increasingly important given industry's focus on investment in applied research and development driven activities, a shift in focus that has been well documented by NSF. Fortunately we are seeing increased interest from private sources who are particularly good at funding "directed research". This type of research is an example of when the problem, if not the actual hypothesis, is provided by the funder, and scientists are asked to find the answer. Some foundations and individual donors do solicit input from external scientific sources to define the focus of their research funding. In addition, private funding in increasingly being used to leverage Federal funding, such as that supported by mission driven agencies, by providing extramural (non-federal) research entities with the resources necessary to increase responsiveness and flexibility to address rapidly emerging issues, such as the Deepwater Horizon oilspill and the Fukushima Daiichi disaster. Another example is Jim Cameron's donation of the *DEEP SEA CHALLENGER* along with a million dollars, to WHOI to assist in the integration of cutting-edge technology from the submersible into the U.S. deep submergence fleet of manned and unmanned underwater vehicles. This support provide a unique opportunity to significantly advance the capacity of U.S. deep sea exploration. By subsidizing work being supported with Federal funds, public investment in research it allows non-federal science institutions to be much more flexible and response than the generally monolithic Federal science enterprise, reinforcing the need to strengthen the public/academic/private partnerships.

Question 4. A number of you have mentioned the importance of educating our next generation of ocean explorers and scientists. How can partnerships between government and industry help to inspire and encourage future explorers?

Answer. This was a hot topic at the Ocean Exploration 2020 workshop, a meeting of both the public and private sector to shape a National—not just federal—program. Michael Jones, the Chief Technology Advocate for Google, advised the participants that while the challenges facing the oceans, and the Earth system as a whole, are sobering, it is important that those advocating for engagement with the next generation remain encouraging about the wonders that wait to be discovered. The power of inspiration is difficult to overstate and the opportunity to explore the huge expanse of "inner space" is compelling when articulated with passion.

Perhaps one of the greatest opportunities to expand interest in oceans are recent advances in telepresence—using video technology on remotely operated underwater vehicles with a fiber optic tether that allows for real-time streaming of underwater footage. The increased capacity for more people to "see" underwater with H–D cameras allows scientists, students and the public to experience the excitement of see new underwater environments, some being seen by humans for the first time ever. This approach provides an attractive platform to engage high tech industries and other corporate sponsors who have a vested interest in generating excitement and enthusiasm among students at all levels of the STEM education spectrum.

During the course of the workshop mentioned above, a fair amount of time was dedicated to helping participants conceive of effective forms of engagement with the public. The term "Citizen Explorer" was developed with the concept that using telepresence and access to the Ocean along all our coastal U.S. states, we can emulate the levels of engagement enjoyed by the Amateur Astronomy and Ornithologist communities in their respective fields. Again, this approach provides a potential vehicle for industry to provide support for programs that engage students and the public,

while providing an opportunity to showcase their role and contributions to advancing our knowledge of the ocean.

At the workshop it was also recognized that the outreach opportunity extended beyond industry to artist. At the workshop, which was held in the Aquarium of the Pacific, an a class at Art Center College of Design, in conjunction with CalTech, was in the process of launching an Ocean Movement, modeled after lessons learned in the Arab Spring. While untraditional, this is they type of out-of-the-box thinking that can help increase the visibility of ocean issues as well as broaden engagement of the public and corporate communities.

Finally, one should not overlook the attraction associated with the human element of exploration. There is no substitute for human eye and brain as the best possible "sensor" one can use when exploring, or generating and communicating the excitement when immersed in this type of experience. As Jim has said in of his discussions with audiences, "Many kids want to grow up to have adventures themselves—few of them want to grow up to be a robot."

RESPONSE TO WRITTEN QUESTIONS SUBMITTED BY HON. JOHN THUNE TO JAN NEWTON, PH.D. AND EDWARD PAGE

NORTHWEST ASSOCIATION OF NETWORKED OCEAN OBSERVING SYSTEMS
22 August 2013

Senator JOHN THUNE,
U.S. Senate,
Washington, DC.

Re: Questions for the Record (QFRs) from the June 11, 2013
Hearing on Deep Sea Challenge: Innovative Partnerships in Ocean Observation

Dear Senator Thune:

Thank you for the opportunity to provide additional information following my testimony on behalf of the Northwest Association of Networked Ocean Observing Systems (NANOOS) at the June 11, 2013 Commerce Subcommittee on Ocean, Atmosphere, Fisheries and Coast Guard hearing on Deep Sea Challenge: Innovative Partnerships in Ocean Observation.

I have coordinated my responses with the U.S. Integrated Ocean Observing System (IOOS) Program Office, the IOOS Association, and my panel cohort, Ed Page from the Alaska Ocean Observing System (AOOS), the Alaskan counterpart to NANOOS. We have attempted to provide you with a national perspective as well as regional perspectives.

Question 1. I am a cosponsor of a bill that would reauthorize the National Integrated Drought Information System (NIDIS). NIDIS seeks, in part, to integrate multiple sources of data in order to provide useful information about drought conditions to end users including those in the private sector and at the local level.

(a) Are there any lessons learned from the Integrated Ocean Observing System (IOOS) experience that you think could apply to the model used by NIDIS?

(b) How has data from IOOS assets been applied to our understanding of weather patterns, like droughts, and how might these assets be better leveraged in the future?

Answer. (a) I think there are many lessons learned from IOOS that could apply to the NIDIS model because these programs share a similar approach in terms of working at the interagency level and drawing from many and diverse sources of data and providing those data to diverse end users including those in the private sector and at the local level. *We have learned that public/private partnerships and leveraging are highly beneficial, but have requirements: building partner relationships based on trust; investing time and effort and sustaining that to maintain the relationships; giving credit to data providers; being policy neutral (e.g., we do not make management decisions; we provide managers with data); and including outreach and education to build an informed constituency.*

Efficiency in using the type of system model IOOS represents is highly dependent upon *effective relationship building* and to achieve that, IOOS has really benefited from having "Regional Associations" (RAs), non-federal entities that connect at the local level to a wide variety of stakeholders, including the private sector as well as connecting with our regional Federal agencies, while working together as a system to assure national consistency. Speaking from the perspective of one of those RAs, NANOOS, we build relationships and trust as well as offer new capacities to data providers on a regional basis. For example, here is the power of that approach: NANOOS funds (partially) 19 *in situ* data streams, yet we serve 176 data streams

to our users. We have integrated various Federal data streams and have also harnessed data streams from local, tribal, private, state, and academic providers. These people *want us to serve their data* because they appreciate the data visualization and services we provide. Data and information should be provided in near real time to disparate stakeholders—usually via intuitive web portal technology.

Also, for this model to work, one must "do it right." Public/private partnerships and leveraging between them are important components for success but it must be understood that these usually *require time and effort* to minimize cultural impedance mismatches, that is, the tendency that different groups (*e.g.,* public vs. private, or academic vs. industry partners) may not work together effectively because of different perspectives, ways of doing business, underlying assumptions, comfort levels, etc. To achieve regional relevance with national consistency, we need to have federal/tribal/state/local governments operating with the private sector, other stakeholders, and the public at large in a cohesive fashion. Again, the IOOS RAs have been very effective at helping to make this happen through establishing years of trusted partnering. Since IOOS and the IOOS RAs do not make policy or management decisions, we are *neutral data providers,* which can enhance trust to a higher level than that often perceived for government or for-profit partners.

Another tenet of this point is that once relationships are built, *sustaining them is critical.* We lose so much efficiency when variable or non-sustained funding causes start/stop/start dynamics. The experience of NANOOS and other RAs is that the private sector will support development projects but looks to the government for sustained funding.

When NANOOS serves partner data, it is clearly credited. Thus *partner providers do not loose ownership or credit for their efforts.* We note, as is in the ICOOS Act, that the IOOS RA providing the data from private providers should not be held liable for data they provide voluntarily into the system.

Lastly, and this pertains to your final question, NIDIS should not consider only serving hydrological data and products as their complete picture. IOOS invests in robust *outreach and education components to build an informed constituency and entrain students and educators.* I think this has been an effective approach that NIDIS also would benefit from.

Answer. (b) *IOOS is built in a modular way from regional, to national to global footprints, all of which contribute.* The U.S. IOOS is a national system that includes all Federal civil ocean observing programs as well as non-federal systems. In addition to serving as the lead Federal agency for IOOS, NOAA contributes in situ, remote, open-ocean and coastal observing systems to IOOS. The global ocean observing systems that NOAA supports monitor changes of the global open ocean and contribute directly to research and prediction capabilities for drought, weather, and climate.

NOAA's Climate Prediction Center (CPC) relies on a range of ocean observing systems including Tropical Atmosphere Ocean Project (TAO), Argo floats, and the Global Drifter Program to provide up-to-date ocean information for use in their forecast models. These in situ open-ocean observing systems are all part of the national, Federal and non-federal enterprise of IOOS. The tropical oceans are particularly critical for forecasts beyond a few weeks. For example, the NIDIS portal (*http://drought.gov/drought/content/products-forecasting/improved-drought-prediction*) describes the importance of the tropical Pacific region for predicting the El Niño-Southern Oscillation (ENSO) phenomena. ENSO is the large-scale circulation pattern driven by changes in surface atmospheric pressure over the equatorial Pacific. The accompanying changes in sea surface temperature (SST) in the Pacific associated with ENSO are known to produce changes in wind, temperature and precipitation patterns in North America. A network of buoys monitor SSTs and deviations from normal are a guide for forecasters producing seasonal outlooks. Research has shown certain weather patterns are associated with El Niño (SSTs warmer than normal), La Niña (SSTs cooler than normal) and ENSO-neutral conditions (SSTs near normal) but there is no guarantee these patterns will emerge with each ENSO event.

Research within NOAA, nationally, and internationally, is actively identifying longer-term changes of droughts, and connections of drought to the oceans, land, and other parts of the earth system. Research tells us that the tropical Pacific and Atlantic, as well as the mid-latitude open oceans are associated with decadal-long droughts (*e.g.,* the Dust Bowl era) in North America. *Whether it is possible to predict such droughts in advance based on ocean and other information within climate models is a very active research area, but it is generally accepted such capabilities will likely require ocean observations deeper in the ocean.* The global oceans are also believed to be associated with droughts on other continents, so we have good reason to be exploring the ocean's role in droughts.

While *prediction of droughts in advance* based on ocean and other information within climate models is a very active research area, it is generally accepted *such capabilities will likely require ocean observations deeper in the ocean.* The *non-federal IOOS partners operate* most of the coastal ocean observing assets that can make *measurements below the surface,* which is essential for understanding heat budgets important for drought prediction.

Focusing beyond droughts, I would say *data from IOOS assets have been applied quite successfully to our understanding of weather.* All throughout IOOS and certainly within NANOOS, our buoy sea surface temperature and meteorological data, as well as High Frequency (HF) surface radar data are going to the National Weather Service to improve weather forecasting. The data are used nationally and by the local Weather Forecast Offices. NANOOS supports not only these local offices, but also the University of Washington's Climate Impacts Group and the Oregon Climate Change Research Institute who focus on longer-term climate forecasting.

There are many examples within IOOS where RA data have made a *big difference to weather forecasts.* A notable one was Superstorm Sandy, where offshore water temperature data from real-time IOOS sensors from RA MARACOOS greatly aided the prediction of hurricane intensity and path. Please see: *http://www.ioos.noaa.gov/communications/superstorm_sandy2013/mts_tech_surge_sandy.pdf.* The coastal ocean observing systems operated by non-federal components of IOOS deliver valuable data and information about water and atmospheric conditions on and near the coast. The influence of coastal oceans on precipitation tends to be more local and shorter-term than the timescale associated with drought.

How might we better leverage these assets in the future? One concrete and relatively low cost way is to get more NDBC verified meteorological stations on existing IOOS buoys or other measurement platforms, especially those operated by non-federal IOOS partners which are located throughout local coastal waters. This is important, since *weather over the water can be quite different than that over land,* e.g., at airports or other more standard weather station locations. These differences can affect the accuracy of weather forecasting.

Question 2. Adequate funding to support research is one factor in maintaining our Nation's competitiveness in science. (a) What other factors have contributed to your success in facilitating partnerships with the private sector? (b) What barriers have you encountered?

Answer. (a) As stated in my response to question 1, what has really contributed to our success in facilitating partnerships with the private sector is *building trust and respect.* We listened to our partners and stakeholders in regard to what data and information they wanted, what skills they could contribute, and then we looked at how we could best leverage this all.

Our partnerships with private industry have two flavors: ones that need data to do their business (*e.g.,* shellfish growers) and ones that have skills or products that could be used as part of the infrastructure of IOOS (*e.g.,* The Boeing Company). In the first type, *we have the data they want.* What was essential to a successful partnership was for us to understand specifically not only the data they want but also, in order to be effective, on what timescales, presented in what units, with what level of manipulation (*e.g.,* graphic or digital data)? Working with smaller user groups informed our design and we present the data to them as a subset of all of our data holdings and in a way that this specialized, versus through our general data explorer. *While in this case, they did not pay for the data, their voice in alerting Congress and the public on the value of these data to their industry was enormous* (Please see "Like putting headlights on a car" quote in my testimony).

In the second type, *we have partners who want to execute with us* part of the IOOS or NANOOS enterprise. The Boeing Company has been one of our regional partners in developing NANOOS's data systems since our inception. Along with three universities and two state agencies, *they are a partner we fund and whose expertise we gain.* Another example of this type would be Microsoft Research, who hosted and funded our successful workshop purely from their interest in our operations. This workshop was part of a national series conducted regionally through assistance of the IOOC (Interagency Ocean Observation Committee). The "Pacific NW Waters–Gateway to our Future" workshop in February 2012 was hosted by Microsoft Research in Redmond, WA, and was attended by more than 150 people included a keynote address by Laura Furgione, NOAA National Weather Services, and panels from five diverse user groups: Fisheries; Alternative Energy; Aquaculture; Coastal Engineering; Hazard Response and Marine Operations filled by federal, tribal, state, academic, industry, and public speakers (*http://www.ioos.noaa.gov/ioos_in_action/stories/industry_workshop_feb2012.html*). An outgrowth of our partnering with Microsoft Research is that one of our NANOOS coastal ocean modelers is taking his

sabbatical there, to work on tool visualization that NANOOS will ultimately benefit from and provide to our users.

Answer. (b) If one takes the approach outlined above where relationships are built on a local level, with trust and respect, over time, and by sustaining that, then the barriers are chiefly funding or related to funding. For instance, will we (NANOOS) be around to partner with them into the future or will this government-supported program fold? Private industry needs to understand risk levels to make informed corporate/financial decisions. *Uncertainties in the level of Federal funding and commitment to IOOS have hindered industry's willingness to fully engage.*

Question 3. In a budget environment where there is little to no new money available for science, how would you prioritize the kind of science that gets funded? For example, some testimony for this hearing discussed the benefits of leveraging Federal assets, but others pointed out that highly-leveraged funding can also be problematic when budgets decrease. How do we best balance "basic" science and applied research portfolios in the ocean sciences? In your opinion, are certain kinds of research better suited to funding by public institutions or by the private sector?

Answer. In my opinion, prioritization for science can be achieved best when it is based on societal needs. However, *balanced funding for both basic science and applied research must be maintained because these two support each other.* I see that today's basic science provides the foundation for tomorrow's applied science. I think of these two as more of a continuum, wherein the fundamental information revealed by basic science is put to use in applied science. We need active funding programs for both and to ignore ocean science is at our peril. I actually cannot think of any ocean science research that is not applied.

Private foundations are well suited to funding large equipment (e.g., buoys, radars), new technologies (e.g., sensors), or infrastructure (e.g., building, ship, computer). NANOOS has benefited from two different $500K awards from the Murdock Charitable Trust for observing equipment (buoys, gliders, sensors). These groups like to offer large sums for discrete items from time to time. Another example would be in funding grand challenges like the X-prize being offered by private industry for a low cost, accurate pH sensor. *However, funding for the sustained operations and maintenance (O&M) is critical for ocean observing systems and is best suited to the Federal Government, because of the stability needed for assurance of the data and information.* Foundations and private industry do not offer opportunities for O&M grants, to my knowledge.

Leveraging is quite effective for infrastructure, platforms, data systems, and other "items." In NANOOS, we use a single buoy for many diverse sensors and applications. We leverage the NANOOS data visualization system to serve many diverse data streams. *But we have no way to support the people's jobs to maintain the buoy or run the data system on a continuous basis except for through Federal or other governmental funding.*

The nation has a National Science Foundation that serves well our ocean science research. IOOS leverages those results every day, since the observing technologies, modeling capabilities and analytical capabilities stem from these investments. *We must balance national funding for sustained ocean observations, such as IOOS, in order to maintain the jobs required to keep the observations coming, the models running, and the information products and data flowing to the public.*

Question 4. A number of you have mentioned the importance of educating our next generation of ocean explorers and scientists. How can partnerships between government and industry help to inspire and encourage future explorers?

Answer. Partnerships between government and industry can help to inspire and encourage future explorers by providing them access to data, information, and technology on ocean environments. The key, however, is to not try to prescribe this. *What is essential is to have the partnership between government and industry be the type of healthy relationships described here. From these partnerships there will be myriad and excitingly unpredictable pathways to inspire and encourage future explorers.* Creative minds love to educate the others through providing ways to enhance exploration.

Examples from NANOOS region: A marine sensor company, Nortek USA, is a NANOOS member. They serve on our Governing Council and some of our PIs utilize their sensors on the observing assets, though this is not mandated. However, Nortek benefits from connecting with our PIs. While ocean sensor providers are in a for profit industry, most of them found that field because of their excitement to study the ocean and their passion to figure out how to do it better. So, it was quite befitting that as their industry has survived, in part because of ocean observing programs like IOOS, they have figured out how to give back and entrain others. Nortek created a scholarship program for students to use their equipment on research

projects and an annual science meeting where students come to present their results. As NANOOS Executive Director, I have been asked to be their keynote speaker in the past; they continue to pull in passionate scientists to this role each year to inspire the next generation of ocean observers.

Another example is the Microsoft Research, a NANOOS partner mentioned in my response to question 2, showcased our observational data and ocean model results in a 3–D presentation at the local Pacific Science Center's first ever Seattle Science Festival . . . a wildly successful event with over 20,000 attendees that is now an annual affair. A quote from one of their leads "Going forward: I'd love to do more with NANOOS, I don't need funds as such but I am always time-limited . . ." implies that creativity, desire, and, in this case, even funds are not the limitation. A successful outgrowth of this partnering has been engagement of both parties in the desire to display ocean data in more immersive ways . . . the partnership still in its formative stage, shows a good match and how the public, via the Pacific Science Center in Seattle, but also via the web worldwide, will benefit.

I think these two examples show that private industry has a wide diversity of ways to inspire and encourage future explorers. The key is to have the partnering infrastructure of humans that can connect locally in a meaningful context.

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