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SEA LEVEL RISE

HEARING

BEFORE THE

COMMITTEE ON ENERGY AND NATURAL RESOURCES UNITED STATES SENATE

ONE HUNDRED TWELFTH CONGRESS

SECOND SESSION

TO

RECEIVE TESTIMONY ON THE IMPACTS OF SEA LEVEL RISE ON DOMESTIC ENERGY AND WATER INFRASTRUCTURE

APRIL 19, 2012

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THURSDAY, APRIL 19, 2012

U.S. SENATE,
COMMITTEE ON ENERGY AND NATURAL RESOURCES,
Washington, DC.

The committee met, pursuant to notice, at 9:34 a.m. in room SD–366, Dirksen Senate Office Building, Hon. Jeff Bingaman, chairman, presiding.

OPENING STATEMENT OF HON. JEFF BINGAMAN, U.S. SENATOR FROM NEW MEXICO

The CHAIRMAN. OK. Why don't we get started? Thank you all for coming. Today we have a hearing on the impacts of sea level rise on domestic energy and water infrastructure.

Over the past century a tremendous amount of high value infrastructure has been built along the coastlines of the United States. This infrastructure serves the needs of coastal communities and is the foundation for developing much of our abundant coastal energy resource. Much of that infrastructure has been built in low lying areas that were already prone to flooding from extreme weather. That's become even more at risk as sea levels have risen.

About 5 million Americans now live in coastal areas that are less than 4 feet above sea level. There are nearly 300 high value energy facilities standing on land below that level. These energy facilities include power plants, oil and gas refineries, and natural gas infrastructure.

Recent history has shown that not only is this infrastructure already vulnerable to extreme weather but also that when coastal energy assets are compromised the energy disruption affects the entire economy. Sea level rise takes the current level of vulnerability and multiplies it. When sea levels rise the storm surge associated with extreme storms gets even worse and even an average storm can have above average consequences. Water systems that were designed based on a lower sea level may not function properly. Salt water intrudes on fresh water resources that communities have depended on for years.

These impacts from sea level rise are not theoretical and they are not disputed and they are not in the distant future. They are being confronted today in places such as Louisiana and Florida. The affected communities there are already paying substantial cost to try to address them.

As the planet has warmed from human emissions of greenhouse gases, the rate of sea level rise has accelerated. It's expected to continue doing so. Improved scientific understanding of ice sheets and glaciers has led to higher projections of sea level rise for this century with the highest estimates indicating that several feet of rise are possible.

When placed in the context of the continued rapid development along the coast, these increased projections of sea level rise are cause for concern and merit consideration by this Congress. It's no secret that the discussion of climate change, of which sea level rise is just one aspect, has become highly politicized here in the Congress. Outside the halls of Congress though, entities that depend on infrastructure at risk of sea level rise are taking the threat seriously and are incorporating the best science into their long term plans.

The Department of Defense, in its 2010 Quadrennial Defense Review Report, highlighted the more than 30 U.S. military installations that are already facing elevated levels of risk from rising sea levels.

The integrated energy company, Entergy, carried out a Gulf Coast adaptation study to assess and manage risks to its energy assets from climate change.

Today we have a witness from Mayor Bloomberg's office in New York to discuss the efforts that New York City is undertaking to prepare for elevated sea levels.

These examples are evidence that those that will be most directly affected by climate change do not have the luxury of delaying their planning process until the politics are more favorable.

The discussion we're having today is an important one. Witnesses will be testifying about real world impacts. I hope that the hearing contributes to restarting a national conversation on this important issue.

Let me turn to Senator Murkowski for any comments she has before introducing the witnesses.

STATEMENT OF HON. LISA MURKOWSKI, U.S. SENATOR FROM ALASKA

Senator MURKOWSKI. Thank you, Mr. Chairman. Welcome to each of you this morning.

Back in 2008 we held a useful hearing on this same topic. It's good to see some new faces at the witness table. I thank you for sharing your time and your expertise with the committee this morning.

We pay a lot of attention to the issue of what is happening with our coastline in Alaska. We have about 6,640 miles of general coastline. The figure that I use is about 33,000 miles if you go around every little island that we have and add it up. It's really quite remarkable. You compare that to just under 5,000 miles of coastline in the lower 48.

So we're paying attention to what is going on with water in the State of Alaska and rising levels. Ice that is receding that is causing greater erosion of our coastline. The Chairman mentions Florida. I was down there not too many weeks ago. When you fly over the delta areas there and recognize that whether it's rising sea levels or land that is basically sinking in many areas, how we deal with these challenges are really quite considerable.

I mention Alaska. I think most say well, you don't have much in terms of population up there. You have limited infrastructure. That is true. But we certainly have our share of energy development. We certainly have some major challenges as it relates to the coastal erosion impacting many of our native villages all along the coastline.

So I'm glad to not only hear about predictions of what the future holds, but hopefully some proposals for how we deal with the challenges that sea level rise will create as well. We face so many different issues within the committee here. It seems like every day we're presented with something. An electric grid that is pushed to its limit, rising gas prices that we talk about quite frequently and extremely costly reliance on foreign Nations, it's a long list of perils of crisis that we deal with.

So I think often times it's easy to forget about these longer term issues that confront us. Taking time this morning to have this discussion about what is going on with our rising sea levels and how we may deal with those impacts is important. So I appreciate you taking the time to join us here this morning and look forward to the testimony.

The CHAIRMAN. Thank you.

Let me introduce our witnesses.

Dr. Waleed Abdalati is the Chief Scientist with NASA. We appreciate you being here very much.

Dr. Ben Strauss is the Chief Operating Officer and Director of the Sea Level Rise Program at Climate Central. We appreciate you being here.

Dr. Anthony Janetos is the Director of the Pacific Northwest National Laboratory's Joint Global Change Research Institute.

Dr. Leonard Berry is the Director of Florida's Center for Environmental Studies.

Mr. Adam Freed is the Deputy Director with the New York City Mayor's Office of Long Term Planning and Sustainability.

We appreciate you all being here. If each of you could take 5 or 6 minutes and sort of make the main points that you think we ought to understand on this issue. We will include your full statement as part of our record. Then we'll have some questions.

Dr. Abdalati, why don't we start with you and just go across the table?

STATEMENT OF WALEED ABDALATI, CHIEF SCIENTIST, NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

Mr. ABDALATI. Thank you. Mr. Chairman, members of the committee, it's my pleasure to appear before you today to discuss the topic of sea level rise.

Sea level rise is really one of the most readily recognizable manifestations of our changing climate because its effects are very visible without the aid of instrumentation. You can actually just see it. Moreover sea level rise evolves relatively slowly and steadily presenting a clear expression of the integrated elements of our changing climate.

Since the late 19th century measurements of sea level rise have been made using tide gauges in coastal regions. Because their measurements are only relative to the adjacent land rather than a global reference frame, and because their limited distribution grossly under samples the ocean, the picture they provide of past sea level rise—and current—is incomplete.

Since 1993 NASA and its partners have been monitoring sea level continuously from space using satellite altimetry which provides more complete and representative information on the changing sea level. Data from these satellites indicate that sea level has risen at a rate of about 3.1 millimeters per year. Not much, but when you stack that up year after year, decade after decade, it's quite substantial.

Estimates based on tide gauges prior to the satellite record offer rates of approximately half that amount. These values represent global averages. On a regional scale, which really is of greater concern to those who have to deal with the effects of rising seas, sea level can vary significantly from place to place.

Some ocean areas including parts of the Eastern Tropical Pacific have experienced a lowering of sea level since 1993, while others such as the Western Pacific exhibit sea level rise rates several times greater than the global average. Since approximately one-third of all Americans live in counties that immediately border the Nation's ocean coasts, understanding this regional variability is very important.

Projections of sea level rise have a large uncertainty as a result of our limited but emerging understanding of the factors that contribute to it. These projections range from a low of two-tenths of a meter (or about 9 inches) by the end of the century to a high of two meters (or about 6 and a half feet). Values near the low end are, the scientific community believes, quite a bit less likely than some of the others because they don't account for some potentially significant contributions for Greenland and Antarctica that have been revealed and better understood in recent years.

However values at the high end are based on the warmest of the future temperature scenarios that we typically use to assess change and make these projections. So more likely we're somewhere in between. But those represent the major bounds.

The expansion of oceans in response to warming temperatures, which is responsible for about a third of the recent sea level rise, is pretty well understood as we look to the future and try and make our projections. Glaciers and ice sheets, which contribute pretty much the remaining two-thirds, are more complicated. Scientists have a good understanding of their melting and accumulation characteristics, the input and the output by melt. But the movement of ice which controls the rate of discharge into the surrounding seas is less clear.

Recent observations from satellites and otherwise show that a number of key outlet glaciers that drain the Greenland ice sheet and drain the Antarctic ice sheet have sped up dramatically in recent years. What's not clear is whether these accelerations are a precursor to much greater ice loss in the future or whether these changes may be self correcting as these glaciers adjust to their new shapes in ways that reduce the forces that drive that rapid discharge of ice. We just don't know and we're working to figure that out.

Current and planned investments in missions like ICESat-2 which measures ice elevation change, the GRACE follow on which measures mass change of ice, airborne observations of ice topography and the geometries of the sub-glacial bed will provide insights into the underlying mechanisms of these changes and indeed, already have. Satellite data from our international partners allow us to examine the variations in flow rates of outlet glaciers and track the magnitude and character of their acceleration. The information gained from these and other complementary endeavors is incorporated into ice sheet models designed to predict how ice sheets will contribute to sea level rise in the next one to two centuries.

The modeling activity is an integrated effort jointly carried out by NASA and the National Science Foundation and the Department of Energy. These observations, along with sustained observations of ocean elevation, temperature and circulation characteristics, and global water transport, will inform models and improve our understanding of the physics, carrying us closer to a more complete and robust sea level rise prediction. The consequences of a one meter globally averaged rise in sea level by the end of this century would be very significant in terms of human well being and economics and potentially global sociopolitical stability. Because the ocean and in part the ice has significant lag in response to temperature changes, the rise in temperatures over the last century has already set an inevitable course for this century. As a result the effects of sea level rise in the coming decades should inform coastal, economic and political planning today.

Thank you for the opportunity to appear before this committee today. I'll be pleased to answer any questions you may have.

[The prepared statement of Mr. Abdalati follows:]

PREPARED STATEMENT OF WALEED ABDALATI, CHIEF SCIENTIST, NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

Mr. Chairman and members of the committee, it is my pleasure to appear before you today to discuss the topic of sea level rise. Sea level rise is one of the most readily recognizable manifestations of climate change, because it is directly observable without the aid of instrumentation, with very visible effects. Sea level rise is not as rapidly variable as many of the other indicators of climate change, such as temperature or precipitation. Rather it evolves relatively slowly and presents a clear expression of the integrated elements of our changing climate.

Since the late 19th century, measurements of sea level rise have been made using tide gauges in coastal regions. These gauges provide tremendously valuable information on local changes in ocean height relative to their adjacent land. However, they provide an incomplete picture of the absolute and global rates of sea level rise because (1) their measurement is relative to the ground surface in which they are mounted, so they do not account for the upward or downward movement of that surface itself, and (2) their distribution is limited, making sample measurements in a few places rather than over the global ocean. These gauges reflect a bias toward the regions in which they are located, grossly undersampling the global ocean; thus they do not offer a picture of sea level rise's considerable regional variability. Since 1993, NASA and its partners have been monitoring sea level continuously from space using satellite altimetry. Satellite altimetry has the advantage of being able to measure globally, for a more complete and representative sampling of the oceans. Moreover, it works in a global terrestrial reference frame rather than a local relative one, making its measurements independent of the local movement of the underlying surfaces.

Since the beginning of the satellite record in 1993, sea level is estimated to have been rising at a rate of 3.1 ± 0.4 mm/yr (see attached figure)*. Estimates based on tide gauges prior to 1993 are for rates of approximately half that amount.

These values represent global averages. Of greater concern to coastal managers and those who have to deal with the effects of sea level rise, are the regional values referred to earlier, which can vary significantly from place to place. Some ocean areas, including parts of the Eastern tropical Pacific, have experienced a lowering of sea level since 1993, while others, such as the Western Pacific, exhibit sea level rise rates several times greater than the global mean. This difference is related to: the rising or sinking of parts of the globe in response to the loss of the great ice sheets that blanketed much of North America roughly18,000 years ago; the global wind patterns, which distribute the water differently around the globe by pushing water toward land in some areas, and away from land in others; and the rotation of the Earth, which also changes the distribution of water. According to the U.S. Global Change Research Program report Global Climate Change Impacts in the US (2009), "Approximately one-third of all Americans live in counties immediately bordering the nation's ocean coasts," and similar scenarios are true—often in greater proportions—for other nations. For this reason, it is very important to understand variations in sea level not just on a global scale, but on a regional scale as well.

Looking toward the future, the projections of sea level rise have large uncertainty as a result of our limited—but emerging—understanding of the factors that contribute to sea level rise. These projections range from a low of 0.2 meters by the end of the century to a high of 2 meters. Values near the low end of the range are less likely than others, since they do not account for some potentially significant contributions for the Greenland and Antarctic Ice Sheets. At the same time, the highest values are based on warmest of the temperature scenarios commonly considered for the remainder of the 21st century.

To understand the current state of sea level rise, and estimate the future rates, it is important to understand the elements that influence it. In the simplest terms, sea level is the combined effects of the following components:

- Ocean thermal expansion is the increase in ocean volume as it warms.
- Input from the world's glaciers and the Greenland and Antarctic ice sheets can either raise sea level, when the glaciers and ice sheets are shrinking and dumping their mass into the ocean, or it can lower sea level, when they are growing, and taking mass out of the ocean.
- Terrestrial storage in groundwater, dams and reservoirs, etc. can either raise or lower sea level.

Our current estimates indicate that about a third of the sea level rise over most of the last three decades is coming from the expansion of the warming ocean, while two thirds is derived from the world's shrinking glaciers and from the Greenland and Antarctic ice sheets. The amount attributable to terrestrial storage is currently negligible.

While sea level is simple to conceptualize, it is difficult to predict, as major contributing factors involved are very complex and not well understood. The biggest wild-card in the sea level equation is the Earth's great ice sheets. With the equivalent of about 7 meters of sea level in Greenland, and 60 meters in Antarctica, their potential for contributing to sea level rise is large. To understand how ice sheets contribute to sea level rise, one first has to understand their mass budget. As with sea level rise, the budget is the difference between the mass input to the ice sheet, which comes mainly from snow accumulation, and the output, which is mainly a combination of melting, discharge or calving of icebergs, and sublimation (direct transition from snow to water vapor). If global average air temperatures continue to increase along the trends observed over the last 100 years, all of these components—accumulation, melting, and discharge rates—are expected to increase.

Analysis of satellite, aircraft and in situ observations, coupled with models of the accumulation and precipitation, make clear that the Greenland ice sheet has been losing mass at a rate that contributes about 0.6 + 0.01 mm/yr to sea level rise, and Antarctica is losing ice that translates to the equivalent of 0.45 + 0.2 mm/yr of sea level rise. What has the attention of the scientific community, however, is that a number of key glaciers in both Greenland and Antarctica have dramatically accelerated their flow to the sea in recent years. Some have more than doubled their speed in just a few years. This is in response to the warming of surrounding seas, which causes the floating ice at the ends of the outlet glaciers that drain the ice sheet to melt, which then reduces their restraining force on the glaciers upstream, causing

* Figure has been retained in committee files.

the ice to accelerate. In the simplest terms, the warmer the seawater gets, the less resistance to flow there is in the outlet glaciers, and the more rapidly they dump their ice into the sea.

This phenomenon is of particular concern in the West Antarctic ice sheet (WAIS), an area about the size of the states of Texas and Oklahoma combined. WAIS contains the equivalent of 3.3 m of sea level, and all that ice rests on a soft-bed that lies below sea level. In this configuration, as warm seawater melts the floating ice shelves, causing them to retreat and the glaciers that feed them to speed up, there is no mechanism to stop the retreat and associated discharge, if warming continues. Thus the WAIS exhibits great potential for substantial and relatively rapid contributions to sea level rise.

In Greenland, the situation is not as dramatic, since the bed that underlies most of the ice is not below sea level, and the potential for unabated retreat is limited to a few outlet glaciers. In Greenland, however, summer air temperatures are warmer and closer to ice's melting point, and we have observed widespread accumulation of meltwater in melt ponds on the ice sheet surface. The water from these melt ponds often drains rapidly to the bottom of the ice, where it lubricates the interface between the ice and the underlying bedrock, and causes a rapid acceleration of the ice toward the sea. Both the acceleration due to ice shelf retreat, and the acceleration due to meltwater penetration, represent potential instabilities and can lead to rapid sea level rise. To be clear, "rapid" in terms of sea level rise means on the order of about a meter or two in a century. There is evidence that during some periods over the last 18,000 years, oceans have risen by as much as 5 cm/yr (5 meters in a century), which is roughly fifteen times the current rate. Such rapid rates of sea level rise are a result of rapid discharge of ice from the Earth's great ice sheets, which, during the last glacial maximum, were much larger than today.

These past high rates amplify the importance of understanding the underlying mechanisms and their likely behavior in the future. The importance is underscored by the vulnerability of coastal populations and infrastructure. Unfortunately, while we have the ability to observe changes in ice sheets, sea level, and ocean characteristics, our ability to predict these phenomena is very limited, and requires a greater understanding of the physical processes at work.

The expansion of oceans in response to warming temperatures is fairly well understood, as are some aspects of ice sheet changes—specifically the loss of ice through melt, and the accumulation of ice through precipitation. But the motion of ice sheets, which control the rate of discharge to the surrounding seas, are not well understood and cannot at present, be predicted with confidence. The speed-up I described earlier may constitute a sustained, enhanced discharge keeping rates of sea level rise high; it may be a precursor to a more substantial discharge through increased acceleration; or it may be self-correcting, as these glaciers adjust to their new shapes in a way that reduces the forces that carry the ice out to the sea.

With the development of satellite and airborne remote sensing capabilities, coupled with ever-advancing field measurements and modeling efforts, we are beginning to understand current changes and gain insights into what the future may hold for the Greenland and Antarctic ice sheets. Our satellite and airborne capabilities are providing observations of glacier flow rates, ice topography (which is indicative of the underlying processes that affect change), mass change, and depth and topography of the bedrock that lies beneath the ice. This last point is particularly important because it is the geometry of the bed, in conjunction with surface elevations, that determine the extent to which glaciers will continue to accelerate or will slow down.

Current and planned investments in missions such as the Ice, Cloud and Land Elevation Satellite 2 (ICESat-2—measuring elevation change) and the Gravity Recovery and Climate Experiment (GRACE) follow-on (measuring mass change) and airborne observations of ice topography bed geometries provide insights into the underlying mechanisms of ice sheet changes. NASA also works with data from its international partners to examine the variations in flow rates of outlet glaciers, tracking the magnitude and character of their acceleration. The information gained from all of these projects is incorporated into ice sheet models designed to predict how ice sheets will contribute to sea level rise in the next one or two centuries. The modeling activity is an integrated effort jointly carried out by NASA, the National Science Foundation, and the Department of Energy (DOE). NSF also invests in basic observations and process studies that are either directly coordinated with or are complementary to NASA's activities, and DOE is building dynamical models of Greenland and Antarctica, where future sea level rise projections take advantage of observations provided by NASA and NSF. Through these investments and activities, the scientific community is making progress toward addressing the wild-card of the sea level rise equation, but we are still a ways off from a level of understanding that would allow us to predict future changes accurately.

Sustained observations of ocean elevation from satellites, in particular with the Jason satellite series operated by NOAA in collaboration with our European partners, combined with tide gauges will provide an ongoing measurement of current rates of sea level rise. Continued observations of ice sheets and glaciers will provide necessary insights into the physical processes that govern their contributions to sea level rise. Ongoing measurements of ocean characteristics will continue to inform our assessments of temperature and circulation characteristics, which affect the rate of expansion. Continued observations of the movement of water throughout the Earth will provide important insights into the characteristics of land-water storage. All of these data are critical inputs used to inform models and improve our understanding of the physics, carrying us closer to a more complete and robust sea level rise prediction.

A complementary method for predicting future sea level rise is to compare past temperatures to past sea levels reconstructed from the geological record of Earth's climate history. There is a fairly robust relationship between the two, and by using this relationship or correlation, one can predict values of sea level rise for estimated values of future temperatures. This method is a statistical, rather than a physical approach, and when applied to future warming scenarios, this method provides the highest estimates (2 meters of globally-averaged sea level rise) for the end of the century. It has the advantage of not requiring a detailed understanding of the complex physics in order to make a prediction, and it produces results consistent with recent history. However, because it does not directly incorporate underlying physical processes, this method provides limited insight into mechanisms and characteristics of future sea level rise.

In summary, we can say with confidence that sea levels have been rising at a rate of approximately 3.1 mm/yr over the last 30 years. About a third of this rise is attributed to thermal expansion and about two thirds comes from the melting, retreat, etc. of glaciers and ice caps. The projections for the future are very uncertain, and range from a low of 0.2 meters by the end of the century to a high of 2 meters. This large uncertainty is a result of our currently limited understanding of instabilities in flow rates of outlet glaciers on the Greenland and Antarctic ice sheets. Moreover, some coastal areas will experience perhaps little or no rise in sea level, while others may experience rates that are far greater than this globally-averaged value. The consequences of a 1 meter rise in sea level by the end of this century would be very significant in terms of human well-being and economics, and potentially global socio-political stability.

Finally, because the ocean and in part the ice have a significant lag in response to temperature changes, the rise in temperatures over the last century has already set an inevitable course for this century. As a result, the effects of sea level rise in the coming decades should inform coastal, economic, and political planning today.

The CHAIRMAN. Thank you very much.

Dr. Strauss.

STATEMENT OF BENJAMIN H. STRAUSS, COO AND DIRECTOR, PROGRAM ON SEA LEVEL RISE, CLIMATE CENTRAL, PRINCETON, NJ

Mr. STRAUSS. Good morning Chairman Bingaman, Senator Murkowski and other distinguished members of the committee. Thank you for your attention to this important topic.

I'm Dr. Ben Strauss, co-author of several recent reports and peer review papers assessing sea level risk to the lower 48 States. I'm also Director of the Program on Sea Level Rise at Climate Central, a New Jersey based, non-profit research organization that conveys scientific information to the public. We take strictly new climate or energy policy positions.

My testimony will address two topics.

First, how sea level rise is amplifying risk from coastal storm surges.

Then, the communities and infrastructure exposed at the lowest elevations.

The nearest term sea level projections I will share in inches may sound small but they are dangerous. The key problem is that rising seas raise the launch pad for coastal storm surges and tilt the odds toward disaster. Just a few extra inches could mean the difference to flood and disable New York City's subway system as an example. You might think of it this way. Raising the floor of a basketball court would mean a lot more dunks.

In the long term we are likely to see many feet of sea level rise and be forced to redraw the map of the United States. The high end of projections for this century would be enough to turn Miami-Dade County, Florida into a collection of islands. But in the nearer term we will mainly experience sea level rise as more and more coastal floods reaching higher and higher. In fact, according to our analysis sea level rise due to global warming has already doubled the annual risk of extreme coastal flooding across widespread areas of the Nation.

Global average sea level has risen about 8 inches since 1880. This means that warming is already contributing to the damage caused by any coastal flood today. Studies back an additional global rise likely this century between one and 7 feet.

In some areas, especially for Louisiana, Texas and the Mid-Atlantic States, sinking land will add to the total effective rise. Taking such local factors into account we made mid range projections for sites around the lower 48 of one to 8 total inches increase by 2030 and 4 to 19 by 2050 depending upon location. All along the Pacific from Seattle to the Oregon coast to San Francisco to Los Angeles, the part of past and projected sea level rise from global warming more than triples the odds of century floods by 2030 in our analysis as you can see from the display to my left.

The places with asterisks have a more than 3 times ratio between the red bar which gets the odds of a century flood by 2030 with global warming projections. The blue bar gets the odds in a world without sea level rise from global warming. The same is true inside the Chesapeake and Delaware bays and many sites to the north, a 3 x or more ratio.

These increases are likely to cause a great deal of damage at over half of the 55 sites where we studied flood risk. Storm surges on top of sea level rise have better than even chances to reach more than 4 feet above the high tide line by 2030. Yet nearly 5 million U.S. residents live in 2.6 million homes on lands below this level. Multiplied by the national average sales price of existing homes in 2010 this stock comes roughly to more than $500 billion of residential real estate.

An enormous amount of infrastructure also lies in the same zone from airports to waste water treatment plants and including almost 300 energy facilities as you can see in the second display along with subtotals for some States and some populations figures. The facilities shown are mainly natural gas, oil and gas, and electric facilities. More than half are in Louisiana, the vast majority of those unprotected by levies.

In 285 municipalities more than half the population lives on land below the 4 foot mark. 106 of those places are in Florida, 65 are in Louisiana and 676 towns and cities spread across every coastal State in the lower 48, except for Maine and Pennsylvania, more than 10 percent of the population lives below the 4 foot mark. Maps and statistics for 3,000 coastal towns, cities, counties and States are name and zip searchable at sealevel.climatecentral.org and I urge you and your colleagues and staff members to explore the places important to you.

In conclusion the risks from sea level rise are imminent and serious. This is not a distant problem only of concern for our children. Escalating floods from sea level rise will affect millions of Americans and threaten countless billions of dollars to buildings and infrastructure.

I look forward to answering any questions you may have regarding this data and being a resource in any way I can to you and your offices. Thank you.

[The prepared statement of Mr. Strauss follows:]

PREPARED STATEMENT OF BENJAMIN H. STRAUSS, COO AND DIRECTOR, PROGRAM ON SEA LEVEL RISE, CLIMATE CENTRAL, PRINCETON, NJ

Good morning, Senator Bingaman and colleagues. Thank you for your attention to this important topic. I am Dr. Ben Strauss, coauthor of two recent peer-reviewed papers making an assessment of sea level risk to the lower 48 states, as well as the summary report* submitted with my written testimony. I am also Director of the Program on Sea Level Rise at Climate Central, a nonprofit research organization that conveys scientific information to the public. We take no policy positions.

In my testimony today as in my research, I will address two topics: first, how sea level rise is amplifying the risk from coastal storm surges, and then, what communities and assets are exposed at the lowest elevations.

The nearest-term sea level projections I will share, in inches, may sound small. But they are dangerous. The key problem is that rising seas raise the launch pad for coastal storm surges, and tilt the odds toward disaster. Just a few extra inches could mean the difference to flood a family's basement—or New York City's subway system, disabling it for months. You might think of it this way: raising the floor of a basketball court would mean a lot more dunks.

In the long term, we are likely to see many feet of sea level rise, and be forced to redraw the map of the United States. The high end of projections for this century would be enough to turn Miami-Dade County, Florida into a collection of islands. But in the near term, we will mainly experience sea level rise as more and more coastal floods, reaching higher and higher.

In fact, according to our analysis, sea level rise due to global warming has already doubled the annual risk of extreme coastal flooding across widespread areas of the nation. Global average sea level has risen about 8 inches since 1880. This means that warming is already contributing to the damage caused by any coastal flood today. Diverse studies bracket additional global rise likely this century between 1 and 7 feet.

In some areas, especially for Louisiana, Texas, and mid-Atlantic states, sinking land will add to the total effective rise and compound problems. Taking such local factors into account, we made mid-range projections for sites around the lower 48 of 1-8 total inches increase by 2030, and 4-19 by 2050, depending upon location. All along the Pacific, from Seattle to the Oregon coast to San Francisco to Los Angeles, the component of past and projected sea rise from global warming more than triples the odds of "century" floods by 2030 in our analysis, as you can see from the display. The same is true inside the Chesapeake and Delaware Bays, and many sites to the north.

These increases are likely to cause a great deal of damage. At over half the 55 sites where we studied flood risk, storm surges on top of sea rise have better than even chances to reach more than 4 feet above the high tide line by 2030. Yet nearly 5 million U.S. residents live in 2.6 million homes on land below this level. Multiplied by the national average sales price of existing homes in 2010, this stock comes to more than $500 billion of residential real estate, in a rough estimate. An enormous amount of infrastructure also lies in the same zone, from airports to wastewater treatment plants, and including almost 300 energy facilities—as you can see in the second display, along with population figures. The facilities shown are mainly

* See Appendix II

natural gas, oil and gas, and electric facilities. More than half are in Louisiana, the vast majority there unprotected by levees.

In 285 municipalities, more than half the population lives on land below the 4-foot mark. One hundred and six of these places are in Florida and 65 are in Louisiana. In 676 towns and cities spread across every coastal state in the lower 48 except Maine and Pennsylvania, more than 10% of the population lives below the 4-foot mark. Maps and statistics for 3,000 coastal towns, cities, counties and states are name-and ZIP-searchable at sealevel.climatecentral.org, and I urge you and your colleagues and staff members to explore the places important to you.

In conclusion, the risks from sea level rise are imminent and serious; this is not a distant problem only of concern for our children. Escalating floods from sea level rise will affect millions of Americans, and threaten countless billions of dollars of damage to buildings and infrastructure.

Thank you for your attention.

The CHAIRMAN. Thank you very much.

Dr. Janetos.

STATEMENT OF ANTHONY C. JANETOS, DIRECTOR, JOINT GLOBAL CHANGE RESEARCH INSTITUTE, PACIFIC NORTHWEST NATIONAL LABORATORY/UNIVERSITY OF MARYLAND, COLLEGE PARK, MD

Mr. JANETOS. Thank you, Mr. Chairman. Members of the committee, thank you very much for the opportunity to come and speak with you this morning. I want to make several points drawing on my written testimony.

One, which we've already heard some of, is that there is—there are known vulnerabilities of the current energy infrastructure to the conditions under which they exist today. Current sea levels, the rate of rise of sea level, however modest in today's world and variability in the climate system, frequency and intensity of storms as we know them now.

But these vulnerabilities are being increased as sea levels inexorably continue to rise with risks of damage, service interruption and longer term service reduction of vulnerability of that infrastructure.

Third, while we immediately think of the Gulf region, for understandable reasons, it is not by far the only part of the U.S. with infrastructure that's potentially vulnerable. In addition to the exhibit that we just saw, I show in my written testimony a map drawn from a very recent scientific assessment showing energy facilities, production facilities, in the State of California that are potentially at risk of inundation from reasonable levels of storm surge.

Fourth, the risk in any particular location depends very strongly on local conditions, subsidence, the status of barrier islands. Barrier islands turn out to be particularly important because they tend to absorb wave energy. As they erode that energy is simply transmitted to the infrastructure and to the coastline. In many parts of both the Gulf and the Southeast and further up the eastern seaboard, including places closer to here in the Newport News, Hampton Roads area, both NOAA and the USGS have identified those areas as being highly sensitive to the impacts of sea level rise including their energy facilities.

As Senator Murkowski noted in her opening statements, Alaska is also seeing very large and rapid changes both due to sea level rise, but also due to the loss of ice and dramatically increased erosion which has the capacity to effect energy development patterns.

We've already seen both short term interruption and longer term reductions in service as a consequence of extreme storms. While Hurricane Katrina is the best known example, it's by no means the only one. Important to keep in mind is that the physical vulnerability of the energy infrastructure itself is not the only issue to keep in mind.

The delivery of energy services, after all, is primarily what we care about in both the short term and the long term. That also depends quite critically on the status of the transportation sector, roads and rails, on communications, on a whole host of other aspects of infrastructure. There was, within the last 5 years, there was an excellent scientific assessment done by the Department of Transportation and the U.S. Geological Survey, for example, to look at the transportation infrastructure in the Gulf which showed clearly, and this is also illustrated in my written contribution, that literally thousands of miles of roads and rails that are below 4 feet of elevation.

It's worth keeping in mind that the storm surge of Katrina, when it made landfall, was over 25 feet. So there's substantial transportation infrastructure that's already at risk.

While we do know these things about the current state of vulnerabilities of both energy and transportation infrastructures, the scientific assessment literature and the risk assessment literature on these topics is really very recent. Most of the major assessments have been done, scientific assessments, have been done within the last 5 years. The two major reports coordinated in the— by colleagues at Oak Ridge National Laboratory, were literally done and submitted within the last 6 weeks. So we are still, I think, at a very, very early stage in trying to assess the depth and the confidence that we have in our knowledge base.

The primary literature itself is still rather sparse. This is an area where research is poised to make significant contributions to our understanding of this risk and what might be done about it as we move forward. In that respect, siting decisions, we've talked mostly about current infrastructure. But siting decisions for future infrastructure are almost completely unexplored. How all the factors that will go into a whole set of siting decisions are really relatively unexplored in today's world.

So this is, in closing, this is an area where our ability to balance known risks and vulnerabilities with our still developing understanding of potential adaptations and actions that might be taken. Our relative lack of knowledge that would contribute to better siting decisions for the future makes this an area where research contributions could make a substantial difference. Thank you.

[The prepared statement of Mr. Janetos follows:]

PREPARED STATEMENT OF ANTHONY C. JANETOS, DIRECTOR, JOINT GLOBAL CHANGE RESEARCH INSTITUTE, PACIFIC NORTHWEST NATIONAL LABORATORY/UNIVERSITY OF MARYLAND, COLLEGE PARK, MD

Good morning, Mr. Chairman and members of the Committee. Thank you for inviting me to testify this morning. I am very pleased to be able to speak briefly on the topic of the vulnerability of the energy infrastructure to sea-level rise, and more broadly to climate variability and change.

A CONCISE SUMMARY OF CURRENT KNOWLEDGE

Other witnesses on this panel will speak to the scientific issues behind rising sea-levels. The figure below, drawn from the last scientific assessment of the Intergovernmental Panel on Climate Change, shows mean global sea-level changes over the past century (figure provided by V. Burkett)*.

By the year 2100, global sea-level could rise somewhere between an additional 20 cm and 60 cm, depending on what emissions trajectory the world ends up on, and how sensitive the interacting processes of thermal expansion and glacier ice dynamics are to rising temperatures, both globally and regionally. The science in this area is quite dynamic, and some of the physical uncertainties are large, making detailed predictions difficult.

In any particular coastal region, sea-level rise is governed not only by the dynamics of the global ocean, but by the particular physical forces at work in that region itself. So, for example, local bathymetry is important on the ocean side, and so are the dynamics of the land itself—whether it is subsiding, as in much of the Gulf Coast, for example, or rising, as in parts of the Pacific Northwest. Examples from several locations in the Gulf are shown below (figure provided by V. Burkett).

But regardless of the particular rates of sea-level rise in any one place, it is clear that there is always some degree of concern about potential impacts of infrastructure to rising sea-level, for many reasons. This concern can be divided into two parts. The first aspect is the degree to which infrastructure is exposed to current or increased physical impacts of rising seas.

One of the biggest concerns in this respect is storm surge, the risk of which increases as sea-level rises for the simple reason that there is more water to be transported by winds, tides, and waves. So even without changes in frequency or intensity of storms, rising sea-levels will lead to greater storm surge, and therefore greater risk to existing infrastructure. An example of why storm surge is of such importance is shown by Hurricane Katrina, whose initial surge was more than 25 feet at the time of landfall. Katrina's effects included a reduction in oil production of roughly 19% for the year through disruption of energy infrastructure, and linked transportation infrastructure (summarized in Wilbanks et al 2012a).

The presence or absence of barrier islands can make a very large difference in the amount of physical energy that near-shore or on-shore infrastructure is exposed to. Barrier islands can absorb a large amount of wave energy by acting in effect as natural seawalls, and thereby reduce (but not eliminate) the exposure of infrastructure to the effects of waves and storm surge (figures below from V. Burkett).

If storm frequency or intensity were to change as a consequence of longer-term changes in the physical climate system, that would also have an effect on exposure to physical impacts. The science is mixed on these points, with recent scientific assessments from the US Global Change Research Program (2010) suggesting that increases in tropical storm frequency is not well-supported by the science, but that tropical storm intensity is likely to increase over the coming decades.

The second major component of the potential impacts of sea-level rise and climate variability and change on energy infrastructure is the intrinsic vulnerability of the existing infrastructure. Infrastructure that is already situated in coastal waters, or energy generation, transportation, or grid infrastructure that is on the coasts is variously vulnerable to storms, erosion, temperature extremes, and other aspects of the physical climate system. Some of this vulnerability comes simply from location. Several scientific assessments and papers identify the locations of major collections of energy and other infrastructure in the Gulf region, for example (Burkett, Wilbanks, CCSP study). These clearly are vulnerable to the effects of tropical storms and the rising sea-level of the Gulf. But the Gulf is not the only region with infrastructure that is potentially vulnerable. The Hampton Roads/Newport News region of Virginia, for example, has been recognized both by NOAA and USGS as being potentially quite vulnerable to sea-level rise impacts, and there are power plants in coastal regions of California that have been identified as potentially vulnerable (figures below from Wilbanks et al 2012a and 2012b).

Operators of equipment in the Gulf already recognize, and have operational policies in place to deal with the existing stresses caused by the physical environment in the Gulf. But it is not clear yet what additional procedures might need to be put in place to adapt to changing conditions, in large part because of the difficulty in projecting climate variability and sea-level rise on regional scales.

Burkett (2011) identifies six primary drivers of vulnerability of coastal (both on-shore and off-shore) energy infrastructure:

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* All figures have been retained in committee files.

- Increased ocean and atmospheric temperature
- Changes in precipitation pattern and runoff
- Sea-level rise
- More intense storms
- Changes in wave regimes
- Increased dissolved CO2 and ocean acidity

This list of physical drivers of vulnerability recognizes that both changes in the ocean environment and the near-shore terrestrial environment (e.g. runoff) as well as the climate system itself have potentially important implications for energy and other infrastructure.

Wilbanks and colleagues (2012a,b) point out that the vulnerability of the energy sector's physical infrastructure is also linked to the vulnerability of other societal infrastructure—in particular, the condition and vulnerability of the transportation sector to similar physical stresses. Likewise, the vulnerability of the grid itself to changes in the physical climate system is important. There are both well-documented case studies from particular events (with an emphasis on the impacts of severe storms), and concerns about the potential for both average conditions and extremes to change over time. A major contribution of these assessments is the recognition that the delivery of energy services is a multi-sectoral phenomenon, and thus considerations of the linked vulnerabilities of major infrastructures should be part of an analysis of potential adaptation options. The figure below (Wilbanks 2012a) illustrates the complexity of sectoral interactions that affect the response of energy infrastructure to climate variability.

A particular example of known vulnerabilities of closely related sectors to energy comes from a major scientific assessment of the vulnerability of the transportation sector in the Gulf Region, jointly conducted by the US Department of Transportation and the US Geological Survey (CCSP 2008). One illustration of their results, the distribution of road and rail networks vulnerable to long-term inundation, is shown below.

WHAT CAN ADDITIONAL RESEARCH CONTRIBUTE?

While the scientific community and both the public and private sectors are assessing what is known about current risks and vulnerabilities, there are many knowledge gaps that make assessing future risks and vulnerabilities difficult. These gaps provide an opportunity for additional contributions from both fundamental and applied research.

In order to help identify some of the knowledge gaps, we provide an overall framework based on a research project in our own laboratory, supported by SERDP, that will do a vulnerability analysis of military installations (Moss, personal communication).

OVERVIEW OF RESEARCH APPROACH FOR VULNERABILITY ASSESSMENT OF DOD INSTALLATIONS

When adapted to the needs of the energy sector, and particularly to issues associated with understanding the vulnerability of that sector to sea-level rise and other changes in the physical climate system, this framework provides a guide to several potentially important interdisciplinary research topics.

- We clearly need to improve our understanding of the interactions of energy demand and supply with other sectors, including land-use and water, but also transportation. Along with this integrated understanding should come the ability to model integrated systems on regional scales.
- At the same time, determine the sensitivity of the energy sector to other stresses and forcing agents, e.g. changes in population, in demand for energy services, in cooling technologies, in the productivity of terrestrial and coastal ecosystems, in the availability of alternative renewable sources of energy such as hydropower and biofuels.
- Understanding and quantifying regional climate change, and other regional changes in the physical environment, such as sea-level rise and storm surge, is also a very high priority. The relationships between global changes in these physical systems and regional changes are complicated, but the scaling questions must be resolved so that decision-makers can analyze different possible scenarios of the future at scales that matter to their decisions.
- It is critically important to understand the potential magnitude of changes in the climate system, including the oceans, for several decades. But just as important will be fundamental research on other modes of variability in the climate

system, including seasonal-to-interannual variability and any potential changes in storm frequency and intensity or other extreme events.

- And as important as it is to understand the changes in the physical environment, their forcing agents, and the processes that control how they affect important features of climate, or important aspects of sensitivity of natural systems, it is just as important to understand the human dimensions of change. A much better understanding, and the ability to model adaptation decisions must be sought in order to understand how different potential futures might be addressed in reasonable and thoughtful ways.

Thank you very much for your attention.

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Wilbanks, T.W. et al. 2012b. Climate change and energy supply and use. Technical Input Report to the US Dept. of Energy in support of the National Climate Assessment. Oak Ridge National Laboratory. 90 pp.

The CHAIRMAN. Thank you very much.

Dr. Berry.

STATEMENT OF LEONARD BERRY, DIRECTOR, FLORIDA CENTER FOR ENVIRONMENTAL STUDIES, FLORIDA ATLANTIC UNIVERSITY, JUPITER, FL

Mr. BERRY. Mr. Chairman, Senator Murkowski, thank you. As we've learned the sky is not falling but the water is rising. That's a problem for Florida.

It's a special problem. I know Florida is always a special case if you read the newspapers. But sea level rise is a special problem for Florida for 3 or 4 reasons.

One, Florida is flat.

Second, many of those people Ben is talking about live within 3 feet above sea level and more are coming there year by year.

Unfortunately Florida is limestone. Limestone is porous. So we're not just dealing with the question of water rising. We're dealing with the question of water infiltrating into our subsurface, polluting, already polluting, our aquifers and potentially bringing real dangers to our water supply with high energy risks.

So those 3 or 4 things are at risk for all of Florida. In some of my remarks I focus on the Southeast. That's because the risks are very heavy there. But all of Florida is impacted, not so much the Gulf Coast, but every other part.

It's not a future problem for us in Florida. At high tides we get flooding. That didn't happen 20 years ago. Drains back up with unfortunate consequences in some houses. I won't go into the details.

The canals which were planned 50 years ago and built 50 years ago are beginning not to function. That 8 inches of sea level rise that we heard about is the difference. The country is so flat that even that 8 inches allows the canals not to drain by gravity.

Water backs up. People get flooded. So we're either dealt with drought or flood.

But that's a current problem. What we're more concerned about is the projections for the future. We're looking at projections locally where we're focusing, not on 2100 because I think people's eyes glaze over at 2100.

We're focusing on 2030 and 2060. Those two dates are well within the planning arisance of most of the agencies. Planning roads, planning airports, planning energy facilities, 2060 is tomorrow.

We're looking at the potential for 3 to 7 inches of rise by 2030, 9 to 27 by 2060. Those are big numbers for us in Florida. The impacts for 2060, we estimate 400,000 square miles of Florida would be impacted, directly or indirectly.

Billions of dollars, with a B, of real estate, problems from schools, hundreds of schools would be impacted. Most importantly and we're worrying about current energy facilities. If we're going to deal with the new water facilities, we're going to deal with the pumping.

We're going to deal with adjusting to this level of impact. A lot more energy is going to be needed. So we're not worrying—we are worrying about current energy.

But we're also worrying about how we deal with future energy. We're going to have to look at the Gulf Stream maybe. We've already got some research efforts there, solar energy as well as our conventional sources.

At the ground level people are responding. I think the example of the Four County Compact in Southeast Florida is an important one. Four counties that normally fight like, whatever, to compete with one another are actually working together on a sea level rise plan because they feel that what happens in one county is going to happen—is going to impact the others.

They, in a brilliant effort, managed to get through the State of Florida legislature some legislation last year that said we are going to form Adaptation Action Areas. They are going to be able by law be able to define areas where special adaptation might be experimented with. That process is beginning.

I'd have to say the universities are working pretty hard on this topic. The Federal agencies on the ground, particularly in association with Everglades National Park and its problems are working on this topic. We realize that inaction is not a permissible response.

We propose, I think, 5 things.

That further effort to be made to identify areas at special risk.

That we should use the Special Adaptation Areas to identify planning and removal and reconstruction efforts which would incorporate sea level rise into all of our future planning, future meaning more than 5 years.

We should look at the Everglades Comprehensive Restoration Plan in the light of sea level change.

Last, but not least, we should look at the future energy impacts that sea level rise will need for the State and for the Nation.

Thank you.

[The prepared statement of Mr. Berry follows:]

PREPARED STATEMENT OF LEONARD BERRY, DIRECTOR, FLORIDA CENTER FOR ENVIRONMENTAL STUDIES, FLORIDA ATLANTIC UNIVERSITY, JUPITER, FL

My name is Dr. Leonard Berry. I am the Director of the Florida Center for Environmental Studies, Distinguished Professor of Geosciences at Florida Atlantic University (FAU) and the Co-Director of the Climate Change Initiative at FAU.

INTRODUCTION

Florida is a special case for sea level rise; it is very flat with millions of people living along the coast. A large portion of the population relies on subsurface water which is being compromised by salt water intrusion due to the porous limestone underlying much of Florida. Sea level rise is also complicated by the threat of hurricanes and storm surge. Water management in Florida is highly organized, but will need major adjustments to accommodate our changing circumstances. Most adaptation responses will require a substantial increase in energy usage, which will test our already limited resources.

PEOPLE AND SEA LEVEL RISE

Florida has a population of nearly 19 million people and this is projected to double in the next 50 years. Approximately 14 million people live along the coast. Most of our coastal assets are in low elevation areas where water supplies, roads, storm sewers, power grids and other infrastructure are at risk from storm surges and flooding at high tide. In view of the current sea level rise projections, the areas most at risk include: the Florida Keys, coastal and inland Miami-Dade County (the City of Miami is the 7th largest city in the country), coastal and inland portions of Broward County, the Florida Everglades, and the cities, Fort Lauderdale, Cape Canaveral, Charlotte Harbor, Cedar Key, and Pine Island Sound. All of these have elevations below two feet (Annex C)*.

Florida has recorded 5-8 inches of sea level rise in the past 50 years, and this intensifies existing water management issues. Future projections suggest 3-7 inches of additional rise by 2030 and 9-24 inches by 2060 (Figure 1)**.

FLORIDA GEOLOGY AND SEA LEVEL RISE

The porous limestone underlying much of Florida resembles Swiss cheese and makes the state particularly vulnerable to sea level rise. Due to this geological structure, building barriers to prevent sea level rise is often impractical and financially prohibitive. The coast is also vulnerable to periodic tropical storms and hurricanes with related storm surge: Hurricane Andrew had storm surges above 17 feet. Every increment of sea level rise adds to the devastation of storm surge. The combination of sea level rise, intense rainfall, and storm surge creates the on-going potential for major flooding.

IMPACTS ALREADY IDENTIFIED

Sea level rise is already creating multiple complications in Florida.

1) Coastal Flooding

Even though Florida has experienced only a few inches of sea level rise, we are already seeing flooding at high tide due to the backup of drainage systems. This new phenomena occurs regularly at lunar high tides and is an indicator of future problems as sea level continues to rise.

2) Flood Control Issues in Miami-Dade County

Sea levels were lower when South Florida's flood gates were constructed in the 1950s and 1960s. With the few inches of sea level rise that we've seen in the past decades, several of these flood gates are unable to discharge storm water at their design capacity during high tides.

There is already a multi-million dollar need to retrofit or rebuild many South Florida flood gates and a recent report finds that only six more inches of sea rise may cripple almost half the area's flood control capacity.

3) Salinization of Aquifers

Many coastal wellfields that withdraw freshwater from the productive Biscayne limestone aquifer are located along the coastal belt of the Lower East Coast. These

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* See Appendix II for Annexes A–C.

** Figures 1–4 have been retained in committee files.

wellfields are extremely vulnerable to saltwater intrusion due to rising sea level and drinking water extraction

For example, because of sea level rise and salt water intrusion into fresh water wells, officials in the City of Hallandale Beach are spending $16 million to upgrade their storm water system and to move the city's entire drinking water supply westward. City officials understand that this is a temporary solution to a problem that will worsen in the coming decades.

FUTURE PROJECTED IMPACTS

1) Water Management

Much of the coastal flood protection infrastructure designed and built by the U.S. Army Corps of Engineers 50 years ago will lose its design capacity if the projected sea level rise for South Florida becomes a reality.

2) Vulnerable Real Estate

There are 4,315 square miles of vulnerable areas that include agricultural land, developed land, forests, mangroves, marsh and tidal flats, other swamp and forested wetlands, pastures, sandy beaches, scrub, grasslands, prairies, and sandhills. Also included are the southern parts of Everglades National Park, billions of dollars of residential real estate, hundreds of schools, hospitals, and hotels, as well as two nuclear reactors and hundreds of hazardous material sites.

3) Transportation Readjustment

A recent study emphasized the need for a detailed assessment of the implications for roads and other transportation taking into account 2060 projections for sea level rise. Local studies of South Florida and the West Central Coast show that some communities and major metropolitan areas such as Fort Lauderdale will lose parts of their transportation networks at this level of sea level rise.

4) Coastal well contamination

Coastal well contamination will extend further inland as sea level rise continues.

Most coastal communities in South Florida depend on wellfields that tap underground freshwater aquifers for their water supply. Saltwater intrusion into these aquifers is due to the current sea level and concentrated coastal development already threatens the region's water supply. Between the years 1995 and 2000, a compilation of data resulted in an approximate location of the freshwater/saltwater interface on the Lower East Coast (Figure 4). The heavily populated area from the Florida Keys to Palm Beach County is considered especially vulnerable. Many coastal wellfields which withdraw freshwater from the productive Biscayne aquifer are located along the coastal belt of the Lower East Coast and will be highly vulnerable if saltwater intrusion is accelerated due to rising sea level. A more detailed analysis is needed to identify the impact of projected sea level rise on selected utility wellfields that are at risk of saltwater intrusion.

IMPLICATIONS FOR ENERGY, WATER, AND RESOURCE MANAGEMENT

Water is already heavily managed in Florida with extensive canal systems. These will need major retrofitting and reconceptualizing as sea level rises. Energy needs will grow rapidly with additional pumping needed both for water supply and drainage, desalinization (which is considerably energy intensive), and with increased cooling needs due to higher temperatures.

Power demands for additional water treatment cannot be supplied by the current grid infrastructure or installed capacity. The results of the current water/energy nexus evaluation suggest the possibility of conflicts over water supplies in the near future. To reduce this potential, resolution of water rights, water quality, and other laws will be important.

Due to the projected increase of energy demands, Florida will need to continue to explore alternative as well as traditional energy sources. There is widespread, long term potential in alternative energy sources such as solar energy, biofuels, and harnessing the readily accessible Gulf Stream as an ocean energy resource.

INITIAL ESTMATES OF ENERGY ADAPTATION AND COSTS

Trigger	Implementation Strategy	Cost
Immediate **0-0.5 foot sea level rise by 2030**	Install stormwater pumping stations in low lying areas to reduce storm water flooding (requires study to identify appropriate areas, sites and priority)	Start at $1.5 to 5 million each, number unclear without more study
	Water conservation	Start at $30 million + $1 million/year
	Armoring the sewer system (G7 program)	$12.5 million start, plus annual cost allocation
0.5–1 foot Sea Level Rise **2031-50**	Additional reclaimed water production	Over $25 million depending on permit requirements
	Aquifer recharge/salinity barriers	Up to $200 million depending on permit requirements
1 – 2 foot **Sea Level Rise** **2043-78**	Desalination	$45-50 million to convert + wells ($750,000 per MGD)
	Control flooding west of the coastal ridge	Start at $1.5 to 5 million each, number unclear without more study – at least a dozen would be need - $25 million

Table 1: Initial Estimates of Energy Adaptation and Costs (source: personal communication with Dr. Frederick Bloetscher, Florida Atlantic University.)

RESPONSES

Many of Florida's decision makers are aware of these problems and are beginning to respond to them.

1) Organizations

Counties and cities are organizing to respond to sea level rise at the local level. The Southeast Florida Climate Change Compact is a unique partnership of four diverse counties and was formed precisely for the purpose of responding regionally to the impacts of sea level rise and other climate related phenomena. This organization has a detailed action plan and needs statement that is summarized in Annex A. One important contribution of this group is that they have identified the need for special adaptation action areas. Legislation incorporating this language was passed by the Florida legislature and signed into law in 2011. Federal adoption of similar legislation would not only benefit Florida but also other states vulnerable to sea level rise.

Coastal cities such as Punta Gorda, Florida, have invested in detailed adaptation plans to monitor and respond to sea level rise. Regional planning councils across the state have undertaken initiatives that will in part address sea level rise issues. Florida's Department of Economic Opportunity has established a multi-agency, multi-disciplinary focus group to address sea level rise future planning. The South Florida Water Management District is conducting extensive hydrological modeling and scenarios, along with collaborating with other organizations and agencies.

2) Research and Education

The Florida State University System is undertaking significant research programs and state and local projects on sea level rise monitoring and adaptation. These include the Florida State University System's Climate Change Task Force, the National Science Foundation-funded Coastal Areas Climate Change Education Partnership, the CLEO institute, the Resilient Tampa Bay Project, and a large-scale NASA/Florida Atlantic University project. The Florida Climate Institute is currently expanding to multiple universities and will continue and build upon the previously mentioned research and projects. Several state and federal agencies have on-going sea level rise studies, these agencies include: the Florida Department of Transportation, the Florida Department of Economic Opportunity, the Florida Division of

Emergency Management, US Fish and Wildlife, NOAA, US Army Corps of Engineers, National Park Service, the US Geological Survey (USGS), the South Florida Water Management District and the Florida Department of Environmental Protection. The USGS and other agencies have on-going programs on the implications of sea level rise and Everglades' restoration. A major summit on the risk and response of sea level rise in Florida is scheduled for June 2012 (Annex B).

3) Data Gathering and Monitoring

There is an on-going need for a thorough vulnerability assessment, particularly for communities affected by sea level rise. Comprehensive data gathering is necessary. Monitoring environmental changes is vital to understanding the impacts of sea level rise. The USGS, in coordination with other local agencies, will need to establish a region-wide, formal saltwater intrusion monitoring network. Federal agencies will also need to develop and implement computer models to understand and predict both saltwater intrusion and flooding under future sea level rise scenarios.

THE COST OF INACTION

It is important to note that:

1. For every dollar spent on hazard mitigation, society saves four dollars in the long term
2. When the mitigation efforts have been on flooding hazards, it is a five to one return on investment
3. The largest return on investment occurs when mitigation projects focus on reducing business interruption from loss of utilities. Most of Florida's utility infrastructure is underground, situated directly on the coast, and at risk.
4. Building resilience now will pay off tomorrow.
5. New coastal infrastructure and large scale, long term restoration projects (i.e. Everglades Restoration) may not be successful and may be a waste of resources and time if sea level rise is not accounted for in the planning and implementation.
6. There will be long-term societal costs as people move from their homes to inland areas.

WHAT SHOULD WE BE DOING NOW

1. We need to further identify areas and communities at special risk using the State of Florida Adaptation Action Area legislation. Efforts should be made to align Federal legislation with these critical state level policies.
2. There is an urgent need to incorporate sea level rise projections into all infrastructure and water management plans, including the Everglades Restoration. We can evaluate and better understand the value and utility of restoring freshwater flow. We need increased motoring activities, including additional National Water Level Program Networks (NWLON), which will be important in understanding and tracking changes in sea level rise for the state. Establishment of a state-wide saltwater intrusion monitoring network is also recommended.
3. We should be identifying future energy needs, including the cost of adaptation, for the coming decades, and moving towards traditional and alternative energy forms to meet these needs.
4. In addition, we need to utilize our past response to extreme events to create more sustainable community systems. Florida emergency management is already successfully working towards such initiatives.

CONCLUSION

The impacts of sea level rise are already a reality in South Florida and, as sea level rise continues, they will further impact all parts of Florida. The actions outlined above need to be taken now to increase our resilience and prepare for and minimize these impacts. People and organizations on the ground are already responding. We are delighted that, through this hearing, the US Senate is also responding. The people of Florida are already concerned about sea level rise as local awareness through major efforts has increased significantly. A larger role for the Federal Government is clearly warranted.

ADDITIONAL RESOURCES AND REFERENCES

Florida Center for Environmental Studies: http://www.ces.fau.edu/
Florida Climate Institute: http://floridaclimateinstitute.org/
South Florida Water Management District: http://www.sfwmd.gov

Four County Compact: http://www.southeastfloridaclimatecompact.org/
Climate Central: http://www.climatecentral.org/
University of South Florida, Resilient Tampa Bay: http://sgs.usf.edu/rtb/index.php

The CHAIRMAN. Thank you very much.
Mr. Freed.

STATEMENT OF ADAM FREED, DEPUTY DIRECTOR, MAYOR'S OFFICE OF LONG-TERM PLANNING AND SUSTAINABILITY, NEW YORK, NY

Mr. FREED. Good morning, Mr. Chairman, Senator Murkowski and members of the committee. On behalf of Mayor Michael Bloomberg, thank you for the opportunity to testify on the impacts of sea level rise in New York City. The steps we are taking through PlaNYC, a long term sustainability plan to increase our climate resilience.

As a city with more than 520 miles of coastline, New York City faces real and significant climate risks even without sea level rise. Today, more than 200,000 New Yorkers live within the Federal Emergency Management Agency designated 1 in 100 year flood zone. These zones contain vibrant neighborhoods, critical infrastructure, natural areas, historic landmarks and approximately 200,000 jobs including Wall Street in Lower Manhattan.

Our current vulnerability was tested by Tropical Storm Irene which resulted in the first mandatory evacuation in New York City affecting approximately 370,000 residents. The New York City Panel on Climate Change, convened by Mayor Bloomberg, found that New York City sea levels have risen about an inch a decade over the past century. This rate is increasing. Our sea levels could rise by more than 2 feet by mid century and by as much as 4 and a half feet by 2100. This will significantly increase the size of our flood zones and lead to greater impacts in areas subject to flooding.

The consequences of sea level rise in New York, if not addressed, could have a significant ripple effect throughout the U.S. economy. The city generates over $600 billion a year in economic activity, roughly 4 percent of the Nation's GDP. New York Harbor is home to the Nation's second and third largest trade gateways handing over $350 billion in exports and imports, over 11 and 20 percent of the Nation's waterborne and air freight, respectively.

Sea level rise will significantly impact our energy and water infrastructure, the subject of today's hearing. New York is one of the most reliable, densest and extensive energy networks in the country including over 90,000 miles of underground power cables, over 200 substations and 17 in-city power plants. Many of our power plants are located near the water to allow fuel deliveries, the use of water for cooling and steam generation and water discharges.

Today, 10 of our 17 in-city power plants are in the 1 in 100 year flood zone. By the 2050s modest rates of sea level rise will increase this number to 13, double the number of substations in flood zones, and increase the miles of power cables, steam and natural gas pipes vulnerable to coastal flooding.

In terms of our water infrastructure the city's drainage and waste water system consists of over 7,000 miles of sewers and 96 pumping stations. Our 780 combined sewer and storm outfalls and 14 waste water treatment plants are located on the water so that gravity can drain the sewer system and treated waste water can be discharged into the harbor. A change in sea level could substantially limit the ability of these systems to drain or discharge requiring system wide and costly system upgrades.

Addressing these risks in a dense urban environment poses significant challenges. It is not feasible, desirable or cost effective to pick up and move New York City to higher ground. Instead PlaNYC includes over 30 initiatives to increase the city's climate resilience, our ability to prepare for, withstand and recover from extreme events and environmental changes. This includes working with FEMA to update the city's flood insurance rate maps which have not been significantly revised since 1983 when sea levels were 3 inches lower.

The FIRMs however, only incorporate historic information and do not and will not reflect future sea level rise. To ensure sea level rise is incorporated into the design and operation of our critical infrastructure, we launched a task force composed of 26 city, State and Federal agencies and 15 private infrastructure operators to identify the impacts of climate change on our infrastructure and to develop coordinated strategies to mitigate these risks. As a part of this effort, we are working with the U.S. Army Corps of Engineers, a critical partner in these efforts, and academic institutions to evaluate a variety of coastal protection strategies. An effort funded in part by HUD's Sustainable Communities Program.

Finally, we are building city projects today to better manage these risks. Several waste water treatment plants include flood gates and plans to rise critical infrastructure above future flood heights. Parks such as Brooklyn Bridge Park on Governor's Island, include shoreline treatments and salt resistant plantings that can accommodate periodic flooding. The entire 60 acre Willets Point's development site in Queens is being elevated out of the coastal flood plain.

Local governments, however, cannot meet this challenge alone.

The Federal Government can assist us by providing information, decisionmaking tools, flexible policies and funding that support local resilience.

FEMA should regularly update its FIRMs and provide flood elevation data for the 1 in 500 year flood zone. They should also include overlays that show where flood lines could be in the future as the buildings and infrastructure we build today are likely to last through the end of the century.

Federal agencies could also provide localities with high resolution LiDAR data which is the most accurate topographical data available.

In addition Federal agencies must recognize the need for regulatory flexibility in urban areas like New York City where we do not have room to retreat from the shoreline. Regulatory flexibility may also be needed for the water supply system as climate events could increase turbidity.

Funding should be allocated to the U.S. Army Corps of Engineers to conduct risk reduction studies in high risk communities, the starting point for decisions regarding major coastal protection measures. If substantial investments in coastal protections are needed Federal funding will be necessary both for these measures and to adapt our aging infrastructure.

We must recognize the seriousness of the challenge posed by sea level rise and our responsibility to meet them. Climate risks should be addressed through an informed, decisionmaking based on the latest scientific information and a thorough understanding of the cost and benefits of action and inaction. New York City is implementing a flexible risk based approach that emphasizes those initiatives that have tangible benefits today and will have even greater benefits as our sea level rise.

But we cannot do this alone. We need the active and ongoing support of our Federal partners. I thank you for the opportunity to testify today.

[The prepared statement of Mr. Freed follows:]

PREPARED STATEMENT OF ADAM FREED, DEPUTY DIRECTOR, MAYOR'S OFFICE OF LONG-TERM PLANNING AND SUSTAINABILITY, NEW YORK, NY

Good morning, Mr. Chairman and Members of the Committee. I am Adam Freed, Deputy Director of the New York City Mayor's Office of Long-Term Planning and Sustainability. On behalf of Mayor Michael R. Bloomberg, thank you for the opportunity to testify on the impacts of sea level rise on New York City and the steps we are taking through PlaNYC, our long-term sustainability plan, to increase our climate resilience.

As a city with more than 520 miles of coastline, New York City faces real and significant climate risks, even without sea level rise. Today, more than 200,000 New Yorkers live within the Federal Emergency Management Agency (FEMA)-designated 1-in-100 year flood zone. These zones contain vibrant neighborhoods, critical infrastructure, natural areas, historic landmarks, and approximately 200,000 jobs. Our current vulnerability was tested by Tropical Storm Irene, which resulted in the first mandatory evacuation in New York City effecting 370,000 residents.

The New York City Panel on Climate Change, convened by Mayor Bloomberg, projects that the city's sea levels could rise by more than two feet by mid-century and by as much as four and a half feet by 2100. This will significantly increase the size of our flood zones and lead to greater impacts in areas subject to flooding.

The consequences of sea level rise on New York City have national significance. The city is the hub of the largest regional economy in the U.S., generating over $600 billion a year—4% of our nation's GDP. New York Harbor is home to the nation's second and third-largest trade gateways, handling over $350 billion in imports and exports—over 11% of the nation's waterborne freight and over 20% of air freight. We are home to the headquarters of 45 Fortune 500 companies. Thus, sea level rise impacts in New York, if not addressed, could have a devastating ripple effect throughout the U.S. economy.

Sea level rise will significantly impact our energy and water infrastructure. New York City has one of the most reliable and extensive energy networks in the country, including over 90,000 miles of underground power cables, over 200 substations, and 17 in-city power plants. Many of our power plants are located near the water to allow fuel deliveries, the use of water for cooling and steam generation, and water discharges. Today, 10 of the 17 power plants located within the city are in the 1-in-100 year flood zone. By the 2050s, modest rates of sea level rise will increase this number to 13, double the number of substations in flood zones, and increase the miles of power cables and steam and natural gas pipes vulnerable to coastal flooding.

In terms of water infrastructure, the City's drainage and wastewater system consists of over 7,000 miles of sewers 95 pumping stations. Our 780 combined sewer and storm outfalls and 14 wastewater treatment plants are located along the shoreline so that gravity can drain the sewer system and treated wastewater can be discharged into the harbor. A change in sea level relative to outfalls could substantially limit the ability of these systems to drain or discharge, requiring costly, system-wide upgrades.

Addressing these climate risks in a dense urban environment poses challenges—it is not feasible, desirable, or cost-effective to pick up and move New York City to higher ground. Instead, PlaNYC includes over 30 comprehensive initiatives to increase the city's climate resilience—our ability to prepare for, withstand, and recover from extreme events and environmental changes.

This includes working with FEMA to update the city's Flood Insurance Rate Maps (FIRMs), which have not been significantly revised since 1983 when sea levels were three inches lower. The FIRMs, however, only incorporate historic information and do not reflect the impacts of sea level rise. To ensure sea level rise is incorporated into the design and operation of the city's critical infrastructure, we launched a task force, composed of 26 city, State, and Federal agencies and 15 private infrastructure operators, to identify the impacts of climate change on the city's critical infrastructure and develop coordinated strategies to mitigate these risks. As part of this effort, we are working with the U.S. Army Corps of Engineers—who remain a critical partner in addressing the risks posed by sea level rise—and academic institutions to evaluate a variety of coastal protection strategies—an effort funded in part by the U.S. Department of Housing and Urban Development's Sustainable Communities program.

Finally, we are building city projects to better manage these risks. Several wastewater treatment plants include flood gates and plans to raise critical equipment above future flood heights. Many parks, such as Brooklyn Bridge Park, include shoreline treatments and salt-resistant plantings that can accommodate periodic flooding. The entire 60-acre Willets Point development site in Queens is being elevated out of the floodplain.

Local governments, however, cannot meet this challenge alone. The Federal government can assist us by providing critical information, decision-making tools, policies that support local resilience, and funding for flood studies and infrastructure. FEMA should regularly update its FIRMs and provide flood elevation data for the 1-in-500 year flood zone, so that we can be better informed to take action. FEMA should also include overlays that show where the flood lines could be in future years—as the buildings and infrastructure we build today are likely to last a century. Federal agencies could provide localities with high-resolution LiDAR data, which is the most accurate topographical data available. They could also issue guidance on the differences between Federal storm surge models, such as SLOSH and ADCIRC, and when it is appropriate to use them. A model for the provision of many of these tools is the United Kingdom's Climate Impacts Programme (UKCIP), which is funded by the national government.

While we all share the objective of protecting and restoring coastal wetlands, federal agencies must recognize the need for regulatory flexibility in urban areas like New York City, where we do not have room to retreat from the shoreline in response to rising sea levels. For example, a recent rule prohibiting the use of Clean Water Act Section 320 funds under the National Estuary Program for certain actions in or near open water or wetlands significantly limits our ability to use these funds to protect our coastline.

Regulatory flexibility may also be needed for water supply systems as climate events could increase turbidity. Funding should be allocated to the U.S. Army Corps of Engineers to conduct storm damage risk reduction studies in high-risk communities, the starting point for decisions regarding major coastal protection measures. If substantial investments in coastal protections are needed based on a thorough cost-benefit analysis, federal funding will be necessary for these measures as well as to adapt our aging infrastructure. We have received funding from the Department of Housing and Urban Development's Sustainable Communities program—a critical program that enables cities to reduce barriers to achieving affordable, economically vital, and sustainable communities—to identify and evaluate flood resilience strategies and design standards that may be compromised by climate change. For FY13, the President has again requested $100 million for the program, which was funded in FY11 but was zeroed out in FY12. I urge Congress to continue this innovative program.

We must recognize the seriousness of the challenges posed by sea level rise and our responsibility to meet them. Climate risks should be addressed through informed decision-making, based on the latest scientific information, and a thorough understanding of the costs and benefits of action and inaction. New York City is pursuing and implementing a flexible, risk-based approach that emphasizes the most effective initiatives that have tangible benefits today and will have even greater benefits as our sea levels rise. But we cannot do this alone. We need the active and ongoing support of our Federal partners.

Thank you again for the opportunity to testify.

The CHAIRMAN. Thank you very much. Thanks to all of you for the excellent testimony.

Let me start with 5 minutes of questions. Then I'll defer to the others here to ask their questions.

I think the testimony Mr. Freed just gave is particularly focused on what we need to be trying to understand here in the Congress. That is what are the actions the Federal Government could take to assist local areas, communities, and States to deal with this sea level rise, which has already occurred, but is expected to increase over the next decades.

As I understand everyone's testimony, I don't think there's any disagreement that we're going to see increased sea level rise in future decades, increased over what we've already seen. I think the figure one of you mentioned a was 9- or 10-inch increase since 1880? Is that accurate?

Mr. STRAUSS. Eight inches.

The CHAIRMAN. Eight inches since 1880. But that's expected to be increased in future decades.

Mr. STRAUSS. Yes, we'll probably get another 8 before 2050.

The CHAIRMAN. So the expectation is that another 8 inches of sea rise is likely before 2050?

Mr. ABDALATI. I think it's well within the range. I'm comfortable with that number. It's well within the range of possibilities. It actually may be at the low end.

The CHAIRMAN. OK.

Let me just ask if there are other suggestions? Several of you have mentioned things.

Dr. Berry mentioned a couple of things—I think Mr. Freed did—that the Federal Government should be doing to try to help local and State governments deal with this thing. Also to make sure that the decisions that are made at the Federal level with regard to siting and design and construction of infrastructure take into account this information that you've all described to us.

Are there things that we ought to be doing that we're falling short on at this point?

Dr. Abdalati, did you have any more thoughts on that point?

Mr. ABDALATI. I think as scientists and as people who deal with the effects of sea level rise there is always the interest and need, frankly, for more information. The challenge, as you are well aware, is balancing that against the resources available.

I think the implications that you have heard have made clear that the risks are great. I shouldn't say the risks, I should say more the vulnerabilities—are quite substantial. Because we don't know—we can't tighten up that range for the future—we have to make plans, I would say, that exercise prudent judgment in the face of that uncertainty.

So, you know what the Federal Government can do, and frankly is doing, is invest. I won't speak to the specifics of adaptation and what supports those approaches. I think that they've been outlined quite nicely.

Where I come from is the information. Trying to get that uncertainty down, trying to understand what's likely on our horizon so that we can plan better. In that sense we are actually making substantial investments in monitoring the ocean characteristics and monitoring the ice sheet and modeling these capabilities.

So what I believe the Federal Government can do and is working to do in terms of information is support the activities that NASA, the National Science Foundation, the Department of Energy, our international colleagues, frankly, are undertaking to tighten those numbers, better understand what's happening so that the policy levers we need to pull can be addressed or utilized more effectively.

The CHAIRMAN. Dr. Strauss, do you have suggestions for things we ought to be doing at the Federal level that would respond to this situation?

Mr. STRAUSS. Yes, I think if we want to reduce the risk and the vulnerability, the actions the Federal Government can take can be divided into a few simple categories. I'll just stop at that high level.

One is to preserve, restore, protect natural defenses like barrier islands, salt water marshes, beaches. Those things form a front line of defense against storm surge. That's being made riskier by sea level rise.

A second area is to build artificial defenses where that is appropriate and efficacious.

A third approach is not to build more in harm's way.

A fourth approach is to consider a planned retreat from places that cannot be effectively protected.

The CHAIRMAN. That sounds like a logical set of options.

Any of the rest of you want to add?

Dr. Berry, did you have something to say?

Mr. BERRY. Picking up on earlier comments, I think we need 2 kinds of information.

I think we need, as was said, that we need information about, better information about what's going to happen in the future.

But I also think, taking a slightly pessimistic view that sea level will go on rising, we need much more detailed information on areas at risk. That needs more specific air photography, more specific mapping.

I think as we, in areas like the Gulf Coast in Florida, which are susceptible to hurricanes, it's not the exact amount of sea level rise. It's the storm surge and the associated flooding. That is not just a coastal issue. It's inland too. I think understanding the risk to communities particularly at some of the disadvantaged communities that are most at risk is really an important part of planning for the future.

The CHAIRMAN. My time is expired on this first round. But I wanted to acknowledge Rafe Pomerance who is in the audience. He has been urging we have a hearing on this subject for some time. I appreciate his persistence on that.

Let me defer to Senator Murkowski.

Senator MURKOWSKI. Thank you, Mr. Chairman.

I'll continue on with your line of discussion here, because I think all we need to do is look to Alaska to see what it is that we have been doing to identify those areas at risk.

We've done an inventory of those coastal villages that are at risk of literally dropping into the ocean. We have done that.

We have looked to evacuation plans.

We have looked to how we can build out revetments along the sea wall.

But our reality is that with the Federal agencies that exist, they are there to help after the disaster has happened. FEMA will only respond once the crisis has occurred. Once you've dropped off the edge.

The Corps of Engineers, we learned, was very limited in terms of what it is that they can do to provide assistance. So Mr. Freed, I listened with interest to your comments about the protection plans. In reality we are not set up well to adapt, to have an adaptation plan in place where you then can take Federal dollars and State dollars, local dollars, to provide for a path forward.

We can help on the mitigation end. We can help with cleaning up the crisis. But we're not very good envisioning and being proactive. I think this is something that we need to look critically at.

I was in Louisiana a few weeks ago, as I mentioned. I think that is one of the most graphic examples that we have in this country of the impact to our energy infrastructure. Because that's what this hearing is about, due to sea level rise, is Highway 1 or Louisiana Highway 1, that narrow little skinny corridor that's nothing but a road connecting you to Port Fouchon that hosts the energy infrastructure truly for the Nation in terms of what is coming in, what is going out, how we service off shore.

It's a pretty phenomenal community, if you will, that is connected by a road that is at or below sea level. The effort to raise that up so that we avoid wiping out the road is one that has been a many year effort, many billions of dollars. They've made some progress to it. But it is a perfect example of our vulnerability. We just kind of close our eyes and hope we make it through the next hurricane.

Senator Landrieu isn't here today to speak to it or she would be, I'm sure, passionately pounding the desk here. I'll do so on her behalf in recognizing that we've got an obligation here with energy infrastructure that we have committed to. Yet we've got one way in. It is truly at risk.

So the question I would have to all of you is on the budget side. The President has sought $769 million in his 2013 budget request to pay for what the Administration is calling Climate Finance. It's my understanding that well over $5 billion to date has been spent and this has been to direct funding overseas to assist.

The question that I have coming from my coastal villages when they find out that it's going to be $150 million to move a village of 350 people and they're told that can't happen. Then they find out that we're spending money, billions over the years, to help overseas. The question is what are you doing to help us at home?

I know that the people of Louisiana ask the same thing. They probably ask you, Dr. Berry, down in Florida. What are we doing here to help?

Can you speak to the issue of how we can better prepare the map that was presented up there in terms of the number of communities that are below 4 foot? I think this should be a real wake up call to us that we've got some obligations that are pending now. What do we do with them?

We'll start with you, Mr. Freed.

Mr. FREED. Yes, thank you for the question, Senator Murkowski.

I think the most critical action or one of the most critical actions the Federal Government can do is ensuring that the FEMA flood maps are up to date and updated regularly.

Senator MURKOWSKI. They're lousy right now, by the way.

Mr. FREED. We know New York City's has a plus or minus 3 foot margin of error which is well within the bounds of what we expect for sea level rise toward the end of the century, so a significant risk. That's our current exposure. So ensuring they're regularly updated, ensuring they're updated with the latest available technology, LiDAR data and ensuring that they are forward looking because the flood maps don't just dictate flood insurance but our building code in the city where we require certain flood protections.

How infrastructure and where infrastructure are sited and to what level is all dependent on the flood maps which by their nature and definition only look at historic storms, only look at historic flooding. We know that that environmental baseline has shifted and is not as relevant as it was looking at future risks. So ensuring those are up to date and regularly updated is critical.

I think when you look at the cost of adaptation it's very hard to think about because much of what needs to be done will be incorporated into existing planning. So as you're upgrading a facility, as you're building a waste water treatment plant, which you would do even without sea level rise, what is the incremental addition that sea level rise and future projections play a role into that. So it's not as if there is a single price tag for these set of projects that absent sea level rise we wouldn't do.

How do you incorporate that into the ongoing infrastructure investments that are necessary to upgrade our aging infrastructure throughout the country and in urban areas? What is that additive that's needed to address for climate risks?

Senator MURKOWSKI. Others want to speak to that?

Dr. Janetos.

Mr. JANETOS. Thanks very much. I would like to move forward on this line of discussion. One of the things that the Federal Government is doing but could continue to do is the creation of a set of tools that actually enable the sort of analysis of potential futures. There are 3 elements of those tools.

One is understanding the energy sector and the investment in infrastructure itself. What is a sector actually vulnerable to, not just with respect to sea level rise but with respect to changes in demand, to the availability of new technologies, how sensitive is it to changes in the up shore, onshore, environment that after all controls how we manage that land, controlled runoff, controls the availability of water, sedimentation.

Second, those integrated tools need to be able to move from the sorts of global observations of which we have many to actually being able to simulate local conditions, to take into effect local subsidence or rising of the land, either sinking or rising, the existence or changes in barrier islands. But changes in the local geography and physical forcings that determine, that help determine, that vulnerability and how it will evolve in the future.

Then the last element that these integrated tools really need to incorporate are aspects. The ability to model different potential consequences of adaptation actions because one of the things that will determine how decisions are made is what options are actually available to local institutions, to cities, municipalities and towns. Without knowing what options are available to them after all, how are they to decide whether one is more effective or more desirable than another?

We really do need to have the development of integrated tools that allow us, with the best fundamental science that we can muster, but then allow us to put that in the service of these decision-making institutions and individuals.

The CHAIRMAN. Senator Franken.

Senator FRANKEN. Thank you, Mr. Chairman. I noticed that there are very few colleagues from the other side of the aisle here in this hearing. But ironically there's an elephant in the room.

[Laughter.]

Senator FRANKEN. Climate change is the elephant. Climate change induced sea level rise is clearly impacting the health and security of our Nation. But this is a fact of life that's going unnoticed by too many Americans because science has taken a back seat to politics.

We saw this on the Senate Floor shortly after the EPA came out with its scientific finding that greenhouse gases endanger public health and welfare. Yet this scientific question turned into mostly a party line vote here in the Senate. Unfortunately this measure to overturn the scientific finding of the EPA did not pass, but underscores the difficulty to address this challenge when we are so divided on the issue of climate change.

I'd like to go right down the list of panelists. Can each of you tell me whether you agree or disagree with the EPA finding that the rise in greenhouse gases endangers public health and welfare?

Mr. ABDALATI. I certainly agree with that. It does so in many ways. Sea level being—particularly getting at the welfare component—sea level being the topic we're discussing today, but also in terms of air quality, pollution, the effects of water distribution associated with that. Where there was a reference to a 100-year flood zone; well, those 100-year zones based on historical data don't really apply today because things are different now. So vulnerabilities: the availability of water resources, the kinds of crops that can grow in one place are now better suited for others, and so on and so forth.

So there is very strong scientific consensus on what is happening and why, and strong consensus on—not as strong because opinions vary—but on the effects associated with climate change. But I do want to be clear, you know, science needs skeptics. When we stop questioning ourselves and when we stop questioning each other, science suffers for it and society suffers for it.

So any respectable scientist welcomes constructive debate and discussion, but on the matter of climate change and its associated impacts, the consensus is strong. It doesn't mean we stop questioning ourselves or each other, but the consensus is strong, and I absolutely agree with the EPA finding.

Senator FRANKEN. OK. I encourage skepticism, but I don't encourage cynicism and denial that's paid for.

Mr. ABDALATI. I totally agree. I appreciate your saying that.

Senator FRANKEN. Dr. Strauss.

Mr. STRAUSS. I agree with EPA's finding. I agree with Dr. Abdalati. There is a strong scientific consensus about what is happening.

On the subject of this hearing, I would like to point out again. That under our noses is the fact and it's been budgeted and detailed and accounted for that we have 8 inches of global sea level rise, more in some places locally, but 8 inches of global rise which has been caused by global warming over the last century. So if your basement was flooded because a 5 inch wall of water came pouring down your stairs you were a victim of climate change.

That's happening with coastal floods today. It's unlabeled. It's unrecognized. But it is, in fact, a current and ongoing impact.

Senator FRANKEN. Dr. Janetos.

Mr. JANETOS. Senator, I've had the privilege of either participating in or leading a number of the impact scientific assessments of climate impacts in the U.S. over the last decade. Every one of them has come to the same conclusion. That for natural resources and as we've seen today, for major parts of our existing infrastructure, the impacts of changes in the climate system are not some theoretical thing that will happen to our children and grandchildren.

Things are happening now. They're well documented. I was actually a reviewer of the underlying scientific assessment that EPA did to support its finding. I agreed with it then and I agree with it now.

Senator FRANKEN. Is it OK if we go through all the witnesses?

The CHAIRMAN. Go ahead.

Senator FRANKEN. Dr. Berry.

Mr. BERRY. Yes. I'll be brief. I agree.

But I also think that from a practical point of view instead of too much debate about global warming focusing on the issues like we are today is a very productive way forward. But I agree totally.

Mr. FREED. Thank you, Senator. I unequivocally agree with that finding. I think there are very few elements of our lives that will not be impacted to some degree by climate change.

Just want to add and thank for the opportunity to be here because while there are national and international debates about whether climate change is happening and what are the impacts from things like sea level rise, it's often the State and local governments who are left to deal with the real impacts that are already occurring. So greatly appreciate being included in today's discussion.

Senator FRANKEN. OK. My time is up. Thank you to all the witnesses.

I just want to say something I've said before that we are paying the price already for this. That part of our debate on what kind of energy we go forward with and what kind of energy we use and what kind of energy we develop. Part of the cost benefit analyses of all of that has to take in account, into account, what we're talking about today.

If we don't we're sticking our head in the sand. Now I've had an ostrich and an elephant in my testimony.

[Laughter.]

Senator FRANKEN. Thank you.

The CHAIRMAN. Senator Wyden.

Senator WYDEN. Thank you, Mr. Chairman. I can't possibly compete with Senator Franken for purposes of analogies, but I very much share your concerns, Senator. I appreciate your making the point.

Gentlemen, you all have raised some important issues. Dr. Strauss, Senator Cantwell and I were just commenting that you kept looking at the two of us, Oregon and Washington. So we understand what the stakes are in terms of storm surges and tsunamis.

My judgment with respect to some of these key questions about rising sea levels also now factors in the fact that I went to Fukushima last week, about a week or so ago. Of course, there they had the triple whammy. They had the earthquake. They had the tsunami which destroyed most of the site's backup generators for the plants even one of their emergency battery banks. Then we had the hydrogen explosions as well.

Now, Dr. Strauss, you noted in your testimony something that I think really hasn't gotten a lot of debate. It certainly should after Fukushima and with the latest evidence. That is that a rising sea level raises the launch pad for storm surges. It is going to raise the launch pad for tsunamis as well.

Now what I'm thinking about on the basis of what I saw a little bit ago at Fukushima, unit four, you know, in particular, particularly damaged one. Just the inventory of the essentially, the hottest, you know, materials. You have another earthquake/tsunami kind of rupture with these spent fuel, you know, rods in these pools. The spent fuel rods are going to melt. They could catch fire.

That's going to release a lot of radioactivity. All of this is compounded by the testimony that you gave essentially this morning with respect to the rising sea level raising this, you know, launch pad. So I believe the question that I'd like to ask and maybe start with you, Dr. Berry.

We've got a lot of nuclear plants located along the coast all over the world because of the need for, you know, cooling water. On the basis of these rising sea levels and also what was seen at Fukushima, what I've tried to outline just in a minute or so. Is it your view that it's time for us to do some rethinking with respect to the location of vulnerable plants? Plants that are near to catastrophic, you know, flooding that was, for example, caused by a tsunami that Dr. Strauss, all but stared down Senator Cantwell and I and kind of talking about?

This is not abstract issues for us in the Pacific Northwest. These are very, very real. So what is your thinking with respect to that point, Dr. Berry?

Mr. BERRY. Florida has the, I think, unique distinction of having two nuclear power stations on barrier islands. Barrier islands are by definition fragile environments. There were good reasons to locate them there.

But as a colleague of mine says, 3 feet of sea level rise would be a problem for Turkey Point. For example, that nuclear power station because Turkey Point when out of commission for a few hours with Hurricane Andrew and the storm surge associated with that, 3 extra feet and with a storm that was a longer duration. Hurricane Andrew was very fierce, but it went through very quickly.

I would recommend very importantly that the NRC begin to look very closely at the implications of sea level rise on our nuclear facilities and our other energy facilities that are near the coast.

Senator WYDEN. One last question if I might for you, Dr. Strauss. Can you amplify a little bit on this question of the rising sea level serving as a launch pad because for us in the Pacific Northwest that is going to be a very real issue? I juxtaposed what I saw at unit 4 and these, as you know, these facilities are right next to the ocean.

There's what amounts to a makeshift bag of rocks that constitutes a sea wall. It just takes your breath away at the thought of sort of what you've outlined in terms of rising sea levels, tsunamis triggered by earthquakes. I mean, give us a little bit more analysis of the implications of an elevated launch pad and what that means in terms of trying to our think through public policies to deal with them.

Mr. STRAUSS. Thank you, Senator. I lived in Seattle for a couple of years and Portland for a summer, maybe that's why I was directing my gaze.

Let me start with something a little different, quickly. The Pacific Northwest seems to get an enormous earthquake magnitude, about 9.0, every 300 to 500 years. The last one was in 1700.

One that that those earthquakes do besides creating a lot of direct damage is lower the elevation of the land sometimes dramatically, very suddenly. The forecast would be for maybe one or two meter drop at the next 9.0 earthquake along portions of the coast. So while a lot of areas in the United States are slowly subsiding that's not very much the case in the Pacific Northwest.

In fact, parts are lifting up slowly because of the tension between tectonic plates. But the earthquake is when that tension relieves, the plate drops. So you could have places that are suddenly a meter lower which is another way of raising the launch pad once you get past the damage from the quake.

The other point is that all along the Pacific sea level rise from climate change is making a big difference—is along the Pacific sea level rise is converting century storms into decade storms or annual storms faster than anyplace else in the United States. That's because while you don't have hurricanes. So the difference today between a 1-year storm and a storm that happens only once in a hundred years is relatively small.

Because that difference is relatively small, a small amount of sea level rise converts what's today a once a century storm into an annual storm fairly quickly. Now if you have steep slopes it may not be a great problem. But in flatter areas or where there are critical facilities, it is.

So what all that means is that on the Pacific Coast you'll start to see water in places where it wasn't more quickly than in other places.

Senator WYDEN. My time is up. But I want to thank you for your work and your scientific expertise.

Dr. Strauss, I think this is going to help provide a wakeup call for us to put in place policies to start dealing with this. I thank you.

The CHAIRMAN. Senator Cantwell.

Senator CANTWELL. Thank you, Mr. Chairman. Thank you Dr. Strauss and panelists for bringing up these issues.

I would just note that my colleague, Senator Collins and I worked on an adaptation bill several years ago. We got this bill out of the Commerce Committee, but not all the way through Congress. I also must tell you that we're seeing the impacts of climate change right now in the Pacific Northwest, on ocean acidification levels, and the related negative affects on the shell fish industry. So we're really seeing economic impacts today.

In regard to your statement about the impact of storms, I'm not so sure we haven't already had those 200-year events back to back in the last few years when we saw major damage. But now you're talking about a century flood more than triples by 2030. I am concerned about these threats because we have so much vulnerable property in the Puget Sound. We have something like $27 billion worth of structures that could be impacted by this rise in sea level.

So, to me, the issue is what do we do now? Do you think that this is partly an issue of getting maps established? Some verification of these maps at local levels? When you think about what we've been doing for emergency response and things of that nature, we have to get the information and develop a plan.

We have to get people to understand what the impacts are and then we can support communities in trying to plan around them. We know this already because of the general threat of tsunamis. But what you're saying is get ready.

We're going to see a lot more of this. It's going to have a very, very dramatic economic impact, much greater than people realize.

Mr. STRAUSS. Thank you, Senator.

Yes. I expect there will be a significant economic impact. That we're already experiencing one, although we may not label it as such.

I agree with my colleagues that we will be able to deal with this problem much more efficiently if we have better information. One side of that better information is improved maps, improved elevation maps at a very fine scale in coastal areas. I know a lot of progress is being made on that front with laser, LiDAR elevation mapping.

I think the more difficult area is actually around understanding storm surge and the water dynamics. You know, our analysis—so our analysis of elevation, in my research, covers all of the area, all the coastal area in the lower 48. But our analysis of storm surge focuses on 55 water level stations that NOAA maintains around the coast. One is in Seattle. But they're scattered.

So understanding in detail what the storm surge patterns are in between those 55 stations involves a lot of scientific fire power, a lot of computing, a lot of simulation of different storms from different angles, at different tides. So there is a tremendous amount of work that I think we could do to improve our understanding of how sea level rise will interact with storm surges and progressively reach new areas posing new risks.

Senator CANTWELL. I can tell you I plan on introducing legislation to make sure that we implement what is necessary to become a weather ready Nation. The notion that we have information that could be helpful to the American public about storms but we just don't have the dedicated computing time to take all the algorithms and run the scenarios is a mistake. We must move forward.

The fact that NOAA now has almost hand held devices that can communicate within an instant of an earthquake what the sea level rise would be in a geographic area—that's the kind of technology we need to have in first responders' hands. So I think we just have to figure out how to be much more aggressive about outlining these maps and scenarios for people, so that we can start planning.

Obviously, we need to do more. I mean, you're talking about effects that are going to take place regardless of whether we do anything about climate change or greenhouse gas emissions through climate change legislation. These are things that are going to happen.

So now the question is if we keep making it worse, what are the scenarios that are going to happen? I believe that this is worth a lot of prevention. To do this, we need the computing time.

Just as an example, we were without a Doppler system in the Northwest. Now we have that state-of-the-art Doppler system on the coast, and it can tell us much more about storm intensity. It can say exactly where that water level is going to be. It helps us communicate this to people.

But, first, we have to get the information to local governments, to individuals, to first responders, so that they can understand what the scenario really is. I think today's hearing, Mr. Chairman, really goes a long way in highlighting how critically important this is to our economy. We just can't sustain this kind of level of sea level rise without a plan.

We need a plan.

Thank you.

The CHAIRMAN. Thank you.

Let me ask, you know, I think the way we've been talking about it and the way I've thought about it most of the time is that we need to have good information in order to make good decisions about investment in infrastructure. But it seems to me that we also need good information in order to make good decisions about investment in protection.

That we have sort of an article of faith here in Congress that we want to help protect wetlands, coastal wetlands and there are a lot of coastal wetlands that are very much at risk. We saw some of the damage to them with the various hurricanes in the Gulf Coast.

What does this expected sea rise tell us about what we ought to do with regard to protection of wetlands. I mean, do we need to be hardnosed about which areas are in fact worth protecting because they are sufficiently resistant to this kind of thing that they can make it? What areas can we just not expect to protect?

Maybe that's too hard or too subjective a question to answer very well. But I don't know if anyone wants to take a shot at it.

Dr. Berry.

Mr. BERRY. I think the Fish and Wildlife Service is putting a good deal of effort in Florida and in the Southeast and generally looking at this very issue. One of the strategies, maybe, that you decide which wetlands are able to migrate inland and which are not. Try to make decisions about the value of protecting coastal wetlands.

The ideal circumstance is to have that wetland migrate inland as the sea level rises. If that can happen and there's space for it. We're actually looking at corridors of protected areas that could be used for natural and people assisted migration, not only of wetlands, but of animals and other characteristics.

But we are in danger of losing 30 to 40 percent of our coastal wetlands through the sea level rise process. That is a very unfortunate view of the future. But it's likely to happen.

The CHAIRMAN. Dr. Freed.

Mr. FREED. Mr. Freed, but thank you for the promotion.

The CHAIRMAN. Mr. Freed, excuse me.

Mr. FREED. You're making my Jewish mother very proud of me now.

[Laughter.]

The CHAIRMAN. Great.

Mr. FREED. You know, New York City already has over 6,000 acres of wetlands. Many people don't think of New York City with the vast natural earth that we have. We have a number of projects working with the U.S. Army Corps of Engineers with the bi-State Port Authority of New York and New Jersey to restore those wetlands for the ecological value that they have.

However, as was just pointed out, you often can't migrate the wetlands back when you have sea level rise, when you have densely populated, already built up areas. What we want to do is look at what is the ecological value of the wetlands that we may lose to the wetlands that we have. Figure out where it makes the most sense to make investments to protect them and preserve them.

One of the strategies we're looking at is creating a mitigation banking system where we can actually use economic growth and development to create a mitigation bank to then preserve those areas and those wetlands that have the greatest ecological value, contiguous areas. I think looking for those strategies where you can pinpoint and really maximize the investments in which you're making are critical to address the issues that we have. Use the ecologically based adaptation strategies, the natural systems that know how to protect us against the risks that we face.

The CHAIRMAN. Dr. Janetos.

Mr. JANETOS. Senator, we understandably focus on the effects of the physical effects of inundation of sea level rise when we talk about coastal wetlands. But there are two other factors to also keep in mind as we start to think about what affects their ability to survive in place.

One of those is the actual acidity of the ocean water itself. The extra carbon dioxide in the atmosphere has actually had the effect of raising the acidity of the ocean, coastal oceans, as well. While we don't understand everything we would like to understand about the sensitivity of plants and aquatic marine plants and animals to that increase in acidity, for many of the species that we do know something about we're starting to see adverse impact.

So that's one thing to keep in mind.

The second is that the survivability of wetlands on the coast also depends, in large part, on what happens upstream. The availability of sediment coming down river, simply the availability of water flow coming down to the coast depends critically on how or if we manage lands upstream. So an integrated knowledge and the integrated strategies of protecting or continuing to value those coastal ecosystems or their ecological value also depends not only on knowing about the sea level rise itself, but on what's happening in the near shore environment upstream on solid land.

The CHAIRMAN. Dr. Strauss, did you want to make a comment?

Mr. STRAUSS. Yes. I, just briefly, I'd like to expand on Dr. Berry's comments to say some salt water marshes will be able to migrate at least within a certain range of rates of sea level rise. But they'll only be able to migrate if there is available adjacent land.

So one possible step that we can take if we want to maximize the ability of marine wetlands to protect us from storm surges is to protect the adjacent land that is available for migration and expand our idea of what the footprint of a wetland is from, you know, the current wetland to the potential future wetland.

The CHAIRMAN. Very good.

Senator Franken, did you have questions?

Senator FRANKEN. Yes, I do. Thank you, Mr. Chairman.

Dr. Abdalati, Minnesota is OK for now, right?

[Laughter.]

Mr. ABDALATI. You're doing fine for now.

Senator FRANKEN. OK. Good. We have Lake Superior in Minnesota. A little known fact is that the Great Lakes? coastline is twice as long as the Atlantic seaboard. Almost 3 times the length of the Gulf of Mexico. So you can see why we're thinking about water too.

But the issue is complex and the international upper Great Lakes study has shown there are major differences between climate impacts on sea levels and on Great Lake levels. We know, for instance, that because of increasing evaporation over the past 60 years, Lake Superior levels have been dropping. But lake levels can rise or drop quickly and the possibility of higher levels at times cannot be dismissed.

These uncertainties impact commerce, recreational uses and water and sewage and sewer infrastructure. If we are going to have sound management of the Great Lakes coast we ought to have a better understanding of the factors impacting those lakes. The study called for a collaborative effort among Federal, State and local agencies on Great Lake management and decisionmaking.

My question, Dr. Abdalati, is, is NASA aware of this collaborative, adaptive management process being developed for the Great Lakes?

Mr. ABDALATI. I would certainly have to check with the Director of our Applications Division in Earth Science for specifics on that. But I will say, you know, you touched on some very important points. The mechanisms that are affecting the levels of the lakes are different. But they are no less a manifestation of our changing climate.

You referred to the increased evaporation. There's also the flip side of that, the ability of the atmosphere to carry more water vapor leads to larger precipitation events as well. The movement of lake water from one shore, you know, as the winds circulate pushing the lake up on one side, lowering it on another and vise versa, happens, is also associated with the complex weather and climate patterns that occur.

So, you know, I agree—or what you put your finger on is—there are multiple manifestations of our changing climate. While the mechanisms of sea level rise and the mechanisms of lake changes are different, they are interconnected in that way.

I think partnerships, as was referred to at all levels of our government, are essential for success because each brings to the table a different perspective, a different element and different capabilities.

Senator FRANKEN. What resources, such as NASA's climate modeling capacity or hydro-climatic data collection abilities can you provide to this Great Lakes Management Process?

Mr. ABDALATI. Certainly our insight to climate prediction, our insight to water movement and water transport—what a lot of people don't realize is we have satellites, a pair in particular called GRACE (Gravity Recovery and Climate Experiment), that measure the movement of water. They get a lot of visibility because they're tracking changes in the ice sheets and their contributions to sea level rise.

But they also track changes in lake volume for lakes that are large enough. Terrestrial water storage, you know, when soil becomes moist that has a gravity signal that these satellites observe.

There are certain space based capabilities. There are higher resolution, visible imagery that can look at the characteristics in coastal regions, the erosion processes, the exposure processes, the health of the surrounding vegetation.

Actually I was glad to hear about the LiDAR mapping application because that was actually pioneered by NASA. We've used it to track elevation changes in glaciers, but one of the activities when I was a post-doc at Wallops Flight Facility was doing beach mapping using LiDAR to track—or measure—the beach characteristics before a hurricane and then after a hurricane to assess—or quantify—the erosion characteristics and get at the underlying physics.

That has been transitioned largely to commercial enterprises. But certainly that capability, those tools and our expertise in that area, I think would be of tremendous value for the vulnerability assessment: management input, or capabilities, or input to management practices, and so forth.

So the satellites, the aircraft, the models, our relationships with industry in making these kinds of observations, and finally the context and the broader climate Earth system characteristics, are all elements that would support a strategy that integrates State functions, Federal functions as well as the local municipalities.

Senator FRANKEN. I would like to ask you or urge you to work with my office and to pursue this aggressively. I think it's a good opportunity.

Mr. ABDALATI. I'd be more than happy to do that.

Senator FRANKEN. Oh, thank you. Thank you very much.

Mr. Chairman.

Mr. ABDALATI. I actually have to because my wife is from Minnesota and I owe it to her. I have to pay back.

Senator FRANKEN. I understand that.

[Laughter.]

The CHAIRMAN. You have that same situation.

Senator FRANKEN. My wife is from Maine.

The CHAIRMAN. Oh.

Senator FRANKEN. So I have to do certain things regarding Maine.

The CHAIRMAN. I see. I see.

Senator FRANKEN. But I understand the dynamic.

[Laughter.]

The CHAIRMAN. I see, general dynamic.

Senator FRANKEN. Yes.

The CHAIRMAN. Alright. Let me ask about a specific issue. My impression is that private insurance companies are not anxious and rushing forward to provide insurance against the kinds of flooding that we're talking about in these coastal areas. So it falls to the Federal Government to provide that insurance.

Do we know if the information you folks have been testifying on this morning is adequately incorporated into the projections for what it's going to cost the taxpayer, the Federal Government, to cover the cost of these expected future climate changes? Is that something that is factored in or is it just we're sort of flying blind here? We don't have any idea we just pay the bills when they come in?

Don't have any expectation as to what—as I've understood the way insurance companies operate they do pretty sophisticated projections of what their liabilities are going to be going forward. Only by doing that are they able to set the premiums at a level that allow them to make money. At the Federal level I don't know if we're doing that.

Have any of you looked at this question or have any information about it?

Mr. Freed.

Mr. FREED. Certainly. In New York City there's a large disconnect, I think, between the information we have and know is coming and what is provided. There are large parts of the city and Long Island where you simply can't buy flood or wind insurance that the private insurance market has abandoned those areas because they view the risk as too great.

Those areas are larger than the 1 in 100 year flood zone. Because they recognize that the risk has migrated out of those zones and is beyond that which then leaves the National Flood Insurance program on the line to provide insurance as a last resort. In many cases the property values are capped at $250,000 in the flood insurance program which can often exceed the full value of the homes that they're insuring.

Therefore there's a large unmet risk that you either need to try to seek the private market to fill or the property owner themselves is left to fill after an emergency which then increases the cost beyond the flood insurance program to disaster aid and recovery. So I think there's an enormous disconnect. You're seeing the private insurance markets reacting by simply not providing insurance to those areas.

The State, local, Federal Government will have to fill that unmet need.

The CHAIRMAN. Dr. Berry.

Mr. BERRY. Very similar situation in Florida. We have Citizen's Insurance which I pay into which is a State insurance. That is not backed by a great deal of reinsurance.

It's not backed by the amount of reinsurance that would enable us to deal with a major hurricane. As time goes on it's going to be more and more difficult, I think, to get insurance.

We do have a meeting in June in which this is an important component. We're looking at it as a specific issue and getting some of the insurance companies at the table.

The CHAIRMAN. Good.

I think this has all been very useful. We appreciate the excellent testimony. We will try to take some of your suggestions for actions we can take here at the Federal level and urge those on our colleagues here.

Thank you. That will conclude our hearing unless you had another question, Senator Franken?

If you did, go ahead.

Senator FRANKEN. Thank you, Mr. Chairman.

Basically I wanted to ask about addressing climate change in the long term. I think it requires that we grow clean energy sources. But many of our Federal incentives that had been in place like the Wind Energy Production Tax Credit are expiring which is a serious blow to clean energy and to tens of thousands of jobs including, Mr. Abdalati, in Minnesota.

So this is a little pressure on you. We actually found a way to extend these incentives. It would require closing a few, well it's not loop holes, it's subsidies that we give to big oil and gas companies. It's the top 5 that made $137 billion of profits in 2011.

I think that if you make $137 billion, if you're those 5 companies, you really don't need tax subsidies from the taxpayer. So the Senate recently voted on the measure to close $2000 billion, $2 billion worth of these subsidies to help our alternative energy sector and that measure failed largely again, along party lines. I find that really troubling.

This means that those who voted against the measure said no to growing our clean energy economy simply because they don't want the profits of big oil to go down $2 billion, I guess, or they argued that this would increase the cost of gas at the pump. Although we had experts on what was causing the price of gas. My question on that they said that eliminating these subsidies would have either a non-existent effect on the price of gas or negligible.

My question is that Minnesota has reached a goal to reach 25 percent renewable energy as early as 2025. We're already ahead of pace on that. Hopefully that's just the starting point.

Could you talk about the importance of expanding clean energy globally as a way to address climate change and rising sea levels?

Mr. ABDALATI. I'll comment because you brought up a very important point. I won't comment specifically on what should be done to increase the development of renewable energies or alternative energy sources. But what I will say is we're well aware the climate is changing. I don't think there's, in the scientific community, any dispute about that.

The climate has always changed. It always will for various reasons. But the success of society in the face of those changes really depends on 3 things:

It depends on how big the changes are.

How rapidly they come.

Our ability to anticipate and prepare for them.

So when you're talking about alternative energy sources you're tackling two of those 3 elements. You're tackling the potential magnitude of the change, not just of climate but ultimately sea level as well. You're tackling the rate of change.

So in my view, if that is not motivation—if the success of society in the face of these changes—is not motivation, I'm not sure what is. You know, there are some who challenge even the assertion—or the assessment—that climate is changing, and for these reasons. But if you look at the fact that we mention insurance companies, those whose economies—or economic models—depend on data and accurate data, are among the biggest users of climate data, are taking this seriously.

Our military charged with the safety of our Nation, protecting our citizens, are taking this very seriously.

So it's clear there are changes coming.

It's clear that the way we use energy is contributing to those changes.

I think it should be equally clear that our success in the face of those changes really depends on slowing them down, keeping them as small as we reasonably can. I'm not talking about going crazy and reeking economic havoc. Although I don't know what it would take to do that.

But investments in alternate energy are, I think, essential for a successful future.

Senator FRANKEN. Dr. Strauss.

Mr. STRAUSS. Thank you, Senator.

I'd like to elaborate for a moment on the big picture, sea level wise. Dr. Abdalati made two excellent points. We have some ability to influence the speed of change and the amount of change. Both of those things are critical.

We can turn to long term history for some guidance about what might be possible like the mutual fund ads say, past performance does not guarantee what will happen in the future. But it is some indicator.

The last time that it was about as warm as it is today, before the last, the warm period before the last ice age, about 125,000 years ago. It was about 4 degrees warmer Fahrenheit. Four degrees of warming Fahrenheit from where we are now is for the scientific community about a best case scenario of what we might limit ourselves to with an aggressive transition to renewable energies.

At that time, when it was 4 degrees warmer, sea level was very likely at least 20 feet higher than it is today. You wouldn't recognize the United States map with 20 feet higher sea levels.

We also know that in the warming, since that time, there was a period when sea levels rose more than one foot per decade for more than 2 centuries. So that's ten feet a century, very fast. So either that amount of rise or that speed of rise would be very crippling.

We don't know that we're headed to either of those things. But we do know that the global ice sheet system is capable of delivering them under some circumstances. So I think it is very prudent for us to look.

You know, it's very important to look at reducing greenhouse gas emissions if we want to reduce the chance of high speed sea level rise or the chance of long term extreme sea level rise.

Senator FRANKEN. Yes. I mean, is that OK, Mr. Chairman?

Mr. JANETOS. Senator, one of the activities that we had underway in our institute for, literally, for a couple of decades is the development and use of models that actually look at the affect of the evolution of the energy mix, the technology mix and how what affect that can have on where you end up on climate forcing, where you end up in terms of atmosphere concentration of greenhouse gases and ultimately affects on the climate system.

As we heard at the beginning of the testimony which sea level rise gets realized over the 21st century depends, quite critically, on which scenario the world ends up on. We don't pretend to predict the future because all those scenarios depend on a whole host of economic and political decisions. But one thing we can say with some confidence is that transition to a mix of energy technologies that produce enough energy as demand rises, but do so in a way that minimize and begin to reduce the actual emissions of greenhouse gases to the atmosphere is a transition that really has to happen rapidly if there's going to be a good likelihood of stabilizing both concentrations and the forcing of the atmosphere within this next number of decades.

Senator FRANKEN. This just seems like such an important hearing for in terms in subject matter, in terms of our future. I think that's sort of an understatement. I think it's something that in this committee, we need to talk about.

I think economically it will only help us to develop these renewable energy sources of solar and wind and biomass. I think that we're going to be competing with the rest of the world because it's going to be so obvious where we're headed and what we need to do.

I just feel that it's our responsibility here in the Senate to be addressing this and addressing it head on and not be afraid to do that. Have the conversation lead us to be the best stewards of this planet for our children and our grandchildren and other generations. So I want to thank the Chairman for calling this important hearing. I want to thank all the witnesses.

Mr. Chairman.

The CHAIRMAN. Thank you very much for being here and being so involved in the issue and the committee work. Thank you all again for testifying. I think it's been very useful.

That will conclude our hearing.

[Whereupon, at 11:15 a.m. the hearing was adjourned.]

APPENDIXES

APPENDIX I

Responses to Additional Questions

RESPONSES OF BENJAMIN H. STRAUSS TO QUESTIONS FROM SENATOR BINGAMAN

Question 1. There are many questions about how reliable sea level projections are. Can you describe in more detail the strengths and limitations of the models and also how best decision-makers should use the information that is available for future planning.

Answer. Sea level projections include a wide range of uncertainty, but there are many reasons for decision-makers to take the high end of current projections very seriously.

Scientists take two main approaches for projecting future sea levels: physical models and semi-empirical models. Physical models have the strength of building directly from known physical processes affecting sea level. However, the scientific community has not yet found a way to model Greenland and Antarctic ice sheets close to accurately, and these are by far the most dangerous factors (representing about 200 feet of sea level rise potential in total, as compared to about 2 feet in total potential from small glaciers, and about one foot per century potential from the expansion of ocean water as it warms). Physical models have generally left out aspects of ice sheet response, and model projections (for example, projections given in the last two reports of the Intergovernmental Panel on Climate Change, or IPCC) have been low compared to observed sea level rise since 1900.

By contrast, semi-empirical models have been able to match historic sea levels over the last 100 years, and even 1,000 years, with great fidelity. Semi-empirical models use historic relationships between global temperature and the rate of sea level change to make their projections. This approach implicitly captures all factors that have contributed to recent sea level changes (including all contributions from ice sheets), and implicitly incorporates all of them into projections. Physical modelers criticize semi-empirical models because they do not tie directly to physical processes, and because the whole approach relies on extrapolation. As temperatures reach farther into new heights not seen in the record on which a model is based, it becomes less clear whether historic relationships will continue to apply.

On the one hand, semi-empirical models probably exaggerate the contribution of glaciers in the future, because the stock of glacial ice will dwindle and disappear (something the model can't "know" based on the last century). On the other hand, the models may well underestimate the contribution of ice sheets—which hold 100 times the water that glaciers do—because ice sheets appear to have only just begun exerting their influence. If ice sheets decay in new ways in the 21st century, compared to the 20th century, big surprises are possible. During the last Ice Age, sea levels bottomed out about 400 feet lower than today. But during the great thaw from about 20,000 years ago until about 8,000 years ago, the sea rose faster at certain times than one foot per decade, a rate much greater than the darkest contemporary projections.

Semi-empirical models generally project more sea-level rise this century than physical models do, but there is a real possibility that both approaches underestimate what could happen. Greenhouse gases are increasing in the atmosphere today at a rate many times faster than anything the planet has seen in at least the last 55 million years, so it is reasonable to expect surprises. This is why, for example, New York State and City have decided to use two sea-level rise scenarios, a traditional one and a fast-melt scenario—one kind of approach decision-makers might consider. (The fast-melt scenario assumes an extra 3+ feet of sea level rise per century, based on the overall average sea level rise rate during the long thaw from the last Ice Age.)

Both physical and semi-empirical models rely on projections of future greenhouse gas emissions, and on global climate models that translate those into temperature projections. It is a common (although not universal) practice to present a range of sea-level projections based on a range of possible emission scenarios in one bundle. Whenever this is the case, it is important for decision-makers to recall that so far, we are on a path close to the highest of all major emission scenarios used. Continuing on such a path would point toward the higher part of any range of sea level projections.

The deep historical record also points toward higher projections. Before the last Ice Age, there was a warm period, about 125,000 years ago, with global temperatures perhaps slightly warmer than today, and certainly cooler than the temperatures projected this century under the higher emissions scenarios. During that last warm period, sea level peaked 20-to-30 feet higher than today. The planet was in a different orbit then, so the warm period is not a perfect analog to today, but it certainly points toward caution about how high we might ultimately drive sea levels.

The international scientific community, as reflected by the IPCC, has a demonstrated track record of underestimating sea-level rise. Based on personal observations, I'd also add that for many climate scientists, it can feel safe, reflexive, or "conservative," to emphasize projections that deviate relatively little from present conditions (despite—or perhaps because of—accusations of "alarmism"). Such projections generally incorporate less novelty, and ask less of their audiences. However, for a decision-maker with responsibilities for public safety or economic wellbeing, ignoring high-end projections would seem to be the opposite of conservative.

One more note about sea level projections is critical for future planning. Most projections are given as a range to be achieved by a given year—say, by 2050 or 2100. This can lead to the impression that the rise would then stop. In fact, under the higher projections, the rate of sea level rise continues to accelerate so it is rising faster than ever at the end date. Both the speed and amount of sea level rise contribute to the dangers it poses, but ultimately, high speed would threaten social stability the most. So the high-end sea-leve rise projections include a double threat.

In conclusion, decision-makers would be well served by taking the high end of model projections for sea-level rise very seriously—for semi-empirical as well as physical models.

Question 2. Opponents of policies to reduce carbon emissions often cite the costs and economic burden of such policies as a main reason for their opposition. Your testimony here today would indicate that the costs of inaction, and also of not planning for a certain level of climate change that we have already committed to, are quite high. Are there studies that effectively quantify these costs, and if so, how do they compare to the costs of being proactive?

Answer. A recent peer-reviewed study by James Neumann and colleagues estimated the value at risk from sea level rise by 2100 for the contiguous US, and also estimated total costs with proactive adaptive measures. For a "mid SLR scenario" of 2.2 feet by 2100 (in fact, this is toward the lower end of most recent projections), the authors found just over $1 trillion at risk ($600 billion with 3% discounting) if no action were taken. By contrast, the estimated total cost plus damages under an optimized program of defense and retreat was estimated at $236 billion under the same scenario ($64 billion discounted). This finding suggests enormous costs and exposure for failure to plan and respond to sea level increases. Under a "high SLR scenario" of 4.1 feet, the estimated total cost plus damages under an optimized program was $324 billion ($75 billion discounted).

A global analysis by Robert Nicholls and colleagues estimated $7 vs. $70 billion in annual coastline defense costs for North America by 2100, for 1.5-foot vs 6.5-foot sea-level rise scenarios. Under the high-rise scenario, the study assumed abandonment of 25% of vulnerable land. The study did not estimate damages, only the cost of defenses—which the Neumann study suggests are many times less than the damage potential.

A third recent study, by Ross Hoffman and colleagues, found 7-9% increases in overall annual storm damage costs along Gulf and Atlantic coasts of the U.S., through 2030, assuming essentially linear continuation of recent historical trends in sea level rise (in other words, a very low sea level rise scenario not allowing for acceleration—although accelerated sea level rise has recently been detected from Cape Hatteras to Boston). Locally, increases of 20% or more were common. Factoring in potentially warmer sea surface temperatures (and thus aggravated storms), the overall annual storm damage increase grew, and ranged from 18-20%.

These studies all focus on direct potential damages and the cost of defenses. The literature on the economics of sea-level rise so far does little to address potential broader negative indirect impacts on economy-wide growth and welfare, although these are regarded as possible. However, the studies cited above do showcase recent thinking and highlight the very large costs of failing to reduce heat-trapping pollution, and of failing to plan for the increasing amounts of sea level rise to which we are already committing ourselves.

At a smaller scale and from a more practical, less theoretical perspective, my answer to question 1a from Senator Cantwell throws some light on costs being scoped by local governments as they contemplate putting defenses in place today.

Overall, the costs of inaction are poorly understood, and very likely underestimated. As a prime example, we are not even counting the cost of the roughly 8 inches of global sea level rise we have already experienced due to warming over the last century. Today, every single coastal flood is wider and deeper due to sea level rise. Therefore, a fraction of the economic damage from every coastal flood can already be linked to climate change. However, no one is yet doing the accounting or labeling required to count this cost.

Values used in this answer are 2010 dollars.

Question 3. From the maps that you submitted with your testimony it appears that the nation's energy infrastructure in Louisiana is particularly vulnerable to sea level rise. What impacts do you expect that could have on the country as a whole?

Answer. The Department of Homeland Security has estimated that having Louisiana Route 1 and Port Fourchon, which it serves, out of service for 90 days would lead to a long-term reduction of 120 million barrels of oil and 250 billion cubic feet of natural gas production, and would have up to an $8 billion negative impact on the US economy (GDP). Rising seas increase this risk.

More broadly, the Gulf coastal region, including low-lying coastal areas of Texas, Louisiana, Mississippi and Alabama, has about $500 billion in oil and gas assets, plus $300 billion in electric utility assets, expected to grow to $930 billion combined by 2030, according to a study by Entergy. The region is responsible for roughly half of the nation's natural gas and oil production, and half the oil imports. Entergy estimates $2.7-4.6 billion in annual extra damages and costs from climate change in the region, by 2030, depending upon climate scenario.

Entergy's research also suggests $0.5-1.1 billion in increased annual impacts in Louisiana, alone, with $0.4-0.7 billion of this directly from increases in flooding and storm surge (aggravated by sea level rise), and the balance from increased wind and rain and business interruption.

Question 4. Are there particular power plants or other pieces of energy infrastructure that are of primary concern? Is it feasible to protect them, or will they simply need to be retired or replaced?

Answer. The analysis I presented is best suited for assessing aggregate exposure (e.g. totals per state or nationally), and not the risk to individual pieces of infrastructure. Certainly there are individual facilities of primary concern—for example, facilities that might pose important dangers if damaged (e.g. nuclear plants), or assets that contribute significantly to the national energy supply (e.g. Route 1 in Louisiana, which serves a large proportion of oil and gas extraction facilities in the Gulf of Mexico). For the most accurate risk assessment, the danger to such vital facilities should be examined on a case-by-case basis using best available elevation data (ideally laser-based LiDAR data) and physical hazard modeling (e.g. simulated storm events), incorporating a wide range of future sea level rise scenarios, including high-end. Individual circumstances will determine the feasibility and economics of protection vs. retirement in each case.

That said, in the long run, I have no doubt that retreat will be the only practical recourse for many sites. The main questions are when, and whether facilities can complete their useful lifetimes first.

Responses of Benjamin H. Strauss to Questions From Senator Murkowski

TOOLS FOR FIXING THE PROBLEM

Question 1. In Congress, it has become apparent that cap-and-trade lacks the support needed to pass, and internationally, the U.N. has failed to develop a treaty that all nations are willing to ratify. What we are left with at the moment are regulations by the EPA under the Clean Air Act, which many of us oppose due to our concerns about their economic impact.

a. How much of a difference will CAFE standards and New Source Performance Standards for power plants actually have on projected sea level rise?

Answer. According to many projections, strong reductions in global total greenhouse emissions would make a large difference for sea level rise by the end of the century. CAFE standards and New Source Performance Standards would contribute toward such reductions, but I am not aware of any analysis that would let us assess what effect those measures alone might have on sea level rise.

By the end of the century, strong reductions could make the difference between keeping or losing South Florida; a defensible or indefensible problem in most coastal areas; and stabilizing or accelerating rates of sea level rise. It is important to note, however, that due to momentum built into the physical system, it may already be too late to slow down sea level rise over the next four decades; and we may already be committed to considerable sea level rise over the long run. A recent study, for example, projected we might see about five feet of rise by 2300 even if all global greenhouse gas emissions permanently stop in 2016. (On the other end of the spectrum, five feet this century—a possibility if we make no cuts in emissions—would be vastly more difficult to adjust to. Like a bullet, the faster sea level rise moves, the more dangerous it is.)

SETTING PRIORITIES

Question 2. A New York Times article from 2007, entitled "Feel Good vs. Do Good on Climate," brings up a number of interesting points on this subject. Using New York as a case in point, the article states that "The warming that has already occurred locally is on the same scale as what's expected globally in the next century." Bjorn Lomborg is also quoted as saying, "No historian would look back at the last two centuries and rank the rising sea level here as one of the city's major problems."

a. In comparison to malaria, famine, and other global problems that are affecting people right now, how much attention should be paid to rising sea levels?

Answer. Many global problems cause great suffering and deserve much attention. Most of them are fairly cyclical: so far in global history, disease and hunger tend to come and go, rise and fall, as even do armed conflict and war. What distinguishes many problems associated with global warming, and sea level rise in particular, is their one-way and irreversible nature. Carbon dioxide lingers in the atmosphere for centuries, and ice sheets that melt or crumble into the sea would take millennia to rebuild. It is true that few or no historians would rank sea level rise over the past two centuries as a major problem, but sea level is already rising about three times faster than it was one hundred years ago, and is expected to accelerate much more, in a world where far more population and assets are concentrated along the coast than ever before.

In choosing whether and how much to invest in reducing global warming and its impacts, versus other problems, this one-way ratchet is important to remember. It is also important to remember that emissions, temperature and sea level rise are all currently accelerating. If and when we choose to cut emissions, research indicates we will already be locked into decades more of increasing damage and distress, before improvements from the cuts become noticeable. There is a great danger that by the time impacts become painful and obvious enough to loom large in most people's eyes compared to other immediate issues of the day, we will already be committed to much greater pain for generations to come. (Pain that could include much more famine—consider this summer's drought a small foretaste of the threat to agriculture—and the geographic spread of tropical diseases like malaria.)

With respect to the local vs. global warming analogy, consider the difference between heating one toe to 105 degrees (say, by dipping it in a hot tub), versus heating your whole body through and through to the same temperature. The former is a minor discomfort, while the latter is a life-threatening systemic crisis. The two situations are not fairly comparable.

ACCURACY TO DATE

Question 3. Scientists and researchers have been making projections about sea level rise for years—if not decades. Climate models are constantly being re-worked, and refined, but hearings like these provide an opportunity to look back as well as forward.

a. To the extent that past projections were made for sea level rise in 2010, 2012, or another point around the current period, how accurate have those projections been?

Answer. The projections for sea level rise by 2010, made by both the third and fourth major assessments of the Intergovernmental Panel on Climate Change—

whose reports are generally regarded as the international scientific consensus near the time they are made—have been markedly too low. Actual sea level rise has been on the very upper edge of the entire wide range of possibilities projected.

For more background on sea level rise projections, please see my reply to Senator Bingaman's first question.

RESPONSES OF BENJAMIN H. STRAUSS TO QUESTIONS FROM SENATOR CANTWELL

Question 1. Knowing the responsibilities states, cities, and localities already have and their limited ability to raise additional resources, it seems like we are going to have to establish some sort of federal program that can direct the billions of dollars needed to adapt our nation's infrastructure to and protect our citizens from the impacts of climate change.

a. Do you believe such a Federal role and funding stream is necessary?

Answer. It seems very likely that many or most coastal cities, counties and states will not be able to afford the cost of adapting to sea level rise, or at least will choose not to pay it. In fact, examples are already accumulating of cities studying the cost of protection, and balking at the price tag, or choosing projects that will not offer meaningful protection.

Norfolk, VA engaged the Dutch engineering firm Fugro to design and cost out defenses. Sea wall cost came to $300 million (compared to an $800 million total annual budget for the city). Norfolk declined the proposal because of its high price and because the solution didn't protect against inland flooding and sewer overflow (which can be complicated by rising seas—drainage of inland water is retarded). Norfolk, population 250,000, is now developing a plan to seek federal aid for a comprehensive $1 billion fix over the next 30 years, according to the Washington Post.

An Army Corps of Engineers levee project that could have protected communities in north and central Lafourche, LA, from storm surge on top of rising seas, at a cost of roughly $1 billion, was recently canceled, according to Houma Today.

The Washington Post reported this spring that Louisiana has so far not been able to find $320 million to raise a vulnerable, low-lying section of LA Route 1, which serves Port Fourchon, a lynchpin in the nation's current energy infrastructure (for more see answer to question no. 3 from Senator Bingaman).

In Seattle, WA, citizens will vote this fall on a $290 million bond ballot measure to repair and rebuild a downtown waterfront seawall. The new seawall will be built to tolerate 11 inches of sea level rise. Climate Central's recent peer-reviewed research projects 11 inches of sea level rise (90% confidence range: 4-21 inches) for the Seattle area by 2050. Even if the citizens vote to pay and the wall is built, it will not protect the city for even close to its planned 100-year life under a wide range of sea-level rise scenarios.

Question 1b. Wouldn't a price on carbon, which could serve to both reduce the severity of these climate impacts and provide the needed funds, make the most sense?

Answer. It is my understanding that the great majority of economists believe a price on carbon would be the most efficient way to reduce emissions and therefore future impacts. Most impact reduction would be realized after 2050, because of the powerful momentum of warming. Although our actions today can reduce future costs, many costly impacts are indeed unavoidable (and already taking place, even if not labeled as costs of climate change).

Question 2. As we think about our economic and energy future, we need to consider the real costs of inaction. A recent study has estimated that the impacts of climate change will cost my home state of Washington 10 billion dollars per year by 2020. This is an enormous burden that will be arriving very soon.

Answer. It is imperative that we get ahead of this curve and prepare for these impacts now. To that end, we must maintain vital funding of research programs and facilities that advance scientific knowledge and understanding and provide the foundation for cost-effective, innovative solutions. Unfortunately, funding carve-outs in the Department of Energy's Office of Science have impacted base program funding for user facilities and research in recent years.

In my home state, PNNL is working on solutions to the challenges climate change imposes, but to succeed, they need our continued support. In these fiscally austere times, it makes even less sense to be a penny wise and a pound foolish. PNNL is conducting important research, for example through the Atmospheric Radiation Measurement (ARM) Program, to get a better sense of what changes in climate are already occurring and will likely occur in the future—advancing our understanding of the climate system that include complex components such as aerosols, clouds, and the carbon cycle.

PNNL is also working to provide better information to plan for the coming impacts. They're developing high resolution models that incorporate critical infrastructure and natural resources of each region to inform mitigation and adaptation decisions at the state and regional level. This information will be invaluable for infrastructure planning by natural resource managers, energy companies, and government agencies that currently face great uncertainties in their decision making in response to changing regional climates.

It seems to me that the upfront costs of this research and planning will be extremely modest relative to the costs coming down the road.

Question 2a. Do all of you agree that proposed cuts to research and development will impede our ability to prepare for and mitigate the worst impacts of climate change?

Answer. Without any cuts at all, the national investment in research on climate change, its impacts, and reducing and coping with those impacts, is almost certainly very small compared to the scale of the threat. What would the defense budget be if an enemy power threatened to annex much of South Florida, the boot of Louisiana, Long Island, and the United States' largest ports and naval bases? This is a sampling of effects from something like a worst-case scenario for sea-level rise this century (and that is just one climate change impact; drought and agricultural effects may be more damaging).

Question 2b. Do you hear from states and localities appreciating your analysis and that they use your data to make better planning decisions?

Answer. Our data have only just been released this spring, so it is early for collecting this kind of feedback, but I understand our work will be incorporated in the coming national climate assessment, and has been used for public education by groups and individuals in at least Massachusetts, Florida, North Carolina, and California.

RESPONSES OF WALEED ABDALATI TO QUESTIONS FROM SENATOR BINGAMAN

Question 1. There are many questions about how reliable sea level projections are. Can you describe in more detail the strengths and limitations of the models and also how best decision-makers should use the information that is available for future planning.

Answer. Two methods have been used for projecting sea level rise. The first is through models that seek to accurately describe the physics that affect sea level changes. These include expansion of oceans as they warm, the physics associated with the movement, melting, and accumulation of glaciers and ice sheets, and the variability in stored groundwater. These models have the strength of being physically based, enabling a representation of the underlying causes of sea level rise. They have the limitation, however, of not being able to fully capture the effects of changes in the flow rates of glaciers on ice sheets, which can contribute substantial amounts to sea level, as a result, this approach, while grounded in physics has historically underestimated sea level rise, and has historically not been able to capture the accelerating ice loss from ice sheets.

The second method is to compare past temperatures to past sea levels reconstructed from the geological record of Earth's climate history. There is a fairly robust relationship between the two, and by using this relationship or correlation; one can predict values of sea level rise for estimated values of future temperatures. This method is a statistical, rather than a physical approach, and when applied to future warming scenarios, this method provides the highest estimates (2 meters) for the end of the century. It has the advantage of not requiring a detailed understanding of the complex physics in order to make a prediction, and it produces results consistent with recent history. However, because it does not directly incorporate underlying physical processes, this method provides limited insight into mechanisms and characteristics of future sea level rise.

Despite the limitations, all of the many peer-reviewed, science-based sea-level models predict that sea-level rise will continue for the foreseeable future, although the models differ as to the precise rate of the average rise, and most models have underestimated current rates of sea level rise.

In addition, there is considerable regional variability in the rate of sea level rise, which makes prediction at a particular location very difficult. This variability is a result of ocean circulation characteristics, changes in land processes and characteristics in different regions, the Earth's rotational characteristics, the sources of sea level rise, etc.

For the purpose of supporting decision-making, the key points to keep in mind are as follows:

- the projections have a very wide range of uncertainty;
- they historically have underestimated rates of sea level rise, largely because there are some physical processes associated with rapid ice loss that the community is just beginning to get a handle on;
- there is considerable regional variability, such that local values may be much higher or lower than the global average, which is currently 3.1+0.4 mm/yr.;
- improving the projections requires continued acquisition and analysis of data on sea levels, ocean characteristics, ice sheets, glaciers, and groundwater storage, and continued improvements in models through the analysis and incorporation of these data.
- Besides scientific uncertainties, some of which are mentioned above, uncertainty in future greenhouse gas emissions also contributes to uncertainty in future sea level rise.

NASA, in conjunction with our partner agencies, both domestically and internationally, continues to invest in the observations and analysis that support current assessments and future predictions of sea level rise, both globally and regionally.

Question 2. Opponents of policies to reduce carbon emissions often cite the costs and economic burden of such policies as a main reason for their opposition. Your testimony here today would indicate that the costs of inaction, and also of not planning for a certain level of climate change that we have already committed to, are quite high. Are there studies that effectively quantify these costs, and if so, how do they compare to the costs of being proactive?

Answer. There is an urgent need to better estimate the economic costs of climate change; without such estimates the cost-effectiveness of measures to mitigate or adapt to climate change cannot properly be assessed.

Economic analysis is out of the purview of NASA's mission. This type of cost estimate should be performed as part of the National Climate Assessments (http://www.globalchange.gov/what-we-do/assessment) that have been conducted by the US Global Change Research Program and which can be found at http://library.globalchange.gov/. However, due to a lack of capacity, both past Assessments and the ongoing Assessment (scheduled for completion in 2013) include very little economic analysis.

Question 3. Are there particular power plants or other pieces of energy infrastructure that are of primary concern? Is it feasible to protect them, or will they simply need to be retired or replaced?

Answer. The protection our domestic energy infrastructure is critical to national safety, security and the livelihood of many Americans. The vulnerability is a combination of the amount of sea level rise, climate and weather patterns in the vicinity of these components of the infrastructure, the elevation and the surrounding landscape of where they are situated, and the resilience of these structures. NASA's efforts and expertise in sea level focus on the magnitude and distribution of sea level rise, which can inform risk assessments, however, determining the vulnerability is beyond the scope of the agency's activities.

Responses of Waleed Abdalati to Questions From Senator Murkowski

TOOLS FOR FIXING THE PROBLEM

Question 1. In Congress, it has become apparent that cap-and-trade lacks the support needed to pass, and internationally, the U.N. has failed to develop a treaty that all nations are willing to ratify. What we are left with at the moment are regulations by the EPA under the Clean Air Act, which many of us oppose due to our concerns about their economic impact.

a. How much of a difference will CAFE standards and New Source Performance Standards for power plants actually have on projected sea level rise?

Answer. There is no question that international and domestic regulatory policies will influence the future state of sea level; however, the relative impact on future sea level rise of CAFE standards and New Source Performance Standards in particular lies outside the current scope of NASA scientific research. Of course, these regulations also have beneficial effects on air quality and human health, and CAFE standards are projected to save consumers $1.7 trillion in fuel costs over the life of the program.

SETTING PRIORITIES

Question 2. A New York Times article from 2007, entitled "Feel Good vs. Do Good on Climate," brings up a number of interesting points on this subject. Using New York as a case in point, the article states that "The warming that has already occurred locally is on the same scale as what's expected globally in the next century." Bjorn Lomborg is also quoted as saying, "No historian would look back at the last two centuries and rank the rising sea level here as one of the city's major problems."

a. In comparison to malaria, famine, and other global problems that are affecting people right now, how much attention should be paid to rising sea levels?

Answer. Sea level rise is one of many global challenges people face right now, in the United States and elsewhere. Each of these challenges has major implications and should be regarded as matters of great importance by the public, the science community, and policy makers. The relative urgency of one problem over another depends on the values we place on life and property, the degree of threat posed by each one, and the risks we as a nation are willing to take. In the United States, sea level rise is very likely to adversely affect the well-being of many of our citizens, and come at a great cost in terms of property and infrastructure. Deferred action on the sea level and climate change fronts means the costs of adapting will be great. Assessing how the sea level threat compares to the other threats humans face depends on information and accurate models. At NASA we continue to acquire this information, and use it to inform models, so that the risks and vulnerabilities can be appropriately assessed.

ACCURACY TO DATE

Question 3. Scientists and researchers have been making projections about sea level rise for years—if not decades. Climate models are constantly being re-worked, and refined, but hearings like these provide an opportunity to look back as well as forward.

a. To the extent that past projections were made for sea level rise in 2010, 2012, or another point around the current period, how accurate have those projections been?

Answer. Past projections of sea level rise have typically underestimated the observed rate of rise. The figure* below is taken from Church et al., Oceanography, 2011 and shows a comparison of projections from the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Sea level projections from this report were matched with observations in the year 1990. The range of projections is shown by the orange band and the beige lines. For the beige lines, an attempt was made to account for a more rapid loss of ice from the ice sheets in light of rapid changes in glacier flow that the climate models could not simulate. Nevertheless, the observations from tide gauges (black line) and from satellite altimeters (red line) fall near the top of all projections.

Reference

Church, J. A., J. M. Gregory, N. J. White, S. M. Platten, and J. X. Mitrovica, Understanding and Projecting Sea Level Change, Oceanography, 24(2), pp. 130-143.

LETTER FROM FORMER NASA OFFICIALS

Question 4. On March 28th, your agency's Administrator, Charles Bolden, received a letter from approximately 50 former NASA officials. The letter asked that NASA "refrain from including unproven and unsupported remarks" in climate-related statements. The letter also mentions "catastrophic forecasts," and I want to ask you about that characterization. As with any prediction of future events, estimating sea levels over the next century is a decidedly difficult task. And it is made more complicated when attempts to forecast specific consequences—to infrastructure, people, or wildlife—are involved.

a. My question is: how important do you feel it is to be clear and transparent about the range of uncertainty associated with these types of predictions?

Answer. It is not merely important, but it is absolutely essential that scientists provide clear characterizations of uncertainty when making predictions about the range of possible future scenarios. If scientists are not transparent about uncertainty it diminishes both the credibility and utility of the results. This is why both the IPCC Assessments and the peer-reviewed literature upon which they are based make such extensive efforts to include characterizations of uncertainty that are rigorous, transparent, and use carefully-defined terminology.

* Figure has been retained in committee files.

It is equally important to remember that while we cannot precisely predict the future, we can make informed estimates based on past and current observations, and our knowledge of physical processes. Therefore, the path to decreasing uncertainty is through observations, and continuously improving our understanding of the physical processes that drive the Earth system. It is also important to remember that, no matter how good our science may become, future climate will always be uncertain because it depends on future human actions.

Unfortunately, in a world where discussion seems to revolve around extremes, some use uncertainty to imply doubt, and subsequently offer it as a reason for inaction. In fact, uncertainty implies the possibility of higher risk, and can be used to support the case for stronger, not weaker, action to minimize risk. None-the-less, for policy to be informed, and for the dialogue on the topic to be honest, scientists must continue to be as clear about what we don't know, as we are about what we believe to be the case.

RESPONSES OF WALEED ABDALATI TO QUESTIONS FROM SENATOR CANTWELL

Question 1. Knowing the responsibilities states, cities, and localities already have and their limited ability to raise additional resources, it seems like we are going to have to establish some sort of federal program that can direct the billions of dollars needed to adapt our nation's infrastructure to and protect our citizens from the impacts of climate change.

a. Do you believe such a Federal role and funding stream is necessary?

b. Wouldn't a price on carbon, which could serve to both reduce the severity of these climate impacts and provide the needed funds, make the most sense?

Answer. As I stated in this hearing, the climate has always changed. It always will, for a variety of reasons. The success of society in the face of those changes really depends on how big the changes are, how rapidly they occur, and our ability to anticipate and prepare for them. There is a significant level of federally funded research under way targeted at determining what the future will likely bring, so that we can be equipped to prepare for the changes that lie ahead. What is learned through this research can also inform policies targeted at slowing and reducing the change, to levels that can be more easily adapted to. The federal government plays a critical role in developing the necessary knowledge to successfully confront the challenges associated with climate change, and this must continue. Placing a price on carbon is one tool that can be used to incentivize people to find alternative forms of energy that may have less of an impact on our environment and sea level. The effectiveness of this approach, and how it compares to others is not clear, and is not something NASA is involved in studying. What is clear, however, is that the reliable evaluation of this effectiveness requires an understanding of the physical processes at work, which is where the contributions from the NASA investments are critical.

Question 2. As we think about our economic and energy future, we need to consider the real costs of inaction. A recent study has estimated that the impacts of climate change will cost my home state of Washington 10 billion dollars per year by 2020. This is an enormous burden that will be arriving very soon.

It is imperative that we get ahead of this curve and prepare for these impacts now. To that end, we must maintain vital funding of research programs and facilities that advance scientific knowledge and understanding and provide the foundation for cost-effective, innovative solutions. Unfortunately, funding carve-outs in the Department of Energy's Office of Science have impacted base program funding for user facilities and research in recent years.

In my home state, PNNL is working on solutions to the challenges climate change imposes, but to succeed, they need our continued support. In these fiscally austere times, it makes even less sense to be a penny wise and a pound foolish. PNNL is conducting important research, for example through the Atmospheric Radiation Measurement (ARM) Program, to get a better sense of what changes in climate are already occurring and will likely occur in the future—advancing our understanding of the climate system that include complex components such as aerosols, clouds, and the carbon cycle.

PNNL is also working to provide better information to plan for the coming impacts. They're developing high-resolution models that incorporate critical infrastructure and natural resources of each region to inform mitigation and adaptation decisions at the state and regional level. This information will be invaluable for infrastructure planning by natural resource managers, energy companies, and government agencies that currently face great uncertainties in their decision making in response to changing regional climates.

It seems to me that the upfront costs of this research and planning will be extremely modest relative to the costs coming down the road.

a. Do all of you agree that proposed cuts to research and development will impede our ability to prepare for and mitigate the worst impacts of climate change?

Answer. For decades our nation's investment in research and development has led to great advances in our understanding of, and ability to predict, sea level rise and climate change. Continued commitment to research and development will no doubt lead to more robust climate predictions and predictions of future sea level rise, and will increase our ability to successfully deal with climate change. In these challenging fiscal times, it is the difficult task of our nation's policy makers to balance the need for these investments against other challenges we face. We at NASA work hard to maximize the science return on that investment, no matter its size.

Question 2b. Do you hear from states and localities appreciating your analysis and that they use your data to make better planning decisions?

Answer. NASA's Earth Science Division includes an Applied Sciences Program, which partners with public and private organizations such as state and local governments on ways to incorporate NASA Earth observational data and science results in their decision-making activities and services. These have proven to be both valuable and appreciated. Some examples of these successful collaborations are given below.

New Mexico Department of Health Utilizes NASA Satellite Products for Dust Storm Forecasting

A NASA-funded project with the New Mexico Department of Health (DoH) led to the production of daily 48-hour dust forecasts drawing on observations from MODIS and CALIPSO. Dust storms are known to trigger asthmatic responses and cardiovascular issues in susceptible individuals. These forecasts are available to the public and end-users throughout the state via the New Mexico DoH web portal (http://nmtracking.unm.edu) and are also linked to the national CDC Environmental Public Health Tracking Network (EPHTN).

NASA/ARRA Project aids California Agricultural Community

Agricultural uses of water account for more than 80% of total water consumption in many Western states, and optimization of irrigation management is a key component of sustaining agricultural water supplies. Knowing how much and when to irrigate can be a complicated and costly decision. Through American Reinvestment and Recovery Act (ARRA) funds, NASA worked with California Department of Water Resources (CDWR) on a project to apply NASA Earth satellite observations in the California Irrigation Management Information System (CIMIS). The project integrated NASA Terra, Aqua, and Landsat satellite measurements with agricultural weather conditions from CIMIS to map key indicators of crop water requirements and agricultural irrigation demand across the entire California Central Valley at the scale of individual fields on a daily basis. The project produced estimates of crop water needs for each field, providing a new source of information that can be used by growers to account for optimal irrigation rates when scheduling irrigation. NASA and CDWR worked with grower associations and individual growers in the project.

NASA's GRACE Data Enhances the U.S. Drought Monitor

The U.S. Drought Monitor provides weekly maps of national vulnerability to drought, supporting state and local effort to focus on preparedness and risk management to manage water supply and deliver drought aid where it is needed most. A project sponsored by NASA's Earth Science Division integrated data products from the GRACE (Gravity Recovery and Climate Experiment) satellite to enhance the U.S. Drought Monitor. The project combined GRACE data and other observations to improve information on soil moisture and groundwater records, which are used to produce weekly maps of wetness conditions in the soil and aquifers. Prior to the addition of the new GRACE-based products, the US Drought Monitor lacked information on deep soil moisture and groundwater storage—water resources that can be used to gauge the impacts of long episodes of wet or dry weather.

> "These maps provide regional to national-level water resource information that was previously unavailable to policy and decision-makers. The novel use of satellite-based gravity data in combination with advanced modeling techniques has given us a unique perspective on groundwater that was not resolvable through just ground-based observations that can provide new information for hydrologic drought monitoring."
>
> —Brian Wardlow, National Drought Mitigation Center.

California Department of Health Using NASA Satellite Products

A NASA-funded project with the California Department of Health led to the operational integration of NASA data products, such as MODIS and Landsat, into the California Vector-borne Disease Surveillance Gateway. Enhanced products are distributed to Gateway users throughout California for improved risk assessment of mosquito-borne encephalitis viruses, including the West Nile Virus.

NASA Satellite Products Support Mapping Carbon Flux in Oregon Forests

Forests play a vital role in the carbon cycle through the absorption of carbon dioxide and release of carbon through events such as wildfires, insect infestations, and timber harvests. This dichotomy complicates forest management strategies that incorporate carbon absorption through the cycle of forest growth, death and regeneration. To help forest managers understand carbon flux, a NASA-funded project developed a unique model that uses remote sensing data to gain insight into the carbon flux of Oregon's forests. Created by the Oregon Department of Forestry (ODF), the Oregon Roundtable on Sustainable Forests uses the project's approach to carbon assessment to assess the feasibility of forest management plans.

> "We have traditional estimates of carbon flux based on inventory plots, but [the project's] data integrates the physiological functions of forest ecosystems with state-of-the-art landscape modeling, satellite remote sensing, large-scale vegetation mapping, and computer simulation. [The project] uses the technology investments of NASA and puts them into a useful format to help us better understand the annual flux of carbon through Oregon forests."
>
> Andrew Yost, Oregon Department of Forestry

Question 3. Shellfish farmers in Washington State are being severely impacted by ocean acidification. In Washington, the shellfish industry employs over 3,200 Washingtonians and has a total economic contribution of $270 million annually.

In 2010, I secured funding to acquire and deploy ocean acidification sensors near major shellfish hatcheries in Washington State. Today, these sensors, combined with buoys from NOAA's Integrated Ocean Observation System program, allow shellfish growers to monitor ocean acidity in real time. Real time ocean acidification data has made all the difference to the shellfish industry, illustrating a strong nexus between ocean acidification data and shellfish recruitment. Without real time monitoring, the shellfish industry cannot survive.

a. Dr. Abdalati, are we getting close to having reliable satellite data on the acidity of the ocean like we do for sea surface temperature?

Answer. Yes, we are getting closer. However, it is not yet possible to directly measure the acidity of the ocean from space. It is possible to estimate some properties of the ocean related to ocean acidity (or pH, a measure of acidity or basicity of an aqueous solution, in this case, the ocean) and the biological, chemical, and ecological impacts of changing ocean acidity from what are known as "ocean color" satellites. Properties of the ocean related to ocean acidity and the impacts of ocean acidification on ocean biology that can be estimated from "ocean color" satellites include new data products such as particulate inorganic carbon (PIC), biogenic silica, and the partial pressure of carbon dioxide (pCO2), as well as standard products such as phytoplankton chlorophyll (chl).

"Ocean color" sensors can measure light coming from the ocean in the ultraviolet to infrared portions of the electromagnetic spectrum. The light coming from the ocean is referred to as the ocean's optical properties or "color", and can provide quantitative, detailed information on the ocean's biology, ecology, and chemistry. Researchers can use ocean color satellite data of the optical properties of the ocean to estimate or model ocean acidity indirectly, as well as the biological impacts of ocean acidification. For example, recently-published NASA-funded research has developed a method for predicting coastal surface-water pCO2 (partial pressure of carbon dioxide, or CO2) from remote-sensing data, based on self organizing maps and a non-linear semi-empirical model of surface water carbonate chemistry (Hales et al., 2012, in press, Progress in Oceanography). In the ocean, the pCO2 is determined from measurements of two of the following: dissolved inorganic carbon, pH and alkalinity. pCO2 in the ocean can change based on location (sampling depth, latitude), ocean temperature, and the ocean's alkalinity (or measure of the ocean's capacity to balance acid, such as hydrogen ions, with base, such as carbonate ions). Biological processes in the ocean also influence the pCO2 in the ocean. While this algorithm is experimental, this type of study not only gives us insight in to what properties from ocean color satellites can be used to estimate ocean acidity regionally and globally, but also provides quantitative information on carbon cycling.

Question 3b. What monitoring sensors and algorithms are still needed to observe the acidification of the ocean remotely from satellites?

Answer. Continued observations from NASA satellite ocean color sensors will provide data on properties of the ocean such as phytoplankton chlorophyll (proxy for ocean plants), which help to detail ecological impacts of ocean acidification on "primary producers" (bottom of the food chain). Understanding the impacts of ocean acidification on the primary trophic level will allow researchers and managers to identify and understand the impacts of ocean acidification on higher trophic levels (e.g., fisheries) that depend on primary producers for food. Satellites can provide this information from a local to a global scale. Continuity of ocean color data from past sensors such as the Sea-Viewing Wide Field-of-view Sensor (SeaWiFS), and existing sensors such as the Moderate resolution Imaging Spectroradiometer (MODIS), and perhaps future data from the Suomi NPP VIIRS (Visible Infrared Imager Radiometer Suite) are critical to providing a time series of biological data in the ocean critical for detailing the response of the ocean's biology and ecology to ocean acidification.

RESPONSES OF LEONARD BERRY TO QUESTIONS FROM SENATOR BINGAMAN

Question 1. Opponents of policies to reduce carbon emissions often cite the costs and economic burden of such policies as a main reason for their opposition. Your testimony here today would indicate that the costs of inaction, and also of not planning for a certain level of climate change that we have already committed to, are quite high. Are there studies that effectively quantify these costs, and if so, how do they compare to the costs of being proactive?

Answer. It is almost common sense to want to understand a problem and build a response to it over time—the old proverb "a stitch in time saves nine". Apart from that, the economics show that the cost of inaction is great. A 2008 study by Tufts University reports that by 2075 in Florida alone, the cost of inaction would be $184 billion and $345 billion by 2100 (Stanton and Ackerman, 2007). Research that is currently being conducted is starting show that this may be an underestimation.

In the recent ClimAID report for New York State (Rosenzweig et al., 2011, ch. 7), a detailed case study of the impacts of a 100 year storm on transportation and economic activity in New York City estimates additional costs (as compared to the present) of $12 billion for a 2-foot rise in sea level, and $26 billion in additional costs for a 4 foot rise. (p. 348.) This is for just one storm, and not the worst conceivable storm. Moreover, NPCC 2010 p. 177 notes that estimates indicate that the current 100-year storm is likely to occur once every 15 to 35 years by the 2080s. This all suggests that we need more detailed information of assets at risk.

Question 2. Are there particular power plants or other pieces of energy infrastructure that are of primary concern? Is it feasible to protect them, or will they simply need to be retired or replaced?

Answer. The critical infrastructure includes transportation, water supply and treatment systems, power stations and buildings among others. There are methods for dealing with relatively near term climate hazards, including flood walls and evacuation plans; for the longer term, larger infrastructure may be required, such as harbor surge barriers in some areas.

We need a national assessment of energy infrastructure at risk to sea level rise. However in Florida we do know during Hurricane Andrew, the Turkey Point nuclear power station was briefly compromised and we must make doubly sure that any new facilities build at least three feet of level rise into their environmental assessment and into their operation.

RESPONSES OF LEONARD BERRY TO QUESTIONS FROM SENATOR MURKOWSKI

TOOLS FOR FIXING THE PROBLEM

Question 1. In Congress, it has become apparent that cap-and-trade lacks the support needed to pass, and internationally, the U.N. has failed to develop a treaty that all nations are willing to ratify. What we are left with at the moment are regulations by the EPA under the Clean Air Act, which many of us oppose due to our concerns about their economic impact.

> a. How much of a difference will CAFE standards and New Source Performance Standards for power plants actually have on projected sea level rise?

Answer. While we can't prevent sea level rise over the next 50-60 years. We can take mitigation efforts in order to prevent further global temperature increases and thus reduce the seas thermal expansion causing much of sea level rise.

SETTING PRIORITIES

Question 2. A New York Times article from 2007, entitled "Feel Good vs. Do Good on Climate," brings up a number of interesting points on this subject. Using New York as a case in point, the article states that "The warming that has already occurred locally is on the same scale as what's expected globally in the next century." Bjorn Lomborg is also quoted as saying, "No historian would look back at the last two centuries and rank the rising sea level here as one of the city's major problems."

a. In comparison to malaria, famine, and other global problems that are affecting people right now, how much attention should be paid to rising sea levels?

Answer. When it comes to future climate change, past is not prelude. Sea level rise is expected to continue at an accelerating rate, making this a critical global problem that, in fact, is happening now. In Southeast Florida freshwater wells are becoming saline and flood control structures are losing capacity. Trillions of dollars of infrastructures are at risk, imperiling our future national economy including—our ability to address other global problems. Because adaptations that involve significant infrastructure changes take many decades to plan, design and build, we must be proactive in making initial adaptations (flood walls and evacuation plans) and also be proactive now as we begin the long planning process for potentially larger solutions. Mayor Bloomberg is treating this issue of climate change seriously enough to set up a special process to examine the impacts on the city and make adaptation plans.

Florida and our nation spends a great amount of time and money on Emergency Preparedness to minimize the future impacts of floods, hurricanes, earthquakes, etc., and to react to relatively short term postdisaster recovery needs. The warming of oceans and rapid increases in ice loss in polar regions are "Leading Indicators" of future sea level rise which will produce important permanent changes in our natural and built environments. These changes will produce large investment losses for those directly impacted by sea level rise and large indirect financial costs or tax burdens in other areas unless society begins to shift new developments to lower risk areas and implements policies that encourage established developments to move to these lower risk areas as appropriate.

ACCURACY TO DATE

Question 3. Scientists and researchers have been making projections about sea level rise for years—if not decades. Climate models are constantly being re-worked, and refined, but hearings like these provide an opportunity to look back as well as forward.

a. To the extent that past projections were made for sea level rise in 2010, 2012, or another point around the current period, how accurate have those projections been?

Answer. Projections have generally been on the low side because the IPCC did not include estimates of polar and glacial ice reductions in its projections.

RESPONSES OF LEONARD BERRY TO QUESTIONS FROM SENATOR CANTWELL

Question 1. In the Puget Sound region, sea level is projected to rise by six inches by 2050—13 inches by the end of the century. And due to potential ice melt from Greenland and Antarctica, increases of up to four feet for Puget Sound are even possible by the end of the century. This is particularly alarming to me and my constituents because structures located in flood hazard areas are valued at 28.7 billion dollars in Puget Sound alone.

Sea level rise and severe storms could be a big problem for the many military installations in Puget Sound that are critical to our national security. We've already seen how Florida's Homestead Air Force Base was essentially destroyed by Hurricane Andrew in 1992. And Hurricane Ivan badly damaged Naval Air Station Pensacola in 2004.

And sea level rise is just one of the many harmful impacts my state is going to have to deal with because of global warming pollution. Climate change is expected to severely disrupt our very supply and demand of energy. Shifts in the amount and timing of stream-flow will lead to substantial changes in our seasonal hydroelectric power generation, which my state depends upon for two-thirds of its electricity needs. Projected snowpack decreases of 29 percent by the 2020s, 44 percent by the 2040s, and 65 percent by the 2080s are frankly quite daunting when we already have too little water to go around and our needs are just going to increase over time.

Unless we act, in coordination with the rest of the world, this snowpack decline is going to cost my constituents billions of dollars in lost hydropower, irrigation water, and industries that depend on salmon recovery.

All of the expected impacts add up to a rather expensive bill. A recent study estimated that climate change impacts in Washington state will reach nearly 10 billion dollars per year by 2020. That's just eight years from now, and it's the same burden on my constituents as an increase of three-and-a-half dollars for a gallon of gasoline.

I am proud that my state is a national leader in developing a climate response strategy. Incorporating climate change into its planning decisions whether they are where to place new infrastructure or where to focus adaptation efforts.

I was struck by Dr. Strauss's recent report that found the threat of a "century" flood in Washington state more than triples by 2030. That's a daunting assessment given that already since 1990, Puget Sound has experienced 16 federally declared flood disasters, and Interstate 5 has closed four times due to flooding. One of those closures resulted in $47 million in lost economic output to the state.

Our states are already struggling to keep their budgets balanced while maintaining critical funding for education, first responders, transportation systems, and other essential government services. As you look at the costs to Florida and New York city, how are you planning to pay for these necessary adaptation measures?

Answer. The preferred way to pay for adaptation is to encourage new growth in low risk areas and provide incentives for existing coastal developments to relocate or rebuild as appropriate. This requires a long lead time and Congressional action to establish strategic long term policies to develop water resources, transportation, and power infrastructure for the new developments. The implementation of the interstate highway system and the subsequent growth of suburbs shows the potential for encouraging growth in new areas. Other policies are also needed to help those in high risk areas who want to relocate. These might include a special tax deduction category for developed property AND land which are subject to sea level rise impacts and are donated to a national seashore trust in advance of functional loss or after loss due to a tropical storm or other event. It might also include reforms to flood insurance and disaster relief programs to encourage or require property owners to relocate to lower risk areas after a damage event.

As far as Florida is concerned, there are no special funds set aside to deal with these issues. Local governments are devoting considerable resources identifying issues and responding to current threats on a somewhat piece meal basis.

Question 2. Knowing the responsibilities states, cities, and localities already have and their limited ability to raise additional resources, it seems like we are going to have to establish some sort of federal program that can direct the billions of dollars needed to adapt our nation's infrastructure to and protect our citizens from the impacts of climate change.

a. Do you believe such a Federal role and funding stream is necessary?

Answer. A key principle for planning, especially long range planning for climate adaptation, is to have vision of a desired future condition and develop a plan to move consistently toward that goal. With regard to sea level rise, that goal would greatly reduce national exposure to sea level rise risk over the next 50+ years with policies that strongly encourage new development and relocations in low risk areas. This might involve federal investment in large scale, next generation infrastructure (transportation, water, sewer, power, and communication systems) as a framework for development of new energy efficient climate friendly communities, much like the way the current interstate system investment has helped energize and shape US community developments since the 1950s. When identifying low risk areas, it will be important to recognize that sea level rise is most likely to continue for multiple centuries and is very likely to accelerate briskly in coming years.

Federal support will be necessary to help coastal areas adjust to rising sea level. The protection and possible relocation of transportation and wastewater treatment systems, for example, will be very expensive and not adapting will have significant adverse local and interstate consequences.

b. Wouldn't a price on carbon, which could serve to both reduce the severity of these climate impacts and provide the needed funds, make the most sense?

Answer. A carbon price would be very important. There are other approaches that can be pursued as well. For example, a recent key article in Science indicates that great progress can be made worldwide using existing technology in reducing methane emissions and black soot.

Question 3. As we think about our economic and energy future, we need to consider the real costs of inaction. A recent study has estimated that the impacts of climate change will cost my home state of Washington 10 billion dollars per year by 2020. This is an enormous burden that will be arriving very soon.

It is imperative that we get ahead of this curve and prepare for these impacts now. To that end, we must maintain vital funding of research programs and facilities that advance scientific knowledge and understanding and provide the foundation for cost-effective, innovative solutions. Unfortunately, funding carve-outs in the Department of Energy's Office of Science have impacted base program funding for user facilities and research in recent years.

In my home state, PNNL is working on solutions to the challenges climate change imposes, but to succeed, they need our continued support. In these fiscally austere times, it makes even less sense to be a penny wise and a pound foolish. PNNL is conducting important research, for example through the Atmospheric Radiation Measurement (ARM) Program, to get a better sense of what changes in climate are already occurring and will likely occur in the future—advancing our understanding of the climate system that include complex components such as aerosols, clouds, and the carbon cycle.

PNNL is also working to provide better information to plan for the coming impacts. They're developing high resolution models that incorporate critical infrastructure and natural resources of each region to inform mitigation and adaptation decisions at the state and regional level. This information will be invaluable for infrastructure planning by natural resource managers, energy companies, and government agencies that currently face great uncertainties in their decision making in response to changing regional climates.

It seems to me that the upfront costs of this research and planning will be extremely modest relative to the costs coming down the road.

a. Do all of you agree that proposed cuts to research and development will impede our ability to prepare for and mitigate the worst impacts of climate change?

Answer. Yes, proposed cuts would have potentially significant negative effects. In fact, additional funding is needed for vulnerability assessments and the monitoring and collection that is needed for these assessments.

b. Do you hear from states and localities appreciating your analysis and that they use your data to make better planning decisions?

Answer. Yes, states and localities have been quite active in sharing information and planning approaches. These include the Southeast Florida Regional Climate Change Compact, Broward and Martin Counties, Florida's Department of Economic Opportunity, The City of Punta Gorda, Florida, The Florida Department of Transportation, and The City of New York.

Question 4. Sea level rise, storm surges, and extreme weather events will increase the risk of flooding and damage to energy production and delivery systems such as power plants, transmission lines, pipelines, and oil refineries. More storm activity will increase the cost of power and infrastructure maintenance and lead to more, longer blackouts and disruptions of services.

As we plan for these potential disruptions, we should be looking for ways to make the electric grid more resilient and reliable. The Department of Energy's 2011 Quadrennial Technology Review found that we are "underinvesting in activities supporting modernization of the grid." This underinvestment delays the nation's transition to a more resilient, reliable, and secure electricity system, which is needed even more urgently due to the additional challenges from climate change.

a. Should grid modernization efforts and making the grid smarter be important parts of our response to electric vulnerabilities created by climate change?

Answer. Yes. Often the demands for power and power generating capacity are not co-located, which means that power will have to move long distances across the grid (note we lose about 6% of power in transmission). At present, the carrying capacity of the grid and the control systems required are not in place. As a result, without reinforcing the grid and migrating to digital controls, the grid will increasingly put populations at risk in the southeast, southwest, and Rocky Mountain states.

b. Is securing our grid against these threats just as important as against other potential threats such as cyberattacks?

Answer. The risks are categorically different. Cyber attacks can bring the grid down temporarily as a result of control interruptions. Hardening the access to the control system is the key to preventing cyber attacks. Climate change issues are associated with the carrying capacity of the wiring system. If power cannot get through the wiring, large scale interruptions will occur during the most vulnerable periods (very hot or cold).

[Responses to the following questions were not received at the time the hearing went to press:]

QUESTIONS FOR ADAM FREED FROM SENATOR BINGAMAN

Question 1. Opponents of policies to reduce carbon emissions often cite the costs and economic burden of such policies as a main reason for their opposition. Your testimony here today would indicate that the costs of inaction, and also of not planning for a certain level of climate change that we have already committed to, are quite high. Are there studies that effectively quantify these costs, and if so, how do they compare to the costs of being proactive?

Question 2. Are there particular power plants or other pieces of energy infrastructure that are of primary concern? Is it feasible to protect them, or will they simply need to be retired or replaced?

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TOOLS FOR FIXING THE PROBLEM

Question 1. In Congress, it has become apparent that cap-and-trade lacks the support needed to pass, and internationally, the U.N. has failed to develop a treaty that all nations are willing to ratify. What we are left with at the moment are regulations by the EPA under the Clean Air Act, which many of us oppose due to our concerns about their economic impact.

a. How much of a difference will CAFE standards and New Source Performance Standards for power plants actually have on projected sea level rise?

SETTING PRIORITIES

Question 2. A New York Times article from 2007, entitled "Feel Good vs. Do Good on Climate," brings up a number of interesting points on this subject. Using New York as a case in point, the article states that "The warming that has already occurred locally is on the same scale as what's expected globally in the next century." Bjorn Lomborg is also quoted as saying, "No historian would look back at the last two centuries and rank the rising sea level here as one of the city's major problems."

a. In comparison to malaria, famine, and other global problems that are affecting people right now, how much attention should be paid to rising sea levels?

ACCURACY TO DATE

Question 3. Scientists and researchers have been making projections about sea level rise for years—if not decades. Climate models are constantly being re-worked, and refined, but hearings like these provide an opportunity to look back as well as forward.

a. To the extent that past projections were made for sea level rise in 2010, 2012, or another point around the current period, how accurate have those projections been?

RESPONSIBILITY FOR FIXING THE PROBLEM

Question 4. Mr. Freed, as Deputy Director of Mayor Bloomberg's Office of Long-Term Planning and Sustainability, you've spent time looking at what projected sea level rise could mean for Manhattan. And the fact that you've looked at this is testament to the number of ways—and the number of entities—that could ultimately find a role in any problems that result.

a. In your view, does responsibility for addressing and preparing for sea level rise reside with state, local, or federal governments, companies, insurance providers, individuals—or some combination of all of them?

QUESTIONS FOR ADAM FREED FROM SENATOR CANTWELL

Question 1. In the Puget Sound region, sea level is projected to rise by six inches by 2050—13 inches by the end of the century. And due to potential ice melt from

Greenland and Antarctica, increases of up to four feet for Puget Sound are even possible by the end of the century. This is particularly alarming to me and my constituents because structures located in flood hazard areas are valued at 28.7 billion dollars in Puget Sound alone.

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Question 2. Knowing the responsibilities states, cities, and localities already have and their limited ability to raise additional resources, it seems like we are going to have to establish some sort of federal program that can direct the billions of dollars needed to adapt our nation's infrastructure to and protect our citizens from the impacts of climate change.

a. Do you believe such a Federal role and funding stream is necessary?

b. Wouldn't a price on carbon, which could serve to both reduce the severity of these climate impacts and provide the needed funds, make the most sense?

Question 3. As we think about our economic and energy future, we need to consider the real costs of inaction. A recent study has estimated that the impacts of climate change will cost my home state of Washington 10 billion dollars per year by 2020. This is an enormous burden that will be arriving very soon.

It is imperative that we get ahead of this curve and prepare for these impacts now. To that end, we must maintain vital funding of research programs and facilities that advance scientific knowledge and understanding and provide the foundation for cost-effective, innovative solutions. Unfortunately, funding carve-outs in the Department of Energy's Office of Science have impacted base program funding for user facilities and research in recent years.

In my home state, PNNL is working on solutions to the challenges climate change imposes, but to succeed, they need our continued support. In these fiscally austere times, it makes even less sense to be a penny wise and a pound foolish. PNNL is conducting important research, for example through the Atmospheric Radiation Measurement (ARM) Program, to get a better sense of what changes in climate are already occurring and will likely occur in the future—advancing our understanding of the climate system that include complex components such as aerosols, clouds, and the carbon cycle.

PNNL is also working to provide better information to plan for the coming impacts. They're developing high resolution models that incorporate critical infrastructure and natural resources of each region to inform mitigation and adaptation decisions at the state and regional level. This information will be invaluable for infrastructure planning by natural resource managers, energy companies, and government agencies that currently face great uncertainties in their decision making in response to changing regional climates.

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As we plan for these potential disruptions, we should be looking for ways to make the electric grid more resilient and reliable. The Department of Energy's 2011 Quadrennial Technology Review found that we are "underinvesting in activities supporting modernization of the grid." This underinvestment delays the nation's transition to a more resilient, reliable, and secure electricity system, which is needed even more urgently due to the additional challenges from climate change.

a. Should grid modernization efforts and making the grid smarter be important parts of our response to electric vulnerabilities created by climate change?

b. Is securing our grid against these threats just as important as against other potential threats such as cyberattacks?

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a. Do you believe such a Federal role and funding stream is necessary?

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Question 2. As we think about our economic and energy future, we need to consider the real costs of inaction. A recent study has estimated that the impacts of climate change will cost my home state of Washington 10 billion dollars per year by 2020. This is an enormous burden that will be arriving very soon.

It is imperative that we get ahead of this curve and prepare for these impacts now. To that end, we must maintain vital funding of research programs and facilities that advance scientific knowledge and understanding and provide the foundation for cost-effective, innovative solutions. Unfortunately, funding carve-outs in the Department of Energy's Office of Science have impacted base program funding for user facilities and research in recent years.

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It seems to me that the upfront costs of this research and planning will be extremely modest relative to the costs coming down the road.

a. Do all of you agree that proposed cuts to research and development will impede our ability to prepare for and mitigate the worst impacts of climate change?

b. Do you hear from states and localities appreciating your analysis and that they use your data to make better planning decisions?

Question 3. All of the testimonies indicate that the impacts from climate change are already here, and more are coming soon. I am wondering how much influence the amount of emissions over the next few decades will have on future climate change impacts.

Predicting the extent of future climate changes and evaluating impacts of alternative mitigation and adaptation strategies will require significant improvement in the accuracy of climate change models. We also need more complete representations of human systems at regional to local scales, where mitigation and adaptation planning occur.

a. In improving the accuracy and scope of our models, how helpful would it be to have a more certain emissions pathway into the future?

b. Would this certainty improve our ability to plan for and adapt to climate change impacts?

APPENDIX II

Additional Material Submitted for the Record

STATEMENT OF BEN STRAUSS AND REMIK ZIEMLINSKI, CLIMATE CENTRAL

SEA LEVEL RISE THREATS TO ENERGY INFRASTRUCTURE

A SURGING SEAS BRIEF REPORT BY CLIMATE CENTRAL

April 19, 2012.

Summary

Sea level rise from global warming is well on the way to doubling the risk of coastal floods 4 feet or more over high tide by 2030 at locations nationwide. In the lower 48 states, nearly 300 energy facilities stand on land below that level, including natural gas infrastructure, electric power plants, and oil and gas refineries. Many more facilities are at risk at higher levels, where flooding will become progressively more likely with time as the sea continues to rise. These results come from a Climate Central combined analysis of datasets from NOAA, USGS and FEMA.

Rising seas

Global warming has raised sea level about 8 inches since 1880, and the rate of rise is accelerating. Scientists expect 20 to 80 more inches this century, a lot depending upon how much more heat-trapping pollution humanity puts into the atmosphere. In the near term, rising seas will translate into more and more coastal floods reaching higher and higher, as sea level rise aggravates storm surges. These increases threaten widespread damage to the nation's energy infrastructure. This brief analyzes the potential risk.

Multiplying risk

Based on peer-reviewed research, Climate Central's March 2012 report, Surging Seas (surgingseas.org/NationalReport), made local sea level rise and coastal flood risk projections at 55 water-level stations distributed around the lower 48 states. At the majority of these sites and across the U.S., according to the projections, climate change more than doubles the odds of near-term extreme flooding, compared to a hypothetical world without warming. Across sites, median odds for floods reaching at least 4 feet above local high-tide lines are 55 percent by 2030. Median odds for floods exceeding 5 feet are 41 percent by 2050. Odds vary regionally, but generally rank highest along the Gulf of Mexico. However, warming multiplies odds the most along the Pacific and then Atlantic coasts. Numbers are detailed in Table 2 of Surging Seas.

Energy infrastructure exposed

A great number of coastal energy facilities lay below these elevations, exposed to increasing risk of floods. This analysis identifies 287 facilities less than 4 feet above the high-tide line, spread throughout the 22 coastal states of the lower 48. More than half of these are in Louisiana, mainly natural gas facilities. Florida, California, New York, Texas, and New Jersey each have 10-to-30 exposed sites, mainly for electricity in the first three states, and for oil and gas in the last two. All told, this brief catalogs 130 natural gas, 96 electric, and 56 oil and gas facilities built on land below the 4-foot line. Below the 5-foot line, the total jumps to 328 facilities with similar geographic and type distribution.

Figure 1* shows a map of coastal facility locations below 4 feet. Table 1 presents total energy facilities below 1-to-10 feet, state by state. Tables 2-4 break out natural gas, electric, and oil and gas facilities.

Analysis methods

To arrive at the values presented here, we overlay point coordinate data for energy facilities from the Federal Emergency Management Agency HAZUS Database / MH (version 1.1), against previously developed flood-risk zones. Surging Seas documents the methodology for developing these zones, which are based on the elevation of land relative to local high-tide lines (as opposed to standard elevation). The Surging Seas analysis employed national datasets from NOAA and USGS.

The HAZUS database breaks down energy facilities into several classes. We lump "Oil / Gas Refinery" and "Oil / Gas Storage Facility / Tank Farm" together with "Oil / Gas Facility"; the database includes only two sites in the first two categories less than 10 feet, vs. 118 for the last category. Similarly, we lump "Substation" (1 below 10 feet) together with "Electric Facility" (201).

Limitations

The results presented here should be presented with certain limits in mind. For example, the FEMA source data used includes only point coordinate values for each energy facility. Actual facilities cover larger areas that may include higher or lower elevations. This analysis uses the best publicly available elevation data covering the entire coast of the lower 48 states. However, like most datasets, the elevation dataset includes errors, so any point may be higher or lower than the value provided. These factors mean that results for any individual facility should be viewed cautiously. We therefore do not present results at the individual level. However, averaged over many facilities, potential errors should cancel out, making the aggregate findings presented more reliable.

This analysis simply tallies facilities under different elevations. It does not account for levees, seawalls, or other features that may offer protection. However, areas depressed below a sea-flood level, even if isolated from the ocean, may be more subject to flooding from rainwater during storms, as drainage would be impeded.

The Surging Seas report presents more thorough and detailed limits that all apply for this brief as well.

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*Figure has been retained in committee files.

Table 1. Total energy facilities on land less than 1-to-10 feet below local high tide. Includes oil and gas, natural gas, and electric facilities, as well as other facilities.

State	1 ft	2 ft	3 ft	4 ft	5 ft	6 ft	7 ft	8 ft	9 ft	10 ft
Alabama	0	0	1	3	3	3	5	6	8	8
California	8	12	19	22	24	27	29	34	40	42
Connecticut	5	5	5	5	5	5	6	7	7	7
Delaware	0	0	0	0	0	3	4	4	4	5
Florida	6	12	19	26	30	33	34	44	47	49
Georgia	2	2	5	5	5	7	8	9	10	10
Louisiana	101	114	131	148	163	170	182	184	203	206
Maine	1	1	1	1	1	1	1	1	1	1
Maryland	1	2	3	4	5	5	6	7	10	11
Massachusetts	2	2	2	3	6	9	11	11	12	12
Mississippi	0	0	0	1	1	2	2	2	2	2
New Hampshire	2	2	2	2	2	2	2	2	3	3
New Jersey	10	12	15	17	21	22	34	40	46	50
New York	7	8	11	13	14	15	16	20	23	27
North Carolina	3	3	5	5	5	5	5	5	5	5
Oregon	1	1	1	1	2	2	2	2	2	2
Pennsylvania	1	1	1	1	1	2	4	6	7	7
Rhode Island	0	0	0	0	0	1	2	2	2	2
South Carolina	1	1	1	1	2	2	3	3	3	3
Texas	4	5	5	17	23	25	27	29	33	35
Virginia	1	1	2	3	5	5	6	8	13	14
Washington	6	6	6	9	10	12	14	14	14	18
Total	162	190	235	287	328	358	403	440	495	519

Table 2. Natural gas facilities on land less than 1-to-10 feet below local high tide.

State	1 ft	2 ft	3 ft	4 ft	5 ft	6 ft	7 ft	8 ft	9 ft	10 ft
Alabama	0	0	1	1	1	1	1	2	2	2
California	0	0	1	1	1	1	1	1	1	1
Connecticut	0	0	0	0	0	0	0	0	0	0
Delaware	0	0	0	0	0	0	0	0	0	0
Florida	1	1	1	1	2	2	3	3	3	3
Georgia	0	0	1	1	1	1	1	1	1	1
Louisiana	84	96	110	123	135	140	150	151	165	166
Maine	0	0	0	0	0	0	0	0	0	0
Maryland	0	0	0	0	0	0	0	0	0	0
Massachusetts	0	0	0	0	0	1	1	1	1	1
Mississippi	1	1	1	1	1	1	1	1	1	1
New Hampshire	0	0	0	0	0	0	0	0	1	2
New Jersey	0	0	0	0	0	0	0	0	0	0
New York	0	0	0	0	0	0	0	0	0	0
North Carolina	0	0	0	0	0	0	0	0	0	0
Oregon	0	0	0	0	0	0	0	0	0	0
Pennsylvania	0	0	0	0	0	0	0	0	0	0
Rhode Island	1	1	1	1	2	2	2	2	3	3
South Carolina	0	0	0	0	1	1	1	2	2	2
Texas	1	1	1	1	1	2	2	2	2	3
Virginia	1	1	2	3	5	5	6	8	13	14
Washington	6	6	6	9	10	12	14	14	14	18
Total	88	100	117	130	145	152	169	166	182	185

Table 3. Electric facilities on land less than 1-to-10 feet below local high tide.

State	1 ft	2 ft	3 ft	4 ft	5 ft	6 ft	7 ft	8 ft	9 ft	10 ft
Alabama	0	0	0	0	0	0	2	2	3	3
California	5	9	12	15	17	19	20	23	27	28
Connecticut	5	5	5	5	5	5	5	6	6	6
Delaware	0	0	0	0	0	3	4	4	4	5
Florida	3	8	15	22	25	27	27	34	36	38
Georgia	1	1	3	3	3	4	5	5	6	6
Louisiana	6	6	8	8	9	10	10	10	14	14
Maine	1	1	1	1	1	1	1	1	1	1
Maryland	1	2	2	3	4	4	4	5	8	9
Massachusetts	2	2	2	3	6	9	10	10	11	11
Mississippi	0	0	0	0	0	0	0	0	0	0
New Hampshire	1	1	1	1	1	1	1	1	1	1
New Jersey	3	4	6	7	10	10	17	19	23	24
New York	6	7	10	12	13	14	15	17	18	21
North Carolina	3	3	5	5	5	5	5	5	5	5
Oregon	1	1	1	1	2	2	2	2	2	2
Pennsylvania	0	0	0	0	0	1	2	4	5	5
Rhode Island	0	0	0	0	0	1	2	2	2	2
South Carolina	0	0	1	1	1	1	2	2	2	2
Texas	0	0	0	3	3	3	3	3	3	4
Virginia	1	1	2	3	4	4	4	4	8	8
Washington	2	2	2	3	4	5	6	6	6	7
Total	42	54	76	96	113	129	147	165	191	202

Table 4. Oil and gas facilities on land less than 1-to-10 feet below local high tide.

State	1 ft	2 ft	3 ft	4 ft	5 ft	6 ft	7 ft	8 ft	9 ft	10 ft
Alabama	0	0	0	2	2	2	2	2	3	3
California	2	2	5	5	5	6	7	9	11	12
Connecticut	0	0	0	0	0	0	1	1	1	1
Delaware	0	0	0	0	0	0	0	0	0	0
Florida	0	0	0	0	0	0	0	3	4	4
Georgia	1	1	1	1	1	2	2	3	3	3
Louisiana	11	12	13	17	19	20	22	23	23	25
Maine	0	0	0	0	0	0	0	0	0	0
Maryland	0	0	1	1	1	1	2	2	2	2
Massachusetts	0	0	0	0	0	0	1	1	1	1
Mississippi	0	0	0	1	1	1	1	1	1	1
New Hampshire	0	0	0	0	0	0	0	0	1	1
New Jersey	6	7	8	9	10	11	15	18	20	23
New York	1	1	1	1	1	1	1	2	3	3
North Carolina	0	0	0	0	0	0	0	0	0	0
Oregon	0	0	0	0	0	0	0	0	0	0
Pennsylvania	1	1	1	1	1	1	2	2	2	2
Rhode Island	0	0	0	0	0	0	0	0	0	0
South Carolina	0	0	0	0	1	1	1	1	1	1
Texas	3	4	4	13	18	20	22	24	27	28
Virginia	0	0	0	0	0	0	1	2	3	3
Washington	3	3	3	5	5	5	6	6	6	7
Total	28	31	37	56	65	71	86	100	112	120

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STATEMENT OF BEN STRAUSS, CLAUDIA TEBALDI, AND REMIK ZIEMLINSKI

A CLIMATE CENTRAL REPORT: SURGING SEAS

SEA LEVEL RISE, STORMS & GLOBAL WARMING'S THREAT TO THE US COAST

March 14, 2012.

Executive Summary

Global warming has raised sea level about 8 inches since 1880, and the rate of rise is accelerating. Scientists expect 20 to 80 more inches this century, a lot depending upon how much more heat-trapping pollution humanity puts into the sky. This study makes mid-range projections of 1-8 inches by 2030, and 4-19 inches by 2050, depending upon location across the contiguous 48 states.

Rising seas dramatically increase the odds of damaging floods from storm surges. For over two-thirds of the locations analyzed (and for 85% of sites outside the Gulf of Mexico), past and future global warming more than doubles the estimated odds of "century" or worse floods occurring within the next 18 years—meaning floods so high they would historically be expected just once per century. For over half the locations analyzed, warming at least triples the odds of century-plus floods over the same period. And for two-thirds the locations, sea level rise from warming has already more than doubled the odds of such a flood even this year.

These increases are likely to cause an enormous amount of damage. At three quarters of the 55 sites analyzed in this report, century levels are higher than 4 feet above the high tide line. Yet across the country, nearly 5 million people live in 2.6 million homes at less than 4 feet above high tide. In 285 cities and towns, more than half the population lives on land below this line, potential victims of increasingly likely climate-induced coastal flooding. 3.7 million live less than 1 meter above the tide.

About half of this exposed population, and eight of the top ten cities, are in the state of Florida. A preliminary independent analysis suggests about $30 billion in taxable property is vulnerable below the three-foot line in just three counties in southeast Florida, not including the county with the most homes at risk in the state and the nation, Miami-Dade. Small pockets or wide areas of vulnerability, however, exist in almost every other coastal state.

The population and homes exposed are just part of the story. Flooding to four feet would reach higher than a huge amount of dry land, covering some 3.0 million acres of roads, bridges, commercial buildings, military bases, agricultural lands, toxic waste dumps, schools, hospitals, and more. Coastal flooding made worse by global warming and rising seas promises to cause many billions of dollars of damage over the coming decades.

This report and its associated materials, based on two just-published peer-reviewed studies, is the first major national analysis of sea level rise in 20 years, and the first one ever to include:

- Estimates of land, population and housing at risk;
- Evaluations of every low-lying coastal town, city, county and state in the contiguous US;
- Localized timelines of storm surge threats integrating local sea level rise projections; and
- A freely available interactive map and data to download online (see SurgingSeas.org).

Summaries of these findings at a state-by-state level are available in fact sheets at SurgingSeas.org/factsheets. The original peer-reviewed studies can be found via SurgingSeas.org/papers. All findings reflect best estimates from the research; actual values may vary.

This report focuses on new research and analysis, not recommendations; but it is clear from the findings here that in order to avoid the worst impacts, the United States must work to slow sea level rise by reducing emissions of heat-trapping gases, and work to diminish the remaining danger by preparing for higher seas in coastal cities and counties everywhere. SurgingSeas.org/plans lists a selection of existing resources, plans and efforts to prepare, from local to national levels.

SEA LEVEL RISING

Background

Global average sea level has increased over 8 inches since 1880,[1] and global warming has caused the great majority, if not all, of that rise.[2] Warming has acted in two main ways: by heating up and thus expanding the global ocean; and by attacking glaciers and polar ice sheets, pouring meltwater and icebergs into the sea.[3] The planet has heated by more than one degree Fahrenheit over the last century, rising faster as we have burned coal, oil and gas faster, and so sent ever more heat-trapping gases into the air.[4] Scientists overwhelmingly agree that these building gases are responsible for most of the warming observed thus far.[5]

Warming and sea level rise[6] are both accelerating, as is the rate of decay of ice sheets on Greenland and Antarctica.[7] Loss of ice from these sources has the potential to raise sea level by many tens of feet over centuries. In the warm period before the last Ice Age—when the planet was as warm as we expect it to become by 2100 or sooner, at least without deep and immediate cuts to pollution—global sea level very likely reached over 20 feet higher than it is today,[8] an eventual sea level we could be committing to within decades[9] if not already.[10] That rise would be enough to drown many major coastal metropolises.

Projections

This century, scientists expect about 20 to 80 more inches of global sea level rise, depending significantly on how much more heat-trapping pollution humankind puts into the sky.[11] The amount also depends on just how strongly pollution translates into warming, and just how strongly warming translates into sea rise. The analysis

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[1] Church J A and White N J 2011. Sea-level rise from the late 19th to the early 21st century. Surveys in Geophysics

[2] Moore J C, Jevrejeva S and Grinsted A 2011. The historical global sea-level budget. Annals of Glaciology. Also Church J A, White N , Konikow L F, Domingues C M, Cogley J G, Rignot E, Gregory J M, van den Broeke M R, Monaghan A J, and Velicogna I 2011. Revisiting the Earth's sea-level and energy budgets from 1961 to 2008. Geophysical Research Letters. Also Shum C K and Kuo C-Y 2011. Observation and geophysical causes of present-day sea-level rise. In Climate Change and Food Security in South Asia, R. Lal et al, eds.

[3] Ibid. Also Bindoff N L and others 2007. Observations: Oceanic climate change and sea level. In S Solomon and others, editors, Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change.

[4] S Solomon and others 2007. Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press.

[5] Oreskes N 2004. The scientific consensus on climate change. Science

[6] Church J A and White N J 2006. A 20th century acceleration in global sea-level rise. Geophysical Research Letters

[7] Rignot E, Velicogna I, Van den Broeke M R, Monaghan A, and Lenaerts J 2011. Acceleration of the contribution of the Greenland and Antarctic ice sheets to sea level rise. Geophysical Research Letters.

[8] Kopp R E, Simons F J, Mitrovica J X, Maloof A C, and Oppenheimer M 2009. Probabilistic assessment of sea level during the last interglacial stage. Nature.

[9] Ibid. and Overpeck J T, Otto-Bliesner B L, Miller G H, Muhs D R, Alley R B and Kiehl J T 2006. Paleoclimatic evidence for future ice-sheet instability and rapid sea-level rise. Science

[10] Rohling E J, Grant K, Bolshaw M, Roberts A P, Siddall M, Hemleben Ch, and Kucera M 2009. Antarctic temperature and global sea level closely coupled over the last five glacial cycles. Nature Geoscience

[11] Vermeer M and Rahmstorf S 2009. Global sea level linked to global temperature. Proceedings of the National Academy of Sciences. Also Pfeffer W T, Harper J T and O'Neel S 2008. Kinematic constraints on glacier contributions to 21st-century sea-level rise. Science. Also Grinsted A, Moore J C, and Jevrejeva S 2009. Reconstructing sea level from paleo and projected temperatures 200 to 2100AD. Climate Dynamics

presented in this report, based on a paper by Tebaldi and others,[12] takes a wide range of possibilities into account. It also factors in the gradual sinking or rising of coastal land around much of the U.S., which leads to faster or slower rates of local sea level rise, compared to global rates.

This study's middle-of-the-road projections for 2030 range from one inch of local sea level rise in the northwest corner of Washington State, where the land is slowly rising, to 8 inches near New Orleans, where it is sinking. By 2050, these projections increase to 4 and 19 inches, respectively. Best-and worst-case projections range from lower to considerably higher values. Table 1 shows findings for all 55 locations studied, plus regional and national summaries.

Storm surge: The risk multiplier

Rising seas dramatically increase the odds of damaging floods from storm surges. For over two-thirds of the 55 locations analyzed (and for 85% of sites outside the Gulf of Mexico), past and future global warming more than doubles the estimated odds of "century" (or worse) floods occurring by 2030—meaning floods so high they would historically be seen with only a one percent (or less) chance per year. For over half the locations analyzed, warming at least triples the odds of century-plus floods. Figure 1* illustrates these changes around the nation, and Table 2 shows results at all flood study sites. Additionally, for two-thirds of the locations, sea level rise from warming has already at least doubled the annual risk of century-plus floods (see Table 2 and footnote 18). These calculations all incorporate the assumption that 90% of historic sea level rise has stemmed from warming.

The increases in odds come despite the fact that sea level rise from warming, over the next two decades and over the last century, is better measured in inches than in feet. In many places, only inches separate the once-a-decade flood from the once-a-century one; and separate the water level communities have prepared for, from the one no one has seen. Critically, a small change can make a big difference, like the last inch of water that overflows a tub. Sea level rise is raising the launch pad for storms and high tides, and being experienced by the ever-more frequent occurrence of extreme high water levels during these events—long before the ocean reaches damaging heights permanently.

Flood waters will reach different levels in different places on different schedules. Part of these differences will come from uneven local rates of sea level rise, part will come from chance, and part will come from how big local storm surges tend to be, which can vary a lot. Mostly because of this last factor, expected heights above high tide are generally about a foot higher than the national average in the Gulf of Mexico, and a foot lower than average in southern California and the southern Atlantic coast. But lower heights do not necessarily imply lower risk. For example, two feet of sea level rise should make an enormous difference in places where two-foot surges are rare extremes, and relatively less in places where ten-foot surges are sometimes seen.

This study found that at over half the sites examined, there is a one-in-two or better chance of water reaching at least 4 feet higher than the average local high tide by 2030, at least once. 85 percent of stations have at least one-in-six odds. By 2050, many locations should experience 5-foot or higher floods, with at least one-in-two odds at nearly half of stations, and at least one-in-six odds at nearly two-thirds. In all cases, sea level rise caused by global warming increases the odds, usually doubling or tripling them or more. Table 2 provides details for each site studied.

U.S. vulnerability

Floods exceeding these levels are likely to cause an enormous amount of damage. Across the country, nearly 5 million people live in 2.6 million homes on land less than 4 feet above high tide. In 285 cities and towns, more than half the population lives below this line, potential victims of increasingly likely climate-induced coastal flooding. And nationwide, over 6 million people live on land less than 5 feet above average high tide. Based on a paper by Strauss and others,[13] this study estimated the land, housing and population less than 1-10 feet above local high tide levels, for every coastal town, city, county and state in the contiguous 48 states. SurgingSeas.org presents full results in a searchable, interactive map and in tables. 3.7 million live on land less than 1 meter above the local high tide.

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[12] Tebaldi C, Strauss B H and Zervas C E 2012. Modelling sea level rise impacts on storm surges along US coasts. Environmental Research Letters.

* Figure 1 has been retained in committee files.

[13] Strauss B H, Ziemlinski R, Weiss J L, and Overpeck J T 2012. Tidally adjusted estimates of topographic vulnerability to sea level rise and flooding for the contiguous United States. Environmental Research Letters

About half of the exposed population under 4 feet, and eight of the top ten cities, are in the state of Florida. A preliminary independent analysis suggests about $30 billion in taxable property lies below the three-foot line in just three counties in southeast Florida, not including the county with the most homes at risk in the state and the nation, Miami-Dade.[14]

Small pockets or wide areas of vulnerability, however, exist in almost every other coastal state, as Figure 2* makes clear. Table 3 shows the top ten states, counties and cities by total population living less than 4 feet above local high tide. State fact sheets at SurgingSeas.org/factsheets provide more summary information at a state level. The map at SurgingSeas.org links each city displayed with the nearest flood analysis site used in this study, as an indicator for when and with what chances a given water height might be achieved in the area. Actual odds may vary over even small distances.

The population and homes exposed are just part of the story. Flooding to four feet would reach higher than a huge amount of dry land, covering some 3 million acres of roads, bridges, commercial buildings, military bases, agricultural lands, toxic waste dumps, schools, hospitals, and more. Coastal flooding made worse by global warming and rising seas promises to cause many billions of dollars of damage over the coming decades. This report focuses on population, housing and land, but future analyses will address infrastructure, landmarks, and property threatened.

A number of state and local governments are beginning to plan or even take action against the challenge of sea level rise. SurgingSeas.org/plans presents a list and further resources.

Research methods

To make maps of low and vulnerable coastal land, this study used the highest-resolution nationwide coastal elevation data publicly available, from the National Elevation Dataset (US Geological Survey; cells ca. 30 feet on a side). We adjusted elevations to indicate heights compared to the nearest average high tide levels, because these can vary by several feet from place to place. Tidal information came from VDatum, a tool created by the National Oceanic and Atmospheric Administration. We then removed from consideration all wetland area as defined by the National Wetlands Inventory, and overlaid the remaining map elevation zones against high-resolution data from the 2010 Census to extract population and housing estimates. SurgingSeas.org/LandAnalysis provides more detail.

To analyze future high water levels from sea level rise plus storm surge and tides, we studied 55 water level gauges around the US. We combined local factors, such as sinking land, and global future sea level rise estimates, to make local sea level rise projections at each site. We then used historic patterns of local extreme water levels to forecast future probabilities of extremes assuming the same patterns continue, but augmented by the projected local sea level rise. Our analysis also included developing confidence intervals around best estimates. SurgingSeas.org/FloodAnalysis provides more detail.

To estimate how global warming shifts the odds of high storm surges, we computed extreme event probabilities in a hypothetical world with no warming-induced sea level rise, past or future, and then compared the results with our first calculations including warming. We retained local sea level change from vertical land movement in the no-warming scenario. Based on a review of scientific literature, we assumed that 10% of the global average sea level rise observed since 1880 came from factors other than warming, and so also retained this 10% of global rise in the no-warming scenario.

For more detail, visit SurgingSeas.org/research, which includes links to fuller descriptions of our methods, and the two core scientific papers upon which this report is based:

Tebaldi C, Strauss B H and Zervas C E 2012. Modelling sea level rise impacts on storm surges along US coasts. Environmental Research Letters.

Strauss B H, Ziemlinski R, Weiss J L, and Overpeck J T 2012. Tidally adjusted estimates of topographic vulnerability to sea level rise and flooding for the contiguous United States. Environmental Research Letters.

Limitations

The results presented here should be interpreted with certain limits in mind. One set of limits comes from the elevation data used. Like almost any dataset, it in-

[14] Draft Regional Climate Action Plan of the Southeast Florida Regional Climate Change Compact, Appendix E, via http://www.southeastfloridaclimatecompact.org/index—files/Page648.htm, accessed January 2012.

* Figure 2 has been retained in committee files.

cludes errors—so any point classified as below a given height, may in fact be above it; and any point classified as above a height, may be below it. These potential errors should cancel out when evaluating the totals of what is affected over larger areas like towns, cities and counties. However, elevation error should be kept in mind when looking at any individual point on the map that accompanies this analysis (SurgingSeas.org/map).

Another issue from the elevation data concerns their horizontal resolution. Cells 30 feet on a side are too large to completely capture fine features like levees or seawalls, which may protect land even when it is below the water level, such as in the New Orleans area. Therefore, this analysis quantifies the land, housing and population below different threshold elevations—amounts not affected by built protection—but does not evaluate how much would be inundated, given each water level. Of course, many areas are not protected; protected areas are protected only to limited heights; and being below water level poses challenges for storm water drainage, increasing the risk of rain-driven flooding.

The analysis of flood odds and timing applies strictly only at the 55 water level gauge sites studied, and can only be considered general indicators for the surrounding areas. This is mainly because storm surge patterns can vary from place to place, even over short distances, due to geography and storm directions. Statistics among gauges sometimes correspond well over wide areas, suggesting wide applicability. But they also sometimes vary greatly over short distances, suggesting the opposite.

This report assumes that recent historic storm patterns do not change in the future. However, global warming may change the frequency or intensity of storms that affect coastal flooding. This analysis also leaves out projected changes in Atlantic circulation expected to add several extra inches of sea level rise along the Northeast Corridor by mid-century;[15] and projected changes in the "gravity fingerprint" of global oceans,[16] which may partly counteract the first change.[17]

Most broadly, this report presents our best estimates for the quantities analyzed, given the underlying data and our assumptions. True values are likely to fall above or below our estimates.

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Table 1. Projected sea level rise with 90% confidence intervals.

		Projected sea level rise (inches)			
		By 2030		By 2050	
NOAA water level station	State	Best estimate	90% range	Best estimate	90% range
National average		5	2-9	12	6-22
Atlantic average		6	2-10	13	6-23
Gulf average		6	3-9	13	8-23
Pacific average		4	0-8	9	2-20
Eastport - Passamaquoddy Bay	ME	4	1-8	9	2-20
Portland - Casco Bay	ME	4	1-8	10	3-20
Boston - Boston Harbor	MA	5	2-9	12	5-22
Woods Hole - Buzzards Bay	MA	5	2-9	12	5-22
Nantucket Island, Nantucket Sound	MA	5	2-10	13	6-23
Newport - Narragansett Bay	RI	5	2-9	12	5-22
Providence - Providence River	RI	5	2-9	11	4-22
New London - Thames River	CT	5	2-9	12	5-22
Bridgeport - Bridgeport Harbor	CT	5	2-9	12	5-22
Montauk - Fort Pond Bay	NY	6	2-10	13	6-23
The Battery - New York Harbor	NY	5	2-9	13	6-23
Atlantic City - Atlantic Ocean	NJ	7	4-11	15	8-25
Cape May - Cape May Canal	NJ	6	3-10	15	8-25
Reedy Point - C&D Canal	DE	6	3-10	14	7-24
Lewes - Ft. Miles	DE	6	3-10	13	6-24
Cambridge, Choptank River	MD	6	2-10	13	6-23
Baltimore - Fort McHenry	MD	5	2-10	13	6-23
U.S. Naval Academy - Severn R.	MD	6	2-10	13	6-23
Solomons Island - Patuxent River	MD	6	3-10	14	7-25
Washington - Potomac River	DC	6	2-10	13	6-23
Kiptopeke - Chesapeake Bay	VA	6	3-10	14	7-24
Lewisetta - Potomac River	VA	7	4-11	16	9-26
Sewells Point - Hampton Roads	VA	7	4-11	16	9-26
Chesapeake Bay Bridge Tunnel	VA	8	5-12	17	10-28
Beaufort, Duke Marine Lab	NC	6	2-10	13	6-23
Wilmington - Cape Fear River	NC	5	2-9	11	4-22
Springmaid Pier - Atlantic Ocean	SC	6	3-10	14	7-25
Charleston - Cooper River Entrance	SC	5	2-10	13	6-23
Fort Pulaski - Savannah River	GA	6	3-10	13	6-24
Fernandina Beach - Amelia River	FL	5	2-9	12	5-22
Vaca Key - Florida Bay	FL	5	2-10	13	6-23
Key West	FL	5	2-9	12	5-22
Naples - Gulf Of Mexico	FL	5	1-9	11	4-22
St. Petersburg, Tampa Bay	FL	5	2-9	12	5-23
Clearwater Beach - Gulf Of Mexico	FL	5	2-9	12	5-22
Apalachicola - Apalachicola River	FL	4	1-8	10	3-20
Pensacola - Pensacola Bay	FL	5	1-9	11	4-21
Grand Isle, East Point	LA	8	7-12	19	14-27
Sabine Pass North	TX	5	3-8	11	7-20
Galveston Pier 21 - Galveston Channel	TX	7	5-10	16	12-24
Galveston Pleasure Pier - Gulf Of Mexico	TX	8	6-11	18	14-26
Freeport, Dow Barge Canal	TX	6	4-9	14	9-22
Rockport - Aransas Bay	TX	6	4-9	14	10-22
Port Isabel - Laguna Madre	TX	6	4-9	13	9-21
La Jolla - Pacific Ocean	CA	5	2-9	11	4-22
Los Angeles - Outer Harbor	CA	4	1-8	10	3-20
Port San Luis - Pacific Ocean	CA	3	0-7	9	2-19
Monterey - Monterey Harbor	CA	4	1-8	10	3-20
San Francisco - San Francisco Bay	CA	4	1-9	11	4-21
Charleston - Coos Bay	OR	4	0-8	9	2-20
South Beach - Yaquina River	OR	5	2-9	12	5-22
Astoria - Tongue Point	OR	3	-1-7	7	0-18
Toke Point - Willapa Bay	WA	4	1-8	10	3-20
Neah Bay - Strait of Juan De Fuca	WA	1	-2-5	4	-3-15
Seattle - Puget Sound	WA	4	1-9	11	4-21

Table 2. Increase in flood odds driven by sea level rise from global warming.[18]

NOAA water level station	State	Historic "century" floods: Height (feet)	Historic "century" floods: Projected Odds by 2030	Historic "century" floods: Global Warming Multiplier	Floods to 4 feet: Projected Odds by 2030	Floods to 4 feet: Global Warming Multiplier	Floods to 5 feet: Projected Odds by 2050	Floods to 5 feet: Global Warming Multiplier
Median, all listed stations		4.7	25%	>3	55%	1.9	41%	2.8
Median, listed Atlantic stations		4.7	27%	>3	43%	2.1	39%	2.9
Median, listed Gulf stations		6.6	20%	1.4	[illegible]	[illegible]	[illegible]	[illegible]
Median, listed Pacific stations		4.1	[illegible]	>3	[illegible]	[illegible]	[illegible]	[illegible]
Eastport - Passamaquoddy Bay	ME	5.4	28%	>3	100%	1.2	98%	>3
Portland - Casco Bay	ME	4.0	36%	>3	24%	>3	2%	>3
Boston - Boston Harbor	MA	5.6	23%	2.5	90%	[illegible]	[illegible]	[illegible]
Woods Hole - Buzzards Bay	MA	4.8	25%	>3	55%	[illegible]	[illegible]	[illegible]
Nantucket Island, Nantucket Sound	MA	4.4	28%	>3	37%	2.9	24%	>3
Newport - Narragansett Bay	RI	4.7	24%	2.7	47%	2.3	37%	2.9
Providence - Providence River	RI	8.5	20%	1.3	93%	[illegible]	[illegible]	[illegible]
New London - Thames River	CT	4.1	37%	>3	35%	[illegible]	[illegible]	[illegible]
Bridgeport - Bridgeport Harbor	CT	5.6	23%	2.6	86%	1.7	75%	2.4
Montauk - Fort Pond Bay	NY	4.2	36%	>3	39%	>3	16%	>3
The Battery - New York Harbor	NY	5.2	26%	>3	[illegible]	[illegible]	[illegible]	[illegible]
Atlantic City - Atlantic Ocean	NJ	5.2	30%	>3	67%	[illegible]	[illegible]	[illegible]
Cape May - Cape May Canal	NJ	4.7	32%	>3	65%	2.7	45%	>3
Reedy Point - C&D Canal	DE	3.9	33%	>3	18%	>3	11%	>3
Lewes - Ft. Miles	DE	5.4	28%	>3	91%	[illegible]	[illegible]	[illegible]
Cambridge, Choptank River	MD	4.1	27%	>3	23%	[illegible]	[illegible]	[illegible]
Baltimore - Fort McHenry	MD	5.7	22%	1.8	66%	1.7	63%	1.8
U.S. Naval Academy - Severn R.	MD	5.3	22%	1.9	53%	1.7	51%	1.9
Solomons Island - Patuxent River	MD	4.4	24%	2.1	28%	[illegible]	[illegible]	[illegible]
Washington - Potomac River	DC	10.1	19%	1.2	95%	[illegible]	[illegible]	[illegible]
Kiptopeke - Chesapeake Bay	VA	3.9	42%	>3	19%	>3	6%	>3
Lewisetta - Potomac River	VA	4.2	29%	2.9	25%	2.1	23%	2.7
Sewells Point - Hampton Roads	VA	5.4	29%	>3	80%	[illegible]	[illegible]	[illegible]
Chesapeake Bay Bridge Tunnel	VA	4.8	45%	>3	77%	[illegible]	[illegible]	[illegible]
Beaufort, Duke Marine Lab	NC	4.9	22%	1.8	39%	1.7	40%	1.8
Wilmington - Cape Fear River	NC	4.0	24%	2.6	19%	2.2	17%	2.5
Springmaid Pier - Atlantic Ocean	SC	4.1	36%	>3	25%	[illegible]	[illegible]	[illegible]
Charleston - Cooper River Entrance	SC	5.1	22%	1.9	50%	[illegible]	[illegible]	[illegible]
Fort Pulaski - Savannah River	GA	3.3	83%	>3	0%	>3	0%	n/a
Fernandina Beach - Amelia River	FL	3.3	55%	>3	1%	>3	0%	>3
Vaca Key - Florida Bay	FL	3.0	25%	2.6	7%	[illegible]	[illegible]	[illegible]
Key West	FL	3.1	24%	2.4	6%	[illegible]	[illegible]	[illegible]
Naples - Gulf Of Mexico	FL	3.9	25%	>3	19%	2.9	12%	>3
St. Petersburg, Tampa Bay	FL	6.5	20%	1.5	69%	1.5	71%	1.5
Clearwater Beach - Gulf Of Mexico	FL	6.6	20%	1.4	67%	[illegible]	[illegible]	[illegible]
Apalachicola - Apalachicola River	FL	15.0	19%	1.1	95%	[illegible]	[illegible]	[illegible]
Pensacola - Pensacola Bay	FL	14.0	19%	1.1	85%	1.1	93%	1.1
Grand Isle, East Point	LA	9.2	20%	1.2	78%	1.3	89%	1.2
Sabine Pass North	TX	6.3	20%	1.4	61%	[illegible]	[illegible]	[illegible]
Galveston Pier 21 - Galveston Channel	TX	7.0	21%	1.5	[illegible]	[illegible]	[illegible]	[illegible]
Galveston Pleasure Pier - Gulf Of Mexico	TX	11.3	20%	1.2	96%	1.1	99%	1.1
Freeport, Dow Barge Canal	TX	5.2	23%	2.1	62%	1.9	59%	2.3
Rockport - Aransas Bay	TX	6.1	20%	1.3	47%	[illegible]	[illegible]	[illegible]
Port Isabel - Laguna Madre	TX	5.9	20%	1.4	45%	[illegible]	[illegible]	[illegible]
La Jolla - Pacific Ocean	CA	3.2	89%	>3	0%	n/a	0%	n/a
Los Angeles - Outer Harbor	CA	3.2	83%	>3	0%	n/a	0%	n/a
Port San Luis - Pacific Ocean	CA	3.5	32%	>3	4%	[illegible]	[illegible]	[illegible]
Monterey - Monterey Harbor	CA	3.4	39%	>3	2%	[illegible]	[illegible]	[illegible]
San Francisco - San Francisco Bay	CA	4.1	27%	>3	28%	>3	14%	>3
Charleston - Coos Bay	OR	4.4	38%	>3	85%	>3	16%	>3
South Beach - Yaquina River	OR	4.6	42%	>3	94%	[illegible]	[illegible]	[illegible]
Astoria - Tongue Point	OR	4.5	43%	>3	[illegible]	[illegible]	[illegible]	[illegible]
Toke Point - Willapa Bay	WA	6.5	24%	>3	100%	1	100%	1.2
Neah Bay - Strait of Juan De Fuca	WA	4.7	21%	>3	100%	>3	28%	>3
Seattle - Puget Sound	WA	4.1	65%	>3	66%	[illegible]	[illegible]	[illegible]

[18] Odds are for floods by given years, not within given years. Flood heights measured relative to local high tide. Century flood levels estimated using historic flooding patterns and assuming 2009 sea level as a baseline. Global warming multipliers indicate how much sea level rise from global warming has multiplied flood odds, compared to a world without warming, to reach the projected odds shown. 90% of historic global average sea level rise since 1880 is assumed to come from warming. Historic century flood odds have already doubled at all sites with multipliers >2 by 2030, except for at Solomons Island, MD and Freeport, TX, where odds have increased by 90% or more.

Table 3. Top ten nationally-ranked states, counties and cities for largest total populations living on land less than four feet above local high tide.

Rank	Top 10 States	Top 10 Counties	Top 10 Cities
1	Florida	Miami-Dade, FL	New Orleans, LA*
2	Louisiana*	Broward, FL	New York, NY
3	California	Jefferson, LA*	Hialeah, FL
4	New York	Orleans, LA*	Metairie, LA*
5	New Jersey	Lee, FL	Pembroke Pines, FL
6	Virginia	Pinellas, FL	Cape Coral, FL
7	Texas	Nassau, NY	Miami Beach, FL
8	North Carolina	San Mateo, CA	Plantation, FL
9	South Carolina	Collier, FL	Miramar, FL
10	Massachusetts	Hillsborough, FL	Fort Lauderdale, FL

* includes significant populations on land already under the local high tide line, and protected by levees

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ATTACHMENTS OF LEONARD BERRY, DIRECTOR, FLORIDA CENTER FOR ENVIRONMENTAL STUDIES, FLORIDA ATLANTIC UNIVERSITY, JUPITER, FL

ANNEX A.—SOUTHEAST FLORIDA SEA LEVEL RISE CONCERNS FOR FEDERAL CONSIDERATION

Based on the findings of the Final Recommendations of the Interagency Ocean Policy Task Force (July 2010), a National Priority Objective in an Area of Special Emphasis is to "Strengthen resiliency of coastal communities . . .and their abilities to adapt to climate change impacts and ocean acidification." Southeast Florida is highly vulnerable to the effects of climate change, especially sea level rise. In order to effectively address sea level rise issues, the Southeast Florida Regional Climate Compact Counties have identified a number of concerns for federal assistance related to adaptation policies, adaptation funding and technical needs.

SOUTHEAST FLORIDA REGIONAL CLIMATE CHANGE COMPACT 2012 JOINT LEGISLATIVE PROGRAM

Statements on Sea Level Rise

SUPPORT—greater incorporation of adaptation strategies in the development of state climate and energy policies, legislation, and appropriations priorities.

SUPPORT—legislation which complements and enhances the utilization and implementation of Adaptation Action Area comprehensive plan designation in law for areas that experience coastal flooding and that are vulnerable to the related impacts of sea level rise. (See expanded language below under Broward County Legislative Program).

SUPPORT—programs and efforts that provide technical assistance and funding to local governments to aid the integration of adaptation planning in local comprehensive plans.

SUPPORT—funding for adaptation planning and investments (see attached letter) in the areas of water management, water supply, transportation and other projects that provide hazard mitigation and serve to reduce immediate and long-term risks (of sea level rise) to infrastructure.

SUPPORT—policies, legislation and funding that will provide for the complete implementation of the Comprehensive Everglades Restoration Plan as fundamental to Everglades Restoration, but also the vitality of local water resource management efforts given the overall contributions of the Everglades to regulated water storage and aquifer recharge which will become increasingly important under variable climate conditions and in the face of sea level rise.

SUPPORT—greater recognition of the role of Everglades Restoration in planning for economic and environmental sustainability, climate adaptation, including the impacts of sea level rise and extreme weather, such as droughts and floods.

2012 Broward County Legislative Program

SUPPORT: Federal legislation that would create and fund a national infrastructure bank or other new infrastructure funding source to finance projects needed by state and local governments to adapt to the impacts of climate change and the growing regional needs for improved infrastructure with emphasis on investments in areas such as water management, water supply, transportation and other projects that provide hazard mitigation and serve to reduce risks to urban infrastructure from extreme weather events and rising sea levels.

SUPPORT: Specific recognition of an "Adaptation Action Area" through designation in federal legislation for those regions, such as Southeast Florida, that are uniquely vulnerable to climate impacts, including sea level rise, for the purpose of prioritizing funding for infrastructure needs and adaptation planning, This specifically includes support for the inclusion of Adaptation Action Area language with the Army Corps of Engineers (USACE) and the Environmental Protection Agency (EPA), enabling at-risk regions to develop long-term plans for adaptation.

Technical Needs Identified in Compact Work Group Discussions

- Continued technical support from federal agencies. The Compact acknowledges the significant role and contributions of federal agency partners in local and regional planning efforts relating to water supply, water resource management, and sea level. These collaborations have served to substantially advance programmatic efforts and the Compact with the applied expertise and resources of the USACE, NOAA, USGS, and EPA staff in local and regional offices. Continued support is need to develop technical tools and aid in the implementation of the Southeast Florida Regional Climate Change Action Plan.
- Improved and expanded hydrologic modeling for the region to understand the impacts of sea level rise with scenario testing for adaptation infrastructure improvements. Particular areas of vulnerability and analysis will include sea level rise, drainage and flood control infrastructure, changing precipitation patterns, impacts on groundwater levels, surface water management, and saltwater intrusion and its influence on potable wellfields and water supplies. The USGS is currently working on this type of modeling in select pilot areas of South Florida.
- Installation of additional National Water Level Observation Network (NWLON) stations. NOAA conducted an assessment of tidal stations along the Florida Coast and identified the need for additional NWLON stations and subordinate gages. This additional monitoring equipment will be important in understanding and tracking changes in sea level rise for the region.

Inventory of infrastructure at risk: While NOAA, USGS, USACE and others have aided the region in the development of inundation maps, vulnerability assessments are impeded by the lack of complete and accurate geographic information system (GIS) coverages for select infrastructure, such as historical and cultural resources. Funding is needed to create these coverages to determine impacts associated with sea level rise and storm surge.

CONGRESS OF THE UNITED STATES

WASHINGTON, DC 20515

May 13, 2011.

Hon. RODNEY FRELINGHUYSEN,
Chairman, House Appropriations Committee, Subcommittee on Energy and Water, 2362-B Rayburn House Office Building, Washington, DC.

Hon. PETE VISCLOSKY,
Ranking Member, House Appropriations Committee, Subcommittee on Energy and Water, 1016 Longworth House Office Building, Washington, DC.

DEAR CHAIRMAN FRELINGHUYSEN AND RANKING MEMBER VISCLOSKY:

As you begin work on the Fiscal Year 2012 Energy and Water Appropriations bill, we respectfully request you to include language with the Army Corps of Engineers enabling at-risk, multi-county regions impacted by rising sea levels to develop long-term plans for adaptation.

Scientists around the world and within our most respected institutions note an alarming level in sea level rise, possibly by several feet over the next century. This will inudate low-lying coastal zones, impacting hundreds of millions of people world-wide and tens of millions of Americans here at home. Our states and local communities are just beginning to grapple with the possible effects of what this kind of massive, permanent flooding will mean. It is critical that local leaders be given the necessary tools to start planning now, so that our communities will have enough time to prepare for these life-altering effects.

We request that the following language be inserted into the Army Corps of Engineer's Operations & Maintenance account, or whichever account you feel is most relevent:

> "Funds will be used to study, define and designate several "Adaptation Action Areas," which are at-risk, multi-county, regions of the country, uniquely vulnerable and significantly impaced by rising sea level."

We hope that this language will enable regional groups to begin effectively strategizing and planning for adaptation to sea level rise. We thank you for your consideration of this important request.

Sincerely,

ALCEE L. HASTINGS,
Member of Congress.
TED DEUTCH,
Member of Congress.
DEBBIE WASSERMAN SCHULTZ,
Member of Congress.
FREDERICA WILSON,
Member of Congress.

ANNEX B.—SEA LEVEL RISK AND RESPONSE SUMMIT
THE FUTURE OF FLORIDA AND THE COAST

Boca Raton Marriott, FL, June 20, 21 & 22, 2012.

Introduction

This Summit will result in raising an awareness and visibility of sea level rise and climate change issues to make them a central agenda item for the future of Florida and to emphasize how local and regional actions can be translated to other regions in the U.S. and abroad. Furthermore, this Summit will result in highlighting the "now" of sea level rise and showcase the myriad of activities taking place in Florida and the organizations that are mobilizing to address the issue to a national and global audience. In addition, the Summit will produce specific recommendations to local, state and federal agencies presented in a report summary and a website where visual aids and publications will be used to educate summit participants before and after the summit.

Format And Purpose

The Center for Environmental Studies (CES) at Florida Atlantic University, the Florida Sea Grant Program, and the United States Geological Survey will hold a Sea Level Rise Risk and Response Summit June 20th through June 22nd. The organizers have collaborated with a diverse group of experts in designing the program, goals and outcomes. The Summit will take place in Boca Raton, Florida and seek to bring in an audience of up to 300.

The purpose of this summit is three-fold: Highlight the interrelationships between sea level rise, limestone geology, and water management in Florida; share the ongoing responses and adaptation planning of agencies, institutions, and civic society to sea level rise; and compare the Florida situation and response with other vulnerable localities in the US and worldwide. This summit will focus on the complex sea level rise issues in Florida and provide examples from other coastal regions within the US and internationally.

Goals And Objectives

The goals are to make a diverse audience of Summit attendees aware of the myriad of adaptation activities currently underway in the region and beyond. From this shared awareness, there will be a plan to continue a process of cooperation and coordination of adaptation responses. The primary objective is to present an awareness and understanding of the effects of sea level rise on the built environment and other social and societal issues and to explore adaptation and mitigations practices and policies that could be used to offset negative impacts. Other objectives include:

- Highlighting current and ongoing sea level rise and climate change research initiatives from academia, regional planning, state and federal projects taking place in Florida.
- Share methods and lessons learned with other states/regions to improve planning, decision making and adaptation.
- Provide scientific information to enable effective decision making to enable effective decision making to address the threats and opportunities posed by climate and sea level rise (similar to US Global Change Research Program goal).
- Identify concerns, compatibilities and links between social and economic issues, underserved populations, and the built environment with regards to sea level rise, salt water intrusion and water supply issues.

ANNEX C.—ADDITIONAL RESOURCES, COLLABORATIONS, AND RESEARCH*

1) Department of Transportation Research: Development of a Methodology for the Assessment of Sea Level Rise Impacts on Florida's Transportation Modes and Infrastructure

In Florida, low elevations can make transportation infrastructure in coastal and low-lying areas potentially vulnerable to sea level rise (SLR). Because global SLR forecasts lack precision at local or regional scales, SLR forecasts or scenarios for parts of the state have been prepared using varying tools and approaches. However, Florida still lacks a consensus on the appropriate methodology to forecast potential, adverse impacts. Also, a comprehensive analysis of transportation infrastructure potentially at risk in Florida from SLR has not been conducted.

In this project, Florida Atlantic University researchers analyzed findings, including data sources and methodologies used to forecast SLR. They recommended data sources and methods for forecasting SLR and related impacts in Florida and investigated integrating SLR forecasts with FDOT information systems to identify at-risk infrastructure. Using the Weiss Overpeck 1-meter (?3 ft) estimate of SLR to illustrate the methodology, researchers linked mapping software and datasets to create a framework for identifying transportation facilities at risk. Project Manager: Maria Cahill, AICP, FDOT Planning Office, Principal Investigator: Dr. Leonard Berry, Florida Atlantic University www.dot.state.fl.us/research-center, www.ces.fau.edu/climate__change/fdot

2) Integrative Collaboration on Climate and Energy (ICCE)

Launched by Florida Atlantic University in the spring of 2009, ICCE is a cross-university program creating relevant linkages across disciplines. With Florida Atlantic University as the lead institution ICCE includes more than 80 faculty members in a multitude of climate change-related disciplines. Collectively, we have strong collaborative linkages with local, state and federal governmental and non-governmental organizations, the business community, and public. Other University collaborators include: University of South Florida, Florida Gulf Coast University, and Columbia University. Our partners provide strong support in topical and regional areas. Based on our expertise, deep community connections, and long-held partnerships, we are uniquely positioned to take research-based knowledge and apply it to practical decision-making that focuses on the needs of the region and its people. Furthermore, we know that the work of ICCE will have implications for ad-

* Map to Annex C has been retained in committee files.

dressing the climate change issues that will soon be faced by much of the Unites States and the world. www.ces.fau.edu/climate_change/icce

3) Resilient Tampa Bay 2011

A Knowledge Exchange with Dutch Experts was hosted by the University of South Florida's Patel Center for Global Solutions in Tampa, Florida, on February 21-23, 2011. The three-day workshop was organized in collaboration with local, regional, state, and international entities. More than 150 attendees heard from Dutch and local water experts on resiliency issues relating to Tampa Bay, particularly on urban flooding, storm surge, and sea level rise. Additionally, key stakeholders formed four geo-focal teams to identify vulnerabilities and to make recommendations on resiliency strategies for four defined locations: Tampa Bay, City of Tampa, City of St. Petersburg, and Gulf Beach Communities.

Today, coastal cities around the world face a range of dynamic regional and global pressures. These pressures make coastal cities more vulnerable to flooding, storm surges, coastal erosion, and more. Global change pressures serve as threat multipliers thus increasing existing problems for these cities. The Tampa Bay region is one of these coastal areas that will become more vulnerable in the future; hence the critical need to improve its resiliency. Tampa Bay's key vulnerabilities related to water include:

- Urban flooding events caused by heavy rainfall induce frequent but limited local damage
- Storm surges caused by hurricanes. Occurrence probability is low but as high-impact events, they can lead to catastrophic flooding along the entire coast.
- Sea level rise caused by climate change. As a long-term driver, it will increase existing flooding problems.

The goal of Resilient Tampa Bay 2011 was to exchange ideas on developing resiliency plans for the Tampa Bay region. The challenge was to consider plans that would protect vital infrastructure, improve conditions for economic development, and minimize the impact of hurricanes and other natural disasters. Key issues addressed were:

- Determining the factors that make Tampa Bay vulnerable
- Establishing progress toward improving resiliency in Tampa Bay
- Understanding existing visions and solutions for improving resiliency in Tampa Bay
- Recommending the next steps for improving resiliency in Tampa Bay

As part of an ongoing effort to engage Dutch water experts in addressing resiliency challenges in Tampa Bay, we partnered closely with the Dutch Consulate in Miami and the Dutch Embassy in Washington, D.C., to secure the participation of several Dutch speakers who shared some of their most effective and reliable solutions for flood resiliency. The Patel Center has been instrumental in establishing a dialogue between Dutch water experts and their counterparts in the Tampa Bay region through two previous workshops in June 2009 and November 2009. Resilient Tampa Bay 2011 built upon the momentum created from the prior workshops and will serve as a springboard to launch ongoing resiliency planning efforts in our region.

4) Florida Water Management and Adaptation in the Face of Climate Change

A WHITE PAPER ON CLIMATE CHANGE AND FLORIDA'S WATER RESOURCES

SUPPORTED BY THE STATE UNIVERSITY SYSTEM OF FLORIDA NOVEMBER 2011

The State of Florida will be faced in the coming years with significant challenges and opportunities for managing water in a highly dynamic and changing climate. The impacts of climate change on water resources management will have consequences for the economic sustainability and growth of the state. A strong awareness of climate change impact issues and potential adaptation strategies that could be implemented by the state will increase its resilience over the long-term to uncertain climatic conditions and sea level rise. To that end, a series of white papers have been prepared by State University System (SUS) of Florida Universities to coalesce our understanding of realized and predicted climate change impacts with a focus on various topics. The report presented herein addresses water resources and adaptation issues across the state.

The primary objectives of this report are: (1) to identify Florida's water resources and water-related infrastructure that are vulnerable to climate change; (2) show demographics in the state that are vulnerable to climate change impacts with a focus on water resources and sea level rise; and (3) highlight some of the alternative technologies currently being used to solve water resource supply issues in the state that are likely to expand and be challenged under various scenarios of climate change.

Florida is highly vulnerable to climate change as a result of its expansive shoreline, low elevation and highly permeable aquifers, and the location of high population centers and economic investments close to the coastline. Further, the state receives a high frequency of tropical storm landings that are accompanied by tidal surges that compound the risks of sea level rise. Because the state is highly vulnerable compared to other regions globally, Florida's academic, governmental and non-governmental institutions are developing adaptation strategies and conducting research on climate change. In this white paper, we highlight climate change issues relevant to water management, but also recognize the financial challenges to implement adaptation measures to address climate change solutions. Implementing adaptation measures will require an unprecedented level of resource leveraging and coordination among academic, governmental, non-governmental, and private sector entities. http://floridaclimate.org/whitepapers/ http://floridaclimate.org/water__management__pdf.php

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