RESTORING U.S. LEADERSHIP IN WEATHER FORECASTING PART II

HEARING

BEFORE THE

SUBCOMMITTEE ON ENVIRONMENT

COMMITTEE ON SCIENCE, SPACE, AND TECHNOLOGY

HOUSE OF REPRESENTATIVES

ONE HUNDRED THIRTEENTH CONGRESS

FIRST SESSION

JUNE 26, 2013

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Wednesday, June 26, 2013

RESTORING U.S. LEADERSHIP IN WEATHER FORECASTING PART II

WEDNESDAY, JUNE 26, 2013

HOUSE OF REPRESENTATIVES,
SUBCOMMITTEE ON ENVIRONMENT
COMMITTEE ON SCIENCE, SPACE, AND TECHNOLOGY,
Washington, D.C.

The Subcommittee met, pursuant to call, at 10:00 a.m., in Room 2318 of the Rayburn House Office Building, Hon. Chris Stewart [Chairman of the Subcommittee] presiding.

LAMAR S. SMITH, Texas
CHAIRMAN

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Congress of the United States
House of Representatives

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Subcommittee on Environment

Restoring U.S. Leadership in Weather Forecasting
Part 2

Wednesday, June 26, 2013
10:00 a.m. – 12:00 p.m.
2318 Rayburn House Office Building

Witnesses

Panel 1

The Honorable Kathryn Sullivan, Acting Administrator, National Oceanic and Atmospheric Administration.

Panel 2

Dr. Kelvin Droegemeier, Vice President for Research, Regents' Professor for Meteorology, Weathernews Chair Emeritus, University of Oklahoma.

Dr. William Gail, Chief Technology Officer, Global Weather Corporation, President-Elect, American Meteorological Society.

Dr. Shuyi Chen, Professor, Meteorology and Physical Oceanography, Rosentiel School of Marine and Atmospheric Sciences, University of Miami.

U.S. HOUSE OF REPRESENTATIVES
COMMITTEE ON SCIENCE, SPACE, AND TECHNOLOGY
SUBCOMMITTEE ON ENVIRONMENT

HEARING CHARTER

Restoring U.S. Leadership in Weather Forecasting
Part 2

Wednesday, June 26, 2013
10:00 a.m. – 12:00 p.m.
2318 Rayburn House Office Building

PURPOSE

The Subcommittee on Environment will hold a second hearing entitled *Restoring U.S. Leadership in Weather Forecasting* on Wednesday, June 26, 2013 in Room 2318 of the Rayburn House Office Building. The purpose of the hearing is to examine ways to improve the National Oceanic and Atmospheric Administration (NOAA) weather forecasting, and to receive testimony on legislation to prioritize weather-related research. The first hearing was held May 23rd.

WITNESS LIST

Panel 1

- **The Honorable Kathryn Sullivan**, Acting Administrator, National Oceanic and Atmospheric Administration.

Panel 2

- **Dr. Kelvin Droegemeier**, Vice President for Research, Regents' Professor for Meteorology, Weathernews Chair Emeritus, University of Oklahoma.
- **Dr. William Gail**, Chief Technology Officer, Global Weather Corporation, President-Elect, American Meteorological Society.
- **Dr. Shuyi Chen**, Professor, Meteorology and Physical Oceanography, Rosentiel School of Marine and Atmospheric Sciences, University of Miami.

BACKGROUND

Recent extreme weather events in the United States have underscored the need for reliable, first-class weather forecasting. Within NOAA, the National Weather Service (NWS), the Office of Oceanic and Atmospheric Research (OAR), and the National Environmental Satellite, Data, and Information Service (NESDIS) play important roles in developing and deploying U.S. weather forecasting capabilities.[1] NOAA is joined in this effort by an ever-evolving weather enterprise with the private sector. The National Academy of Sciences recently emphasized the importance of this partnership, noting that "[p]rivate sector and other organizations provide sensor data, weather forecasts, and end-user services to a broad set of customers."[2]

Weather impacts American lives, and extreme weather poses significant risks to important parts of the U.S. economy. NOAA has traced a rise in weather disasters costing the economy up to $1 billion in damage per weather event, and a recent analysis found that substantial parts of the economy are sensitive to weather variability, representing more than three percent of Gross Domestic Product and nearly $500 billion a year.[3]

In a 2012 report on the National Weather Service, the National Academy of Sciences stated that "[a]s an outgrowth of public and private sector investment in weather, climate, and hydrological research, new observational, data assimilation, prediction, and other technology advancements are exceeding the capacity of the NWS to optimally acquire, integrate, and communicate critical forecast and warning information based on these technological achievements."[4] Similarly, a *USA Today* editorial last October following Superstorm Sandy highlighted concerns about American weather forecasting abilities, concluding that "[t]he American model is the basis for many forecasts, and its reliability problems beyond the short term suggest something major is amiss.... The European model's embarrassing superiority on Sandy ought to accelerate efforts to identify and fix what's wrong."[5]

In response to the destruction of property and loss of life associated with Superstorm Sandy, Congress approved the *Disaster Relief Appropriations Act of 2013* which included $50 million in funding to NOAA's research office and $48 million to the Weather Serviceto improve forecasting equipment and supercomputer infrastructure.[6] This appropriation has been characterized as a "down payment" for "game-changing improvements" for U.S. weather prediction.[7]

Citing ongoing concerns about potential data gaps for NOAA's polar-orbiting and geostationary satellite programs, including a potential polar-orbiting gap of 17 to 53 months, the Government Accountability Office added NOAA's satellite programs to its High Risk List in 2013. This potential gap in weather satellite coverage and management problems with NOAA's

[1] For more information on these responsibilities, see: "To Observe and Protect: How NOAA Procures Data for Weather Forecasting," March 28, 2012, http://science.house.gov/hearing/subcommittee-energy-and-environment-hearing-how-noaa-procures-data-weather-forecasting.
[2] http://dels.nas.edu/resources/static-assets/materials-based-on-reports/reports-in-brief/Weather-Services-Report-Brief.pdf.
[3] http://journals.ametsoc.org/doi/pdf/10.1175/2011BAMS2928.1.
[4] http://www.nap.edu/catalog.php?record_id=13429.
[5] http://www.usatoday.com/story/opinion/2012/10/30/sandy-forecasting-ecmwf-gfs/1670035/.
[6] http://www.gpo.gov/fdsys/pkg/PLAW-113publ2/pdf/PLAW-113publ2.pdf
[7] Jason Samenow, "Game-changing improvements in the works for U.S. weather Prediction, The Washington Post, May 15, 2013, http://www.washingtonpost.com/blogs/capital-weather-gang/wp/2013/05/15/game-changing-improvements-in-the-works-for-u-s-weather-prediction/.

satellites has been the subject of several Science, Space, and Technology Committee hearings over many years.[8] The GAO emphasized the potential effects of a gap:

> According to NOAA program officials, a satellite data gap would result in less accurate and timely weather forecasts and warnings of extreme events, such as hurricanes, storm surges and floods. Such degradation in forecasts and warnings would place lives, property, and our nation's critical infrastructures in danger. Given the criticality of satellite data to weather forecasts, the likelihood of significant gaps and the potential impact of such gaps on the health and safety of the U.S. population and economy, GAO has concluded that the potential gap in weather satellite data is a high-risk area and added it to the High Risk List in 2013.[9]

In addition, independent reviews of NOAA's weather research portfolio have also recommended a stronger emphasis on moving research-to-operations within NOAA's weather portfolio. In 2010, the National Academy of Public Administration stated that OAR "provides particularly important institutional glue to support innovation across NOAA."[10] In April 2013, NOAA's Science Advisory Board stated that "unless… science is transitioned into operations… NOAA will fail in its mission. NOAA must make certain that the intended end use of the scientific information is understood from the start by its researchers working on scientific questions and, ensure that internal as well as external end-user needs are incorporated explicitly into the problem formulation."[11]

NOAA plays an important role in making procurement decisions about observing systems that provide data for weather prediction in the U.S. NOAA currently uses information from over 100 observational networks, including space-based remote sensing, atmospheric observations, surface observations, and ocean observations. One method to analyze the value of weather data from observing systems is called an Observing System Simulation Experiment (OSSE). OSSEs employ computer modeling used to investigate the potential impact of planned observing systems or to test current observational and data assimilation systems. NOAA has stated that OSSEs "could play a critical role in…identifying future observation systems and data assimilation systems for improvement."[12]

For these reasons, the Weather Forecasting Improvement Act of 2013 (H.R. 2413) introduced by Environment Subcommittee Vice Chairman Jim Bridenstine will prioritize the mission of NOAA to include the protection of lives and property, and make funds available to improve weather-related research, operations, and computing resources. The bill directs NOAA to undertake quantitative, cost-benefit assessments used in obtaining data for forecasts. It also directs NOAA

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[8] http://science.house.gov/hearing/subcommittee-investigations-and-oversight-hearing-continuing-oversight-nation%E2%80%99s-weather; http://science.house.gov/hearing/joint-hearing-investigations-and-oversight-energy-and-environment-subcommittees-polar; http://science.house.gov/hearing/subcommittee-investigations-and-oversight-hearing-polar-weather-satellites.

[9] http://www.gao.gov/highrisk/mitigating_gaps_in_weather_satellite_data.

[10] http://www.napawash.org/wp-content/uploads/2010/09/NAPA-Final-Report_NOAA-Climate-Service-Study_September-20101.pdf.

[11] http://www.sab.noaa.gov/Reports/2013/SAB%20R&D%20Portfolio%20Review%20Report%20to%20NOAA%20FINAL.pdf.

[12] http://laps.noaa.gov/met/osse.html.

to prepare a report outlining the options of commercial opportunities for obtaining space-based weather observations.

ADDITIONAL READING

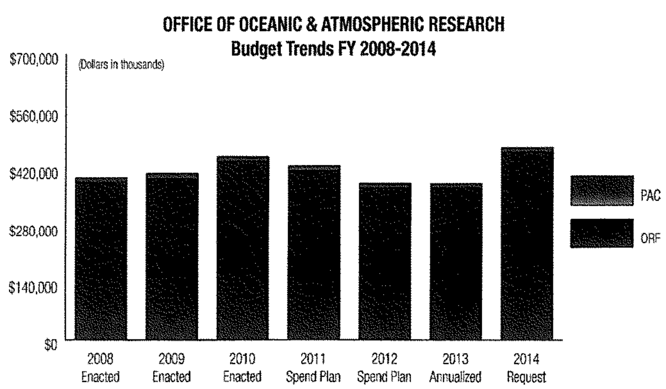
- National Academies of Science Report, *Weather Services for the Nation: Becoming Second to None, August 2012.*
- Dan Vergano, USA Today, *U.S. Forecast's Late Arrival Stirs Weather Tempest*, October 2012.
- NOAA Science Advisory Board Report, *In the Nation's Best Interest: Making the Most of NOAA's Science Enterprise*, April 2013.

Appendix 1: OFFICE OF OCEANIC & ATMOSPHERIC RESEARCH BUDGET[13]

NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION FY 2014 BUDGET SUMMARY

OFFICE OF OCEANIC & ATMOSPHERIC RESEARCH

(DOLLARS IN THOUSANDS)	FY 2012 SPEND PLAN	FY 2013 ANNUALIZED CR	FY 2014 REQUEST	INCREASE (DECREASE)
OAR — ORF				
Climate Research	$181,044	$141,394	$188,840	$47,446
Weather and Air Chemistry Research	67,779	68,191	81,624	13,433
Ocean, Coastal, and Great Lakes Research	114,719	156,165	179,806	23,641
Information Technology, R&D & Science Education	8,946	9,000	11,786	2,786
Total, OAR - ORF	372,488	374,750	462,056	87,306
Total, OAR - PAC	10,296	10,350	10,379	29
GRAND TOTAL OAR (Direct Obligations)	$382,784	$385,100	$472,435	$87,335
Total FTE	755	755	769	14



ORF: Operations, Research, and Facilities
PAC: Procurement, Acquisition, & Construction

[13] http://www.corporateservices.noaa.gov/nbo/fy14_bluebook/FINALnoaaBlueBook_2014_Web_Full.pdf.

The Weather Improvement Act of 2013
Section-by-Section Analysis

Section 1. Title. Weather Forecasting Improvement Act of 2013.

Section 2. Public Safety Priority. Directs Under Secretary (NOAA Administrator) to make weather forecasting to protect lives and property NOAA's top planning and management priority in relevant line offices.

Section 3. Weather Research and Forecasting Innovation.

(a) Establishes/codifies NOAA weather research program, directing agency to place "priority emphasis on development more accurate and timely warnings and forecasts of high impact weather events that endanger life and property."
(b) (b)(1) and (b)(2) describe specific program elements to be pursued—advanced radar, aerial systems, computing/modeling, and OSSEs.
(b)(3) codifies longstanding joint OAR-NWS tech transfer program, moving its funding from NWS.
(c) Directs NOAA to support academic weather research through competitive grants and contracts.

Section 4. Tornado Warning Extension Program. Establishes a Tornado Warning Extension Program focused on developing and extending accurate tornado forecasts and warning beyond one hour in order to reduce loss of life, injury, and damage to the economy.

Section 5. Weather Research and Development Planning. Directs NOAA to develop a prioritized weather research plan to guide activities authorized under the Act and restore U.S. leadership in weather modeling, prediction, and forecasting. Specifies that the plan shall identify, through consultation with the National Science Foundation, research necessary to integrate social science knowledge into weather forecast and warning processes.

Section 6. Observing System Planning. Directs NOAA to maintain a list of observation data requirements and systematically evaluate the combination of systems necessary to meet such requirements, including as they related to potential data gaps. Directs NOAA to develop a range of options to address any identified gaps.

Section 7. Observing System Simulation Experiments. Directs NOAA to undertake Observing System Simulation Experiments (OSSEs) to quantitatively assess the relative value and benefits of observing capabilities and systems. Specifies under what conditions OSSEs should be performed.

Section 8. Computing Resources Prioritization Report. Directs NOAA to issue a plan for assuring that NOAA aggressively pursues the newest, fastest, and most cost effective high performance computing technologies in support of its weather prediction mission, and identifies opportunities to reallocate existing advanced computing resources from lower priority uses to improve operational weather prediction.

Section 9. Commercial Weather Data. Clarifies that restrictions in existing law prohibiting the sale of weather satellite systems to the private sector do not extend to the purchase of weather data through contracts with commercial providers or the placement of instruments on private payloads.

Section 10. Definitions.

Section 11. Authorization of Appropriations. Authorizes, out of funds made available to OAR's operations, research, and facilities appropriations account, $100 million for each of fiscal years 2014 through 2017 to carry out the weather research program established under section 3. Also authorizes $20 million annually to carry out the joint technology transfer initiative described in section 3(b)(3).

Chairman STEWART. The Subcommittee on the Environment will come to order.

Good morning, everyone. Welcome to today's hearing entitled "Restoring U.S. Leadership in Weather Forecasting, Part II." In front of you are packets containing the written testimony, biographies, and truth-in-testimony disclosures from today's witness panels.

And I now recognize myself for five minutes for an opening statement.

I would like to thank the excellent witnesses for being with us today. We have two panels, and first, Dr. Sullivan, I thank you especially for being with us. We had the chance to spend some time together last week, and I enjoyed that and appreciated the opportunity to get to know you, and we look forward to working with you on many important issues.

I would also like to welcome the Subcommittee's new Vice Chairman, the gentleman from Oklahoma, Mr. Bridenstine.

Mr. BRIDENSTINE. Thank you.

Chairman STEWART. This hearing is the second installment in a process that we began last month to discuss legislation to enhance weather forecasting throughout targeted research investments at the National Oceanic and Atmospheric Administration.

Severe weather routinely affects large portions of the United States, and this year is no different. As we discussed in Part I of this hearing, the United States needs a world-class weather predicting system that effectively safeguards American lives and property.

Today, we are discussing legislation that was recently introduced by Vice Chairman Bridenstine, a bill that I am proud to cosponsor. The Weather Forecasting Improvement Act of 2013 prioritizes forward-looking weather research, improves procurement of observing systems data from space and land, and opens up NOAA processes to encourage private sector weather solutions. The legislation is a down payment to upgrade our weather predicting systems that has fallen behind according to international standards.

Now, let me be clear what the goal of this bill is. It makes the protection of lives and property through improved forecasting the top priority for NOAA. The bill does not micromanage the Agency—and I know, Dr. Sullivan, you will appreciate to hear that—but instead expands resources available for achieving this objective.

I appreciate the wise counsel of the witnesses testifying today, and I think we can all agree that improved weather prediction is a goal worth pursuing. We should not let the perfect become the enemy of the good, and in these tight fiscal times, it is absolutely vital that our first and most important research programs are authorized by Congress and thus more protected from future budgetary constraints.

At this time I would like to yield the remainder of my time to the Vice Chairman from Oklahoma, Mr. Bridenstine, to discuss his legislation and the positive impacts it would have to protect his State and this Nation from the life-threatening severe weather.

[The prepared statement of Mr. Stewart follows:]

PREPARED STATEMENT OF SUBCOMMITTEE CHAIRMAN CHRIS STEWART

Good morning and welcome to this morning's Environment Subcommittee hearing titled "Restoring U.S. Leadership in Weather Forecasting Part II." I'd like to thank our excellent witnesses for being here today. I'd also like to welcome the Subcommittee's new Vice Chairman, the gentleman from Oklahoma, Mr. Bridenstine.

This hearing is the second installment of a process we began last month to discuss legislation to enhance weather forecasting through targeted research investments at the National Oceanic and Atmospheric Administration (NOAA). Severe weather routinely affects large portions of the United States, and this year is no different. As we discussed at part I of this hearing, the United States needs a world-class weather prediction system that effectively safeguards American lives and property.

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Let me be clear about the goal of this bill: It makes the protection of lives and property through improved forecasting the top priority for NOAA. The bill does not micromanage the Agency, but instead expands resources available for achieving this objective. I appreciate the wise counsel of the witnesses testifying today and I think we can all agree that improved weather prediction is a goal worth pursuing. We should not let the perfect be the enemy of the good, and in these tight fiscal times it is absolutely vital that our most important research programs are authorized by Congress and thus more protected from future budgetary constraints.

At this time I would like to yield the remainder of my time to the Vice Chairman from Oklahoma, Mr. Bridenstine, to discuss his legislation, and the positive impacts it would have to protect his state and this nation from life threatening severe weather.

Mr. BRIDENSTINE. Thank you, Mr. Chairman, and thank you for your leadership and for your co-sponsorship. And I look forward to working with you on this. I wanted to take just a few moments to recognize some important points about today's hearing for me and the people of my State.

Let me begin by saying how truly honored and proud I am to be here. This is my first hearing as the Vice Chairman of the Subcommittee on the Environment, and recent events have made me even more appreciative of the opportunities we as a committee will have to do important work for the American people over the next 18 months.

As every Oklahoman knows, tornadoes are an unavoidable challenge faced by millions of Americans. But we know equally well that every minute we can add to our tornado detection and alert system has a direct effect on the number of lives that can be saved.

As the Subcommittee with jurisdiction over the agency responsible for weather research and prediction—the National Oceanic and Atmospheric Administration, or NOAA—I believe we have a moral obligation to advance legislation to the full House that forces NOAA to place its highest priority on what is undoubtedly its most important duty: enhancing public safety through timely and accurate forecasts of severe weather systems.

To implement these much needed reforms, I have recently introduced the Weather Forecasting Improvement Act of 2013. This legislation would establish within NOAA a Tornado Warning Extension Program aimed at improving the average time for a tornado warning from a few minutes to an hour or more. NOAA itself has indicated that this is a worthy and achievable goal, but sufficient resources and a dedicated effort is needed to make it a reality.

This legislation aims to accomplish this not by requesting or spending any new funds at NOAA, but rather by shifting their priorities and resources away from lower priority climate and ocean research and towards weather forecasting research and innovation.

The inadequacy of attention to potentially life-saving advances in weather forecasting is evidenced by the fact that NOAA's research arm currently spends more than three times as much on climate change research as it does on weather forecasting research. Across all government agencies, the difference in these misplaced priorities can be measured in the billions of dollars. Today's hearing is an important step towards the legislative solution needed to fix this problem.

Finally, I want to thank Acting Administrator Sullivan and all of our witnesses for appearing here today, and extend a particularly warm welcome to Dr. Kelvin Droegemeier, who will be joining the second panel from my home State of Oklahoma.

Dr. Droegemeier has been an invaluable resource both for my office and the staff of the Science Committee as we have developed this legislation, and I thank him for making the trip from the University of Oklahoma today to lend his perspective and answer questions for our committee.

Thank you, Mr. Chairman, and I yield back.

[The prepared statement of Mr. Bridenstine follows:]

PREPARED STATEMENT OF SUBCOMMITTEE VICE CHAIRMAN JAMES BRIDENSTINE

Let me begin by saying how truly and honored and proud I am just to be here. This is my first hearing as the Vice-Chairman of the Subcommittee on the Environment, and recent events have made me even more appreciative of the opportunities we as a committee will have to do important work for the American people over the next 18 months.

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Chairman STEWART. Thank you, Mr. Bridenstine.

I now recognize the Ranking Member, the gentlewoman from Oregon, Ms. Bonamici, for her opening statement.

Ms. BONAMICI. Thank you, Chairman Stewart, for holding this hearing today.

This is our second hearing to consider legislation to improve the National Oceanic and Atmospheric Administration—NOAA's—forecasting abilities. And I appreciate your willingness, Mr. Chairman, to work together to plan this hearing, and I am very pleased that we ended up with such a distinguished panel of witnesses.

The views of NOAA, as represented by Dr. Sullivan, as well as those of the other three witnesses from the nongovernmental portion of the weather enterprise, will greatly enrich our understanding of how to improve weather forecasting. And I wanted to thank you, Chairman Stewart, for the bipartisan spirit you have shown in inviting collaboration on legislation.

The draft bill we took testimony on in the first hearing has been replaced and expanded upon in the bill introduced by Subcommittee Vice Chair Mr. Bridenstine. There are many elements of that bill that are promising and I am particularly enthusiastic about the new section on tornado forecast research. I want to applaud the gentleman from Oklahoma for including that provision.

We all agree that weather forecasting can and must be improved. As we learn more about weather forecasting in the United States, how it is done, and the partnership that has evolved among NOAA, academic researchers, and private businesses, it becomes evident that the core of the bill should be refocused away from its emphasis on research at OAR, or the office of Oceanic and Atmospheric Research, and more on the actual forecasters' needs at the National Weather Service. Putting all of our legislative emphasis on the OAR seems inconsistent with our stated intention of improving forecasting and protecting lives.

OAR is a research arm in NOAA that manages oceans, Great Lakes, climate, weather, and computer research. It makes more sense, Mr. Chairman, to authorize the National Weather Service directly and put the forecasting operation in the lead on guiding research into innovations that have real utility. If our goal is to enhance forecasting, empowering the forecasters would seem to be the obvious way to proceed, and this is in fact the way the Army, Navy, and Air Force all do their research-to-operations efforts.

Additionally, the bill as drafted may create unnecessary conflict between the researchers at OAR and the forecasters and researchers at the National Weather Service, as well as between the weather portion of OAR and the oceans and climate portfolios at OAR. We need progress in all of these areas to improve forecasting.

As Dr. Sullivan concisely explains in her testimony, in the scientific world, weather is classified at shorter timescales which technically extends to two weeks. Any forecast timescales beyond two weeks are classified as climate. So emphasizing weather research over climate research is likely to be counterproductive.

As Dr. Droegemeier states in his testimony, all of us recognize the importance of balance between weather and climate investment in our Nation's research and operations portfolio. Yet the traditional line dividing weather and climate is increasingly blurred as climate models are now run at resolutions approaching those of weather models. Consequently, we would do well to consider weather and climate not as two distinct elements at the extreme ends of the spectrum but rather as inseparable parts of the Earth's system. And I look forward to Mr. Droegemeier's testimony further on that.

Mr. Chairman, I am confident that working together we can craft a bill that is on target with the needs of the weather community, fiscally responsible, and protective of the public safety. I am very optimistic that your Subcommittee can draft a bill that is constructive and truly bipartisan. If we closely study the testimony we have received, it will give us a good guide for how to move forward, and I hope we can do that together.

And with that, Mr. Chairman, I yield back.

[The prepared statement of Ms. Bonamici follows:]

PREPARED STATEMENT OF SUBCOMMITTEE RANKING MEMBER SUZANNE BONAMICI

Thank you, Chairman Stewart, for holding this hearing today. This is our second hearing to consider legislation to improve the National Oceanic and Atmospheric Administration's (NOAA's) weather forecasting abilities. I appreciate your willingness to work together to plan this hearing, and I'm pleased that we ended up with such a distinguished panel of witnesses. The views of NOAA, as represented by Dr. Sullivan, as well as those of our three witnesses from the non-governmental portion of the Weather Enterprise, will greatly enrich our understanding of how to improve weather forecasting.

I want to thank you, Chairman Stewart, for the bipartisan spirit you have shown in inviting collaboration on legislation. The draft bill we took testimony on in the first hearing has been replaced and expanded upon in the bill introduced by Subcommittee Vice Chair Mr. Bridenstine. There are many elements of that bill that are promising. I am particularly enthusiastic about the new section on tornado forecast research and I want to applaud the gentleman from Oklahoma for including that provision.

We all agree that weather forecasting must be improved. As we learn more about weather forecasting in the United States—how it is done and the partnership that has evolved between NOAA, academic researchers, and private businesses—it becomes evident that the core of the bill should be refocused away from its emphasis on research at OAR, the Office of Oceans and Atmospheric Research, and more on the actual forecasters' needs at the National Weather Service (NWS).

Putting all our legislative emphasis on the OAR seems inconsistent with our stated intention of improving forecasting and protecting lives. OAR is a research arm in NOAA that manages oceans, Great Lakes, climate, weather, and computer research. It makes more sense, Mr. Chairman, to authorize the National Weather Service directly and to put the forecasting operation in the lead on guiding research into innovations that have real utility. If our goal is to enhance forecasting, empowering the forecasters would seem to be the obvious way to proceed; this is, in fact, the way the Army, Navy, and Air Force all do their research to operations efforts.

Additionally the bill appears to create unnecessary conflict between the researchers at OAR and the forecasters and researchers at NWS, as well as the between the weather portion of OAR and the oceans and climate portfolios at OAR. We need progress in all of these areas to improve forecasting.

As Dr. Sullivan concisely explains in her testimony, "In the scientific world, 'weather' is classified at shorter time scales, which technically extends to two weeks. Any forecast timescales beyond two weeks are classified as 'climate'."

Emphasizing "weather" research over "climate" research is likely to be counterproductive. As Dr. Drogemeier states in his testimony, "All of us recognize the importance of balance between weather and climate investments in our nation's research and operations portfolio. Yet, the traditional 'line' dividing weather and climate is increasingly blurred as climate models are now run at resolutions approaching those of weather models. Consequently, we would do well to consider weather and climate not as two distinct elements at the extreme ends of a spectrum, but rather as inseparable parts of the Earth system."

Mr. Chairman, I am confident that, working together , we can craft a bill that is on target with the needs of the weather community, fiscally responsible, and protective of public safety. I am very optimistic that this Subcommittee can draft a bill that is constructive and truly bipartisan. If we closely study the testimony we have received, it will give us a good guide for how to move forward and I hope we can do that together.

Chairman STEWART. Thank you, Ms. Bonamici. And let me state as well that we look forward to working with you and other Members in a bipartisan fashion as I think is appropriate for a Subcommittee such as this.

If there are Members who wish to submit additional opening statements, your statements will be added to the record at this point.

It is now my honor to introduce our first witness panel. And our first witness today is Hon. Kathryn Sullivan, acting Under Secretary of Commerce for Oceans and Atmosphere and Acting Administrator for the National Oceanic and Atmospheric Administration.

Previously, Dr. Sullivan served as Assistant Secretary of Commerce for Environmental Observation and Prediction, as well as performing the duties of NOAA's Chief Scientist. She is a distinguished scientist, a renowned astronaut, which is in my opinion very cool, and an intrepid explorer. Dr. Sullivan earned her doctorate in geology.

And as I am sure, Doctor, you know, spoken testimony is limited to five minutes after which the Members of the Committee will have five minutes each to ask questions. So I now recognize Dr. Sullivan for five minutes to present her testimony.

TESTIMONY OF THE HONORABLE KATHRYN SULLIVAN, ACTING ADMINISTRATOR, NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION

Ms. SULLIVAN. Thank you, Chairman Stewart, Ranking Member Bonamici, Members of the Committee. It is a pleasure to be with you this morning.

I would like to start by thanking you for your support for NOAA. We share a goal of improving the United States' weather forecasting, and so we welcome your interest in something about which we throughout the Agency also care very strongly.

While the intent of the legislation as submitted is a very good one, we do have still a few serious concerns about some aspects of the bill. We look forward to working with you to discuss those in the weeks ahead. The products and services that the Nation has come to rely on from NOAA require research across many science disciplines and scales. I look forward to working with you to refine some aspects of the bill that will ensure that we can reach our shared goal of improved weather services and products.

NOAA is entrusted with the responsibility of providing environmental intelligence to American citizens, businesses, and governments. This is what we all need to enable informed decisions on a range of Earth science issues and scales from the local to the global and the short-term to the long-term. We provide a suite of products and services, including reliable and timely delivery of public weather warnings that save lives and property and enhance our national economy.

Much of our success in providing these products and services comes from scientific and technological breakthroughs produced by research across scientific disciplines and a range of time and space scales. Therefore, we caution and appreciate the Committee's concerns about erecting artificial boundaries between these disciplines or across these scales that would hinder the advancement of our mission and the critical research that can help achieve the goal we share.

Our understanding of Earth system phenomena along short and long timescales strengthens our weather products and services and allows us to examine the ways in which we can make improvements such as highly accurate hurricane track predictions further in advance. Emergency management officials have indicated to us that at ideal capacities, NOAA would provide highly consistent and accurate hurricane landfall predictions at days five and six, allowing for pre-positioning of crews and enhanced evacuation efforts. Many economic sectors would see significant cost savings with highly accurate drought predictions ranging 6 months to several years in advance.

If NOAA is to achieve these goals and also achieve the improved warning we need on severe and acute events like tornadoes and severe storms, we must have the flexibility to research both shorter and longer timescale phenomena.

Historically, weather and climate models only incorporated atmospheric inputs and outputs. In recent years, scientists have recognized the need for these to be integrated with ocean observation and science to provide a more accurate picture of how our entire Earth system works.

For example, the El Nĩno Southern Oscillation, or ENSO, is a recurring pattern of periodic warming and cooling in ocean temperatures off the coast of South America. These significant changes in tropical Pacific water temperature affect weather patterns worldwide. Daily and seasonal weather in the United States are affected by these slightly longer-term seasonal climate events. So improving our weather forecasts requires that we follow the science and apply our research and observational efforts appropriately across the continuum of time and space.

Advanced computing assets and modeling methods are also crucial elements of our national forecasting infrastructure. Over the past two decades, our tornado warning lead times have more than doubled and we share your aim of continuing to improve the timeliness of such warnings. Computing capacity and computer modeling are indispensable to this.

The upgrade to NOAA operational computers that is scheduled to be completed next month marks a big step forward and we thank you for supporting the Disaster Relief Appropriations Act of 2013 that made this possible. In addition, the President's Fiscal Year 2014 budget requests further funds for NOAA to take the next vital step forward in operational supercomputing, ultimately providing a 27-fold increase in computing capability by 2015 and putting us on par with the world-leading forecast centers again.

NOAA uses many tools to help determine what new data or technologies will yield the best improvements in forecast accuracy and so warrant investment. Observing System Simulation Experiments, or OSSEs, are just one of these tools. They are computationally intensive and time-consuming. Observing system experiments and adjoint simulations are two other tools that can provide similar analytical insight and rigor much more efficiently. Thus, we would hope the final bill would not stipulate that only OSSEs be used to assess the relative value and benefits of observing systems.

NOAA regards the protection of the people of the United States from the devastation that weather can bring as a sacred trust and duty. Fulfilling this obligation requires a robust, flexible, and integrated program of sustained environmental observations, scientific research aimed at computing our forecasts and warnings, and cutting-edge modeling and computing. Our end goal is a weather-ready Nation. We appreciate the bill's intent to advance this cause and look forward to working with you to refine its provisions.

I thank you again for the opportunity to testify on this important matter and am happy to take your questions.

[The prepared statement of Ms. Sullivan follows:]

WRITTEN STATEMENT OF
KATHRYN SULLIVAN, PH.D.
ACTING UNDER SECRETARY OF
COMMERCE FOR OCEANS AND ATMOSPHERE
AND ACTING NOAA ADMINISTRATOR
NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION
U.S. DEPARTMENT OF COMMERCE

ON
"RESTORING U.S. LEADERSHIP IN WEATHER FORECASTING, PART 2"

BEFORE THE
SUBCOMMITTEE ON ENVIRONMENT
HOUSE COMMITTEE ON SCIENCE, SPACE, AND TECHNOLOGY
U.S. HOUSE OF REPRESENTATIVES

June 26, 2013

Introduction

Chairman Stewart, Ranking Member Bonamici, and Members of the Committee, it is my honor to testify before you today on the state of United States (U.S.) weather forecasting capabilities and opportunities to improve forecasting of high impact events such as hurricanes, tornadoes, and winter storms. We at the National Oceanic and Atmospheric Administration (NOAA) welcome your interest in something we care strongly about. NOAA is trusted with the responsibility to provide environmental intelligence to American citizens, businesses, and governments to enable informed decisions on a range of issues and scales local to global and short-term to long-term. NOAA provides a suite of products and services to the American people, including the reliable and timely delivery of public weather warnings which help to safeguard lives. To do so, we work closely with the larger community of emergency officials, other federal agencies, and the commercial weather enterprise to deliver the best possible information that science and technology can provide. Put simply, this is information that saves lives and enhances our national economy.

NOAA continually strives to provide the most accurate and timely forecasts that the best advances in science and technology can deliver. Much of our success in providing these services and products comes from scientific and technological breakthroughs produced by research across disciplines, time and space scales. Therefore, we caution against actions that would insert rigid boundaries between advancing our mission and the research that helps achieve that goal. The dynamic systems of this planet are interconnected in rich and complex ways, and the past successes we have achieved in forecast improvement have come by looking broadly across those linkages. Furthermore, the NOAA National Weather Service (NWS), driven by demand from our customers, has evolved to provide more than just short-term weather forecasts. NOAA's prediction capabilities are becoming a fusion point that emergency managers, broadcasters, and the public increasingly turn to as a trusted one-stop shop that distills scientific information into "impacts coming my way." This is done by embracing a number of interrelated fields of science, and not just physical science, examining the atmosphere, oceans, land, ice, and space, but also the social and economic sciences.

While we do have concerns with the legislation, it does set a clear goal of delivering substantial improvements to our weather forecast capabilities for high impact events. Improved weather forecast capabilities are a goal of NOAA's. It is a significant and worthwhile endeavor, and it is an ambitious, yet achievable goal. In fact, it harkens to a similar goal set forth by President Kennedy to put a man on the moon. That goal led to a concerted national effort, with government and industry partnered together. It also forced us to pursue advances across a wide range of scientific fields. To get to the moon and back, we didn't just need powerful rockets. We needed advances in metallurgy, chemistry, physics, computing, instrumentation, human physiology and countless other fields. In other words, if we had focused solely on building better rockets, we never would have achieved our goal. I believe there are similar analogies to be made here. In order to advance weather forecasting we must realize advances across all of the interdisciplinary fields of earth science and research. We must leverage partnerships within government, academia, and the commercial sector, and we must actively pursue a balanced program to advance all of the factors critical to success in concert.

NOAA's weather prediction capabilities are supported by four fundamental pillars: observations; scientific research; computer modeling; and our people – who provide the forecasts, warnings, and decision support services to key decision makers. In order to advance forecasting capabilities, we must strengthen all four of these components together. In my testimony, I will highlight the importance of each of these pillars by elaborating upon:

- The interconnectedness of our earth systems and the need for making sustained observations across a range of temporal and spatial scales;
- The robust and vital national foundation that these pillars represent, and the importance of continuity and synergy between observations, research, and forecast operations;
- The products and services that NOAA provides to the Nation that help save lives, protect property, make communities more resilient and safe, and foster private sector growth; and
- How NOAA has gotten to where it is today, what we have learned, and where NOAA must go in the future.

Today's priorities may require surges in resources for immediate action, but we cannot ignore the investments in observations and foundational research that set the stage for long-term environmental sustainability and future service advancements. We must maintain equilibrium between the push-pull of research and operations, and between responding today and preparing for tomorrow, in order to increase our effectiveness and value to the American public.

Research Flexibility

As a former astronaut, I can tell you that one view out the shuttle window vividly illustrates what every textbook, research project, and phase of human history also teaches: that the Earth's systems are interconnected in complex ways, and we must seek to understand these linkages if we wish to improve any application of earth science to our everyday life. For example, historically, weather and climate models only incorporated atmospheric inputs and outputs. Only recently have these been integrated with ocean models to provide a more robust picture of our earth system. The Earth system models of the future will increasingly involve coupling atmospheric data with ocean, land, ice, ecological, and space-based data. A better understanding of how these dynamic Earth systems are interconnected is vital to advancing weather forecasting. This is what our researchers and forecasters strive for every day.

In the scientific world, "weather" is classified at shorter time scales, which technically extends to two weeks. Any forecast timescales beyond two weeks are classified as "climate." But the "climate" forecast timescales we are talking about here are weeks, months, seasons, and years - not centuries. For example, one takes into account the weather prediction when deciding what clothing to wear tomorrow, while climate information will determine the composition of your winter wardrobe and aid in scheduling a winter getaway at a ski resort. The American public and vital industries rely not only on our weather products but also on our climate outlooks. Furthermore, our weather products and services are strengthened by our understanding of the weekly, monthly, seasonal, annual, and inter-annual earth system phenomena. If the goal is to achieve actionable seasonal hurricane outlooks, or accurate drought forecasts six months to two years in advance, one needs to conduct our research beyond two weeks. In other words, we often need to work on climate timescales in order to improve weather forecasts and services.

There is an ever increasing demand for additional lead time ahead of severe weather events. Emergency management officials have indicated that at ideal capabilities NOAA would provide highly consistent and accurate hurricane landfall predictions at days five and six, allowing for pre-positioning of crews, enhanced mitigation and evacuation efforts, and improved recovery planning – all of which can result in many more lives saved and significantly less money spent. Similarly, an hour of warning before a powerful tornado, versus the minutes of warning we can give today, might allow people to seek secure shelter and avoid being caught in vehicles, homes, or schools not robust enough to withstand a powerful storm. Many economic sectors such as agriculture, energy, and water management would see significant cost savings with highly accurate drought predictions from six months, to several years in advance. Imagine the benefit for a farmer in the Midwest of knowing before spring planting that a severe drought is expected throughout the entire growing season. If NOAA is to achieve these goals, we must research both shorter time scales and longer time scales.

The links among weather, climate variability, and climate change are pervasive and important to understand in order to improve weather prediction. We caution against actions to increase one important mission area to the detriment of the NOAA research programs in climate or ocean science. In the long term, this would weaken and undermine NOAA's weather forecasting enterprise in that weather is closely linked to the state of the ocean and variations in climate. As weather forecasting seeks to extend forecasts beyond ten days, and climate modeling seeks to shrink the resolution and time scale to less than a year, we are refining the intersection between where weather ends and climate begins.

We share the Committee's goal of enhancing weather research and improving forecasts. However, as NOAA's integrated response to Hurricane/Post-Tropical Cyclone Sandy (Sandy) demonstrated, protecting society today from "weather hazards" requires the ability to fuse information about all the impacts a hazard will have, such as flooding, storm surge, and navigation impacts. While NWS remains dedicated to the operational forecast mission, their success is not just measured in their ability to predict atmospheric pressure and temperature, but in the ability of the rest of the agency, such as that of the Office of Oceanic and Atmospheric Research (OAR), to conduct cutting edge research, and in NOAA's ability to translate and integrate information into useful guidance for the surrounding community.

This past October, NOAA mobilized programs and efforts from across the agency to help the public prepare for, respond to, and recover from Sandy. In the weeks prior to Sandy, NOAA used models informed by satellite, aircraft, and other weather observations to predict the path of the storm. NOAA gave emergency personnel and the public an accurate track forecast a full four days before the October 29 U.S. landfall. We also provided forecasts of total rainfall, storm surge, wave height, and other phenomena that would impact the mid-Atlantic and northeastern states. Our accurate predictions enabled emergency managers to more precisely evacuate coastal areas in the path of this unprecedented storm, saving countless resources and lives.

Once the storm passed through the Northeast, NOAA coordinated with Federal, State, and local agencies to aid on-the-ground responders to help communities get back on their feet. For example, NOAA vessels were instrumental in identifying and clearing marine hazards blocking New York and New Jersey ports, enabling ships to provide critical fuel resupply just days after the storm. Maritime traffic resumed more quickly, thanks in good part to NOAA regional navigation managers embedded within command centers and survey assets we mobilized rapidly after the storm passed. In addition, NOAA planes and scientists conducted aerial surveys of the affected coastlines and immediately published the photos online, allowing emergency managers and residents to examine the damage even before ground inspections were permitted. More than 3,000 miles of coastline were surveyed, and more than 10,000 images processed to document coastal damage and impacts to navigation.

NOAA is now working to help affected communities recover. The Disaster Relief Appropriations Act of 2013 (P.L. 1132) appropriated $326 million to NOAA that will enhance our ability to help coastal States recover from the impacts of Sandy. The technical tools and information that NOAA's coastal programs provide—such as coastal inundation products, maps, and storm surge modeling capabilities—are helping communities rebuild in a manner that is smarter and safer, and improvements in our forecasting capabilities will ensure that we are better prepared for similar events in the future. NOAA's integrated response to Sandy demonstrates how our agency leverages its diverse capabilities to support the nation from preparedness to response to recovery: **data** collected from a spectrum of platforms enables the development of **environmental intelligence** from science-based models to support a suite of **products** to provide decision support to individuals, communities, and governments.

I am proud of the work NOAA did during Sandy. Our people rose to meet the challenge that great storm presented. Last month we released our Sandy assessment and while it found that NOAA's forecasts saved lives and property it also highlighted areas we can improve. Most significantly it recommended that NOAA accelerate improving our storm surge products. Consistent and accurate storm surge forecasts further in advance will help affected states in their response to tropical cyclone hazards. We are committed to improved storm surge products and how best to communicate that information – because we are committed to serving our users. To make good on that commitment we must continue to direct resources to ocean and coastal research, observing, and mapping, not away from them.

The success of NOAA's mission should be measured by the strength of its research, the accuracy of its information, and by the effectiveness of its application to societal needs. As such, NOAA is pursuing a number of innovative approaches not only to provide significantly more lead time for forecasts, but also to ensure that people hear these warnings and take informed and appropriate actions to protect their own safety. Our Nation needs to be ready for weather impacts, respond to them, and be resilient to recover from them. This mixture of technological and social science advancements is a new approach to building a "Weather-Ready Nation" and one that we expect to provide large returns – measured in avoided economic losses and saving of lives and property.

Observations, Research, and Prediction

NOAA's Weather Mission

Since it was established, NOAA has relied on mission-focused research and innovation to improve our services to the Nation. NOAA has the sole federal responsibility of issuing severe weather warnings to communities across the country. NOAA-led weather innovations spanning decades - such as the national Doppler Radar network, dual-polarization radar, weather modeling improvements, and next generation geostationary and polar-orbiting satellites - continue to provide our Nation with increases in advanced warnings that help save lives and property from severe weather events that can devastate communities. The weather and climate disasters for 2012 exceeded $110 billion in damages, making that the second costliest year since 1980. Eleven events each had losses exceeding $1 billion in damages, including seven severe weather and tornado events, two tropical cyclones, and the yearlong drought and its associated wildfires.[1] NOAA was able to provide advanced and accurate forecasts to the states and communities facing these challenges, thanks to its continued investment in the long-term research and development that fuel innovation. There is much more to be done if we are to achieve new life-saving advancements in the future, and NOAA is committed to working with its federal, academic, private sector, and international partners in the broader enterprise to continue this record of success.

As I stated above, NOAA's environmental predictive capabilities are supported by four foundational pillars: observations, scientific research, computer modeling (including High Performance Computing), and our people – who provide forecasts, warnings, and decision support services to key decision makers. In order to advance forecasting capabilities, we must strengthen all four of these pillars in concert. For example, our forecast models are only as good as the data we put in them. Without sustained investments and continuity in high quality observational data, the accuracy of our operational forecast models would suffer. Only by evolving in concert across each of these realms can we revolutionize forecast capabilities.

Similarly, while near-term advances in observing, computing, and forecast model development are important, long term research and the effective transfer of research into operations are equally important. NOAA must have a continued investment in longer term research (looking five to fifteen years ahead) aimed at developing the next-generation radars, prediction models and services that will make, and keep, the U.S. and our NWS "second to none." In the wake of severe storm events, there is often a tendency to focus on the operational mission above all else. We see time and time again that the best way to ensure future advances and innovation is to maintain a robust research program independent of, but tied richly to, the operational mission.

Similarly, innovation is necessary in order to meet the Nation's weather and water needs. Specifically, investing in shoring up aging infrastructure, improving scientific understanding, and implementing enhanced services are necessary to reduce risk to the Nation. Perfect forecasts

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[1] http://www.ncdc.noaa.gov/news/preliminary-info-2012-us-billion-dollar-extreme-weatherclimate-events

don't save lives without the infrastructure to disseminate them and an understanding of how best to communicate to spur individuals to take action. In addition, NOAA must increase its capacity to collect and assimilate ever-growing quantities of data to improve model performance, and hence weather predictions and forecasts. This, too, can only be achieved through advancements in scientific research and technological advancements. Future technology improvements and computing assets are crucial pieces of our national infrastructure.

The State of NOAA's Weather Forecasting

The tornadoes that caused so much devastation last month in Oklahoma, as well as those of Alabama and Missouri in 2011, and the huge toll from hurricanes such as Sandy and Katrina, underscore the importance of delivering the best possible weather information with as much lead time as possible. For example, NOAA's four-day predictions for hurricane track have become as reliable as our two-day predictions were prior to 1995. Today's 5-day temperature forecasts have the same level of accuracy that 3-day forecasts had 20 years ago. Our tornado warning lead times have more than doubled over the past two decades, to an average of 13 minutes. This is possible because NOAA's weather and climate research and development efforts are integrated into operations as a mainstay of NOAA's forecast and warning operations and capabilities. However, there are still significant areas for improvement.

Environmental Observations

Our current forecast process uses observations gathered by NOAA-operated systems such as *in situ* weather stations, balloons, buoys, radars, and satellites, as well as data collected by other federal agencies, international partners, and the commercial and academic sectors. These observations provide the critical foundation for the continuum of research models, operational models, and accurate forecasts and warnings.

NOAA's current satellites, both the polar-orbiting satellites and the geostationary satellites, provide critical data to support daily weather forecasting, including detection and monitoring of severe weather and space weather, and measuring the state of the atmosphere to incorporate in weather models. NOAA augments the data it requires by leveraging relevant data from foreign satellites and by purchasing data from the commercial sector to meet the agency's needs. We are in continual dialogue with the commercial sector and our international partners, and we recognize the value and importance of these public-private and international partnerships.

Weather Research Partnerships

NOAA's research endeavors include strong connections to academia, the federal government, international agencies, and the commercial sector. NOAA works hand-in-hand with the academic sector. More than half of NOAA's 18 Cooperative Institutes, several Sea Grant Colleges, and two Cooperative Science Centers are advancing various aspects of weather research. Other federal contributors include, but are not limited to, the National Aeronautics and Space Administration (NASA), the Department of Defense (DoD), U.S. Geological Survey (USGS), and investigators supported by the National Science Foundation (NSF), with notable contributions from the NASA/NOAA/DoD Joint Center for Satellite Data Assimilation.

Interagency Collaboration

NOAA and NASA have partnered for more than 40 years in the area of Earth Observations. As outlined in the 2010 National Space Policy,[2] NOAA and NASA collaborate to provide research-to-operations transition of capabilities and measurements that NASA has developed into ongoing and long-term observations aboard NOAA operational platforms. This arrangement has resulted in the successful transition of the satellite altimetry (sea surface height) capability (known as Jason) to operations, due in large part to the utility of the data for many of NOAA's programs, especially hurricane forecasting. Data and imagery from NOAA's polar-orbiting and geostationary satellites, in conjunction with sea surface height measurements, have proven extremely useful to predicting hurricane intensification. Future satellite systems, including those currently being procured, will continue to provide enhanced observations to support more accurate weather forecasts and more timely warnings.

NOAA has two critical partners, USGS and the U.S. Army Corps of Engineers (USACE), in flood-fighting, forecasting, and prediction. USGS funds and operates the vast majority of the nearly 6,000 river and stream gauges that NWS uses to monitor and forecast river flooding. Without these real-time gauges, and without their historical data, NOAA would be severely hampered, and in many cases unable, to issue its lifesaving flood warnings. Similarly, as USACE manages river and reservoir projects, the two-way communication of data and information about the timing and amount of discharge is critical to our river modeling and flood forecasting. Through the tri-agency Integrated Water Resources Science and Services partnership, the three agencies are joined in a common mission to provide critical data and information to each other, and to the public.

A program this Committee has long supported, the National Integrated Drought Information System (NIDIS) program, is built on longstanding efforts among the agencies and institutions that have historically focused on drought risk assessment and response. The NIDIS Act prescribes an interagency approach, led by NOAA, to "enable the Nation to move from a reactive to a more proactive approach to managing drought risks and impacts." The goals of the program are to (a) improve public awareness of drought and attendant impacts and (b) improve the coordination and capacity of counties, states, and watersheds to reduce drought risks proactively. NIDIS partners include the National Drought Mitigation Center (NDMC) at the University of Nebraska-Lincoln, U.S. Department of Agriculture, Department of Energy, Department of Homeland Security, Department of the Interior, Department of Transportation, USACE, NASA, and NSF, just to name a few. The number of watershed, state, and local drought and water plans using NOAA-based information has increased significantly since NIDIS was initiated in 2007. The support that NIDIS has generated and the ability of the program to meet the needs of the Nation are a result of the strong partnerships that the program has with other agencies, outreach organizations, and an enabling set of programs and observational capabilities. In December 2012, the Secretary of Agriculture and the Acting Secretary of Commerce signed an updated DOC-USDA Memorandum of Understanding (MOU) that is aimed at improving cross-agency collaboration on drought risk reduction, the development and delivery of drought information services at local and regional scales for relevant economic sectors, and the fostering of improved understanding by end-users. Necessary advancements in drought prediction, forecast products, and services require the integration of multiple scientific disciplines across

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[2] http://www.whitehouse.gov/sites/default/files/national_space_policy_62810.pdf

multiple time scales. Such advancements cannot be achieved if efforts are limited to short timescales and isolated in single scientific disciplines.

International Collaboration
NOAA also partners with international satellite agencies to share the responsibilities of acquiring specific data or capabilities beneficial to both parties. Perhaps the best-known example is the collaboration with Europe's operational weather satellite agency, the European Organisation for the Exploitation of Meteorological Satellites (EUMETSAT). Through this partnership, NOAA has provided 11 instruments to fly aboard three MetOp satellites, which provide data in the mid-morning orbit that are used by NWS in its numerical weather prediction models. By providing the instruments to EUMETSAT, NOAA avoided the hundreds of millions of dollars it would have cost to procure a spacecraft bus and pay for launch services to get the data NWS needs for reliable forecasts.

Commercial Sector Collaboration
To provide the best possible weather services to the Nation, NOAA has also developed a close working relationship with the U.S. commercial weather sector. This has been growing since the 2003 National Academy of Sciences report, *Fair Weather: Effective Partnerships in Weather and Climate Services,* and has gained momentum in recent years with NOAA's "Weather Ready Nation" initiative. The NOAA Science Advisory Board established, and has recently re-chartered, the Environmental Information Services Working Group to strengthen connections between public and commercial sector activities in weather and climate. The American Meteorological Society also responded to the report and sponsored a productive set of meetings and interactions among the full weather enterprise, including Federal, academic, and commercial sectors. NOAA works to encourage more participation from the commercial and academic sectors in the development of advanced prediction capabilities that have operational potential. NOAA's work also fosters development of the commercial sector to significantly tailor products for increasingly specific audiences and needs.

Over the past decade, NOAA has purchased data from the commercial sector to fulfill a number of specific requirements. For example, NOAA purchased synthetic aperture radar data from the MDA Corporation to support operational sea ice and oil spill detection and monitoring programs. NOAA plans to continue this practice with commercial entities that have data that NOAA needs, as long as it is supplied within NOAA's operational construct. Looking to the future, NOAA is assessing the possibility of expanding data purchases from commercial sources and is closely monitoring ongoing international demonstration projects in this area. The President's FY 2014 Budget Request for NOAA also proposes to formally establish the National Mesonet Program, with a request of $5.5 million to promote the use of mesonet data. This request enables NOAA to procure and use surface and near-surface, localized weather data from commercial and academic sources, to improve forecasts and warnings of small-scale, high impact weather events that can quickly threaten lives and property.

Evaluating New Data Sources and NOAA's Data Policy
The NOAA Observing System Council (NOSC) studies existing and emerging observing systems to determine the best technologies that should be incorporated into operations. The NOSC compares the capabilities of these systems to NOAA requirements, and determines optimal solutions for the evolution of its entire system. NOAA and the NOSC use many tools,

including Observing System Simulation Experiments (OSSEs) and Observing System Experiments (OSEs), in their ongoing development of the integrated system. Even though these quantitative analyses require a significant investment of manpower, High Performance Computing, and funding, NOAA believes that the increased rigor available from these quantitative tests will allow us to be more effective as the acquisition of observing systems becomes more complex. They are useful tools and have the potential to give NOAA better capability to weigh options before procurement of assets. We recognize their role in helping to prioritize and determine the potential use of commercial sources for major satellite and ground-based observing systems in the NOAA observing suite. However, NOAA cautions against requiring OSSEs to quantitatively assess the relative value and benefits of *all* observing system capabilities. In some cases, for example, evaluating systems that already exist, simpler OSE's (e.g. data denial studies) can be used. If the legislative language is too prescriptive, NOAA could consume its observation programs in OSSEs for years before being able to actually use the data. This would be entirely counter to the stated constructive intent of the legislation.

NOAA's data activities are governed by a "full and open" data policy consistent with the Office of Management and Budget's (OMB's) Circular No. A-130, the May 9th, 2013 Executive Order titled "Making Open and Machine Readable the New Default for Government Information", and the aforementioned 2010 National Space Policy. These policies provide the framework that allows NOAA to widely distribute its products and services to support its public safety and global environmental monitoring mission. There are significant benefits to providing publicly-funded data for free such as promoting advances in predictive capabilities and supporting a robust private weather industry. The U.S. weather services model recognizes the role played by the private sector weather enterprise, including the media, in developing tailored, value-added products and services and in communicating important weather information to citizens. By ensuring weather data are easily accessible and freely available, NOAA seeks to foster the growth of the environmental information enterprise to best serve the public interests in both public safety and commercial opportunity. In contrast, European service models for weather services are fundamentally different than in the U.S., in that they seek to recoup costs through fee-for-services. The U.K. Meteorological Office, for example, is self-sustaining via fee-for-services - in effect a government consulting service. If these European business models were applied in the U.S., it would most likely be seen as government competition that impedes private sector growth.

U.S. weather services are provided through an "environmental information enterprise" composed of government, private, and academic sectors. As noted by the National Academy of Sciences, "this three-sector system has led to an extensive and flourishing set of weather services that are of great benefit to the U.S. public and to major sectors of the U.S. economy."

Looking to the Future: Opportunities for Weather Research and Technology Development

NOAA is proud of its record of accurate storm forecasts and warnings. We are fortunate that the science and technology of weather prediction is in a period where new advances are rapidly becoming available, thanks in large part to Federal researchers working in close partnership with external partners. For example, NOAA is developing concepts that apply high-resolution models in shorter-range forecasts to increase tornado warning lead times. An estimated 16 minutes of warning lead time was provided for the recent Moore, Oklahoma tornado. With advances in observing and modeling, we will continue to extend warning lead times to help save lives and property, but we need to maintain strong observations and research portfolios, as identified in the FY 2014 President's Budget request, in order to realize these potential improvements in weather forecasting.

The topics of weather research and the implementation of the best research into operations are particularly timely. A recent study by the National Academy of Public Administration (NAPA), called *Forecast for the Future: Assuring the Capacity of the National Weather Service* emphasized the importance of transitioning research efforts to operations, as well as the communication of operational needs to the researchers. It summarized the need for ongoing change in NWS, such as:

> *The Panel found enormous support for the weather, water, and climate products and services provided by the NWS. However, both internal and external stakeholders see additional and ongoing change as necessary to continue to enhance NWS performance. To continue to provide the range and caliber of current products and services, the NWS, like any technologically dependent organization, will need to refresh or replace aging technology, infrastructure, and systems.*

The National Academy of Sciences Report, *Weather Services for the Nation: Becoming Second to None,* also makes a number of recommendations regarding weather research. This report emphasized the community enterprise that is needed to improve weather forecasts, from academic and government research, through technology transition, and with special emphasis on the connection between NOAA's weather enterprise and the U.S. commercial weather sector.

Observing Systems Technology Innovation

In addition to ongoing research and partnerships, NOAA is working on numerous innovations for future weather operations and research in the observing arena. To continue the march of progress represented by the recent deployment of the NOAA-developed dual-polarization radar system, NOAA is supporting emerging next-generation radar technology via the Multifunction Phased Array Radar (MPAR) program. A joint development effort of NOAA, the Federal Aviation Administration, the DoD, and other agencies, MPAR, if implemented, would reduce the number of U.S. surveillance radars by nearly 40%, with associated cost savings of nearly $4.8 billion over the lifecycle of the system. MPAR can serve weather surveillance and other purposes simultaneously. Nationwide deployment would provide much greater protection to the people of the U.S. as it's solid-state, stationary construction allows for sampling the atmosphere much more frequently and with higher resolution than is presently the case with NEXRAD radars.

The follow on to the current NOAA polar and geostationary satellites (JPSS and GOES-R respectively) are in development, and when launched later in the decade, will yield significant increases in timeliness, resolution and accuracy over the existing satellites they will replace. New satellite-based observing technologies and applications, such as the Global Positioning System Radio Occultation-based systems, are also showing significant positive impact in both global and regional data assimilation and forecasting. Finally, initial tests suggest that new technologies such as Unmanned Aircraft Systems have potential to improve hurricane and other storm predictions.

Advanced Data Assimilation and Forecast Modeling Innovations

Forecast quality depends critically on the ability to add, or assimilate, observed information on the initial state of the atmosphere, ocean, land surface, and ice regions to forecast models. Advanced data assimilation techniques, increased forecast accuracy through higher resolution and improved representation of the atmospheric, oceanic and land physical processes are important factors for improving operational forecasts. While substantial data assimilation and model improvements have occurred over the past five years, considerable progress is yet to be made. Over the next decade, global and regional data assimilation and model capabilities and techniques will become more integrated into a single system capable of providing forecast data from less than one hour to more than two weeks.

Global models are the basis of predictions from one day to two weeks in advance. With broader geographic coverage, global models are the key to the forecasting of major storms with oceanic origins, such as hurricanes and nor'easters. Global models are also critical to NOAA's success in preparing the public three to eight days in advance for conditions that could lead to major tornado outbreaks. By the end of the decade, the next generation of global models will run at horizontal resolutions of a few miles, with more accurate representation of physical processes. As model resolution increases, research will be required to understand how to formulate and incorporate new physical processes into the models. When these steps are accomplished, the ability to forecast both large and small storms will take a big step forward. The best way to ensure these advances take place is through a sustained research and technology transfer effort.

Trends in yearly-averaged tornado warning lead time suggest that the present weather warning process, largely based upon a warn-on-detection approach using Doppler radars, is reaching a plateau and further increases in lead time will be difficult to obtain through this method. A new approach, referred to as the "Warn on Forecast" paradigm in NWS *Weather Ready Roadmap* plan, is needed to extend warning lead time. National scale high-resolution models are particularly promising and critical for predicting the details of severe weather events such as tornadoes and hurricanes. The NSF National Center for Atmospheric Research led the initial development over the last 15 years, of the regional Weather Research and Forecast (WRF) model. Based on this model, NOAA researchers and partners have developed the High Resolution Rapid Refresh (HRRR) model, a key to the "Warn on Forecast" paradigm. This model has exhibited very promising results. Running in an offline experimental model, it forecast the derecho that affected the eastern U.S. on June 29, 2012 twelve hours before the storm hit the Washington DC area. This same model forecasted nine hours in advance the dangerous conditions and general characterization of the thunderstorms that formed the destructive tornadoes that affected Alabama on April 27, 2011.

Another notable advancement in forecasting resulting from investment in research is the new hurricane prediction model that will come on line for the 2013 hurricane season. The operational Hurricane Weather and Research Forecast model represents a significant step forward in our understanding of hurricane structure and intensity forecasting. The research has been a joint effort across NOAA as part of the Hurricane Forecast Improvement Project. This advancement highlights the importance of the research and operational entities working hand-in-hand: as research improves, so do the forecasts. NOAA has achieved much higher skill in recent years through improved computing capability, the ability to zoom in observationally for a "deeper look" at specific areas of storms as they form, and the ability to assimilate critical observation data from a variety of platforms.

Advances in Computing Capability
Computing capacity and computer modeling are indispensable requirements for extending weather warning lead times to save lives. While many nations run their own numerical weather prediction computer models, the European Centre for Medium-Range Weather Forecasts (ECMWF) model is repeatedly singled out as the "best in the world." For example, the ECMWF model was able to predict Sandy's landfall almost precisely a full eight days in advance. Meanwhile, the NOAA's Global Forecast System (GFS) eight day forecast predicted Sandy to move further offshore instead of making landfall. It was not until the five day forecast that the NOAA GFS model track became equivalent to the ECMWF track. Running at a higher resolution on nearly ten times the computing power of the GFS, the dominance of the ECMWF model highlights the need for the very best computing capability. It is important to note that NOAA forecasters used all available information, including the ECMWF, as they made their official forecasts for Sandy's track and eventual landfall in New Jersey.

Major advances in weather research depend critically on increases in computing capability. Top-end supercomputing has maintained a growth rate of doubling every three years for the past five decades. In recent years, as computer processing unit speeds have met physical limits, further increases in computational power have been achieved by increasing parallelism – or carrying out many computations simultaneously. NOAA will continue to pursue new technologies to ensure computing capacity continues to increase and meet the demand for increased accuracy, resolution, and extended forecasts and warnings.

A major upgrade to NOAA operational computers is scheduled to be completed next month, July 2013, in which NOAA operational computing will undergo a threefold hardware capability increase. This upgrade will include major resolution enhancements and an advanced global model that runs more economically on the new hardware. The Disaster Relief Appropriations Act of 2013 is providing additional funds to improve operational and weather research computing in both FY 2014 and FY 2015. With these funds, NOAA's operational computing capability will increase tenfold by 2015. The FY 2014 President's Budget requests additional funds for NOAA to upgrade operational computing, which will provide a 27-fold increase in operational computing capability by 2015. That advancement will give NOAA unmatched operational computing capability and the ability to run the latest long-range forecast models with improved resolution.

While we appreciate the Committee's interest in upgrading our operational computing capabilities, we would like to point out that this work is already well on its way. We would caution against directing funding away from research and to High Performance Computing because it would have a serious negative impact on NOAA's ability to develop the next generation of ocean, weather, and climate models. In addition to operational supercomputing, cutting-edge high performance computing for ocean and climate research is also essential to the development of next-generation weather services and products. For example, seasonal to inter-annual "earth system" climate models are essential to advancing long-term weather forecasts for extreme events such as drought and floods. We recommend that the balance between research and operation requirements be driven by the needs of the user community, which is why we encourage the subcommittee to further consider the balance between weather operations and ocean and climate research supercomputing reflected in this bill.

Since researchers are often working on models that will not become operational for three to five years or more, and with computer speed doubling every two to three years, a good rule of thumb is that researchers should have computing capabilities that are two to four times the current operational needs in order to ensure continued advancement of operational products and services. Therefore, with the significant investment in NOAA's operational computing through the Disaster Relief Appropriations Act of 2013, the next challenge is how to ensure NOAA's research computing continuously keeps pace with NOAA's growing operational computing capabilities.

Research to Operations

NOAA is continually working to enhance the transfer of research advances into NOAA's operational and information services. NOAA research has developed the capability to provide improved longer range computer forecasts, but NWS has lacked the operational computing capacity to transition these research developments to operations. The Disaster Relief Appropriations Act of 2013 not only brings funds to improve our computing capabilities, but also to implement scientific research activities into operational weather, storm surge and coastal forecast models, to accelerate weather research, and to enhance observations. The President's FY 2014 budget submission continues this trend of increasing computing capacity and pulling proven research improvements into operations.

Recent Research to Operations Examples

The weather warning improvements in recent years are the result of intensive research by NOAA and its academic, international, and commercial partners. Without our current operating model of drawing on resources from within and outside of NOAA, and our policy of open and free access to our data, we would not be where we are today. Here are just a few examples of some of the recent advances we have achieved:

- **Dual-Polarization Radar** is the next generation of Doppler radar, which NOAA recently finished upgrading. It provides real-time measurements that improve forecasts of rainfall and snowfall amounts, tornado and hail detection, and other meteorological elements.
- **Advanced Weather Interactive Processing System (AWIPS)** has been developed, operationalized, and deployed by NOAA and is used at every weather forecast office nationwide.
- **HYSPLIT** is a model developed by NOAA and utilized by NOAA and other customers for emergency response operation for smoke, dust, volcanic ash, and nuclear events.

Improvements continue in forecast operations, but significant strides are needed at all spatial and temporal scales – from small scale prediction of tornadoes and severe thunderstorms, to the medium scale eastern U.S. derecho that ravaged the mid-Atlantic States last year, and to the larger scale prediction of the track and intensity of hurricanes, winter storms, and drought. These modeling advances are possible only through validated, robust observations taken from multiple platforms.

<u>Achieving a Weather-Ready Nation</u>

With the destruction we have already seen this year from weather events, we take little solace in knowing that outcomes could have been worse without the work of NOAA and our federal, state, local, academic, and commercial partners. There is much more that needs to be done to improve the Nation's resilience. In addition to improved forecast and warning accuracy and lead times, integrated research, education, and outreach are essential ingredients to improving preparedness. Realizing a Weather-Ready Nation, where society is prepared for and responds to high impact weather events, is vital.

NOAA is continuing a dialog with the Nation's top experts to examine what can be done in the short- and long-term to improve how NOAA communicates severe weather forecasts and warnings. We've engaged leaders in broadcast meteorology, social sciences, and emergency management, as well as outreach specialists such as Sea Grant extension agents and Warning Coordination Meteorologists, and the weather industry to focus on the community response to and preparedness for severe weather. Included in this effort are innovative technologies and social media to improve our effectiveness in reaching those in harm's way and provoking appropriate response, whether to the urgency of a tornado or tsunami warning, or to the longer-term likelihoods of flooding or drought. Social science research includes the development of new or reconfigured graphics, such as evolving the hurricane forecast cone of uncertainty, and visualization techniques to better communicate tropical cyclone risk, such as storm surge inundation maps. It includes analysis of the promise and possible pitfalls of using Twitter in severe weather forecast operations, the assessment of how the public uses NOAA's online tools to understand and prepare for flood risk, and the identification of factors relevant to an individual's response to a tornado warning. Most NWS offices have established Facebook pages, providing an additional medium for conducting outreach and education, as well as highlighting information about ongoing or upcoming weather events. Additionally, NOAA uses NWSChat to give core external partners an invaluable opportunity to interact with NWS experts and to refine and enrich their communications to the public, and more private companies are carrying weather warnings on wireless networks, providing real-time alerts to your cell phone or email. And this year NOAA is running tests to evaluate different language to include in blizzard and severe storm warnings that may more effectively communicate the severity of the warnings. NOAA is exploring ways to make its information easier to find, easier to understand, and easier to apply in operations by the public and the Emergency Management community, which will result in improved decision making for risk management of life and property.

Conclusion

NOAA forecasts, warnings, and community-based preparedness programs are vital in enhancing the economy and saving lives and property. It all starts with a commitment to environmental observations, to research and improved forecasting and warnings, and ends with a Weather-Ready Nation in which businesses, governments, and people are prepared to use those forecasts to mitigate impacts. In spite of our best efforts, severe weather events still cause loss of life and significant damage. We recognize that there is always room for improvement and more of these impacts could be mitigated with more timely, accurate, and focused forecasts, watches, and warnings. The impacts and lives lost from the disasters experienced over the past year alone would have been far worse without NOAA's observations, research, forecasts, people and the extensive work of NOAA and our federal, non-federal, state, and local partners to improve the Nation's preparedness for these events through education and outreach.

While NOAA supports the ambitious goals of improving the Nation's weather forecasting capabilities, we are concerned about the bill's funding impact to other mission critical activities identified the FY 2014 President's Budget, including climate and oceans research, observations, and research supercomputing. It is critical that NOAA support its observations and research portfolios if advancements in weather forecasting are to be realized. We look forward to working with the subcommittee to identify the appropriate balance between operations, research, and observations to best support NOAA's missions.

NOAA regards protection of the people of the U.S. from the devastation that weather can bring as a sacred trust and duty. Despite our concerns, NOAA appreciates the evident thought and foresight that the Committee has shown in development of "The Weather Forecasting Improvement Act of 2013." We look forward to working with Committee on this bill, and thank you for allowing me to testify today.

NOAA Leadership

Dr. Kathryn D. Sullivan

Dr. Kathryn D. Sullivan, Assistant Secretary of Commerce for Environmental Observation & Prediction / Deputy Administrator and Acting Chief Scientist

On May 2, 2011, Dr. Sullivan was appointed by President Obama as assistant secretary of commerce for environmental observation and prediction and deputy administrator for the National Oceanic and Atmospheric Administration (NOAA). She is also serving as NOAA's acting chief scientist. She is a distinguished scientist, renowned astronaut and intrepid explorer.

As assistant secretary, Dr. Sullivan plays a central role in directing Administration and NOAA priority work in the areas of weather and water services, climate science and services, integrated mapping services and Earth-observing capabilities. She provides agency-wide direction with regard to satellites, space weather, water, and ocean observations and forecasts to best serve American communities and businesses. As Deputy Administrator, she oversees the smooth operation of the agency.

Dr. Sullivan's impressive expertise spans the frontiers of space and sea. An accomplished oceanographer, she was appointed NOAA's chief scientist in 1993, where she oversaw a research and technology portfolio that included fisheries biology, climate change, satellite instrumentation and marine biodiversity.

Dr. Sullivan was the inaugural director of the Battelle Center for Mathematics and Science Education Policy in the John Glenn School of Public Affairs at Ohio State University. Prior to joining Ohio State, she served a decade as President and CEO of the Center of Science and Industry (COSI) in Columbus, Ohio, one of the nation's leading science museums. Dr. Sullivan joined COSI after three years' service as Chief Scientist.

Dr. Sullivan was one of the first six women selected to join the NASA astronaut corps in 1978 and holds the distinction of being the first American woman to walk in space. She flew on three shuttle missions during her 15-year tenure, including the mission that deployed the Hubble Space Telescope. Dr. Sullivan has also served on the National Science Board (2004-2010) and as an oceanographer in the U.S. Navy Reserve (1988-2006).

Dr. Sullivan holds a bachelor's degree in earth sciences from the University of California at Santa Cruz and a doctorate in geology from Dalhousie University in Canada.

Chairman STEWART. Thank you, Dr. Sullivan, for your testimony today. Thank you for your extraordinary service to your country for many years.

I would remind the Members that Committee rules limit questioning to five minutes. And the Chair will at this point open the round of questioning, and the Chair recognizes himself for five minutes.

Dr. Sullivan, you mentioned a couple things in your testimony I would like to maybe expand on a little bit. And the first one I would like to go a little quickly, saving time for, perhaps, a second question as well. You mentioned the money provided by the Super Storm Sandy relief funding that was appropriated recently and that NOAA has committed to Congress to immediately undertake two very important OSSEs, or the Observing System Simulation Experiments, to assess potential gap-filling satellite technologies. And in our meeting last week, we had a chance to talk about this just a little bit, GPS radio occultation and the geostationary hyperspectral sounding.

For this latter technology can you explain to the Committee your evaluation criteria? Are you going to evaluate a constellation of six instruments around the globe or only a single sounder here in North America? And can you then give us some insight into, you know, with that decision how that will affect the results of these experiments?

Ms. SULLIVAN. Thank you, Mr. Chairman.

That Observing System Simulation Experiment, as I understand, is still being formulated. I don't have at hand the detail of whether a—whether the initial plan is to do a single instrument or then a full complement of 6 or what the time and computational resource required to do either and both of those would be, but I would be happy to get that for you.

Chairman STEWART. Okay. Help me understand. Can you get meaningful data with just one or do you really need six to draw very meaningful conclusions?

Ms. SULLIVAN. That is a very subtle, technical answer that goes to how the data would be incorporated into global forecast models. I would have to get some of our scientific experts to give you a view on that.

Chairman STEWART. Okay. Well, I look forward to those—you know, that reply from you. It would be helpful for us.

And, you know, I wouldn't presume that you can't achieve what you want to do with only the one, but it would certainly seem like six is much more meaningful and I am sure you have constraints regarding funding that would impact that.

Ms. SULLIVAN. Certainly to provide—and when you run a global model, you need to initialize it, start it out with some initial conditions. And to do that you need to sample the entire globe.

So we take today, for example, polar satellite data, sounding data, from all across the globe and we take ground-based instrumentation data from all across the globe shared by international partners at no cost to each nation. So that is the current initialization. It does make first-order sense. If indeed the performance of the hyperspectral sounder proved out, as is postulated in the written literature, it certainly might make sense, but that density and precision could aid in the initialization of global models.

Chairman STEWART. Okay. Thank you. And again, we look forward to more detailed response on that.

I think you will like my second question. It is a little easier perhaps. What are—you know, we have seen so much—so many advances in technology, so much—such a greater result over the last couple decades, certainly from when I was younger, and it is remarkable really. But, of course, there is much more that we can do and so I would ask you, what are some of the promising technologies and some of the promising research areas that you are not able to pursue because of some perhaps restrictions in funding? What would you like to be doing that you are not able to do right now?

Ms. SULLIVAN. I would focus on two things, and my answer will pick up the piece of Mrs. Bonamici's statement. One of the things that we have found most fruitful within NOAA to making—really advancing the research, making sure we have got a sharp focus on the most important things to move forward on, and ensuring it couples closely and rapidly into the forecast world are co-locations and testbeds.

So I can cite two, one from the Vice Chairman's home State, which I know he knows well. At the National Weather Center at the University of Oklahoma in Norman, we have co-located the National Weather Service's Weather Forecast Office, the actual operational forecasters; our National Center for Severe Storms Prediction. Anytime you see "the Severe Storm Center says" on your television, that is coming from NOAA, from the main forecasting engine that produces American weather forecasts; and finally, our Office of Oceanic and Atmospheric Research's National Severe Storms Lab.

Putting those three entities so close together, letting the scientists and the forecasting experts really work very flexibly and fluidly with each other and work together around what has been developed—they are called a hazardous weather testbed—has really been a—made a tremendous difference in the rate of advance and refinement of the forecasters' tools.

So what we aim to do at NOAA, frankly, in essentially all of our research, we are not really a blue sky research agency. Yes, we do research that is labeled climate. Far the great majority of that research within NOAA is seasonal to interannual and very directly oriented towards understanding the longer-term underlying patterns that shape daily and seasonal weather in the United States. And these close couplings with the Severe Storms Lab, the testbed, the Storm Prediction Center, and the forecasters have proven very fruitful. I would love to replicate that model in more places.

Chairman STEWART. Okay. Great. You know, and my time is—has now ended. Maybe I could close with just these two observations. The first is obvious, and that is as Mr. Bridenstine has indicated in what took place recently in his home State. There is more that we can do and the technology is available for us now perhaps where we can take some generational leaps forward in providing a longer warning period and more safety and security for people. And we look forward to working with you in helping that come to pass.

The Chair now recognizes Ms. Bonamici for her questions.

Ms. BONAMICI. Thank you very much, Mr. Chairman.

And I want to follow up on your previous answer, Dr. Sullivan, but before that, I want to join the Chairman in thanking you for all your service. I really liked reading in your testimony about your view from the shuttle showing the interconnectedness of all the systems.

So following up on your last answer, Dr. Sullivan, according to some weather experts and people who have raised concerns about proposals to reallocate significant resources from NOAA's climate and ocean investments to weather forecasting. So I noted in several places in your written testimony where you caution us against actions to increase one important mission area to the detriment of NOAA research programs in climate or ocean science. So will you please explain how climate and ocean research and research flexibility are critical to NOAA's mission providing more timely accurate weather forecast?

Ms. SULLIVAN. Thank you, Mrs. Bonamici. I would be delighted to do that.

Let me open by saying that weather forecasting and the protection—the forecast services that protect American lives and livelihood already—are already NOAA's highest priority. They are encoded in national security functions that we are directed to fulfill by the President of the United States in support of the Commerce Department's mandates. So they stand already far head and shoulders above many other things that we do.

How is this flexibility important? How does it help us? Let me cite our Hurricane Forecast Improvement Program to give you an example of that. This was assembled after a state of land falling hurricanes, very devastating hurricanes. We brought together academic, federal, outside researchers and forecasters. We looked at the spectrum of underlying causal factors, what patterns in the atmosphere lend to the formation of hurricanes, shape them, steer them, stop them? What phases of things do we need to understand?

The answer is a mixture of things ranging from understanding decades-long oscillations in the Earth that put the Earth sometimes in a phase we are in now where the Atlantic basin is very active, and then a few decades later in the phase when the Atlantic basin is not very active. That is a deep underlying heartbeat of the planet. To know the predictability of hurricanes, we need to understand those kind of longer-term heartbeats.

But to really get track and intensity right is also clear on the other end of the scale. We need to have models that can resolve the actual inner core of a hurricane very precisely. So this Hurricane Forecast Improvement project set out an array of research endeavors coupled to this purpose across that timescale. They cross-check regularly and frequently which ones are advancing. They created a stream that could advance and yield benefits to forecasting with the operational supercomputing assets in place at the moment and they yielded a second stream that could take us even further if we could step ahead the capacity of the operational supercomputer, like way ahead. And then they created another stream to bridge them and make sure that we didn't leave good results sitting on the sidelines for any longer than are necessary.

The flexibility of this sort of integrated team to move those pieces back and forth under a broad charge given by the Congress to get better hurricane forecasting, get these targets by these times, and then the throttle-setting that the Congress can allow us each year in the appropriations has really made that a tremendously fruitful program. I think that is a great model to emulate.

Ms. BONAMICI. Thank you. And this is similar to the Chairman's second question. Based on your years of experience and your expertise, what changes if any should be made to the structure or processes at NOAA to provide continuing improvement in weather forecasting? Are there some structural things that could change that would help improve them?

Ms. SULLIVAN. We are trying to make some of those now, and I think a couple others could help. Again, I would cite the Hurricane Forecast Improvement Program. It had many strands of activity under it but it was agreed upon with the Congress at the level of the program and then appropriated at that level each year. That, in my view, is a sound and healthy balance of the rightful prerogatives of the Congress and the flexibility needed to adjust programs as they evolve and deal with setbacks when they occur as—you know, as they will in the research arena.

We have also—I think if we can improve the way we all look at keeping NOAA's operational supercomputers closer to the cutting edge, we would find a great improvement there.

And I will give you one great example. We have research models running. In fact, the research model that runs under the hurricane program cannot be put into the operational supercomputer right now. So during hurricane season we run the National Hurricane Center, and we run this research model in real time because we can't fit it into the operational supercomputer. We should be able to fit it in. We have a model that could have forecasted last year's diverter 12 hours in advance. It did. It did but it was running in research mode. We need to be able to move those more rapidly into supercomputing rather than waiting so long for big-step functions in our supercomputers.

Ms. BONAMICI. That is very helpful. Thank you very much, Dr. Sullivan.

And I see my time is expired. I yield back, Mr. Chairman.

Chairman STEWART. Thank you, Ms. Bonamici.

We now recognize the Vice Chair, Mr. Bridenstine, for five minutes.

Mr. BRIDENSTINE. Thank you, Mr. Chairman, and thank you, Dr. Sullivan, for being here. I have just a few questions.

You would agree that increasing tornado warning lead times is as much as one hour is a priority of NOAA's?

Ms. SULLIVAN. I wouldn't set one hour necessarily as a priority, Mr. Bridenstine. There is a significant response question as to what people would do with one hour. And I think we have begun mounting in concert again with the weather center down in Norman some social science and risk communication research lines to understand A) is that the right target to set? And B) if it were, what do we need to understand about how to present and communicate that so that it doesn't become something somebody heard and then got busy on something else and then by the time the hour came they were immersed in a video game and the tornado ran right over them.

Mr. BRIDENSTINE. So more lead time would be more dangerous?

Ms. SULLIVAN. More lead time if it triggered the inappropriate response to take safety——

Mr. BRIDENSTINE. Is it——

Ms. SULLIVAN. —could be inimical to the gain——

Mr. BRIDENSTINE. —you are impugning the motives of the people we are trying to protect. If they had an hour lead time, that would be better than 16 minutes, which is what the people in Oklahoma got this time, correct?

Ms. SULLIVAN. I do believe longer than 16 would be beneficial. I am simply saying there is a genuine question about how humans respond to impending risks that are—risk scientists tell us we need to be cautious about in just imagining that an hour or a day is the right time frame to communicate on.

Mr. BRIDENSTINE. So the——

Ms. SULLIVAN. So I consider it an open question.

Mr. BRIDENSTINE. And so the government should make decisions about how much lead time we give people because we know better than they know how to protect themselves?

Ms. SULLIVAN. No, we should understand how to communicate the information we have so that it is effective for the people who have those decisions to take.

Mr. BRIDENSTINE. So, let's say we had an hour lead time. Would you suggest we should withhold that information because an hour is too much and people aren't smart enough to take cover?

Ms. SULLIVAN. We provide five and three day outlooks now to citizens and to emergency managers in a rich dialogue that has evolved over time to where we know how—we all know how to respond to that information. And again, there are powerful instances from your home State and town of communities doing just that. I will defer to Dr. Droegemeier to amplify on it. He has lived through them.

So I am not saying withhold it. I am simply saying that the challenge of communicating forecast information effectively to decisionmakers is a genuine question that needs to be approached thoughtfully, and the best scientists I know on this question cautioned me, including scientists at the National Weather Center, cautioned me the questions we need to probe together to be sure we would communicate that information effectively and not unintentionally have exactly the result we didn't want.

Mr. BRIDENSTINE. Okay. Are you—you are familiar with the phased array radar, obviously, that is in Norman, Oklahoma——

Ms. SULLIVAN. I am.

Mr. BRIDENSTINE. —and I am a Navy pilot myself and certainly I have been involved in these kind of technologies from a war-fighting perspective and the ability to detect targets from long distances and direct energy in a very specific and dynamic way to get precise measurements I think is critically important. Is this technology something that you believe we could advance to the point where we could deploy it in a way where we could get an hour lead time?

Ms. SULLIVAN. It is—I don't have the technical acumen to conclude that phased array radar itself is pivotal to that. We are still learning a lot about what the dual polarization NEXRAD radars can give us. I would go back to the example that I cited to Mrs. Bonamici in assimilating NEXRAD current radar into very fine resolution models, which we are running in research mode.

Last year, in June of 2012, in fact very accurately forecast the retro line of very severe storms which were tornadic-strength storms 12 hours in advance. So we do already know finer-scaled modeling, which requires better—much better computing capacity operationally than we currently have, and proper incorporation of that data, all 3 ingredients are critical. It is not just by a radar. But those three we have demonstrated could give us a 12-hour very good—not just the convective probability but there is the storm line and here is where we are propagating.

MPAR is certainly—offers additional promise but we have had one of them that we are still experimenting with to understand just what that potential could be. And as your bill suggest, be sure that we really understood its contribution before we might make any nationwide deployment decision.

Mr. BRIDENSTINE. Let me ask you, if you were in Moore, Oklahoma, and somebody said to you maybe we shouldn't have this type of research because if we gave you too much information too early you might not act on it, how do you think my constituents in Oklahoma would respond to that?

Ms. SULLIVAN. But that is not what I am saying, sir. I am saying that I want to be sure I say to you, go now or some communication that you really register as the one that will prompt you to the action that you should take. And that—the language style mode of that communication is something that needs to be studied and worked with people like your constituents.

Mr. BRIDENSTINE. Okay. I yield back.

Chairman STEWART. All right. Thank you, Mr. Bridenstine.

And now, we turn to Ms. Edwards.

Ms. EDWARDS. Thank you, Chairman Stewart, Ranking Member Bonamici. I appreciate today's hearing on weather forecasting. In my view, it is a necessary part 2 on a subject that greatly impacts the American public and our greater economy.

And I am pleased that NOAA, which is headquartered in my Congressional District—thank you, Dr. Sullivan—has the opportunity to be before our committee today and to discuss efforts to improve weather and climate forecasting.

Today's panels are an improvement, I think, on the last that we have had. I am concerned about the legislation that we are discussing today. And, as indicated in the testimony of our witnesses, the legislation is really flawed in its execution in my view. NOAA is a multi-mission agency, and that means its priorities—ocean, atmosphere, climate, and weather—are interconnected. I think Dr. Sullivan has testified to that today.

And given what we have learned and experienced with increasingly severe and more frequent severe storms, hurricanes, tornadoes, flooding, it is hard for me to believe that you can separate or slash funding of climate research when all of our weather scientists and our forecasters indicate the kind of interconnectivity that Dr. Sullivan has discussed. Our Earth is a system, and I think in order to understand the processes, we have to understand it as a whole.

And so with that, Dr. Sullivan, I know we have had a couple of one-on-one conversations about NOAA's work and concern about where we stand vis-à-vis Europeans in weather forecasting. And I know we talked about our—the lagging in our supercomputer computing power as evidenced by some of the different modeling that we saw with Hurricane Sandy. And so I wonder if you could explain to the Committee some of the institutional differences between the U.S. Government's role in weather forecasting versus Europeans' that keep NOAA from being as cutting edge is we would like it to be?

Ms. SULLIVAN. Thank you, Mrs. Edwards.

The model that received such acclaim, rightfully, during the evolution of Hurricane Sandy, especially the early days, is a model run by the European Center for Midrange Weather Forecasting. That is a combination research and operational forecasting center that is charged with one and only one thing and that is to run a global model that gives a 12—10- to 12-day forecast.

They have become very good at that. They—it is definitely one of the leading models at that time range. What else to say? That is all they do at the European Center so the rest of the products and services that most national hydro-meteorological services like NOAA are charged with fall to the U.K.'s Meteorological Office or Météo-France or the Deutscher Wetterdienst.

So to really understand what Europe is doing, you need to take a look at both the European Center and the collection of Federal or national-level weather services throughout each of the European states. That is closer to comparable.

What does it—what else does European Center do that we would like to emulate more closely? They make consistent progressive investments in their main operational supercomputer. They have set a target and a policy of staying very close to the leading edge of computational capacity. In the United States, in contrast, we tend to step forward an operational supercomputer and live with it for quite a while as it falls further and further behind the cutting edge and then make a big step forward and let it fall back again. That has certainly been the case with work that has been going on at NOAA in the last five years.

Europe has also focused on methods that determine how you take data into a model to a method called data assimilation or a step called data assimilation. It is almost—it is in some respects more important than what data do you have. You get the data in properly and understand the errors that it contains. They have pioneered new methods over at the European Center for data assimilation. They are very computationally intensive. We have not been able to adopt those methods in NOAA's operating supercomputers because they are so intensive.

Ms. EDWARDS. Do we need to?

Ms. SULLIVAN. Well, I was just going to transition and say we know it is a good advance and so our scientists again—OAR scientists plus our satellite data scientists and our weather service scientists altogether developed a method that is as effective and less computationally intensive, and proof of that—solidity of that advance is that the Europeans are now going to adopt our method because it does the same work more efficiently.

So stay closer to the cutting edge in our operational supercomputer. It would be good. Places like our Science Center down in Norman that I cited as an example, emulate the kind of close coupling of research and operations that the European Center has. So we do know how to do that and we do it but we do it in a little more distributed and more topic-oriented fashion around aviation weather challenges, severe storm challenges, and tropical storm challenges than they have chosen to do in Europe. But we have a greater array and greater variety of weather phenomena in the United States than all of Europe combined. And so I think our plurality and our diversity suits this country's needs.

Ms. EDWARDS. Thank you very much.

Thanks, Mr. Chairman.

Chairman STEWART. Yes, Ms. Edwards.

We now—Dr. Broun for your five minutes of questioning.

Mr. BROUN. Thank you, Mr. Chairman.

Dr. Sullivan, the Chairman, the Vice Chairman and I are all three pilots, and so we have been very engaged in weather issues for a long period of time and concerned about weather, and we are concerned not only from a pilot operational perspective but also how it affects all of our constituents and not only in our district but all across this country.

The Fiscal Year 2014 request proposes 180 million for climate research and $82 million for weather research. If Congress were to spend 158 million on climate research and 112 million on weather research, would this help or hinder weather forecasting?

Ms. SULLIVAN. Additional funding in weather forecasting would certainly help that effort. My concern would simply be to understand where—what are we giving up? NOAA's climate research is not multi-decadal, century-scale climate research. It is climate research aimed at understanding and more closely relating phenomena such as the Pacific decadal oscillation or the Atlantic meridional oscillation to the weather phenomena that affect the United States so that we can extend our lead times on forecasts out beyond five days to maybe seven or ten days.

These broad underlying patterns that are at climate timescales, we are—we believe are critical to unlocking the secrets.

Mr. BROUN. Well, to just tag on to what Commander Bridenstine was just saying about time interval between tornado forecasts, I just found it incredible that you would even question giving people more advanced time for a warning of an impending tornado.

But let me go back to that same question and let me ask it in a different way. Which contains—contributes to weather forecasting more? A dollar for climate research or a dollar for weather research?

Ms. SULLIVAN. It depends on what the—each dollar is spent for, Dr. Broun. I can put a dollar into some aspects of weather research that are going to make only a minimal advance then I might make an advance in understanding just how El Nĩno effects seven day storm tracks and sets up convective patterns in the central United States that would do a lot better for Oklahomans than understanding when they are prone to tornado outbreaks.

Mr. BROUN. Well, I am sure the people in Oklahoma would like to have had an hour warning on their tornado that was bearing down upon them, and I think a dollar in weather forecasting research would have helped in that regard.

Let me kind of change tracks a little bit. Dr. Sullivan, as you know, in 2012 a financial scandal was uncovered at the National Weather Service where a senior official moved money certainly without authorization and very highly unlike—illegally they moved that. They moved it between different accounts. It was reported that the amount of unauthorized transfers of money may have exceeded $100 million over several years. Did these transfers in any way negatively impact programs focused on transitioning new technologies from research into operations?

Ms. SULLIVAN. Those transfers, Dr. Broun, were all within the National Weather Service itself and they were typically transfers from systems accounts, software upgrade accounts and things like that, into operations and management. So they were, as the investigation indicated, well-intentioned on the part of the offending individuals, which doesn't justify the act but well-intentioned to try to support the forecasters in their everyday work where they felt they had budget shortfalls.

Mr. BROUN. $100 million is a lot of money and moving things around illegally is certainly—should not be done by anybody, and my concern is that when we talk about tornadoes, when we talk about what I faced when I climbed into a cockpit in with these other gentlemen did, weather is an important issue.

I understand climate research and I understand weather research, and I just disagree with maybe my Democratic colleagues over where our priorities should be set and obviously what you seem to be so wedded to as far as doing climate research.

But the folks in Oklahoma need more advanced warning, and I don't think it is the government's responsibility to decide how they respond to that warning. We need to give people as much advanced warning as they possibly can for a tornado or hurricane or anything else. And doing weather research, I think, is extremely important.

Now, I applaud the Vice Chair's bill that he has put together and I think it is important for us to proceed, and hopefully, it will be marked up and we will pass it into law.

Thank you so much, Mr. Chairman, and I yield back.

Chairman STEWART. Thank you, Mr. Broun.

And our final questioner for this panel would be Mr. Weber from Texas.

Mr. WEBER. Thank you, Mr. Chairman.

Let me follow up, Dr. Sullivan, what Dr. Broun was asking about. I think when he asked you about the transfers that might have been illegal, you said the individuals were well-intentioned, I think?

Ms. SULLIVAN. In their own mind, Mr. Weber, they professed to be doing things that they felt kept the weather forecast enterprise healthy as it needed to be in their mind. I don't defend the statement. I am just reporting what they said in their depositions.

Mr. WEBER. So were you aware of that when it took place?

Ms. SULLIVAN. I was not aware of it when it took place.

Mr. WEBER. How soon thereafter did you possess the knowledge that it had happened?

Ms. SULLIVAN. I try to recall that timeline. There—it came to NOAA's attention through an Office of Investigator General complaint that was referred to us for action by the OIG. We very promptly acted on that, established in concert with the Office of the Secretary, an investigation and inquiry panel, placed some individuals on administrative leave, and proceeded to conduct an inquiry.

Mr. WEBER. And was that time frame a month, a week, a year?

Ms. SULLIVAN. The time frame from our receiving word of the problem to initiating the inquiry was hours. The inquiry was completed over some several months.

Mr. WEBER. Okay. Do you have knowledge as to what has happened to those particular individuals?

Ms. SULLIVAN. I do have knowledge and I—as I know the panel appreciates under the privacy laws of this country, I can't speak to individual matters in open session. We have shared those details with our appropriators.

Mr. WEBER. Okay. Have they—and I am not asking for names or specifics, but have they been disciplined? Has anybody lost their job?

Ms. SULLIVAN. Individuals have been disciplined. Individuals are no longer with NOAA. Financial controls have been thoroughly reviewed across the entire department and modified and strengthened, and training has been put into place for all senior officials.

Mr. WEBER. I find the term well-intentioned individuals kind of interesting because I am just thinking when they—when those—as you called them well-intentioned individuals play fast and loose, if you will, with the rules, would you agree that one can certainly make that assessment——

Ms. SULLIVAN. I——

Mr. WEBER. —that they have played fast and loose with the rules?

Ms. SULLIVAN. Oh, that they were either willfully and inexcusably ignorant of the rules or played fast and loose——

Mr. WEBER. Or they played fast and loose. We hear that a lot in this capacity that people are ignorant of certain things that go on, and I keep thinking to myself they should probably run for Congress at that level of ignorance.

Nonetheless, when we up here look at a situation where someone plays fast and loose with the rules, can you understand that it gives us pause for concern when somebody brings a budget request to us and says this is going to negatively impact our ability to predict climate change and then we have to think, well, there has been reported incidences of people in that agency playing fast and loose with the rules. And I believe the quote is well-intentioned individuals who we would ascertain that played fast and loose with the rules. So when someone comes up with the budget request and they say this is going to impact us negatively, can you understand how we might draw a similar conclusion that may be that is a fast and loose playing with the rules that we might question that? Could you understand how we could come to that conclusion?

Ms. SULLIVAN. I follow your logic, Mr. Weber. I would ask that you attribute the fast—the well-intentioned to the people who said it and to the people who were doing the actions.

Mr. WEBER. Okay.

Ms. SULLIVAN. It is certainly not my characterization of them.

Mr. WEBER. Okay. You don't want to be associated with it. I don't blame you.

Ms. SULLIVAN. I don't care to be associated with it——

Mr. WEBER. Right.

Ms. SULLIVAN. —and I think I feel, judging from your comment, my reaction to and response to that incident and those behaviors——

Mr. WEBER. Right.

Ms. SULLIVAN. —are very close to yours.

Mr. WEBER. Right. Well, we would hope that it—that there would be enough oversight and enough safeguards in that agency that that kind of playing fast and loose with the rules A) as it purports to moving money—well, some of us have been afraid it was actually illegally—would also purport, too, that when you come to this committee or when you come to the Congress and say we need money for climate change and, yes, there is a discussion—this is going to be about climate change—that there is not the same kind of fast and loose playing with the facts. And that is what is our concern.

And I know that you can't speak for everybody but we just simply ask you to—implore you to make sure that that kind of fast and loose playing goes away and that if you have anything to do with it, well-intentioned individuals or otherwise, you make sure we get the facts.

Ms. SULLIVAN. I assure you that I will do that, Mr. Weber.

Mr. WEBER. Okay. I appreciate that. And I yield back.

Chairman STEWART. I thank you, Mr. Weber.

Dr. Sullivan, thank you for your time today. Thank you for your testimony. There is one item I would like to follow up with if I could, and that is, as I—you may remember, last September you testified before the Committee's Oversight Subcommittee on a hearing about the National Weather Service, and on November 6, Committee staff sent follow-up questions for the record to you as well as to one of your colleagues, Mrs. Maureen Wylie.

The Committee has not yet received a response to those questions for the record. And I would ask if you would commit to me and to other Members of this Committee as well that you would answer those questions as soon as possible?

Ms. SULLIVAN. I certainly will make that commitment to you, Mr. Chairman. The formal clearance processes, as I know you understand, sometimes wreak havoc with the actual timeliness and delivery. It is my understanding that we have had staff-to-staff conversations on those matters but the formal transmittal has been delayed.

Chairman STEWART. Okay. Can you——

Ms. SULLIVAN. I admit we will work on that.

Chairman STEWART. Can you give us some indication of when you—that would—that process would be complete and we could expect answers to those questions?

Ms. SULLIVAN. I will probe where that is—where things stand and get back to you on that.

Chairman STEWART. Okay. So we are going to—you are going to get back to us on when you are going to get back to us. Is that—okay.

Ms. SULLIVAN. I will get back to you on the timeline that I believe I can commit to.

Chairman STEWART. Okay. All right. Thank you for that.

Again, one more time, thank you for your testimony today.

And, Members of the Committee, as we have discussed, can have additional questions for you and they—and we will ask you to respond to those in writing in an appropriate and timely fashion.

And the witness is now excused and we will now move on to our next panel. Thank you, Dr. Sullivan.

Ms. SULLIVAN. Thank you, Mr. Chairman.

Chairman STEWART. At this time, I would like to introduce our second witness panel, and I will introduce them individually and then allow them time for their opening statements.

Our first witness today is Dr. Kelvin Droegemeier, Vice President for Research and Regents' Professor of Meteorology at the University of Oklahoma. Dr. Droegemeier is a Fellow of the American Meteorological Society and a member of the National Research Council Board on Research Data and Information.

In 2004, Dr. Droegemeier was appointed by President Bush to the National Science Board and was reappointed in 2010 by President Obama. He holds a Ph.D. in atmospheric science from the University of Illinois.

And I will remind all of the witnesses that, as has already been stated, your spoken testimony is limited to five minutes each and after which Members of the Committee will have five minutes to ask questions.

And I now recognize Dr. Droegemeier for five minutes to present his testimony.

TESTIMONY OF DR. KELVIN DROEGEMEIER, VICE PRESIDENT FOR RESEARCH, REGENTS' PROFESSOR FOR METEOROLOGY, WEATHERNEWS CHAIR EMERITUS, UNIVERSITY OF OKLAHOMA

Dr. DROEGEMEIER. Good morning, Chairman Stewart. Thank you so much. Ranking Member Bonamici, Mr. Bridenstine, good to see you. Thank you so much for the privilege to speak to you this morning on a very important matter. I appreciate all the work that you are doing to help protect our citizens from the destructive forces of nature.

I offer my perspectives as a Professor of Meteorology at the University of Oklahoma. I have been there almost 30 years working at the National Weather Center as a meteorologist really at the nexus of severe weather in the Nation, in fact, in the world. I witnessed firsthand last month as these tornadoes ravaged parts of our State and many thousands of people no doubt would be dead today were it not for the extraordinary warning and prediction system we have in this country.

So great—thanks to NOAA and all the wonderful work they have done, but yet, in fact, our work is not done and we still have people dying. Even one death is really intolerable.

I would like to make three very brief points for you this morning. First, I really do welcome this bold, focused initiative on high-impact weather prediction. It builds upon a strong foundation that we have in this country, a very, very solid foundation. It prioritizes key topics, and really the only thing I would add would be to build on what Dr. Sullivan said in terms of the prescriptiveness of the bill really allowing scientists to focus on the best tools and techniques to do things like assess observational needs. And I want to let you know that the academic community stands ready to work with you and to help you however we possibly can. You can marshal all of those resources.

The second point was talked about in the last session. It is extremely important. As a meteorologist it may seem heretical for me to talk about the social sciences, but in fact this is a real people problem. Really, ultimately, what we are dealing with here is a loss of life, and our ability to deal with that means that we have to address the issues of how people understand and predict and prepare and so on, respond to warnings. We need to understand how we convey and formulate uncertainty in messaging to the public, how the public responds and comprehends warning information. There are issues of trust and source security of information and so on.

And I think we have to even ask ourselves whether or not the whole current warning and watch system really needs to be rethought from the ground up starting with people because the people are the ones who are affected ultimately.

Also, I would like to talk to the issue of tornado warning lead time. As specified in the Act, this is a very, very important issue, extremely important. It has to be looked at. But I think we want to be careful about not focusing entirely on that magical number because, ultimately, the question is, as Dr. Sullivan mentioned, what are people going to do with that one hour?

In my written testimony, I give you a little narrative of what I saw firsthand on May 31 in Oklahoma as thousands of people fled their homes, put themselves in harm's way because they had a very large amount of lead time without really knowing what to do with it. This issue resides in the domain of the human behavioral sciences. It is not a weather or technology problem. It is something we really have to learn how to address. And so I would argue that really our focus ought to be on the goal of zero deaths. Zero deaths. We achieved that in microbursts.

Wind shear—you folks are pilots. You know, we had a lot of planes crashing back in the '70s. We had a concerted attack on understanding the causes of wind shear we put in technology and training and over 20 years now have passed since then and no one has died in an aircraft accident due to wind shear. Zero deaths is not an unattainable goal and that puts our focus on people.

Finally, I would like to highlight the importance of a truly interdisciplinary approach. Dr. Sullivan and Ranking Member Bonamici talked about this a little bit. In terms of our testbeds, these operational test beds that we have that integrate research and operations are very important. They exist but they need to be expanded and improved and enhanced. They do a really wonderful job but we could yet do more.

And I would suggest to you that this notion of research to operations is probably a little bit misconceived. It really says there is research over here and operations over here. I suggest that research plus operations, working hand-in-hand with the operational folks, working with the researchers hand-in-hand as we do in Norman, this wonderful hazardous weather testbed that truly is credited with saving lives, developing new technology, and the rigors of operational activities with scientists and operations people working together, that to me is the way that it ought to be done.

I would like to close by showing you a brief movie here of the May 20 tornado in Moore and it gets to the question I was asked earlier about the value of MPAR and this movie, I will introduce it to you. We will go ahead and start it.

[Video shown.]

The first clip is of a TV station, KWTV Channel 9 in Oklahoma City. There is the Moore tornado. It is hailing; there is debris falling. And I am going to freeze it on a radar picture from the TV station you will see in a moment that shows where the current warning time comes from before you have a given thunderstorm, and then the path of the tornado is extrapolated based on its previous history. So there you see it. That hook-shaped image there in the lower left part is the tornado itself. That great part is the debris ball and the line moving from it to the Northeast is the track of the tornado at various times. So that is where we got the 16, 30, 40 minutes of lead time. People in harm's way saw that image.

[Slide.]

What I am showing you now is sort of the future. This is a picture of counties in Oklahoma and the two lines of inverted triangles are actual tornado paths in 2011. We reran the forecast of this situation there. You see the radar echoes forming. And as as this thing plays forward, you will see these black contours, these dark circles. Do you see them forming along the tornado track? This forecast was produced an hour in advance, experimentally, not in real time, but we got very, very close to predicting the occurrence of a real tornado of a real event an hour in advance.

This is what is possible. Can we do it this good every time? No. You see some tornadoes down there in the lower right that have no real counterpart associated with them. And so the science is not there yet, but 20 years ago we didn't think this was even theoretically possible. Now, we are not only able to show it is possible, but in the hazardous weather testbed, we are able to demonstrate it in real time working with operational forecasters.

Thank you, Mr. Chairman.

[The prepared statement of Dr. Droegemeier follows:]

WRITTEN STATEMENT OF
DR. KELVIN K. DROEGEMEIER
VICE PRESIDENT FOR RESEARCH, REGENTS' PROFESSOR OF METEOROLOGY, PRESIDENTIAL PROFESSOR, WEATHERNEWS CHAIR EMERITUS, DIRECTOR EMERITUS OF THE CENTER FOR ANALYSIS AND PREDICTION OF STORMS
UNIVERSITY OF OKLAHOMA

ON
"RESTORING US LEADERSHIP IN WEATHER FORECASTING, PART 2"

BEFORE THE
SUBCOMMITTEE ON ENVIRONMENT
U.S. HOUSE OF REPRESENTATIVES COMMITTEE ON SCIENCE, SPACE AND TECHNOLOGY

26 JUNE 2013

I wish to thank Chairman Stewart, Ranking Member Bonamici, and other Members of the Committee for the privilege of testifying on the important topic of US leadership in weather forecasting. I especially applaud your efforts to improve our ability to protect citizens from the destructive forces of nature, and I thank you for considering my earlier suggestions regarding the Weather Forecasting Improvement Act of 2013.

As a professor of meteorology and researcher at the University of Oklahoma's National Weather Center, I have, for nearly 30 years, both lived in and worked at the global epicenter of severe weather. My research involves using computer models, initialized with fine scale data such as those provided by Doppler radars, to explicitly predict intense local weather such as thunderstorms and, hopefully one day, tornadoes.

We have been reminded this spring, as in many years past, that high impact weather can cause heartbreaking loss of life, extraordinary property damage, and long-term economic and societal disruption extending far beyond the areas directly affected. As I witnessed firsthand last month, hundreds and perhaps thousands of people in Moore, Oklahoma are alive today because of our nation's forecast and warning system. The same is true for Joplin, Missouri, Tuscaloosa, Alabama, and countless other places that have been ravaged by severe weather. To the many exceptional public servants within NOAA, including its outstanding leader, Dr. Katherine Sullivan, we owe a tremendous debt of gratitude. We also must acknowledge academic, government and private sector researchers, along with the media and private weather companies, the latter of which play a vital role in developing products and delivering services to the public.

Yet more can and needs to be done. Even one death from hazardous weather is intolerable and should be prevented.

We have in place a foundation of unprecedented capability upon which to build. Our understanding of the atmosphere, our technologies and tools, our research facilities and capabilities, and our recognition of the most important roadblocks and challenges equip us not for incremental change, but rather for a bold transformation that will lead us to achieve the ultimate goal: ZERO DEATHS. With that focus, we are led naturally to look at all aspects of this enormously complex problem, and all metrics for assessing progress, in a comprehensive, interdisciplinary fashion – to include observations, computer models, human behavior, communication of threat information, sheltering, building codes, and response and recovery, to name but a few. We achieved the goal of zero deaths for airline crashes resulting from wind shear, and we should be no less bold here.

1. STATE OF WEATHER FORECASTING CAPABILITIES AND HOW THE US COMPARES WITH OTHER COUNTRIES

Although the United States is not unique in facing high impact weather, including thunderstorms, hurricanes and tornadoes, the incidence of such weather in the US is higher than any other location on the planet. During the past three decades, due principally to the use of numerical simulation models and theoretical analyses of their output, and more recently as a result of the nationwide NEXRAD Doppler radar network as well as experimental observing systems such as mobile Doppler radars, our understanding of, and ability to predict, high impact weather have increased dramatically.

For example, vertical changes in wind, temperature and humidity, measured by balloons and vertical profiling radars and also predicted by global and regional models, now allow for the accurate determination of general storm features – such as type (supercell, squall line, cluster, isolated weak cells) and likely motion – many days in advance. US models continue to improve relative to their counterparts in other countries, and with planned computer upgrades at NOAA along with other enhancements, the US should soon claim the global lead.

New finer-scale models in the US, such as the Weather Research and Forecast (WRF) and High Resolution Rapid Refresh (HRRR), are being run at spatial resolutions capable of capturing important storm details, thereby allowing forecasters to state with reasonable certainty, up to a few days in advance, that particular events, such as supercells or squall lines, are likely to occur in a given area during a specified period of time. The assimilation of fine-scale observations, especially from the NEXRAD radar network but also from satellites and wind profilers, is a key step toward providing even greater fidelity in the forecasts, and is receiving considerable attention within the research community. Other nations, especially China, Japan, and Korea, are investing in new radar and modeling capabilities to achieve similar goals.

A notable example of the impact of capabilities just described occurred in central Oklahoma on April 13, 2012. For only the second time in its history, a day-two outlook of "high risk" for severe weather was issued by the NOAA Storm Prediction Center, suggesting a major tornado outbreak in the southern Plains. A rare high probability for tornadoes was issued on the 13^{th}, and experimental models, run at the NOAA Hazardous Weather Test Bed in Norman, Oklahoma, accurately predicted the location, type and timing of the storms. On another occasion, so far in advance was the information available that many State offices, businesses and schools in central Oklahoma closed early, as frequently happens in anticipation of winter storms. This suggests consideration be given, especially by schools, to declaring "Tornado Days" in a manner analogous to "Snow Days."

Our inability to measure all key atmospheric variables at fine scales, and limitations in models and our understanding of the atmosphere, lead to uncertainty or error in the starting conditions and other parameters of any computer model forecast. Because of the fundamental nature of the atmosphere, such uncertainty can cause forecasts, started from nearly the same conditions, to diverge with time. To account for the many facets of uncertainty, the so-called ensemble approach is used, in which dozens of forecasts, rather than only one, are produced, each starting with slightly different initial conditions. This allows for the creation of probabilities and the quantification of uncertainty in any given forecast – a critical element and the subject of the NRC report entitled *Completing the Forecast*.[i] Ensembles are now foundational to the US forecasting portfolio at global and regional scales, and are being tested experimentally at the scale of individual storms. They represent the only meaningful strategy for numerically predicting high impact weather.

At the highly tactical level of detecting and characterizing severe storm threats, and providing associated warnings, the principal tool of choice is the Doppler weather radar. Formally commissioned in 1994, the more than 150 Doppler radars operated within the tri-agency (Commerce, Transportation, Defense) NEXRAD program have saved countless lives. In concert with other tools, described below, NEXRAD has dramatically improved tornado warning lead time from an average of approximately 6 minutes in 1994 to approximately 14 minutes today, though with a false alarm ratio that has remained disturbingly high – at around 75% – for nearly 20 years.

The recently completed upgrade of NEXRAD to dual polarization capability, which provides for characterizing precipitation type (such as rain, snow, and hail), will be of immense benefit in flood forecasting, aviation safety and efficiency, and computer model prediction. The multi-function phased array radar (MPAR), which is under development as a NEXRAD replacement and offers a ten-fold improvement in storm scanning time with simultaneous tracking of aircraft, may lead to additional improvements in warning lead time, possibly on the order of several minutes. However, as described below, extending the average warning lead time to an hour or more, which is a goal of the bill under consideration, can only be achieved using numerical prediction models (reflecting NOAA's Warn on Forecast concept), and must be pursued carefully lest it create unintended negative consequences.

Other important advances contribute to notable capability in the US forecasting enterprise. NOAA's Advanced Weather Information Processing System (AWIPS), and outstanding training, including that provided by the NOAA Warning Decision Training Branch (WDTB) in Norman, Oklahoma, allow forecasters to deal with vast amounts of information in a highly structured, efficient manner. National Weather Service Test Beds, operated by the National Centers for Environmental Prediction (NCEP) in collaboration with OAR laboratories, NOAA Cooperative Institutes, and universities, are a vital mechanism by which research outcomes and translated into operational practice. The aforementioned Hazardous Weather Test Bed, the Aviation Weather Test Bed in Kansas City, Missouri, and the Hydrologic Test Bed in College Park, Maryland, are but three examples, and all are poised to play a critical role in future activities, as described below.

2. IMPORTANCE OF TIMELY AND ACCURATE WEATHER FORECASTS AND OPPORTUNITIES FOR WEATHER RESEARCH AND TECHNOLOGY DEVELOPMENT TO IMPROVE FORECASTING OF SEVERE WEATHER EVENTS

Our society is increasingly vulnerable to the impacts of severe weather for many reasons. For example, urbanization, and significant development in coastal zones, have dramatically increased our nation's exposure to high impact weather and, in especially dense population areas, have substantially decreased the ability to efficiently move citizens out of harm's way. These points are underscored in the 2007 National Science Board (NSB) report titled *Hurricane Warning: The Critical Need for a Hurricane Research Initiative*[ii]:

> To place the Nation's vulnerability in perspective, 50 percent of the U.S. population lives within 50 miles of a coastline.[6] The physical infrastructure in coastal regions has grown dramatically over the past few decades and in the late 1990's was worth about $3 trillion in the Gulf and Atlantic regions alone.[7] Trillions of dollars in new seaboard infrastructure investment are expected over the next several decades. As our economy grows and the value of built-infrastructure continues to increase, the economic and

> societal impacts of hurricanes also can be expected to escalate. Although not all coastal regions are directly vulnerable to hurricanes, impacts from those regions that are affected can have national consequences, for example, via increased fuel prices and displaced citizens. Additionally, even though decaying tropical storms are an important source of fresh water for inland regions, associated flooding – occurring hundreds of miles from the coast and days after storm landfall – can be astonishingly destructive. Historically, flooding has claimed more lives in the U.S. than any other weather phenomenon[iii] and destructive tornadoes frequently accompany hurricanes.

Sensitive electronics systems, including the power grid, cellular towers, microwave links, surveillance cameras, and high-capacity communications infrastructure, are vulnerable to high impact weather and, ironically, represent essential elements for both communicating information prior to, during, and following major disasters. Likewise, energy production and storage facilities, and the entire national airspace system, are subject to tremendous disruption owing to severe weather. Finally, the entire supply chain, especially with regard to the delivery of perishable goods, is highly vulnerable.

The notion of a timely and accurate forecast, as a means for reducing exposure and mitigating loss, is very complex and highly dependent upon the needs of the recipient and even the particular weather situation at hand. In assessing opportunities for forecast improvement via research and development, this point must receive careful consideration.

For example, with regard to timeliness, an industrial chemical plant may require an entire day to secure for a hurricane, whereas an airline may need three to four hours to plan for a significant weather event that will last only 30 minutes over a hub airport. The time needed for a school to react to a significant tornado threat likely depends upon the grade levels involved, the location of the school, access to major roadways, and sheltering options. A different time and procedure no doubt would be utilized for a possible blizzard.

With regard to accuracy, conventional statistical measures of skill are quite limited in their applicability to phenomena such as thunderstorms, which have a high degree of spatial and temporal intermittency. For example, a thunderstorm perfectly predicted by a computer model, but with a position error of 20 miles such that no overlap exists with the real storm, would have zero skill by most conventional metrics. Yet, the forecast may have significant practical value, especially if made in a probabilistic framework. Research is needed to develop measures of accuracy, skill and value for high impact weather, and strategies developed to convey this information, in appropriate ways, to end users, especially the general public.

Another important consideration in the context of research and development leading to forecast improvements – and arguably THE most important consideration – stems from the fact that although high impact weather is the destructive force of concern, loss of life is related to our ability to understand, prepare, predict, warn and respond. This is an enormously complex, multi-faceted challenge that fundamentally involves human behavior and thus transcends physical science and technology.

To underscore this point, in 1953, 519 people died in tornadoes in the US – when only one in four US households had a television set, when telephones were bulky and wired, when no national radar network was in place, when centralized operational weather prediction was in its infancy, and when our principal mobile information device was the transistor radio. In 2011, 550 people in the US died in tornadoes. Although the population was significantly higher and denser than in 1953, the nation had at its disposal sophisticated computer models, a world-leading national Doppler radar network, the Internet, cell phones, social media, 24-hour television with multiple sets in nearly every home and streaming broadcasts on mobile devices, and a national weather radio network. Considering the population caveat noted above, why was the death toll so high two years ago and nearly six decades after enormous advances had been made in physical science, technology and operations?

I believe the answer relates, in part, to ineffective understanding and incorporation into our operational enterprise of the human dimensions of high impact weather. We need to understand how the public perceives weather risk and the factors influencing that perception. We need to understand how to formulate and convey threat information and uncertainty to the public and understand its comprehension and response, as noted in *Completing the Forecast*. And we must address issues of trust and source verification, and study whether the current watch/warning system needs to be re-thought from the ground up, starting with the human dimension.

A preliminary study[iii], conducted at the University of Oklahoma, regarding public perception of tornado warning accuracy underscores the importance of social sciences research. Of the more than 3000 people surveyed, roughly 25% of respondents noted they would take *no protective action* for a hypothetical tornado warning in the "light" intensity category. Once the warning level rises to "significant," 7% said they would take no action. For "severe," devastating and incredible events," roughly 7% continue to report they would take no action in any of the categories. Also for these categories, up to 18% of respondents reported they would *drive way from the warned area*. These early results clearly suggest a correlation between the level of threat communicated in a tornado warning and resulting human behavior, though perhaps not in the intended direction.

Related to the above, improving tornado warning lead time to more than an hour, as noted specifically in the bill, is a necessary and very important goal. However, it is not sufficient. Too great an emphasis on this metric will lead to missing the real point. The ultimate question to be addressed concerns how people will use that hour, and the answer resides in domain of the human and behavioral sciences. Indeed, achieving a one hour lead time via physical science and technological advances may actually worsen the situation, as noted in the preliminary study described above, if the human dimension is not considered throughout.

I witnessed precisely this circumstance on May 31, 2013, when in the presence of long-lived and slowly moving tornadic storms over Oklahoma City, thousands of residents of south Oklahoma City, Norman, and surrounding communities fled their homes, heading south. City streets, highways and Interstates became parking lots, placing individuals in great peril (an automobile is the worst possible refuge from tornadoes, especially violent ones). The substantial advance notice available during that evening, coupled with fresh memories of tornadoes just 11 days earlier, led to a reaction in the citizenry unlike any seen to date. It is difficult to imagine an example that provides a more compelling argument for making social sciences research foundational to a high impact weather initiative.

In light of the above, I suggest that the overall goal of improving forecasts of high impact weather be one of ZERO DEATHS, not solely improvement of metrics such as warning lead time. Our nation achieved zero deaths for airline crashes resulting from wind shear, and we should be no less bold here.

Turning to opportunities, by definition, an opportunity is a convergence of favorable circumstances that provides a likelihood of advancement or progress. The opportunities before us for improving the forecasting of high impact weather are profound because of the tremendous Federal and private sector investments made to date, which have produced a world class foundation upon which to undertake a transformative program. For example, as shown in the video during my oral testimony, we have demonstrated the ability of a cloud-resolving numerical model to predict the location and timing of intense vertical rotation consistent with tornadoes actually observed on a given date. Although representing important progress, an enormous amount of work remains before this sort of forecast might be provided operationally with requisite accuracy, reliability and value.

Specific opportunities before us include using unmanned aerial systems, and special radars[iv] such as those developed by the NSF-funded Center for Collaborative Adaptive Sensing of the Atmosphere (CASA), to gather data on temperature, moisture, wind, and precipitation from the ground to 4-5 kilometers in altitude. This region of the atmosphere plays an extremely important role in severe weather and in fact is where most severe weather actually occurs; however, as noted in the NRC study *Observing Weather and Climate from the Ground Up*[v], this region also is among the most poorly sampled.

Although other observations are needed, especially from satellites for improving global and regional models, those which focus on the lower parts of the atmosphere are likely to have the greatest impact on the performance of cloud-resolving models. Tools and techniques such as adjoint sensitivity models, Observing System Experiments (OSEs), and Observing System Simulation Experiments (OSSEs) can be deployed to authoritatively address this issue. Note that such studies are needed because placing observational systems where none exist can, in some cases, actually degrade a forecast, and because data assimilation systems sometimes are able to provide retrieved information of sufficient quality in gap areas so as to preclude the need for additional observing resources. In the context of the bill under consideration, I therefore suggest avoiding narrow prescription of approach (for example, using OSSEs), thus allowing the community of researchers to define observational needs and forecast goals and determine which specific tools and approaches are best suited for meeting them.

Cloud resolving models, which are the foundation of high impact weather prediction, have become quite sophisticated during the past several years. Advances in computational techniques, grid structures, physics, and in particular, the assimilation of observations from a vast array of sensors, have opened new horizons for fine scale forecasting. One of the most important challenges, related not only to effectively capturing storm dynamics but also to precipitation forecasting and storm electrification, involves the assimilation of hydrometeor data from dual polarization Doppler radars, and concomitant improvements in how models represent both liquid and frozen water species. Because the entire NEXRAD network is now producing dual polarization data, the utilization of it in forecast models is not only an opportunity but an imperative.

The final important opportunity concerns the exploration of new strategies for utilizing high performance computing systems, with particular emphasis on elastic/cloud computing rather than static, centralized resources. In this manner, the prediction system is operated not in a fixed mode using the same configuration each day, independent of the weather, but rather is adjustable so as to optimally address the particular weather situation at hand. This concept, known as dynamically adaptive numerical prediction, was prototyped in the $11.5 million NSF project titled Linked Environments for Atmospheric Discovery (LEAD)[vi] and evaluated in the NOAA Hazardous Weather Test Bed.

Continuing to test this strategy, and others, would benefit substantially from involvement by private technology companies such as Google, Microsoft, Yahoo, and others. Making progress toward bold goals in high impact weather prediction requires a true partnership among academia, the government and private sector, bringing to bear unique resources (e.g., the Blue Waters supercomputer, funded by NSF, at the University of Illinois) and strategies provided by them.

3. SPECIFIC RECOMMENDATIONS INCLUDING RESEARCH AND R2O

Vitally important to a high impact weather initiative is a thoughtfully formulated, effective program structure and execution strategy, including a pathway to operations. The complexity of the multi-faceted challenges involving transforming the prediction of high impact weather must not be underestimated, and critically important is true integration of multiple perspectives and strategies from the physical, social, and behavioral science research communities with those of operational practitioners and end users.

In that regard, the highly successful Hurricane Forecast Improvement Project (HFIP)[vii] would serve as a superb role model as HFIP rapidly brought science-based changes to operational hurricane forecasting. The identification of key challenges, and early delineation of prioritized goals and approaches for meeting them, are essential elements of such a successful program. These tasks can best be accomplished by researchers, with NOAA leading the overall program and Congress providing the mandate, funding, and oversight.

Consideration also should be given in the high impact weather initiative to creating an analog of the National Hurricane Research Test Bed, which was suggested by the National Science Board in the aforementioned report. It represents a framework for optimally coordinating research and operational collaboration. Quoting from the NSB report:

> The proposed NHRTB will involve linking relevant theoretical, physical and computational models from atmospheric, oceanic, economic, sociological, engineered infrastructure, and ecologic fields, conducting experimental research to understand the complexities of hurricanes, and obtaining measurable results in a comprehensive framework suitable for testing end-to-end integrative systems. Test Bed results can be applied experimentally to real situations and provide simulations of important transfer linkages to operational entities and decision makers. NHRTB could be a single facility or a physically distributed environment; regardless of its structure, NHRTB should be operated an interdisciplinary working laboratory where much of the basic research from NHRI can be experimentally substantiated using suitable quantitative metrics, and where a culture of interaction and collaboration can be promoted.

Supporting the concept just described, the National Weather Service operates a number of exceptional test beds ideally, cited previously, that are ideally suited to composing a physically distributed collaborative environment. Indeed, they should even be expanded, though going beyond the traditional <u>linear</u> model of research to operations (R2O) and into a new research <u>plus</u> operations (R+O) concept involving government, academia and the private sector.

Other specific recommendations presented below build upon many of the opportunities described in the previous section.

1. Develop strategies to assess the skill, accuracy and value of high impact weather predictions, taking into account the temporal and spatial intermittency of associated phenomena and using this information as a foundation for developing appropriate message content and communication strategies.
2. The human and behavioral sciences must be a foundational component of a high impact weather initiative <u>from the very beginning</u>, and efforts therefore must be directed toward identifying social science scholars who can contribute and operate in a highly multidisciplinary environment. Additionally, key social science questions need to be identified early and

approaches determined for addressing them – not in isolation, but as an integrated component of the initiative.

3. Use appropriate tools to determine which new observations will lead to the greatest improvements in high impact weather forecasts, particularly emphasizing low cost and rapidly, adaptively deployable technologies such as unmanned aerial systems.
4. Continue making improvements in forecasting models and data assimilation techniques, with particular emphasis on the assimilation of dual polarization Doppler radar data and new data platforms from item 3 above. Test such methods in real time utilizing NWS test beds.
5. Use test beds to evaluate dynamically adaptive prediction strategies built upon new computational modalities (e.g., cloud computing). Further, seek to understand the operational (technological as well as behavioral) consequences of their potential implementation.
6. Architect, in a practical conceptual framework, a completely new threat communication/warning system that starts with the human dimension and proceeds upstream toward operational capabilities enabled by physical science and technology.

Finally, I strongly suggest that studies be undertaken to understand the fundamental predictability of high impact weather. We know, for example, that experimental cloud-resolving models are able to predict certain types of thunderstorms for periods of time much longer – up to 24 hours – than theory suggests should be possible. But unlike for larger-scale weather, which has a predictability limit of about two weeks, we have no idea of the predictability limits for thunderstorms and larger storm systems. Such knowledge is needed for many reasons, but would be especially useful to policy makers in guiding financial investments.

For example, suppose predictability theory indicates that numerical models have achieved 90% of the theoretical limit in forecasting storms capable of producing tornadoes, and that achieving the final 10% will provide little added benefit yet cost $500 million. Such information might lead the required funds to be directed toward addressing other challenges.

4. COMMENTS ON THE ACT ITSELF

I applaud the efforts of the Committee, and those of Mr. Bridenstine via the bill he introduced, to improve our ability to protect citizens from the destructive forces of high impact weather. The challenges before us are immense, and the need for more than incremental progress is unquestionable. I recognize that a single bill, and the funding recommended within it, will not solve every problem or satisfy every constituent. Yet, it is an appropriate down payment on the future if it considers the important recommendations made herein regarding less prescription and greater flexibility, wherein NOAA and the relevant other agencies and communities involved define specific goals and decide which tools and approaches are needed to achieve them.

My final comment concerns climate and weather in a mutually reinforcing context. All of us recognize the importance of balance between weather and climate investments in our nation's research and operations portfolio. Yet, the traditional "line" dividing weather and climate is increasingly blurred as climate models are now run at resolutions approaching those of weather models. Consequently, we would do well to consider weather and climate not as two distinct elements at the extreme ends of a spectrum, but rather as inseparable parts of the Earth system.

To illustrate, recent dramatic improvements in severe weather forecasts are due, in part, to two important factors: a greater understanding of complex relationships between storm type/severity and the environments in which storms form, and the ability of our global and regional models to accurately predict those environments. Climate models have proven capable of reproducing environments hundreds of years in the past and thus can be useful for determining future environments and hence the types of storms that might be expected to form within them. Conversely, our understanding of, and ability to predict, high impact weather will improve climate model representations of storms, precipitation, the radiation budget, and even chemical processes. We are moving toward the day when we will no longer use separate models for weather and climate, and our investments likewise should reflect that trajectory.

ENDNOTES

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Dr. Kelvin K. Droegemeier
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Kelvin K. Droegemeier earned a B.S. with Special Distinction in Meteorology in 1980 from the University of Oklahoma, and M.S. and Ph.D. degrees in atmospheric science in 1982 and 1985, respectively, from the University of Illinois at Urbana-Champaign. He joined the University of Oklahoma in September, 1985 and in 1989 co-founded the NSF Science and Technology Center (STC) for Analysis and Prediction of Storms (CAPS) and served as its director for over a decade. In 2003, he co-founded the NSF Engineering Research Center for Collaborative Adaptive Sensing of the Atmosphere (CASA) and served for several years as its deputy director. Dr. Droegemeier's research interests lie in thunderstorm dynamics and predictability, variational data assimilation, mesoscale dynamics, computational fluid dynamics, massively parallel computing, and aviation weather. In 1999, he founded Weather Decision Technologies, Inc., located in Norman Oklahoma, which provides a wide variety of science and technology based solutions to address weather, climate and hydrology challenges.

In 2004, Dr. Droegemeier was appointed by President George W. Bush to a 6-year term on the National Science Board, the governing body of the National Science Foundation that also provides science policy guidance to the Congress and President. He chaired the Board's Committee on Programs and Plans and served on or chaired several task forces, including those on hurricane science and engineering, transformative research, cost sharing, and NSB nominations. In 2010, Dr. Droegemeier was nominated by President Barack Obama for a second term on the National Science Board and was confirmed by the Senate in 2011 for a six-year term ending in 2016. He was elected in 2012 for a two-year term as Vice-Chairman of the National Science Board.

In 2009, Dr. Droegemeier was appointed Vice President for Research at the University of Oklahoma. He is a Fellow of the American Meteorological Society, a member of the Board of Directors of the Council on Governmental Relations, and a member of the National Research Council Board on Research Data and Information. He presently serves on Oklahoma Governor Mary Fallin's Science and Technology Council and chairs the Sub-Committee on Academic Research and Development. Dr. Droegemeier also is a Trustee of Southeastern Universities Research Association. Elected to the University Corporation for Atmospheric Research (UCAR) Board of Trustees in 2002 and as its Vice Chairman in 2003, he served as Chairman of the Board from 2004-2007. He also served as a Councilor to the American Meteorological Society and is a former member of the Boards of Oak Ridge Associated Universities and the Oak Ridge Associated Universities Foundation.

Chairman STEWART. Thank you, Mr. Droegemeier. I appreciate your testimony.

Our second witness I would like to introduce as Dr. William Gail, Chief Technology Officer of the Global Weather Corporation and President-Elect of the American Meteorological Society. He was previously a Director in the Startup Business Group at Microsoft, Vice President of Mapping Products at Vexcel Corporation and Director of Earth Science Programs at Ball Aerospace. He is a lifetime associate of U.S. National Academy of Sciences Research Council, and Dr. Gail received his Ph.D. in electrical engineering from Stanford University.

And Dr. Gail.

**TESTIMONY OF DR. WILLIAM GAIL,
CHIEF TECHNOLOGY OFFICER,
GLOBAL WEATHER CORPORATION,
PRESIDENT-ELECT, AMERICAN METEOROLOGICAL SOCIETY**

Dr. GAIL. Thank you. Chairman Stewart, Ranking Member Bonamici——

Chairman STEWART. Turn your microphone on, please.

Dr. GAIL. Thank you. Chairman Stewart, Ranking Member Bonamici, and distinguished Members of the Subcommittee, it is a privilege to be here today and provide testimony. Thank you for your invitation.

As was mentioned, I am Cofounder and Chief Technology Officer of Global Weather Corporation, a startup company providing precision weather forecast to businesses within the energy, media, transportation, and consumer sectors. I am also President-Elect of the American Meteorological Society, and I was a member of the recent National Research Council study advising on future directions for the National Weather Service.

This is a tremendous time to be part of the weather community. We have an opportunity to serve the Nation, our citizens and businesses, far more effectively than has ever been possible. The reason is simple. Our work involves three basic cavities: observing the current weather, converting that information into forecasts, and getting the results to the people who need it.

Each step in this process has been sequentially revolutionized. Beginning in the 1960s with the advent of satellites and ultimately Doppler radars, continuing through the 1980s with rapid improvements in computing and weather forecast models, and finally, today, with broad adoption of the internet and mobile phones. We are now beginning to deliver the ultimate vision: individualized weather information matched to every user's need, time, and place.

So why is this important? Well, Sandy and the Oklahoma tornadoes reminded us that we can and must do far more to protect lives and property, but often forgotten is the great potential of weather information to drive economic growth. On average, economic output at the state level varies by up to three percent from one year to the next due to weather variability. In four of the eight States represented on this subcommittee, the variation is over 8 percent.

Improved weather information can clearly be a growth engine for the Nation's economy. Indeed, in every market my company enters, we find opportunity for efficiency improvement.

For example, Xcel Energy uses ten percent of America's wind farm capacity. An improved wind forecast system saved $22 million for the ratepayers in 2012 alone.

The trucking industry lost $18 billion in 2011 to weather-related accidents and delays, yet weather forecasts are not routinely used. A company called Telogis is about to change that, providing weather and road surface forecasts for every mile of major road in the country.

All this is made possible by the American Weather Enterprise, a truly remarkable collaboration between academia, government agencies such as NOAA, and the private sector. Working cooperatively allows us to be bigger than the sum of our three parts, a key reason for our success.

One current goal is to unify our voice and provide prioritized community-based guidance for legislation such as this. To this end, a group of enterprise leaders recently met and agreed to build an advocacy organization called the Weather Coalition.

It is important to recognize that our strength arises from breadth. Space weather, hydrology, oceanography, and coastal meteorology are key sister disciplines to weather. Both near-term and long-term weather are important. One often hears that businesses need a predictable regulatory environment to plan long-term growth. Predictable climate is needed for the same reasons.

Whether it is a military strategist analyzing regional vulnerabilities over the coming decade or simply a parent planning a sunny day for their daughter's wedding next year, understanding climate and its variability are integral to weather forecasting. Rather than dividing the weather and climate communities, we need to bring them together to improve forecasts and ever-longer timescales.

Now, we do have problems to address as a community from the looming satellite gap to forecast model performance. The Sandy Supplemental already helps substantially, but our problems are not simple. The issues are interlinked requiring collaboration across NOAA and often the entire enterprise. The proposed legislation, while admirable for furthering forecast improvement, is too limited in scope, too prescriptive, and not sufficiently guided by broad community input to accomplish what the Nation deserves. I urge you to build from this legislation drawing on community advice and encouraging innovative solutions within NOAA and across the enterprise.

Unlike most people who have the honor to serve as the AMS president, my career has not been entirely within the field of weather. It gives me a bit of an outsider perspective. My experience is that the people in this field—and I enthusiastically include those in NOAA—are the most dedicated, passionate, and innovative people I have ever met. To a person, they have one focus: make the Nation safer and more productive. Give these people your legislative support and they will return the investment many times over.

Thank you.

[The prepared statement of Dr. Gail follows:]

WRITTEN STATEMENT OF

William B. Gail, PhD
Co-founder and Chief Technology Officer, Global Weather Corporation (GWC)
President-Elect, American Meteorological Society (AMS)

Before the
Subcommittee on Environment
Committee on Science, Space, and Technology
United States House of Representatives

A Hearing on: *Restoring U.S. Leadership in Weather Forecasting, Part 2*

26 June 2013

Chairman Stewart, Ranking Member Bonamici, and distinguished members of the Subcommittee: It is a privilege for me to be present here today and provide testimony to you. Thank you for your invitation. My name is Bill Gail. I am co-founder and Chief Technology Officer of Global Weather Corporation, a provider of precision weather forecasts to businesses within the energy, media, transportation, and consumer sectors. I am also President-Elect of the American Meteorological Society (AMS), and I was a member of the recent National Research Council study *Weather Services for the Nation: Becoming Second to None* that recommended future directions for the National Weather Service. My academic training is in physics and electrical engineering and I have nearly two decades of experience in the fields of meteorology satellites, weather services, and location-aware software.

Though I'm speaking to you today from my personal perspective, I wear two hats: first as a voice of the weather community through my AMS position, and second as a member of that community building my own startup company. My company has been successful in today's difficult economy precisely because high quality weather information is increasingly needed by businesses across many industries to serve their customers and improve operations.

Let me first commend you for the attention you are giving to the topic of weather forecasting. Support for our nation's weather infrastructure pays off many times in benefit to the nation, and legislation to accomplish that is wise. Properly crafted legislation, sufficiently comprehensive in scope and not overly prescriptive, can help achieve what I believe is a broadly supported objective of elevating the nation's weather capabilities.

A REVOLUTION IN SERVICE TO THE NATION

This is a tremendous time to be part of the weather community. We have the opportunity to serve the nation – our citizens and businesses – far more effectively than has ever been possible. The reason is simple. Our work involves three basic activities: observing the current weather, converting that information into forecasts, and getting the information to the people who need it. Over the last fifty years, this three-step process has been revolutionized. Starting in the 1960's, the advent of advanced observing systems such as satellites and Doppler radar gave us new ways to view current weather. Then in the 1980's advances in both computing power and modeling techniques began to make possible far more accurate forecasts of future weather. More recently, rapidly expanding Internet access and now smartphone ownership have allowed us to make great progress in delivering the right information to people and businesses - at the time they need it.

For us, getting to this point is a dream. After fifty years, the fruits of the weather information revolution are now within reach. We can finally start delivering on the ultimate vision: individualized weather information matched to every user's need, time, and place. With that, we in the weather industry can do phenomenal new things, not only for the nation but also as leaders in the weather market internationally. NOAA's newly-developed strategy, the *Weather-Ready Nation*, is nicely aligned with this vision.

Why is this important? We have all been touched recently by the tragic tornados in Oklahoma and the devastation of Superstorm Sandy. With Sandy, we were successful in anticipating an unusual westward turn toward New York City – it made a huge difference in our preparedness. In Oklahoma, we forecast with over 30 minutes lead time, but more accurate track estimates and personalized communications would have helped. Getting the right information to people and businesses at the right time is critical.

A GROWTH ENGINE FOR THE ECONOMY

We know more can be done to protect lives and property, and we must do so. But often forgotten is the importance of weather information as a growth engine for our economy. A recent study showed that, on a state-by-state basis, variability in U.S. economic output due to weather-related supply and demand inefficiencies averages more than 3 percent. In some states, it is over 10 percent. A significant portion of this can be recovered as economic growth through improved weather information. Doing so would be a huge boost to the nation's welfare. As we seek ways to grow our economy, better use of weather information can provide large returns from small investments. This is true across virtually all business sectors.

Many of us today, from academia to NOAA to the private sector, are focused on ways to accomplish this. I would like to provide three examples from my own company's experience reflecting innovative approaches to business growth through better use of weather information.

- The BH Media Group, owned by Berkshire Hathaway, has recently acquired nearly 100 small- and mid-sized newspapers. Their vision is that newspaper companies are not dying, but rather the best source of critical local information, which will be delivered by these companies increasingly over web and mobile. Accurate weather forecasts are often the most important information they provide to smaller communities. The move to web and mobile allows them to customize forecasts for each reader, creating new ways for businesses to become more efficient and individuals more productive. My company is helping them implement the vision.

- Xcel Energy is the off-taker utility for 10 percent of America's wind farm capacity. Starting in 2009, Xcel privately-funded R&D at the National Center for Atmospheric Research (NCAR), focused on improving the accuracy of wind forecasts. The resulting forecast system has since been successfully transitioned to my company. Its operational use saved $22 million for Xcel ratepayers in 2012 alone.

- Telogis is a provider of information services to the commercial vehicle industry, including back office and in-cab navigation. They support nearly a million trucks in the

US. In 2011, this industry lost nearly $18 billion dollars to weather-related accidents and delays, yet weather information is not routinely used by trucking companies. My company is working with Telogis to change that, providing atmospheric weather and road surface conditions for every mile of major road through interfaces that can be easily and safely used by truckers.

THE REMARKABLE WEATHER ENTERPRISE

None of this could happen without a remarkable collaboration between three organizational sectors: research entities including academia, government agencies such as NOAA and the DoD weather services, and the private sector. We refer to this as the American weather enterprise. Academic and research organizations are the foundation, providing the basic knowledge that drives innovation and the education for our workforce. Government agencies including NOAA provide the core data and forecast capabilities used across the enterprise. The private sector customizes information for end-users and delivers it across many channels. For example, though NOAA is the original source for virtually all weather information in this nation, today 95% of delivery occurs through television, websites, and apps from the private sector. By working together, this enterprise has greatly improved the quality of weather forecasting and the ability to deliver that information effectively. Collaboration allows us to be bigger than the sum of our three parts – a key reason for our success. Barry Myers of AccuWeather, in prior testimony to this committee, described the American weather enterprise as "better than anywhere on Earth", and I fully agree with his statement.

This shining example of how government works productively with the academic and commercial sectors can be held up to other industries to help them do the same. But it has not always been this way. We have worked hard at making this happen. Indeed, we are entering what might be called the third phase of our enterprise. The first phase, through the 1990's, was characterized by mistrust and competition, particularly between the government and commercial sectors. A decade ago a National Research Council report called *Fair Weather* laid out a process for fixing the situation, and the result has been dramatic. It led us into a second phase of the enterprise characterized by communication and mutual respect. We have made much progress as a result.

As we enter the third phase, much deeper collaboration is needed. We are just beginning to build the mechanisms that make this possible, such as a recent AMS-led pilot effort to identify enterprise-wide priorities for forecasting improvement. We need more collaboration like this if we are to meet the nation's growing needs.

AN ENTERPRISE-DRIVEN PATH FORWARD

A common criticism of our community has been the lack of a unified voice and clear priorities. It is a valid criticism. For nearly a century, the American Meteorological Society (AMS) has been the primary professional organization for those involved in weather. Other organizations, such as the National Weather Association (NWA), the American Weather and Climate Industries Association (AWCIA), and the American Commercial Space Weather Association (ACSWA) have more recently taken on leadership roles in various aspects of the community. AMS provides objective informational advocacy, but does not cross the line into legislative processes. Doing so would compromise our membership, a third of which works in the government sector. Though individual weather companies and organizations have long advocated for their particular needs, the enterprise has not had an organization that can bring Congress a unified plan with clear priorities.

We as a community recognized this shortcoming, and a proposal was put forth last fall to form a congressionally-chartered Weather Commission, similar to the successful Oceans Commission about a decade ago. This, some believed, would allow us to address policy issues at a level appropriate to their national importance. A group of community leaders, representing the private sector, academia, and non-profits, met in March at a summit in Dallas to consider this along with alternatives. AMS co-sponsored and facilitated the meeting. The Dallas group recently released a proclamation in which we agreed to a two-prong approach. In the near-term, we will build an advocacy organization called the Weather Coalition and use that as a voice for the community, particularly with regard to possible legislation. For the longer-term, we will pursue options for foundational change, including the possibility of a Weather Commission. The Dallas meeting was a milestone in our ability to speak with a unified voice. You will be hearing from the

Weather Coalition in the near future, and they will work with you on this legislation as it progresses.

The Weather Coalition, however, will be only the face of a much larger community-driven planning activity. Much of the planning input to guide the Weather Coalition will come from professional organizations such as AMS which have the broad membership to access and organize community thinking. For example, the AMS-led forecast improvement group, which I mentioned previously, brings together our three sectors to explore development of a joint plan for the nation's forecast capabilities. The resulting recommendations will be publicly available soon.

SELF-IMPROVEMENT

We are not without flaws as an enterprise. Over the last decade and more, we have struggled with our satellite system and worked to stay competitive with our European counterparts in weather forecast models. We have labored to build mechanisms that help us collaborate across the enterprise and speak with a single voice. NOAA in particular has faced challenges in areas such as the transition from research to operations. These issues have been openly documented in reports from the National Research Council, the National Academy of Public Administration, and NOAA's own Science Advisory Board.

Such reports reflect broad input from the community and professional advisory groups. To progress, we do not need to wait for more studies. It is time to build on those we have and start implementing the changes needed to fulfill the vision, including NOAA's *Weather-Ready Nation*. Legislation that can accelerate this, and in particular motivate the cultural and organizational changes within NOAA recommended in these reports, is welcome. Moving forward, additional planning guidance will become available from the Weather Coalition and other sources.

STRENGTH IN OUR BREADTH

I have talked mostly in terms of weather for the sake of simplicity, but it is important to realize how our strength derives from a breadth of disciplines. For example, we increasingly recognize that space weather is a fundamental counterpart to atmospheric weather. Hydrology and oceanography are key sister disciplines. Disciplines such as coastal meteorology have specific but essential roles.

Climate must be included. For the real world in which my company operates, weather and climate can't be separated. There just is no good place to draw a line between them. Should we forecast weather out to two weeks, but no longer? Businesses would not like this - forecasts for coming seasons are enormously valuable to companies in energy and agriculture. The travel and leisure industries take an even longer view; they can benefit directly from improved forecasts of the El Niño cycle even years ahead. Construction companies need to anticipate flood zones and coastal erosion decades out. Businesses want to anticipate weather on time scales from months to years, human influence or not. Our commodities markets – from heating oil to orange juice – could not function without seasonal climate forecasts. Whether it is a military strategist analyzing regional vulnerabilities, or simply one of us planning a sunny day for our daughter's wedding a year ahead, information about climate and its variability is central to the nation's wellbeing.

Put simply, understanding the fundamentals of climate variability is essential to forecasting weather. What we learn from climate modeling significantly improves our weather forecast skill. Arbitrarily distinguishing between weather and climate makes no sense. Rather than dividing the weather and climate communities, we need to bring them together to improve forecast accuracy at ever-longer timescales.

EFFECTIVE LEGISLATION

The issues we must address to make progress are not simple. The problems are interlinked and the solutions require collaboration across many elements of NOAA. Increasingly, this collaboration must be extended to include the enterprise as a whole. The proposed *Weather*

Forecast Improvement Act of 2013, while admirable for taking on an important part of the problem and furthering the goal of forecast improvement, is both too limited in scope and too prescriptive to accomplish what the nation deserves. I urge you to consider legislation that broadens what you have started - building it on existing recommendations from advisory bodies such as the National Research Council, reflecting ongoing input from community-based organizations such as the Weather Coalition, and coordinating across other Federal agencies as needed.

In saying this, I do not want to preclude passage of more focused legislation as a step toward that broader goal. Either way, the leadership of our community, including those within NOAA, should be encouraged to innovate and to bring forth new ideas for improving how we work. A truly novel approach to public-private partnerships that enables low-cost use of commercial data – not just the old data buy paradigm - is but one example. Rather than prescribing specific methodologies, legislation that promotes broad innovation in response to community guidance, and provides the resources to accomplish it, would produce results.

IT'S THE PEOPLE

Unlike most people who have the honor to serve as AMS president, my career has not been entirely within the field of weather or climate. In addition to weather, I have also worked in consumer software and satellite construction, serving commercial, scientific, and military customers. That gives me a bit of an outsider perspective. My experience is that the people in this field – and I enthusiastically include those in NOAA – are the most dedicated, passionate, and innovative people I have ever met. To a person, they have one focus: make the nation safer and more productive. That commitment to integrity is a rare quality today. In your role as legislators, this can be leveraged to improve our nation. Give these people your legislative support, and they will return the favor many times over.

William B. Gail is president-elect of the American Meteorology Society as well as co-founder and Chief Technology Officer of Global Weather Corporation, a provider of precision forecasts for renewable energy and other weather-sensitive business sectors. He was previously a Director in the Startup Business Group at Microsoft, Vice President of mapping products at Vexcel Corporation (where he initiated its 2006 acquisition by Microsoft), and Director of Earth science programs at Ball Aerospace (responsible for Earth science and meteorology spacecraft). Dr. Gail received his undergraduate degree in Physics and his PhD in Electrical Engineering from Stanford University, where his research focused on physics of the Earth's magnetosphere. During this period, he spent a year as cosmic ray field scientist at South Pole Station.

Dr. Gail is a lifetime Associate of the US National Academy of Science's research council, having participated on a number of committees including the recent review of the National Weather Service and the 2007 Decadal Survey that recommended a 10-year satellite plan for NASA and NOAA. He serves or has served on a variety of editorial, corporate, and organizational boards including Women in Aerospace, Imaging Notes magazine, SPIE Journal of Applied Remote Sensing, IEEE Geoscience and Remote Sensing Society, NOAA Advisory Committee on Commercial Remote Sensing (acting), NASA Senior Review, NASA Earth Sciences Roadmap Committee, and NASA Applied Sciences Program Advisory Group.

Chairman STEWART. Thank you, Dr. Gail.

Today's final witness is Dr. Shuyi Chen, Professor of Meteorology and Physical Oceanography at the Rosentiel School of Marine and Atmospheric Science at the University of Miami. She previously served as an editor for Weather and Forecasting Journal at the American Meteorological Society. She is a Member of the National Academies Board on Atmospheric Science and Climate and a Fellow at the American Meteorological Society. She received her Ph.D. in meteorology from Pennsylvania State University.

Dr. Chen.

TESTIMONY OF DR. SHUYI CHEN, PROFESSOR, METEOROLOGY AND PHYSICAL OCEANOGRAPHY, ROSENTIEL SCHOOL OF MARINE AND ATMOSPHERIC SCIENCES, UNIVERSITY OF MIAMI

Dr. CHEN. Chairman Stewart, Ranking Member Bonamici, and other respected Members of the Subcommittee, thank you for the opportunity to testify before you on the important issue of improving weather forecast.

So I would like to focus my testimony on three points regarding the bill and many have been stated. I wouldn't repeat. These are my personal opinions, although they are very much based on the number of studies conducted by the National Research Council of the National Academies.

The first point will be probably the most important point. I will come back to that. So I would first like to make a comment on the second and the third. The second referred to a point in the bill about specific technology, evaluating observing systems in terms of using models. I would say in its present form it is narrow and prescriptive, so we would like to see that to be broadened to address the challenge that we are facing in terms of a—having that technology more flexible and including other new technologies that are currently in place.

In terms of weather prediction, we have made tremendous progress. The point I would like to bring your attention to is that we are at a crossroads that we face new challenge. One of the issues is that we can actually make weather forecasts beyond two weeks. This is where I think the weather and climate will come together because this is an important area.

In fact, in Florida, when we make a forecast for hurricanes, the long-term projection into the next several weeks, a probablisitic forecast, is important because that is the time we need to make plans, for instance, for water management. The science that can be done nowadays is much better than we can imagine before.

So, again, follow the same theme. I think weather and climate forecasts are connected. They both are needed by society. I think we are ready to do that and we certainly would like to see that happen.

Now I am going to the first point of my testimony in terms of a need for a holistic approach to the transition from research to operations. As you all know that we have made tremendous progress in terms of forecasting high-impact weather like the event in

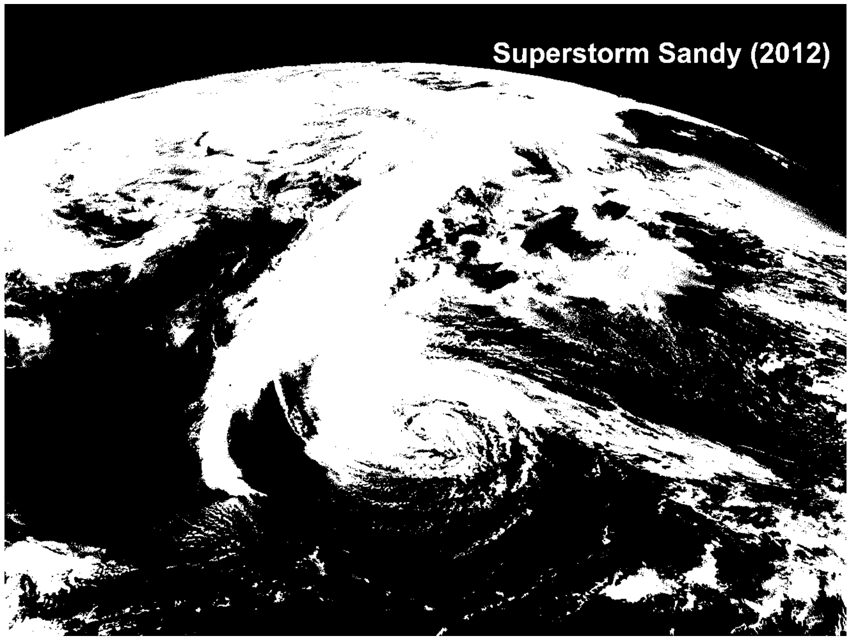
Moore, Oklahoma, and Super Storm Sandy. The problem that we are facing, the challenge that needs to be resolved, is the following: the research and the operations are sitting in two boxes. They are not well-connected. They are well-intentioned, as we probably heard before, but there is no connection between them or no link, so we have not made much progress even though a lot of the studies have suggested we should.

I think Congress can help us in terms of providing that linking piece. This is where I think a National Advisory Board would help to make that decision for transition from research to operations, not only at OAR or within NOAA but also a broad research community that is driven by users' needs, and at the same time we would like that the oversight for this important effort to making decisions for transition to the National Weather Service.

Currently, many models not only they are not running in real time by NOAA operations; they have no pathway to even getting into NOAA operations. So this is where I think Congress can help to bridge that gap.

I would like to show you a research that is done—many research has been done for Super Storm Sandy. And this is a familiar picture, and I would like you to be the judge to see what research has come along and whether they should be going to operations.

[Slide.]


Superstorm Sandy (2012)

This storm taught us a lot of things. Many things have worked well. One thing we recognize Sandy as a hurricane does not to operations, with its environment, and many models had made forecasts quite far in advance. If you look at the panel on the right that many global models prodicted the storm track way in advance, especially one of the models from Europe that prodicted nine days before the storm would have a high probability of hitting the Northeast.

On the other hand, our high-resolution model to the left on the slide can really get into the nitty-gritty details of the storm impact in terms of rainfall and so on, interaction between the storms. And furthermore, the models conducted at a universities have made much more progress in terms of resolving the surface winds. For instance, the right panel is model prediction and the left panel is observed from satellite. Those—you can't really almost tell them apart. The research is really making progress.

In terms of forecasting impact, these are—you are looking at, the surface wave and ocean sea level height. This was not imaginable many years before, but recently, we can really quantitatively forecast the sea level heights when the storm is approaching, especially to the right of the storm track where you have water pushing onshore and offshore to the south. So we can quantify this information much more accurately by going to high-resolution storm surge impact forecasts. All this is available now in the research community.

[Video shown.]

The last thing you will see is a movie that is model simulation of the weather systems that are interacting with each other. One is Sandy as it is approaching the land and the upper atmosphere has a wave that interacts with Sandy. They wrap around each other, dancing around, and this has made Sandy extremely special.

This type of research is available, but unfortunately many of these models developed by the research community have no pathway to go into operation. We would really like the Congress to address this important issue going forward.

Thank you.

[The prepared statement of Dr. Chen follows:]

TESTIMONY

Shuyi S. Chen, Ph.D.
Professor of Meteorology and Physical Oceanography
Rosenstiel School of Marine and Atmospheric Science, University of Miami

Before the
Subcommittee on Environment
Committee on Science, Space, and Technology
United States House of Representatives

A hearing on:
Restoring U.S. Leadership on Weather Forecasting, Part 2

June 26, 2013

Chairman Stewart, Ranking Member Bonamici, and other Members of the Committee, thank you for the opportunity to speak with you today on the need for improving weather forecasting for the Nation. My name is Shuyi Chen and I am a Professor at the Rosenstiel School of Marine and Atmospheric Science of the University of Miami. I am a member of the Board on Atmospheric Sciences and Climate (BASC) of the National Academy of Sciences. I am a Fellow of the American Meteorology Society. It is an honor for me to testify on Restoring U.S. Leadership on Weather Forecasting.

My research and professional service have centered on understanding and improving prediction of tropical weather systems, especially hurricanes. I served as an Editor for *Weather and Forecasting* of the American Meteorological Society. I am currently a member of the Science Advisory Board for the Development Testbed Center (DTC). I also serve on the Advisory Board for the Weather Research and Forecast (WRF) model community. I was on the National Research Council's (NRC) Committee on Progress and Priorities of U.S. Weather Research and Research-to-Operations Activities, which produced the NRC report (2010) "*When Weather Matters – Science and Services to Meet Critical Societal Needs.*" Most recently I was appointed by the National Academy of Sciences Division on Earth and Life Science to oversee the review of the NRC Report (2012) "*Weather Services for the Nation – Becoming Second to None.*"

I have devoted more than 20 years conducting research to further understanding of weather systems and improve weather prediction through observations and numerical modeling. My research group at the University of Miami has developed a next-generation high-resolution coupled atmosphere-wave-ocean model to better understand and predict hurricane structure and intensity. I was a principal investigator for three major hurricane/tropical cyclone research programs. One is the National Science Foundation supported Hurricane Rainbands and Intensity Change Experiment (RAINEX), which used three Doppler radar aircraft and collected unprecedented in-situ data in Hurricanes Katrina, Rita, and Ophelia during the 2005 Hurricane Season. The other two are the Coupled Boundary Layer Air-Sea Transfer (CBLAST)-Hurricane in 2003-04 and the Impact of Typhoons on the Ocean in Pacific (ITOP) in 2010 sponsored by the Office of Naval Research, which aimed to better understand the role of air-sea interaction in hurricane structure and intensity change. These research results have been published in ***Science***[1], ***BAMS***[2], and ***JAS***[3] among others. Currently I am a lead scientist of the National Oceanography Partnership Program (NOPP) model development team to build a new, high-resolution, fully coupled atmosphere-wave-ocean model with a unified air-sea interface that is designed with inter-operability to facilitate research to operations. This new modeling approach is current under testing in the U.S. Navy atmosphere-ocean prediction modeling system.

As we all know, accurate weather forecasts and warnings can save lives and help prevent natural hazards from becoming disasters. Improving weather forecasts and warnings must be a national priority. Over the last two decades, weather research in U.S. has made tremendous progress in better understanding weather processes and in advancing our ability to observe and predict weather. Atmospheric scientists of the United States are among the best in the world. Our weather research capability is admired by all other nations. The United States led the field of numerical weather prediction (NWP) since its inception in the 50's and 60's. However, we are no longer the leader of the field and our operational weather prediction skill fell behind those of some other nations as found by three recent NRC reports (2010a[4]; 2010b[5]; 2012[6]). I believe we can fully materialize our potential in numerical weather prediction and our weather forecasts can be the best in the world. But first we need to identify our weaknesses and the challenges we are facing, otherwise we cannot find solutions to them and we will not make progress. I commend the Committee for taking the leadership to address this important issue of restoring U.S. leadership in weather forecasting.

In this context, I will focus in my testimony on three themes:
- A holistic approach to transition from research to operations;
- Integrated quantitative assessment and planning for new observing systems; and
- Weather forecasting beyond two weeks.

1. A Holistic Approach to Transition from Research to Operations

U.S. weather research has been on the leading edge in terms of innovation and breath in basic research that has led to improvement in weather forecasting, especially in the area of high-impact weather forecasting and warnings in NOAA. This is clearly evident during the recent severe weather events in Moore, Oklahoma and the Superstorm Sandy along the east coast seaboard. Basic research has played a vital role in advancing weather research and forecasting in the U.S.

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[1] Houze, R.A., S.S. Chen, B. Smull, W.C. Lee, M. Bell, 2007: Hurricane intensity and eyewall replacement. ***Science*, 315**, 1235-1239.

[2] Chen, S.S., J.F. Price, W. Zhao, M.A. Donelan, and E.J. Walsh, 2007: The CBLAST-Hurricane Program and the next-generation fully coupled atmosphere-wave-ocean models for hurricane research and prediction. ***Bull. Amer. Meteor. Soc.*, 88**, 311-317.

[3] Chen, S.S., W. Zhao, M.A. Donelan, and H.L. Tolman, 2013: Directional Wind-Wave Coupling in Fully Coupled Atmosphere-Wave-Ocean Models: Results from CBLAST-Hurricane. ***J. Atmos. Sci.*, 70**, doi: http://dx.doi.org/10.1175/JAS-D-12-0157.1.

[4] NRC, 2010a: *When Weather Matters – Science and Services to Meet Critical Societal Needs.* National Academy Press, Washington, DC.

[5] NRC, 2010b: *Assessment of Intraseasonal to Interannual Climate Prediction and Predictability.* National Academy Press, Washington, DC.

[6] NRC, 2012a: *Weather Services for the Nation – Becoming Second to None.* National Academy Press, Washington, DC.

and worldwide. Much of the advancement today would have not been possible without a broadly based research from the academic, government, and private research community funded by the National Science Foundation, the Office of Naval Research of DOD, DOE, NASA, NOAA, and others over the last several decades. However, the fruits of the weather research have not been fully harvested by the operations in NOAA. This issue has been the focus of several NRC studies and reports. Many have reached similar conclusions as those found in "*From Research to Operations in Weather Satellites and Numerical Weather Prediction: Crossing the Valley of Death*" (NRC 2000[7]) – a lack of a national strategy and leadership. A similar view was expressed in a provocative article entitled "*The Uncoordinated Giant: Why U.S. Weather Research and Prediction Are Not Achieving Their Potential*" by Mass (2006)[8]. Despite an awareness of the problem and recommendations from many entities, there has been little progress in improving the transition of research to operations, especially in terms of NWP models.

Within NOAA, the National Center for Environmental Prediction (NCEP)/National Weather Service (NWS) has been developing its own NWP models for operations, while the Office of Oceanic and Atmospheric Research (OAR) laboratories have developed separate NWP models. With limited resources NCEP is unable to replace its aging modeling system such as GFS and is unwilling to support extramural research and model development (UCAR, 2010[9]), which leads to intellectual isolation. This vicious cycle continues today. At the same time, the research community outside of NOAA continues to develop a number of next-generation high-resolution NWP models. Unfortunately, there is no pathway for these models to become operational at NCEP.

I applaud the efforts of the Committee for taking the initiative to address this pressing issue in the proposed ***Weather Forecasting Improvement Act 2013*** [e.g., Section 3 (b)-(3)]. I would urge you to go further.

To develop a national strategy and a systematic approach to transition of start-of-the-art weather research into operations, NOAA cannot do it alone. It needs to "***Engage the entire (weather) enterprise to develop and implement a national strategy for a systematic approach to research to operations and operations to research.***" – A key recommendation by NRC (2012).

Recent development of the Rapid Refresh (RAP) model and data assimilation system and the High-Resolution Rapid Refresh (HRRR) hourly updated model is perhaps the best example of a community effort linking both the research and operational communities toward NCEP model implementations to replace an aging NWP system known as Rapid Update Cycle (RUC) model for short-range forecasts, especially for the aviation community. The RAP and HRRR both use a version of the Weather Research and Forecast (WRF) model developed at the Center for Atmospheric Research (NCAR), which has more than 7,000 users from a broad research community both in the U.S. and worldwide. Scientists and forecasters at the Global System Division (GSD)/OAR and NCEP worked closely with NCAR on the development of WRF for

[7] NRC, 2000: *From Research to Operations in Weather Satellites and Numerical Weather Prediction: Crossing the Valley of Death.* National Academy Press, Washington, DC.

[8] Mass, C., 2006: *The Uncoordinated Giant: Why U.S. Weather Research and Prediction Are Not Achieving Their Potential.* ***Bull. Amer. Meteor. Soc.***, **87**, 573–584.

[9] UCAR, 2010: *2009 community review of the NCEP Office of the Director.* Boulder, CO.

operations. The RAP and HRRR have also benefited from using a community data assimilation system, the Gridpoint Statistical Interpolation (GSI) system. GSD has also worked closely with NCEP, NASA, NCAR, and the Air Force Weather Agency (AFWA) on development of GSI, including enhancements (e.g., radar, cloud, near-surface data assimilation) specifically needed for RAP and HRRR, which is now available to the GSI community. Recent improvement on forecasts of convective weather systems using RAP and HRRR shows the benefit from the broad collaboration at a grass root level.

However, without a national strategy, a systematic approach, and a viable infrastructure to facilitate a smooth transition from research to operations, the goodwill from individuals alone cannot meet the ultimate challenge of research-to-operations at the national level.

To restore U.S. leadership in weather forecasting, we need a new, transformative, integrated system to transfer state-of-the-art weather research to operations. This system should be overseen by a group/organization of experts from research, operations, and user community of the weather enterprise and should be capable of:

- Developing a community-based NWP modeling and data assimilation system that is flexible using a community-standard source code to incorporate innovations in weather research and technology (e.g., the next-generation, unified global non-hydrostatic, fully coupled atmosphere-wave-ocean-land model and data assimilation system);
- Rapidly transferring research products and new technologies to NOAA and other operations (including private sectors);
- Providing accurate weather forecasts and emerging needs for impact forecasts (e.g., tornado outbreaks, hurricane-related storm surges, flash floods and power outage) and warnings on the short lead time of days to hours, and potential risk for drought, floods, wild fires, hurricane genesis and track on extended lead time of weeks.

The next-generation community-based system(s) should also have the capability of providing user-driven impact forecasts, which has been one of the key recommendations in the NRC "*When Weather Matters*" report (NRC, 2010a). It will be more transparent and efficient for:

- Communicating with federal and local government to optimize the utility of the forecast and assessment products in public response;
- Training the next-generation of scientists and forecasters with innovative tools for prediction and impact mitigation;
- Educating vulnerable residents on the application value of the new information coming out of the integrated forecast system on short and long lead times.

2. Integrated Model-Data Assimilation for Observing System Assessment and Planning

Another key in improving weather forecasting is the capabilities of observing states of the atmosphere, land, and ocean, which is absolutely essential to our understanding and new discovery of nature and to meet the need for numerical weather prediction and data assimilation. It is critical for us to understand the impact of current observing systems on weather prediction as well as anticipate future observing system needs and requirements. We must put in place an advanced, systematic, assessment and evaluation system for current and new observing systems. The traditional approach has been using observing system experiments (OSEs) to assess impacts of existing observations on numerical model prediction, and observing system simulation experiments (OSSEs) for future observations. However, OSSEs are rarely used because of its large uncertainty due to model biases and a lack of independence between the model simulated "nature" state and its data assimilation system.

Because the shortcomings of OSSEs, some operational centers including the U.S. Navy, NASA, and the European Center for Medium-Range Weather Forecasts (ECMWF) have chosen to develop new alternative approaches using adjoint and/or ensemble data assimilation (EDA) system for observing system assessment and planning. New and better technologies are likely continue to be developed in the future (NRC, 2012). For these reasons, I would urge caution for legislate specific technologies for observing system assessment and planning (re. Section 7 in the proposed ***Weather Forecasting Improvement Act 2013***), but will be best to encourage innovations and new technology development.

3. Weather Forecasts Beyond Two Weeks: A New Frontier

Focusing on the near-term improvement of weather forecasts and warnings, especially high impact weather such as tornadoes and hurricanes, is important. But we must also recognize that the need and economic values of extending weather forecasts beyond one week, known as extended weather forecasts on subseasonal time scale (1–4 weeks). Recent research has found that the occurrence probabilities of tornados and hurricanes significantly fluctuate on that time scale. Other phenomena also fluctuating on that time scale include drought, flooding and heat waves, all having great impacts on society. A better understanding and improvement of subseasonal forecasts are needed to bridge weather and seasonal forecasts at the weather and climate interface, which has been documented in the World Weather Research Program (WWRP) Implementation Plan[10] and the NRC report (2010b).

From the end-user perspective, extended weather forecasts are very important, because many management decisions, such as in agriculture and preparation for high impact weather (flood, heat waves, hurricanes, wild fires) and proactive disaster mitigation, fall into this scale. Reliable and skillful subseasonal forecasts for this timescale would be of considerable value.

Recent research has indicated important potential sources of predictability for this time range such as slowing evolution in tropical convection, stratospheric influences, and land/ice/snow interactions. Recent improvements in computing resources and model development may make it possible to develop a better representation of these sources of extended weather predictability. Several operational centers are now producing operational subseasonal forecasts.

In principle, advanced notification, on the order of two to several weeks, of the probabilities of hurricanes, tornados, severe cold outbreaks and heat waves, torrential rains, and other potentially high impact events, could help protect life and property; humanitarian planning and response to disasters; agriculture and disease planning/control (e.g., malaria and meningitis); river-flow and

[10] WWRP, 2013: *Subseasonal to Seasonal Prediction.* Research Implementation Plan. WMO.

river-discharge for flood prediction, hydroelectric power generation and reservoir management; landslides; coastal inundation; transport; power generation; insurance. There are tremendous potential benefits from reliable extended weather forecasts to reductions in mortality and morbidity and to economic efficiencies across a broad range of sectors.

In recent years, operational forecasting systems dedicated to subseasonal prediction have been implemented in many NWP centers (including NCEP and ECMWF). Demands for such forecast have been increasing. Types of subseasonal forecast products are, however, still limited. Errors and uncertainties of subseasonal forecasts are still large. With focused research-operation integration, substantial improvement of subseasonal forecast skill and elevated societal benefit are within our grasp.

The weather enterprise has entered a new era of extended weather forecasts beyond two weeks. Science and technology advancements have made it not only possible but also practical to made substantial improvement in extended weather forecasts. What we need is a determination and well thought of plan. A consortium of academic, government, and private sectors within the weather enterprise is recommended to lead the Nation's effort to make measureable advancement in extended weather forecasts to meet the society's need and to be the best in the world.

4. Conclusion

To restore U.S. leadership in weather forecasting should be a national priority. NOAA cannot do it alone. It will take the entire weather enterprise. Congress can help. You must.

There is no doubt that improving the weather forecasts and response to save lives and reduce economic loss should be a national priority. The rapid advancement of science and technology presents us with an unprecedented capability and opportunity to develop the integrated weather forecast and response system that will support risk assessments and emergency management by reducing warning areas and providing forecasts with longer lead time. There is critical need for the involvement of the NSF to support the ambitious and risky interdisciplinary research agenda, in ways that go beyond what is feasible in individual mission-oriented government agencies. The development and operation of such an integrated weather forecast and response system requires collaboration and coordination among many research disciplines and among the research community and government and impacted sectors. Further, successful implementation of such a system requires the education of a new generation of scientists, technicians, forecasters, government managers, and will guarantee a smooth transition from research to NOAA operations.

Brief biography - Dr. Shuyi S. Chen

Shuyi Chen is a Professor of Meteorology and Physical Oceanography at the Rosenstiel School of Marine and Atmospheric Science (RSMAS) of the University of Miami (UM). She is a widely published author whose work focusing on the dynamics and air-sea interactions in tropical convection and cyclones/hurricanes. Prof. Chen leads a research group at UM that has developed a new generation fully coupled atmosphere-wave-ocean model for coastal and hurricane research and prediction. She has been a lead scientist on several global tropical cyclone research programs, among them: the Coupled Boundary Layer Air-Sea Transfer (CBLAST); the successful Hurricane Rainbands and Intensity Change Experiment (RAINEX) using three Doppler radar aircraft collecting unprecedented *in-situ* data in Hurricanes Katrina, Rita, and Ophelia in 2005; and the largest international program to study typhoons in the West Pacific, Impact of Typhoons on Ocean in Pacific (ITOP) in 2010. She is also a lead aircraft scientist in the DYNAMO field campaign in 2011 collecting data over the Indian Ocean to improve our knowledge of the Madden-Julian Oscillation (MJO) and its impacts on global weather. She is currently working with a team of scientists focusing on understanding the impact of oil spill on the environment in the Gulf of Mexico. Dr. Chen is a recipient of the NASA's Group Award on Tropical Convection Program in 2006. She served on a panel of experts for the Congressional briefing on the National Hurricane Initiative at U.S. Senate and House of Representatives in July 2007, and later testified at the Joint Hearing on: *The State of Hurricane Research and the National Hurricane Research Initiative Act of 2007*, before the Subcommittee on Energy and Environment and the Subcommittee on Research and Science Education, Committee on Science and Technology of United States House of Representatives in June 2008. Dr. Chen served as an Editor for *Weather and Forecasting* journal of the American Meteorological Society. She is a member of the National Academies' Board on Atmospheric Sciences and Climate (BASC) and a Fellow of American Meteorological Society. Dr. Chen received her Ph.D. in Meteorology from the Pennsylvania State University in 1990.

Three Recommendations

1. *Need a holistic approach to transition from research to operations:* **Congress can help provide mandate for a new National Advisory Board to develop a national strategy and a transformative, systematic approach**.

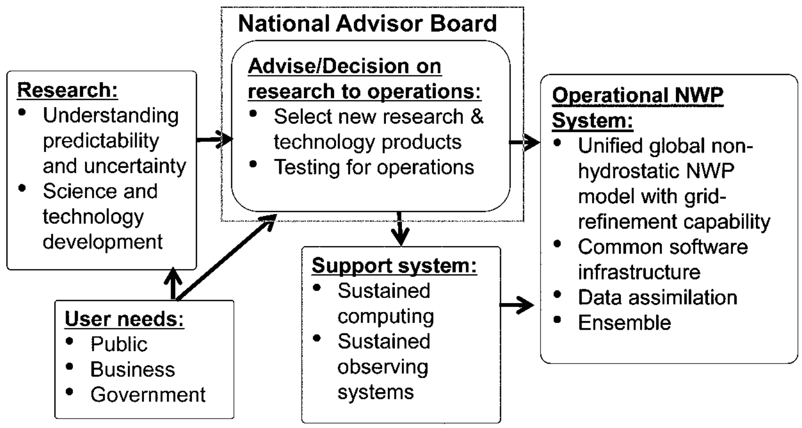
1. *Observing system assessment and planning:* **the proposed legislation is too narrow and prescriptive – it should be revised to encourage innovation and new science and technology development.**

2. *Weather forecasts beyond two weeks: A new frontier* **Congress can help develop a national strategy to address this emerging need of society.**

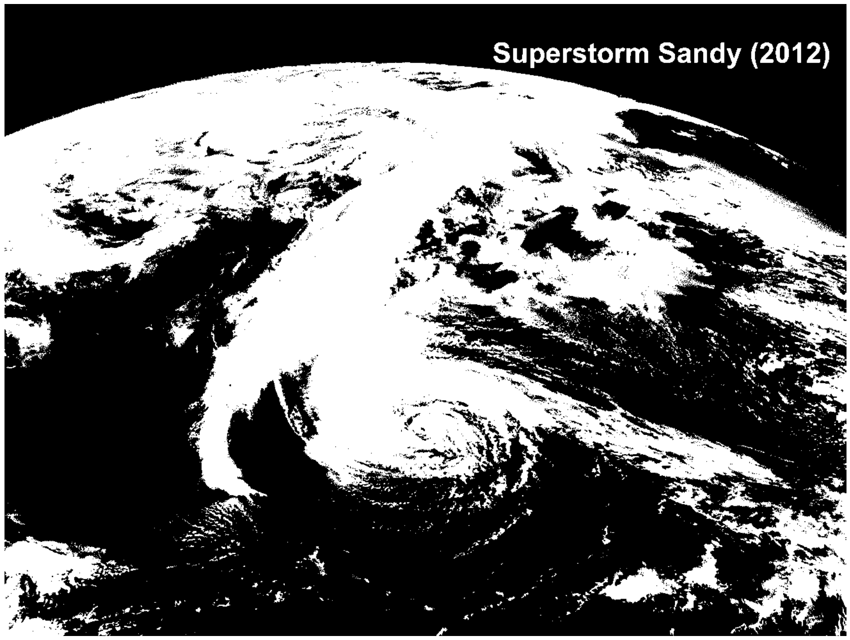
Shuyi S. Chen (schen@rsmas.miami.edu), University of Miami, 26 June 2013

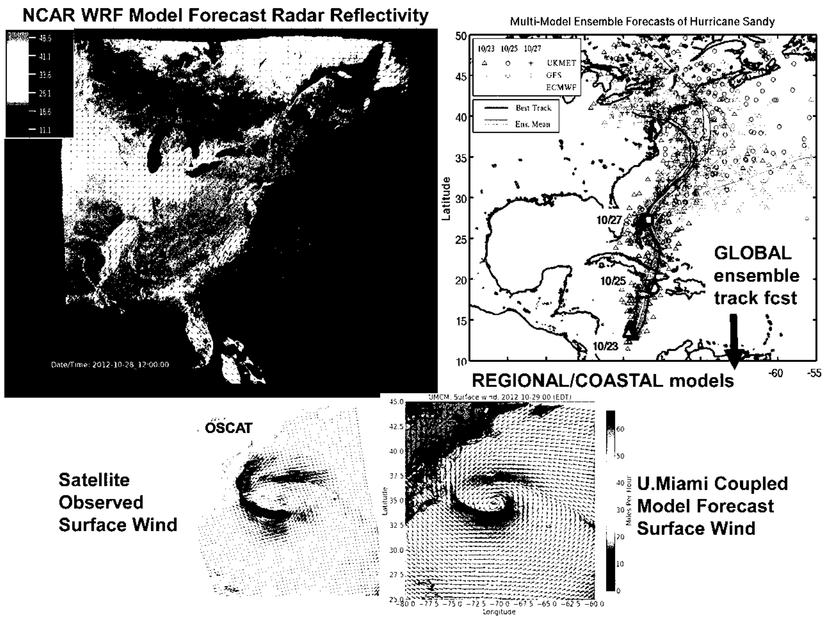
UM Hurricane and Coupled Modeling Group

National Strategy and Systematic Approach to Weather Forecasting

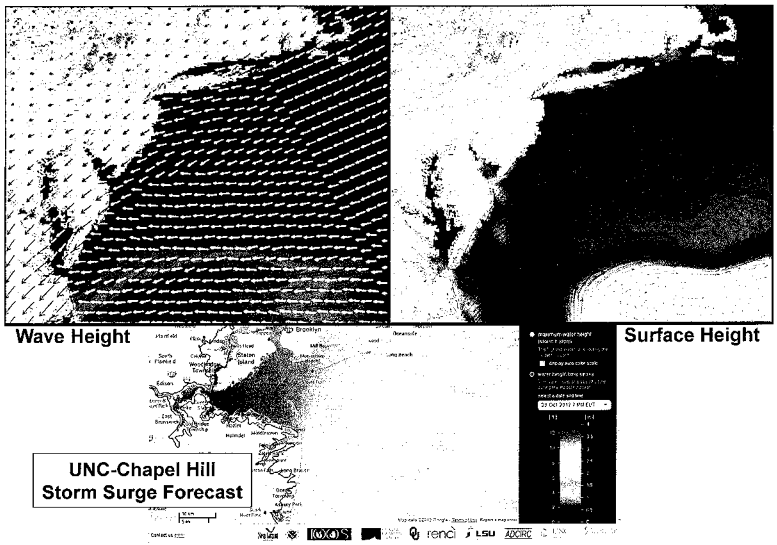


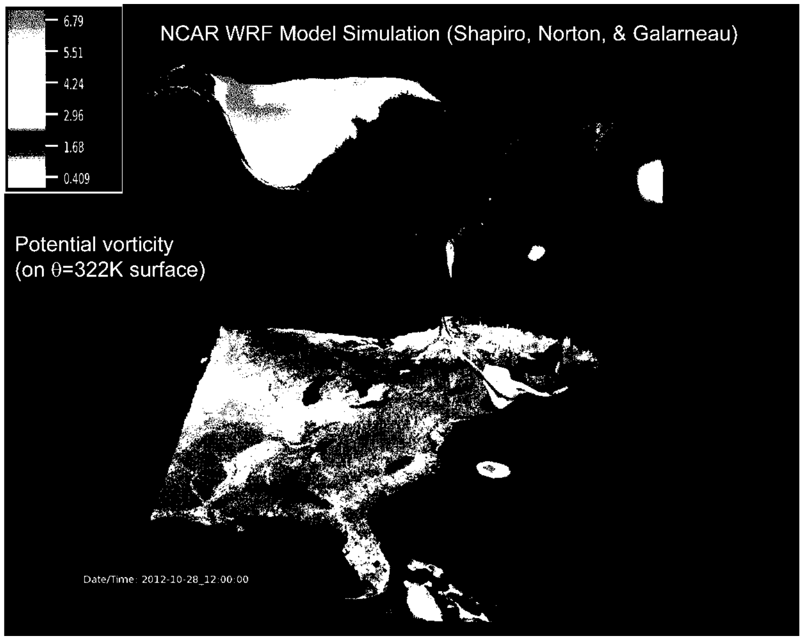
UM Hurricane and Coupled Modeling Group


Superstorm Sandy (2012)


NCAR WRF Model Forecast Radar Reflectivity
Multi-Model Ensemble Forecasts of Hurricane Sandy
10/23 10/25 10/27
UKMET
GFS
ECMWF
Best Track
Ens. Mean
Latitude
10/27
10/25
10/23
GLOBAL ensemble track fcst
REGIONAL/COASTAL models
Date/Time: 2012-10-28, 17:00:00
OSCAT
Satellite Observed Surface Wind
U.Miami Coupled Model Forecast Surface Wind
Longitude
Miles Per Hour

Hurricane Sandy Impacts - University of Miami Coupled Model Forecasts




6.79
5.51
4.24
2.96
1.68
0.409
NCAR WRF Model Simulation (Shapiro, Norton, & Galarneau)
Potential vorticity
(on θ=322K surface)
Date/Time: 2012-10-28_12:00:00

Chairman STEWART. We thank the witnesses for your testimony today and we remind Members of the Committee that rules limit questions now to five minutes. And the Chair at this point will open the round of questions and the Chair recognizes himself for five minutes for questioning.

I would like to expand a little bit on some things that have been said both in this panel and in the previous panel. And, Dr. Droegemeier, I would like to begin with you and your desire—I think the goal where we said we had theCan objective of trying to have zero deaths from hazardous weather, and you said that that was an achievable goal.

I would like to open that to the other members of the panel. Do the rest of you believe that that is an achievable goal as well? Dr. Gail?

Dr. GAIL. My specific knowledge on this issue is somewhat limited so I prefer not to say what an achievable goal is, but certainly we have continued to make progress in our ability to forecast. And so improving beyond what we are currently doing towards an hour, to an hour, passed an hour is a—definitely a worthy goal, absolutely.

Chairman STEWART. Okay. And Dr. Chen?

Dr. CHEN. I think in terms of scientific knowledge, the predictability which means how long or how far in advance we can predict a certain phenomena, it is very much skewing the research that we are trying to search for these answers because answer ocean as a system that has a limited predictability. In terms of scientific findings, we are not at a stage where we can tell exactly which phenomena, how far in advance we can—but it will certainly search for the answer, including hurricanes. Is a hurricane predictable 7 days out or 30 days out? That is an open question.

Chairman STEWART. Okay. And, look, I understand you can't account for people doing foolish things. You can give people adequate warning and they can ignore it, they can run into the face of the storm. People will do dumb things sometimes. But the point is you give them the information that would allow them to protect and—their property and their own lives in many cases.

And, Dr. Droegemeier, I am wondering, do you want to expand on that or we just leave it at that, that this is an achievable goal? Because I believe that it is an achievable goal with the exception again of sometimes foolishness.

Dr. DROEGEMEIER. Yes, sir, Mr. Chairman, I agree. And I think the—part of the point of that is to get our focus on what is really important. There are lots of metrics that we can use to measure forecast accuracy, reliability, lead time; all of those things are floating around. At the end of the day, though, it is about people dying. And I think if we say what is it going to take to get us to that place of zero deaths, then it really forces us to confront the difficult challenges of understanding what those deep problems are.

But you are quite right. I think there are going to be circumstances where people will die unnecessarily due to decisions they made, but I think we can do a lot better job of conveying information, formulating it, and helping them understand what the consequences of their actions are.

Chairman STEWART. Yes. The money that we spend on weather research and weather studies is money well spent. We have an achievable goal here that would be dramatic and some would say fanciful, but it is not. And I think we would obviously support any efforts in order to move towards that goal.

In my remaining time, I would like to come back. We had an interesting exchange between Mr. Bridenstine and the previous witness, Dr. Sullivan, where there was this—a bit of an idea about, you know, well, we—can we give 16 minutes or could we give an hour? And I would like to explore that just a little bit and that is, again, the idea that just very quickly from the three of you, if we could give someone an hour's warning, that is always better than giving them 15 minutes' warning. Does anyone disagree with that?

Okay, no, of course not. I mean, clearly, it is better to give them an hour than 15 minutes. But then if any of you would like to talk about some of the concerns we have with giving people more time and what some of the reactions that people have that make it so they don't take advantage of that or how you have to communicate that? Any on the panel like to address that? Dr. Gail?

Dr. GAIL. Sure. One of the big challenges we face not only in this area but in all aspects of weather it is how to get the right information to the right people at the right time. So you can have an hour warning but to get it to them in a way that they can act on it and they can choose to do the most appropriate thing for themselves is still a big challenge. And so when we say we want an hour warning, the next step is to make sure that that information doesn't in fact get to people; it doesn't just come out on some single website. That is a challenge, being able to get it into—to them in a way that they can make best use of it.

Chairman STEWART. Okay. Thank you. Then it seems that we have two problems. One is the technology and the research in actually providing the—whatever it is, 45 minutes or an hour, as long as it might be, and then kind of the human element of helping people to take advantage of that. But we don't want to make perfect the enemy of the good. Recognizing that there are challenges on the backside doesn't diminish the great—the good that can come from expanding and lengthening the amount of time we could warn people.

Okay. And my time is expired again. Thank you to the witnesses and I now recognize the Ranking Member, Ms. Bonamici.

Ms. BONAMICI. Thank you very much, Mr. Chairman. And thank you to this very distinguished and knowledgeable panel of witnesses.

And in some of the testimony it mentioned three reports, recent reports that have studied how we can improve weather forecasting, one from the National Academy of Science, one from the National Academy of Public Administration, and then NOAA's own Scientific Advisory Board.

And in those reports they did discuss the issue that you brought up, Dr. Chen, about the moving innovation and research from labs to the weather forecasting operations. My impression is that there has been a lack of communication and an inability to—for those entities to connect and that is something that hopefully we can address through this legislation.

But I wonder, could you talk also about other recommendations in those reports? Are there recommendations in those reports that could help improve the legislation? Because we all have the same goal here of improving weather forecasting. Can we make use of those reports in other ways?

Do you want to start, Dr. Chen, and then the others?

Dr. CHEN. Thank you. I would like to follow up on that. There have been many studies from the National Research Council, and each report recommends almost exactly the same thing. We need a systematic approach to research—from research through operations and then transfer the technology. Our current system so far has not worked as well. Like I mentioned, the research and the operations are somewhat separate.

So I think that this particular panel and this particular bill could help us to address that in terms of providing that mandate, perhaps a National Advisory Board. Even though the funding has been appropriated to do this work, right now, the problem is the structure that are not allowing the smooth transition from the research arm of NOAA to the operations, and more importantly, from the research community, from outside. From academia and private sectors we have not been able to make that transition to NOAA because the system is not allowing that flexibility. I think that——

Ms. BONAMICI. Thank you, Dr. Chen.

And, Dr. Gail or Dr. Droegemeier, do you agree with that? Do you want to add to that, the information in the reports that may help inform NOAA?

Dr. GAIL. Yes, these are all excellent reports and provide a substantial basis of community input upon which legislation could be based. Helping NOAA move forward with implementation of these recommendations within legislation I think would be a very valuable thing.

Ms. BONAMICI. Thank you. Dr. Droegemeier?

Dr. DROEGEMEIER. Yes, thank you very much. I think we do have some exemplars of these kinds of testbeds that truly are integrative where you bring in the operational folks that are already there, you bring in the academics, you bring in other researchers, and they all work together toward the common goal.

And not being parochial, but the one we have in Oklahoma, truly is unique because we have the university co-located, as Dr. Sullivan said, with an OAR lab, with National Operational Centers, plus a Forecast Office. When those folks get together, wonderful magic things happen, and that sounds a little trite but it is really true. And I think we can replicate that model.

Ms. BONAMICI. All right. Thank you. Dr. Sullivan agreed with you in terms of her testimony.

Dr. DROEGEMEIER. Yes, ma'am. Thank you.

Ms. BONAMICI. And there is a requirement in the draft legislation about the OSSEs. And do you—can you explain briefly other kind of evaluative tools that might be used? There is a requirement that may be too constraining we heard in the testimony, so if anyone wants to address. Are there other kinds of evaluative tools that might be used instead of OSSEs, and is that flexibility important?

Dr. DROEGEMEIER. I could address that real quickly. There are a variety of techniques and tools, one of which Dr. Sullivan mentioned is the adjoint technique. Basically, it tells you where the forecast error will be large and where you need observations. What is important about that is you can, if you are not careful, put observations where in fact they are going to degrade the forecast because it will put errors where you don't want errors to be and they might grow. And sometimes, these other assimilation techniques will actually create observations where they don't exist and you actually don't need observations.

So we need—it is a very, very complex problem. We need to understand it. And I think the only thing that we are saying is basically there are many tools available. Probably let the scientists decide which ones are most appropriate. We are not at all discounting the value of OSSEs. We are just saying there are other techniques used in concert would be helpful.

Ms. BONAMICI. Thank you. We heard testimony about that flexibility. And in my remaining time I just want to follow up on the social science research. Dr. Droegemeier, you talked about and the Chairman mentioned about the importance of how to communicate. Of course, the timing is important but the message is important as well, so it was an issue in Katrina as well, how that communication is and how we get people's attention. So could—maybe if any of you want to, in my remaining time, just add how that research can be furthered through that bill, please?

Chairman STEWART. In the remaining two seconds.

Ms. BONAMICI. Sorry, I am out of time. Well, I yield back and maybe I will ask for some input in writing from the witnesses about that important issue.

Thank you, Mr. Chairman.

Chairman STEWART. Thank you, Ms. Bonamici.

To the Vice Chair, Mr. Bridenstine.

Mr. BRIDENSTINE. Thank you, Mr. Chairman.

Mr. Droegemeier, I had a question for you specifically about the Multifunction Phased Array Radar. Earlier, you showed a video and you had those two lines and you were in—you were suggesting that we were able to predict tornadoes an hour ahead of time. Is that accurate?

Dr. DROEGEMEIER. Correct. And that was with a numerical forecast model if I failed to mention that. It was initialized with radar data but you are seeing simulated with the model radar data.

Mr. BRIDENSTINE. Okay. So as far as our numerical model, how do we compare to the rest of the world in our ability to use that?

Dr. DROEGEMEIER. With these particular models, we called them cloud resolving models. We lead the world. There is no question. In fact, we pioneered this whole area of the fine scale prediction. Other groups are now doing a lot of wonderful work but we really lead the way on that.

Mr. BRIDENSTINE. And on this Multifunction Phased Array Radar, is there anywhere else in the world that has that?

Dr. DROEGEMEIER. In military circles, phased radar is used a lot, as you know. As far as phased array, weather radar is really—I think we are leading the area there as well.

Mr. BRIDENSTINE. Are there multiple of those in the United States or is there only one?

Dr. DROEGEMEIER. Right now, there is one testbed in Norman called the National Weather Radar Testbed. There is a lot of development going on. The FAA and NOAA are jointly looking at a system that would not only track weather but also track aircraft as well.

Mr. BRIDENSTINE. Wonderful. So if you were to have—is there any talk of maybe one day eventually networking multiple Multifunction Phased Array Radars together, networking maybe throughout the greater Oklahoma City area to provide as much energy as possible into a specific target for purposes of, no kidding, enhancing that one-hour capability that you have already identified?

Dr. DROEGEMEIER. That is an excellent question. In fact, the National Science Foundation, almost ten years ago, funded a center to focus just on that where instead of having large phased array radars you actually have small ones and they talk to one another and they collaborate——

Mr. BRIDENSTINE. Right.

Dr. DROEGEMEIER. —and say, hey, there is a tornado over here. Let's focus our attention on that because that is what is really important right now, and then later on, focus attention on something else. So that has been done experimentally and we are looking at that as part of the operational system going forward.

Mr. BRIDENSTINE. The distributed networking capability that we have leveraged inside the United States military it seems would be highly valuable to get better information for weather.

But certainly one other thing, when you think about the Multifunction Phased Array Radar, is this a technology that would be kept in the public sphere or is this something that the private sector could eventually advance and develop a part? Is there any revenue model by which this could be valuable for a private enterprise?

Dr. DROEGEMEIER. That is an interesting question. The private sector is actually involved in helping develop the prototypes. Various companies are doing that. As far as the operational structure, that is a good question. Would it be a government-run system or could it be a privatized system by which the government would purchase data or—I think that needs to be looked at. That hasn't been decided yet.

Mr. BRIDENSTINE. Okay. I yield back. Thank you, Mr. Chairman.

Chairman STEWART. Thank you, Mr. Bridenstine.

We now turn to Ms. Edwards, the gentlewoman from Maryland.

Ms. EDWARDS. Thank you, Mr. Chairman. And thank you to our witnesses.

I want to focus on behavioral and social sciences research because in the time that I have been on this committee we have held hearings, not recently, on the use and effectiveness of social science research, and there are a number of Members of this Committee who have point-blank rejected the use of that kind of research and the work that we do, and so I am intrigued, Dr. Droegemeier, by your testimony, and in particular on page 5 of your testimony where you point both to a University of Oklahoma preliminary study, as well as to the events surrounding the May 31st hurricane and—or tornado rather in Oklahoma City in Norman and surrounding communities. And you make a really compelling argument for the integration building on a foundation of social science and behavioral research that would augment the kind of weather forecasting that we also need to invest in.

And so I wonder if you could be a little bit more specific. You have one recommendation for building on that, but where and what agencies would it be most appropriate if the Federal Government were involved in funding some of that research? I know that we do fund some research in other agencies—NIH, National Science Foundation, and the rest—but it is not all focused on weather forecasting. So if you could share your thoughts about that.

Dr. DROEGEMEIER. Well, thank you very much, Congresswoman. That is a really important point. And I think the term "social sciences research" is misunderstood. I think a lot of folks don't really know what all that involves. But the questions that we need to address are really fairly clear. They do involve human behavioral work.

You are right. The National Science Foundation, National Institutes of Health, a lot of studies have been done. People that look at trust in terms of information and communication and verification. There is a broad body of literature already out there, but a lot of the social scientists—in fact, most of them—I don't think realize the opportunity that is available for them to come and link up with the weather community to really understand how to apply this body of scholarship, number one, that already exists; and number two, to do new studies that are geared specifically toward the weather challenges.

But I think a lot of it is misunderstanding of what the social sciences are really about. And I have to say I had the same misunderstanding until I began working with them and really seeing the virtue of their activities.

Ms. EDWARDS. And I did until I came to serve on this committee. I didn't get it at all. I thought it was kind of silly making. But it turns out that understanding behavior really should connect with the kinds of technology advances that we see.

Do you have an idea of how much is spent or whether it would be worth it to have some of those resources actually engage through the National Weather Service and NOAA?

Dr. DROEGEMEIER. I think that is a good question. I don't know the amount of money that is spent across agencies or even within agencies, but I do think that NOAA—it doesn't need to stand up a whole big social sciences activity. I mean universities have entire social sciences programs across many, many departments. So I think NOAA is in a position to leverage that, but I do think there has to be a presence within NOAA that recognizes and helps, as Dr. Chen mentioned, transfer that—those research outcomes into the operational mainstream of decision-making and behavior in terms of how we do the warning and watch system.

Ms. EDWARDS. Great. And just with my remaining minute-and-a-half, I want each of you, if you could, to comment on the link—a link that you see or don't see between balancing NOAA's work on climate with the work on weather forecasting and whether or how those things are connected and whether you think that we struck the right kind of balance.

Dr. GAIL. Let's imagine that we didn't have a debate on anthropogenic climate change and climate change. I believe we would be doing the same research on climate that we are currently doing just to improve our weather forecasting. So what we are doing is really essential to what we are doing in climate.

Dr. CHEN. Yes, I want to comment on the jointedness of the weather and climate because if the system is together, there is no artificial dividing line. For instance, hurricanes, we are very much needing information of few weeks outlooks so exactly for the water management. And the same time as each storm close to landfall, we do transition to the forecast part very smoothly.

So I just want to also possible follow-up on the question of the using social science to address this issue. Hurricane, for instance, is 7 days ahead. Whether we can get warnings and then whether it is good because that is interesting social science question. A lot of times our forecast is not precise and that could be—or a warning can actually do harm in terms of people's actions, so those are connected to issues that need to be addressed.

Ms. EDWARDS. Thank you, Mr. Chairman.

Chairman STEWART. Thank you, Ms. Edwards.

And we appreciate your comments regarding the social science. And some of you may be interested to know that Section 5 of this proposed legislation has extensive foundation therefore encouraging the social science and some of the communication process as well.

Our final questioner then today is the gentleman from California, Mr. Rohrabacher.

Mr. ROHRABACHER. Thank you very much. Let me just note that there has been a great deal over the last 15 years of money spent specifically to prove that humankind is causing the climate change. To suggest that that would at the same time benefit weather forecasting stretches credibility because people were given grants specifically to prove that and other people were denied grants unless they were willing to prove that.

Let me go back to the question that seems to have been asked before, something about this climate research going back to challenge the point you just made, for the dollars that we are spending in climate research, would not those dollars be better spent on weather research that we know affects and puts people in danger right now?

Dr. GAIL. Yes, thank you for the clarification. And that was really specifically referring to NOAA where really the large part of the climate research is focused on improving weather forecasting. And so——

Mr. ROHRABACHER. Department of Energy, et cetera, et cetera, has spent enormous sums of money on trying to prove that human beings are changing the climate. That has not helped weather forecasting. But let's—let me get into this one last thing because I have got three minutes to ask questions as well to get the answers from you folks.

I understand that there is a gap—let's go right to weather forecasting—that there is a gap that will be appearing, if it is not already there, in the data provided by polar-orbiting and geostationary satellites. There will be a gap in that information. Is that correct? Is that predicted? Is it happening now? Is that something that is predicted? Whoever.

Dr. GAIL. That is certainly anticipated. I do come from the satellite industry a while back and you can never know how long a satellite is going to last, but there are certainly risks and widely recognized risks.

Mr. ROHRABACHER. So this is a—there is a significant gap that is—that we are facing in the information that we have been getting from these satellites? Now, we had—there was a hearing last year in which Dr. David Crane stated that possibly commercial satellite data doing this—getting that data commercially might actually be the most cost-effective way of doing this, but yet, in this Observing System Simulating Experiments that NOAA hasn't really looked at that option. Should NOAA be looking at that? Should the OSSE system focus on whether or not we can cost-effectively utilize private satellites for—to fill this gap that is expected? Anybody?

Dr. DROEGEMEIER. Well, I would just say the OSSEs themselves are really agnostic in terms of who operates and build the satellites.

Mr. ROHRABACHER. Right.

Dr. DROEGEMEIER. It really is telling what sensors are needed and how rapidly and so on. So it really doesn't—the OSSE itself doesn't address the question that you are asking.

Mr. ROHRABACHER. Right, but should NOAA then be doing—taking the steps to see if this would be a cost-effective way of meeting this need that we will have in the future in terms of the data gap? Is there some reason we shouldn't use private satellites?

Dr. GAIL. Oh, absolutely not. I think there is a lot of room for innovation here in terms of how we access data, whether it comes from the private sector, whether it comes from the government, and it should be done in the most effective way possible, absolutely.

Mr. ROHRABACHER. Right. Let me just note, Mr. Chairman, that there are some things the government has to do and there are other things that can be contracted out. And before SpaceX arrived on the scene, everybody thought the government had to provide all the transportation systems to and from space station, for example. We have already saved about $500 million using SpaceX. Perhaps using commercial satellites, which have other functions that they can sell to the private sector, might be a good way to get in the information that would protect us from this data gap that we are going to face in the future.

Thank you very much, Mr. Chairman.

Chairman STEWART. Thank you, Mr. Rohrabacher, and I share your concern as well that satellite coverage gap between 2015 and 2017 is troubling for us and we hope this legislation is able to address some of that.

Let us conclude then. We thank the witnesses for your valuable testimony and for the Members for their questions as well. And once again, the Members may have additional questions for you, and we will ask that you respond to those in writing. The record will remain open for two weeks for additional comments and written questions from the Members. The witnesses are then excused and this hearing is adjourned.

[Whereupon, at 11:39 a.m., the Subcommittee was adjourned.]

Appendix I

Answers to Post-Hearing Questions

ANSWERS TO POST-HEARING QUESTIONS

Responses by The Hon. Kathryn Sullivan

U.S. HOUSE OF REPRESENTATIVES
COMMITTEE ON SCIENCE, SPACE, AND TECHNOLOGY
Subcommittee on Environment

Hearing Questions for the Record
Restoring U.S. Leadership in Weather Forecasting Part 2

Dr. Kathryn Sullivan
June 26, 2013

THE HONORABLE CHRIS STEWART

1. **The National Academy of Sciences and the National Academy of Public Administration have recommended that NOAA establish a weather-focused advisory committee under the Federal Advisory Committee Act, while some in the weather community have recommended a weather commission modeled after the ocean commission.**
   a. Dr. Sullivan, does NOAA need external feedback on weather forecasting?
   b. What is the best mechanism to provide feedback on weather forecasting?

Response:
a. Yes, NOAA needs and does receive important external feedback on weather forecasting in order to improve its science as well as its services. NWS has been building on and improving its feedback methods throughout its over 140 year-long history.

b. There is no one "best" mechanism for feedback on weather forecasting, but NWS seeks to gather feedback via multiple mechanisms and from multiple stakeholders.. There are currently many useful mechanisms for NOAA to receive that feedback, including the University Corporation for Atmospheric Research Community Advisory Committee for NCEP, a semi-annual Partners Meeting for the National Weather Service (NWS) that includes feedback from the weather enterprise including the private sector, numerous conferences, forums, and sessions held by or with the American Meteorological Society, where feedback is provided by broadcasters, researchers, operational forecasters, the international meteorological community and others. NWS uses additional mechanisms of varying sizes and scope for critical feedback on its services for the aviation, marine, water resource, and other sectors, as well as direct local feedback from the public and emergency managers in their communities on products and services key to community resilience. High impact weather events trigger service assessments, led internally but used to gather extensive amounts of critical external feedback on NWS performance and forecasts. These assessments are used to determine both lessons learned and best practices, and carry a great deal of influence on agency priorities. Related but not directly tied to weather forecasting, NOAA's Science Advisory Board (SAB) provides advice on research. The SAB is an advisory body established under the Federal Advisory Committee Act, which formed an Environmental Information Services Working Group (EISWG) specifically to engage in providing external advice relating to NWS services in general, not necessarily forecasting. EISWG was instrumental in developing, and the SAB recommended, the "Open Weather and Climate Services" concept that is gaining momentum today.

2. **During the hearing you brought up the fact that giving more advanced notice to citizens before a tornado was not enough; that it also needed to be coupled with social science research to find the best way to communicate severe weather warnings to communities. Can you please elaborate on that statement?**

Response: An NWS warning that is not received or heeded provides little benefit to its intended audience. Social scientists and meteorologists have only begun to understand how the public would react if the current approach to tornado warnings were extended to 30, 60, or more minutes in advance. Some early research in 2008[1] suggests that extending the lead-time of traditional tornado warnings beyond 15 minutes may have a negative effect on reducing fatalities and expected injuries, likely due to concern over false alarms. Simply extending warning lead times would necessarily decrease their accuracy without a commensurate increase in the science and technology behind the forecasts and warnings themselves.

Further social science research is needed to ensure warnings are communicated in a way that is easy to understand and provide the most benefit to the public. Furthermore, even if extended warnings were provided, lack of adequate shelter and/or ineffective design of shelters may also result in fatalities. Science-based research in the design and construction of shelters in schools, day-care centers, nursing homes, and residences that are cost-effective and constructed of materials that resist penetration of debris is also warranted.

Bottom line, one hour of lead time, while valuable in that any additional minutes afforded can help save additional lives, does not necessarily produce needed results if the message is not effectively conveyed. Warning messages and forecast information must be received in a manner that incites life-saving action or else recipients may ignore or put off responding to the warnings.

3. **Can you provide a status of the transition to MPAR technology? Specifically, what is the timeline for deployment and how might this technology help increase the warning times for severe events like tornadoes?**

Response: Multi-function Phased Array Radar (MPAR) technology will allow for faster scan times, reducing the delay in gathering data from the current four to five minutes to less than one minute over the current NEXt generation weather RADar (NEXRAD) system. This faster scan time by MPAR has the potential to improve tornado warning lead times by about five minutes or so beyond the current nation-wide average of 13 minutes, simply due to quicker detection. MPAR's increased resolution and detailed data, when ingested in near real-time by sophisticated high resolution models, shows potential in one day providing nearly an hour advance notice of impending severe weather. Current research into this concept, known as "Warn-on-Forecast" (WoF), show real promise for this capability of issuing a "probabilistic" warning based on a model forecast rather than waiting until a precursory or tornadic signature is detected on radar. Extensive additional research, development and demonstration will be required to prove this concept and transition it to operation.

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[1] K. M. Simmons, and D. Sutter. 2008. Tornado Warnings, Lead Times, and Tornado Casualties: An Empirical Investigation. *Weather and Forecasting* 23: 246-258.

Many of the current Federal Aviation Administration (FAA) radars are already past their predicted end of life. Assuming the planned Service Life Extension Program is completed within the next 8 years, joint NWS, FAA, and Department of Defense (DoD) NEXRAD radars will reach their expected end of life in the next 15-20 years. FAA's target date for first operational deployment of MPAR is FY 2023, with completion estimated between 2030 and 2037 depending on the number deployed each year. Historically, it takes 20-25 years to perform the research, develop a prototype, test, and deploy new weather radar systems that meet NWS operational requirements for high impact forecasts and warnings. Given the research already conducted, and the steps still required for completion, key milestones for the MPAR Program in order to be deployment-ready by 2023 include the following:

- FY15: FAA Investment Readiness Decision (Analysis of Alternatives)
- FY16: FAA Initial Investment Decision (selection of preferred alternative)
- FY18: FAA Final Investment Decision (Go/No Go decision)
- FY23: FAA first deployment (assuming all participating agency mission requirements met)
- FY30: NWS first deployment (tentative)

To that end, the FY 2014 President's Budget for NOAA requested an increase of $2.9 million for next-generation weather observing platforms, for a total of $13 million. This funding will focus on ground-based observing platforms, such as MPAR or platforms that provide continuous measurements of the vertical distribution of water vapor and winds. Specifically, the increase will provide the necessary funds to develop and operate an MPAR demonstrator capable of simultaneously performing weather surveillance and aircraft tracking. This demonstrator array will enable the program to bring all MPAR components together into an operating radar system to demonstrate its full capabilities. Successful demonstration of multi-functionality with the MPAR demonstrator is important for NOAA and FAA to make a well informed Go/No Go decision on MPAR in 2018.

4. What combination of research and technology would allow for one-hour of lead time for a tornado warning?

Response: On May 20, 2013, NOAA provided an estimated 16 to 36 minutes of warning lead time for the Moore, Oklahoma tornado depending on the location measured along its path. NOAA is currently working to increase tornado warning lead times from the current average of less than 20 minutes, as seen recently in Moore, to a period of up to an hour. An hour of warning lead time might allow people to be transported to secure shelters rather than sheltering in place within structures not robust enough to withstand such a powerful tornado.

Currently, tornado and severe thunderstorm warnings are based on radar-based detection of tornado precursor signatures using the "Warn-on-Detection" (WoD) capability (Figure 1). Typically, an NWS forecaster must "see" a tornado forming on radar – or have visual, on-the-ground observation – prior to issuing a warning. Increasing warning times by more than several minutes requires a change in methodology to a WoF capability using an operational computer-based forecast (Figure 2). This forecast methodology and necessary technology would be critical as it would allow a probabilistic tornado warning to be issued based on computer forecasts rather than waiting until a precursory or tornadic signature is detected on radar. A WoF capability potentially could provide 30-60 minutes of tornado lead time while the WoD system is typically limited to at best 10-25 minutes of lead time. WoFs use a family, or ensemble, of 30 or 40 models to produce an effective weather forecast. Additional and extensive research and development is needed prior to transitioning this WoF technology to operations.

Figure 1 – Current Tornado and Severe Thunderstorm Warnings, using NEXRAD Radar-based Detection

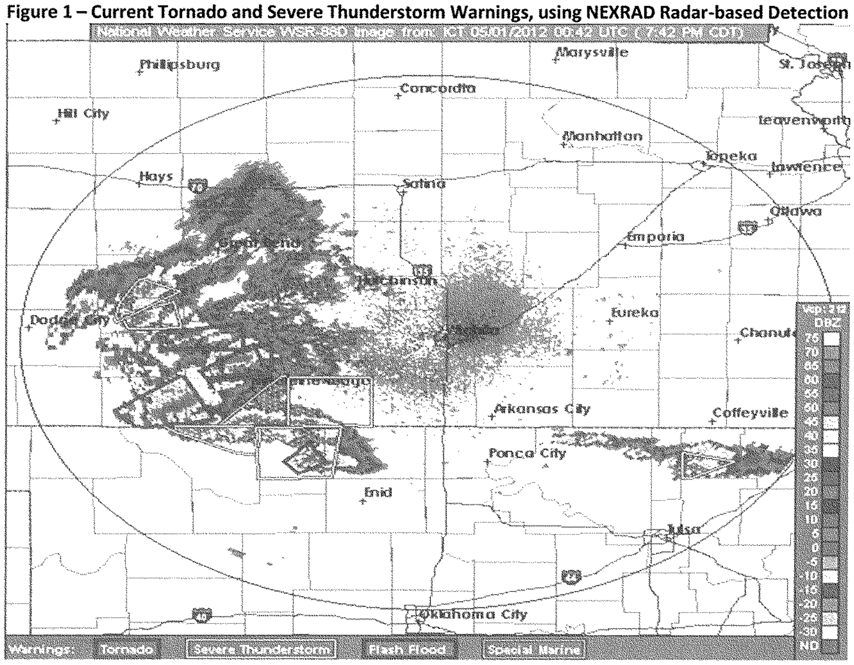
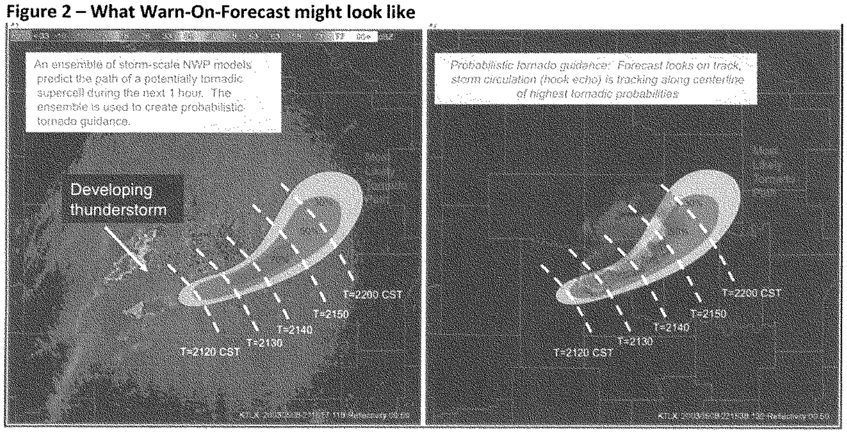


Figure 2 – What Warn-On-Forecast might look like



For WoF technology to be realized operationally, NOAA will need a combination of research and operational factors to be met, including:

- A next generation of radar systems technology that will allow for faster refresh rates and increased confidence. The current NEXRAD radars sample the air every five minutes, which is too slow to work for these models.
- Additional operational computing capabilities, capable of focusing on geographically-specific areas at very high resolution, are required for running the computer-based forecast models for WoF. Computing is becoming less expensive and speeds are ever increasing. If research and operational computing are augmented, it will be possible to have the capacity to run these models in NWS operations during the next decade (2020-2025).
- Better understanding of the science of storms through continued research.
- Incorporating better understanding of the science of storms and the higher spatial resolution into models.
- Incorporating social science into the warning paradigm to ensure effective outcomes to save lives and property.

An NWS warning that is not received or heeded provides little benefit. Whether a tornado warning is issued 16 minutes before impact, as we saw during the tornado in Moore, OK on May 20, 2013, or issued the conceptual one hour in advance, public preparedness and action remain critical links in the chain. A sustainable community presence where public preparedness and, effective and accessible decision support services for emergency managers remains a top priority for NOAA in becoming a Weather-Ready Nation. Infusing social and behavioral sciences, exploiting communications technologies, integrating water resource prediction and management efforts, and researching methods to improve tornado warnings are just a few areas of focus needed to improve services, especially if one hour tornado warnings are to be effective.

5. During the hearing there was some discussion about the role of the private sector in weather research, but can you elaborate on the role of federal researchers in weather

and climate research and how they coordinate with work being done in academia and in the private sector?

Response: NOAA's partnerships with the academic and private sector are strong and have assisted in advancing NOAA's mission goals. The role of federal researchers is also a critical component of a successful weather research enterprise. Almost all major systems used by NWS have benefited greatly from NOAA's "hybrid research model." This model relies on a central research enterprise within the agency's Office of Oceanic and Atmospheric Research (OAR), as well as mission-driven, extramural research. NOAA scientists have the stability and support to conduct long-term projects. This focus on long-term advancements compliments these shorter-term academic research projects which are supported by grant funding cycles of a few years or less. NOAA's "hybrid research model" is a central and critical aspect of virtually all research efforts within OAR. OAR federal researchers partner with other NOAA line offices, NOAA Cooperative Institutes (CI), other universities, and non-profit research organizations in nearly every scientific, research, and technology development effort performed. The CI relationships within OAR often go back many decades.

This model requires a balance between the following elements:

- A stable cadre of federal researchers that can focus on long-term advancements, with an eye toward operational requirements;
- Valuable co-location of federal researchers with CI employees to ensure infusion of cutting-edge science as well as the ability to address emerging areas of new research and sudden environmental disasters (e.g., Deepwater Horizon);
- Mission-driven external research funding opportunities from NOAA that supplement our research;
- Ongoing interactions with NWS to understand operational needs;
- Products developed in response to specific operational mission needs; and,
- Research supplemented by other federal grants (e.g. National Science Foundation (NSF)) that focus on targeted topics related to NOAA's mission and have 2-5 year grant cycles.

Examples of technology developed using this hybrid research model include:

- Research and development for the **NEXt generation weather RADa**r (NEXRAD) and Dual Polarization systems were largely done by OAR's National Severe Storms Laboratory (NSSL), with significant research collaboration with the Cooperative Institute for Mesoscale Meteorological Studies and other academic partners at the University of Oklahoma.
- **Advanced Weather Interactive Processing System** (AWIPS) technology fundamentally changed how NWS forecasters access radar, satellite, model outputs, and other weather data streams and has been operational since 1996. This forecast office information system was largely developed by OAR's Forecast Systems Laboratory (now Earth Systems Research Laboratory/Global Systems Division), with a very significant role played by the Cooperative Institute for Research in the Atmosphere located at Colorado State University.
- As part of the **Tsunami Warning System**, both the Deep-ocean Assessment and Reporting of Tsunamis buoys and the advanced tsunami prediction system were developed by OAR's Pacific Marine Environmental Laboratory and the Cooperative Institute for Marine Resources Studies, located at Oregon State University.

- **Hybrid Assimilation System for NOAA's Global Forecast System model** was researched and developed by OAR's Earth System Research Laboratory Physical Sciences Division and National Center for Environmental Prediction's Environmental Modeling Center with major parts developed with the Cooperative Institute for Research in Environmental Sciences researchers at the University of Colorado at Boulder.
- **EMILY, an unmanned surface vehicle** was originally developed by Hydronalix Inc. for a variety of uses, including assisting lifeguards in choppy seas, but has been modified by NOAA researchers for sea surface hurricane research. Hydronalix was able to develop the hurricane version using a Small Business Innovation Research grant with funding support from the NOAA Unmanned Aircraft Systems Program Office. The EMILY unit includes sensors that can record barometric pressure, air and sea surface temperatures, salinity, wind speed and wind direction at the ocean surface.

6. **At the hearing you gave an example regarding the state of supercomputing for weather at NOAA, stating that, "[i]n fact, the research model that runs under the hurricane program cannot be put into the operational supercomputer right now. So during hurricane season we run the National Hurricane Center and we run this research model in real time because we can't fit it into the operational supercomputer. We should be able to fit it in. We have a model that could have forecasted last year's diverter [derecho] 12 hours in advance. It did. It did but it was running in research mode. We need to be able to move those more rapidly into supercomputing rather than waiting so long for big-step functions in our supercomputers."**
   a. **Dr. Sullivan, doesn't this exemplify the limited amount of computational ability devoted to weather models as opposed to other NOAA priorities?**

Response: Operational supercomputing capacity has been a limitation for NOAA in the past in providing forecasts for severe weather events, such as the 2012 derecho and Hurricane/Post-tropical Cyclone Sandy, which were well predicted in research models. We recognize these limitations have existed and have been working across the agency to improve our operational products through the development of more advanced observing, modeling, and forecasting capabilities, as well as smoother research to operations transitions. Our basic process for transitioning research to operations depends on the computing capacity of the operational system. A new Weather and Climate Operational Supercomputer System computer was recently funded, and is now becoming operational. Bringing a new supercomputer into full operations is a time-consuming process, as variances are inevitably introduced into model results and these issues must be rectified completely before launching the global replacement. NOAA received additional funds through the Disaster Relief Appropriations Act of 2013 (P.L. 113-2) for operational computing capacity which will enable the NWS National Centers for Environmental Prediction to more rapidly integrate proven research improvements into operations. The Act also provided additional funding for research computing capacity to ensure that our research abilities are tackling models to be operationalized in the future. Models progress in a lifecycle of research, development, testing/evaluations, and operations, so research capacity and funding is a necessary counterpart to operations capacity and funding.

NOAA continually strives to provide the most accurate and timely forecasts that the best advances in science and technology can deliver. This is, however, only one part of NOAA's mission: to understand and predict changes in climate, weather, oceans, and coasts; to share that knowledge and information with others; and to conserve and manage coastal and marine ecosystems and resources. Because climate, weather, oceans, and atmosphere are intertwined in a larger earth system, much of our work in other mission areas directly affects our ability to make advances in weather forecasting. Many of our successes in providing weather forecasting products and services have come from scientific and technological breakthroughs produced by research across disciplines, time and space scales. To forecast changes in the weather, we must observe and predict changes in the oceans, on land, at the poles, and in space. It is critical to continue to fund the resources needed to meet NOAA's operational mission, as well as the cutting-edge research across NOAA mission areas, that helps drive those goals.

b. Would the provisions of this bill increase the agency's supercomputing ability for weather research-to-operations initiatives?

Response: Funds from this bill could increase NWS research to operations computational capability as noted above. However, the President's FY 2014 Budget request continues the increase in operational supercomputing capability at the NWS provided for in the Disaster Relief funding, supporting research to operations activities.

7. At the hearing I asked you about the Observing System Simulation experiments which NOAA will conduct from funds recently appropriated by Congress. Please explain the evaluation criteria as well as NOAA's intent to use a constellation of six instruments around the globe or a single sounder in North America. Please elaborate on how each scenario will affect the results and influence NOAA's decision making.

Response: The OSSEs will evaluate the relative impact of different observing scenarios on:

- standard objective measures of forecast skill that are used by all numerical weather prediction centers (e.g. root-mean-squared error and anomaly correlation),
- predictions of cyclone track and intensity for both mid-latitude and tropical cyclones, and
- forecasts of precipitation location and amount, severe local storm potential, and air quality.

NOAA intends to evaluate different sounder options to determine which provides the largest improvement to forecast skill. This will include the constellation of 6 geostationary hyperspectral infrared sounders, but may also include hyperspectral infrared sounders with higher-resolution in polar orbit, and/or geostationary microwave sounders. There are tradeoffs between the different instruments that need to be evaluated. For example, NOAA must compare and evaluate high-resolution in polar orbit to coarser-resolution in geostationary orbit satellites. Other questions to be investigated are related to the technology of the instruments. For each observing system evaluated, the evaluation will quantify its specific ability to contribute to improved forecasts.

8. A 2010 National Academy of Public Administration report highlighted the importance of the Office of Oceanic and Atmospheric Research, stating that, "This line office provides particularly important institutional glue to support innovation across NOAA." Do you agree with this statement?

Response: Yes, I agree with this statement. As the central research entity for NOAA, one of the critical roles of OAR is to integrate research across the agency. Research underpins NOAA's ability to provide services, and OAR supports innovation across all of NOAA's line offices via several initiatives.

The OAR Assistant Administrator (AA) accomplishes this via his roles as chair of the NOAA Research Council and acting Chief Scientist. In addition, the OAR AA works with other Line Office AAs through NOAA's planning and evaluation process to ensure research priorities are met NOAA-wide and integrates the needed research, science, and technology to meet NOAA's mission.

9. **The 2013 National Academy of Public Administration report entitled "Forecast for the Future," discussed the working relationship between the Weather Service and Research Office, stating that, "The National Weather Service and the Office of Oceanic and Atmospheric Research are working together to communicate early about operational shortfalls, assign technical readiness levels to projects, and more closely synchronize the operational budget with project maturity." How vital is strengthening the relationship between the Weather Service and the Research Office?**

Response: The relationship between NWS and OAR is critical because operators and researchers must work together to continuously improve existing products and services as well as develop the next generation of operational products and services. It is vital that this relationship be maintained and continually strengthened. The strong relationship provides focus and integration for weather research that is being conducted in other parts of NOAA, the federal system (i.e., DoD, NSF, NASA, etc.), academia, and by international partners. The Office of the Federal Coordinator for Meteorology provides an important venue for interagency discussions.

OAR provides the research to advance operational products and services to ensure the best research, models and observations are available. This role is performed in direct service to operational mission requirements such as those of the NWS, and includes providing the science needed to support informed decision-making. NWS does development and integration of research relevant to its operational systems. In addition, OAR looks ahead for NOAA and focuses on developing cutting edge technology that will provide the next generation of products and services - many of which Line Offices do not know they need yet.

OAR and NWS have a long history of working with one another with many successes in transferring weather research to operations that have benefited our Nation with better operational weather products and services, for example:

- AWIPS was developed by OAR's Earth System Research Laboratory with the NWS. This technology fundamentally changed how NWS forecasters access radar, satellite, model outputs, and other weather data streams and has been operational since 1996.
- In the 1990s, OAR's NSSL, the NWS, the FAA, and the U.S. Air Force's Air Weather Service, led successful testing of the Doppler radar, which resulted in the development of NEXRAD. The development of NEXRAD and AWIPS is credited with our increased ability to provide advance severe storm warnings. More recently, the NEXRAD upgrade to dual-polarization technology completed in June 2013 was a major success because of the partnership between OAR's NSSL and the NWS.
- Rapid Refresh model is a central element of the NWS weather forecast suite as it provides hourly updated weather forecasts for the North American continent and is used

continuously by NWS forecasters on a fully-operational basis (some with an emphasis on severe weather, aviation, and energy applications). This model and its predecessor, the Rapid Update Cycle model, were developed by Earth System Research Laboratory's Global Systems Division with significant participation by both Cooperative Institutes for Research in Earth Science and the Cooperative Institute for Research in the Atmosphere. This development continues with the High Resolution Rapid Refresh, currently in development, which will bring substantial improvements in weather forecasting in the next 2 years.

The two Line Offices are continually looking for ways to improve their working relationship. OAR and NWS have implemented a number of ways to better their working relationship, such as:

- The NWS Assistant Administrator and the OAR Assistant Administrator meet monthly to discuss priority issues, including collaborations between the two Line Offices; research to operations transitions; and funding levels for joint Service Level Agreements between the two line offices. Beginning in FY 2013, OAR and NWS formalized collaborations using a number of service agreements for OAR services to be provided using NWS funds. This process has significantly helped both line offices better coordinate their collaborative work with program and budget planning.
- Government and academic researchers and forecasters work together through NOAA's testbeds (see *www.testbeds.noaa.gov*). These testbeds provide an environment for researchers and forecasters to work within an operational structure to test new research ideas collaboratively and to test the feasibility of using the research results within the constraints of the operational environment. These testbeds allow an ongoing exchange of ideas between researchers and forecasters.

In addition, many NOAA researchers and operators are working side-by-side everyday out in the field. These co-located researchers and operators share their experiences, lessons-learned, and needs, and exchange ideas on a daily basis, which leads to better communication, a better working relationship between NWS and OAR, and ultimately, a better end product that serves our Nation.

10. The bill codifies an existing technology transfer program managed jointly by the NOAA Research Office and the National Weather Service. I understand funding for this program has been reduced significantly in recent years, perhaps due to operational pressures on the Weather Service. Do you know how much this program has been cut, and how important it is to ensuring the Weather Service continually infuses operations with new technology?

Response: OAR and NWS have a formula for technology transfer that has been successful for 35 years. The model is that, based on requirements, NWS and OAR work jointly on the specific research improvements needed to develop a better forecast or product. These systems are then tested in forecast offices and testbeds, where the operational forecasters are there to ensure that the product/system is able to be smoothly transitioned into operations. This system works in part based on the mutually-developed requirements, and because OAR and NWS worked hard to co-locate their laboratories and forecast offices. Many OAR laboratories are located near NWS offices, so the working relationship between and among the scientists at any individual site are very strong. The table below outlines a 5-year history of funding transfers from NWS to OAR. The amounts range from a high of $24.6M in FY 2010 to $14M in FY 2013. This transfer of funds represents the primary source of weather-related Research to Operations funding in OAR. In recent years, a tighter fiscal environment, including sequestration, has required NOAA to make significant reductions, which will affect future research to operations activities. These were tough decisions and choices, but all of those decisions were aimed at mitigating effects on critical missions and services, and employees.

NWS to OAR: Annual Transfer of Funds

Fiscal Year	FY 09	FY 10	FY 11	FY 12	FY 13
Amount ($K)	22,533	24,558	17,332	14,738	113,994

**year to date, also includes Sandy Supplemental funding*

11. With money provided after Superstorm Sandy, NOAA is undertaking two Observing System Simulation Experiments for potential gap-filling satellite technologies.

a. Based upon NOAA's decision to pursue these experiments, I assume you agree with your predecessor, Dr. Jane Lubchenco, that they are a "powerful tool used to assess the impact that variations in data have on forecasts in model systems"?

Response: Yes, I agree with that statement.-As I stated in my June 26th testimony, OSSEs are useful tools and have the potential to give NOAA better capability to weigh options before procurement of assets. OSSEs have the capability to assess the potential impact of proposed/future observing systems on numerical weather, ocean, and climate prediction systems and to inform decision-makers prior to acquisition or construction of the proposed observing system. This type of experiment can demonstrate the benefits of an observing system or type of observation can be estimated before it is designed, built, and launched into orbit.

However, NOAA cautions against requiring OSSEs to quantitatively assess the relative value and benefits of *all* observing system capabilities. OSSEs are not always the most effective tool for accomplishing that goal, because they can be expensive and time-consuming. In some cases, for example, evaluating systems that already exist, simpler Observing System Experiments (OSEs; e.g., data denial studies) can be used. Therefore, NOAA needs flexibility to determine the most appropriate quantitative analysis tools to assess observing systems.

b. These experiments provide a cost-benefit assessment of potential new data for weather forecasting, the bang for our taxpayer bucks. Is it true that the design of these experiments can impact the results?

Response: Yes, there have been OSSEs in the past that have been designed incorrectly and have yielded inaccurate results. NOAA currently has the most experience with performing OSSEs in the world, and will ensure that these OSSEs will be designed and executed correctly.

c. Why, then, is NOAA evaluation a single-satellite version of one of these observing systems, despite the fact that these sounder technologies are designed to include a constellation of 6 instruments? Could that affect the results?

Response: NOAA appreciates the support of the Committee and Chairman Stewart to perform OSSEs on the potential global observing systems including Radio Occultation and the 6 instrument global geostationary constellation of Hyperspectral satellites that may be commercially available. NOAA is currently evaluating the impact of one sounder which will provide information over the Atlantic Ocean where many of the harmful hurricanes and nor'easters originate. The Disaster Relief Appropriations Act of 2013 funding will be able to evaluate the full constellation. Globally, the results will depend strongly on the number of instruments. NOAA is tracking the planning that European and Japanese space agencies are doing in their assessments of whether to deploy hyperspectral sounders in geostationary orbit. We are also aware of, and monitoring closely, the work of the commercial sector to build and launch such a capability over Asia.

12. Historically, has more extramural research money been provided to universities by NOAA's Research office or the Weather Service?

Response: NOAA consistently provides extramural research and development funding to academic institutions and academic consortia. OAR has historically provided more extramural research funding than NWS. The table below outlines the research and development contributions from OAR and NWS to academic institutions and academic consortia for FY 2011 and 2012.

R&D Annual Funding by Line Office to Academic Institutions and Consortia

	FY 2011	FY 2012
OAR	$116.9M	$87.6M
NWS	$3.4	$1.6M

13. Do you agree that NOAA's weather, research, and satellite office should have the protection of lives and property through enhanced weather forecasting as a priority mission?

Response: One of NOAA's long term goals is a Weather-Ready Nation where our society is adequately prepared for and able to respond to weather-related events. NOAA's objective is to reduce loss of life, property, and disruption from these high-impact events. Advancing weather forecasting is a crucial component to meeting this objective. All of NOAA - including our weather, research, and satellite offices - must work together along with our public, private, and academic partners to achieve this objective. We are extremely concerned that we maintain the current accuracy of our 5-10 day forecasts, to ensure that citizens and state and local governments have as much lead time as possible for onset, duration, and intensity of severe weather events

14. Which weather forecasting research programs at NOAA have been authorized by Congress? In light of sequestration and future necessary belt-tightening, aren't you

concerned that these unauthorized programs will be vulnerable to cuts? Why would you oppose a bill to provide additional resources for weather forecasting research?

Response: Weather forecasting research programs are authorized under a variety of authorization legislation, including the following:

- **Weather Service Organic Act**, 15 U.S.C. § 313 - The Act is the implementing statute for NOAA to forecast, record, report, monitor, and distribute meteorological, hydrologic and climate data. The Secretary of Commerce has responsibility for these and other essential weather-related duties for the protection of life and property and the enhancement of the Nation's economy.
- **America Competes Act**, 33 U.S.C. §§ 893, 893a, 893b - This Act requires NOAA to implement programs and activities to a) identify emerging and innovative research and development priorities to enhance U.S. competitiveness, b) promote U.S. leadership in oceanic and atmospheric science in the applied use of such knowledge, and c) advance ocean, coastal, Great Lakes, and atmospheric research and development, including transformational research, consistent with NOAA's mission.
- **Meteorological Services to Support Aviation Authority**, 49 U.S.C. § 44720 - This provision of the Federal Aviation Act of 1958 requires the Secretary of Commerce to cooperate with the FAA in providing meteorological services necessary for the safe and efficient movement of aircraft in air commerce; *i.e.*, to support aviation. The Secretary of Commerce is required to observe and study atmospheric phenomena, and maintain meteorological stations and offices; provide reports that will facilitate safety in air navigation; cooperate with those engaged in air commerce in meteorological services; maintain and coordinate international exchanges of meteorological information; participate in developing an international basic meteorological reporting network; coordinate meteorological requirements in the U.S. to maintain standards and promote safety and efficiency of air navigation; and promote and develop meteorological science, including support for research projects in meteorology.

Additional authorization legislation provides important support to weather forecasting skill and capabilities, including:

- **National Climate Program Act**, 15 U.S.C. §§ 2901-2908 - The Act authorizes a National Climate Program. The Act grants NOAA the authority to enter into contracts, grants or cooperative agreements for climate-related activities. These activities include assessments of the effect of climate on the natural environment, land and water resources, and national security; basic and applied research to improve understanding of climate processes and climate change; methods for improving climate forecasts; global data collection and monitoring and analysis activities; systems for management and dissemination of climatological data; measures for increasing international cooperation in climate research, monitoring, analysis, and data dissemination; mechanisms for intergovernmental climate-related studies and services including participation by universities; and experimental climate forecast centers.
- **Global Change Research Act**, 15 U.S.C. §§ 2921 *et seq.* - The Act establishes a comprehensive and integrated U.S. research program aimed at understanding climate variability and its predictability. The Secretary of Commerce shall ensure that relevant

research activities of the National Climate Program are considered in developing national global change research efforts.

NOAA supports the intent and goal of this bill to provide authorization for these programs and to increase funding for observational, computing and modeling capabilities to deliver substantial and much needed improvement in weather forecasting and prediction of high impact weather events, such as tornadoes and hurricanes.

NOAA does not oppose the goal of the bill, but rather NOAA remains concerned about the bill's intent to "prioritize and redirect NOAA resources" toward this goal and the bill's focus on short term research, at the expense of long term research activities that are necessary to maintain forecasting capabilities in the future. NOAA continually strives to provide the most accurate and timely forecasts that the best advances in science and technology can deliver. Much of our success in providing these services and products comes from scientific and technological breakthroughs produced by research across disciplines, time and space scales. Therefore, we caution against actions that would insert rigid boundaries between advancing our mission and the research that helps achieve that goal. NOAA welcomes and appreciates your interest in weather research, a topic about which NOAA cares strongly.

15. Recent reports that GOES-13 was taken offline due to a meteoroid strike were of great concern to many in the weather community who rely on the GOES satellites during a time of severe weather. While GOES-13 is now back online, this incident resulted in the activation of GOES-14 – the on orbit spare – and meant that for three weeks the U.S. was without critical backup capability for geostationary weather observations. GOES-13 actually captured real-time imagery on the Oklahoma tornado days before the meteoroid strike. That tornado's impact could have been much worse if we were without geostationary weather satellites.

I understand that NOAA has a completed Imager and Sounder for the GOES-Q system currently in storage. These sensors have already been built, but NOAA decided not to fly the GOES-Q satellite in 2002 due to longer life spans of existing weather satellites. Is this accurate that we have GOES sensors built and in storage for a satellite that did not fly?

Response: The original GOES-NO/PQ firm fixed price spacecraft contract awarded to Hughes, now Boeing, in January 1998 was for two spacecraft (GOES-N and O) with separate options for two additional spacecraft (GOES-P and Q). The option for the GOES-P was exercised in July 2003 coincident with a change in Launch Vehicle to Delta IV in order to accommodate a heavier spacecraft that would allow up to ten years of operating life. The option for a GOES-Q spacecraft was never exercised and expired in 2010.

The GOES-NO/PQ Imager and Sounder instrument sets were procured under a separate contract to ITT, now Exelis, and were provided to the Boeing spacecraft contract as Government Furnished Equipment (GFE). The Q instruments were delivered in 2006. When the GOES-Q spacecraft option was not exercised, the GOES-Q Imager and Sounder were maintained in flight-qualified ground storage at Exelis. This was done because the Boeing spacecraft contract had a requirement to provide a replacement mission should any of the GOES-NOP satellites fail, and as a possible contingency for GOES satellite gap mitigation.

The GOES-Q flight spare Imager and Sounder continue to be stored at Exelis until the launch and on-orbit checkout of GOES-R in order to preserve NOAA's options for the use of these instruments.

16. **The JPSS program is going to give us early warning of hazardous weather conditions and enhanced weather prediction capabilities to enable advanced planning. I believe we've turned the corner with our polar weather satellite program and JPSS has reportedly been executing very well.**

    We still face a potential gap in polar weather satellite coverage when the NPP satellite is expected to expire around 2016 prior to the 2017 launch of JPSS-1. After years of instability in our polar weather satellite program, it's high time for Congress and NOAA to do all we can to keep JPSS on track. I'm willing to support funding stability for JPSs and think it's the right thing to do given the importance of JPSS critical sensors to weather forecasting models.
    How much would it coast NOAA to expedite funding for JPSS-2 sensors in order to ensure stability for our weather forecasting satellite program while also decreasing the risk of a devastating gap in coverage?

Response: NOAA appreciates the Committee's support of its satellite programs. In the President's FY 2014 Budget request, the JPSS program focused on NOAA's core weather mission aimed at strengthening the likelihood of mission success and delivery of polar satellite observations to the NWS. Full funding of the FY 2014 President's Budget request is required to minimize any growth in a potential gap between JPSS-1 and JPSS-2, if, for example, JPSS-1 suffers a launch failure or early on-orbit failure.

The JPSS program now has a life cycle cost estimate of $11.3 billion through year 2025. Within those funds, JPSS Program will bring forward the JPSS-2 launch to the first quarter of FY 2022. The JPSS program is in the process of placing all the JPSS-2 instruments under contract by January 2014.

17. **NOAA has stated that they are accelerating the JPSS-2 launch readiness date by two years to mitigate the potential JPSS-1 to JPSS-2 gap as recommended by the 2012 Young Independent Review Team Report. To that end:**
    a. **What is the status of the JPSS-1 instruments, spacecraft bus, ground segment, and launch vehicle? What contingency planning has been executed to mitigate schedule delay risks?**

Response: We are pleased to report that the flight and ground segments are making excellent progress on JPSS-1 and are on track to meet the scheduled launch in the second quarter FY 2017 launch.

Status of JPSS-1 Instruments

With respect to the status of the JPSS-1 instruments, the initial assembly of the Ozone Mapping Profiler Suite-Nadir (OMPS-N), Advanced Technology Microwave Sounder (ATMS), Visible Infrared Imaging Radiometer (VIIRS), and the Cross-tack Infrared Sounder (CrIS) are complete.

The OMPS-N and ATMS instruments are in final environmental testing.

The VIIRS and CrIS instruments are in pre-environmental testing.

The ATMS, OMPS, CrIS and VIIRS instruments are scheduled to be shipped from the contractors to the spacecraft contractor for integration between March and October 2014.

The Clouds and Earth Radiant Energy System (CERES) sensor has completed final acceptance testing. Shipment has been delayed to address a calibration lamp issue. Shipment is expected in the second Quarter of FY 2014.

Status of JPSS-1 Spacecraft Bus
The JPSS-1 spacecraft bus successfully completed the Critical Design Review in December 2012. The spacecraft bus is on track to complete assembly and test by December 2014, and then it will be ready to support instrument integration and final testing.

Status of the JPSS Ground System
The JPSS Ground System is being used to support Suomi National Polar-orbiting Partnership (Suomi NPP) operations. Suomi NPP has maintained data availability of 99.9 percent over the past five months. Ground redevelopment / upgrade to Block 2.0 is underway to add robustness for Suomi NPP operations as well as prepare for JPSS-1. The JPSS Program is on track for installation of the Block 2.0 hardware which is scheduled to start at the end of calendar year 2013 at NOAA's primary and backup ground facilities. Completion of test and verification is scheduled for the end of 2015 and transition to operations in January 2016. The new Block 2.0 will operate Suomi NPP starting over a year before the launch of JPSS-1, allowing more than a year for integration testing for JPSS-1.

Status of Launch Services
NASA awarded the contract in July 2012 to launch the JPSS-1 on a Delta II rocket from Complex 2 at Vandenberg Air Force Base, CA. Initial integration analyses are proceeding successfully.

Status of Contingency Planning to minimize Schedule Risks
With regard to contingency planning to mitigate delay risks, the JPSS program is holding appropriate schedule margins, and is holding required reserves for technical uncertainties. The JPSS Program Director monitors all execution closely to take immediate steps to prevent problems from impacting the critical path. The JPSS program requirements are prioritized and there is a JPSS-1 descope plan to mitigate schedule impacts if external or internal factors arise beyond expected uncertainties covered by margins and reserves. Additionally, instruments can be integrated onto the spacecraft in any order to maintain schedule, and we are developing an incompressible test list so we know the minimum necessary to be ready to launch.

b. What is the status of the JPSS-2 requirements, instruments, spacecraft bus, ground segment, and launch vehicle?

Response: The JPSS-2 Level 1 requirements are baselined. The JPSS-2 Level 2 requirements are derived from the JPSS-1 Level 2 requirements with minimal change and are being reviewed and updated.

The JPSS-2 instruments are the same design as JPSS-1. The VIIRS JPSS-2 authority to proceed was given in April 2013, and the OMPS-Nadir, ATMS, and CrIS instrument proposals have been received. Contract award for all three of those instruments is expected in January 2014.

NOAA, in consultation with NASA, is finalizing the procurement strategy for the JPSS-2 spacecraft bus.

The Ground Segment will undergo a technical refresh and tailoring for the JPSS-2 mission. This will support Suomi NPP, JPSS-1 and the JPSS-2 mission. The requirement review for the JPSS-2 Ground upgrade is scheduled for early FY 2016.

The JPSS-2 launch vehicle will be addressed beginning in FY 2016. Launch Services funding requirements are phased to allow for the earliest possible launch readiness, Q1 FY 2022.

c. What specific activities are underway or planned by NOAA to achieve a two year acceleration of the JPSS-2 launch readiness date?

Response: As discussed above, the FY 2014 President's Budget request for the JPSS program is the result of a decision that supports NOAA's primary satellite mission of a weather-based program to strengthen the likelihood of mission success and to ensure NWS receives polar weather satellite observations in a timely manner. The JPSS program was also subjected to a rigorous review by the Administration to find cost savings and efficiencies within NOAA satellite programs, while strengthening satellite management and likelihood of success.

The FY 2014 Budget request proposes a new life-cycle cost of $11.3 billion through 2025. As discussed above, the JPSS-2 development and launch is accelerated to increase robustness of the constellation. The reduction in life-cycle cost is partly due to moving select climate sensor responsibilities to NASA, and due to the transfer of program content to the Polar Free Flyer Program.

NOAA will continue to support JPSS-1 and its instruments, including VIIRS, CrIS, ATMS, CERES, and OMPS-Nadir. CERES has already reached completion, while CrIS, ATMS, and OMPS-Nadir will be built and delivered in FY 2014.

NOAA proposes to support the build of the JPSS-2 spacecraft and the following instruments: VIIRS, CrIS, ATMS, and OMPS-Nadir. In fact, in August 2013, a contract was awarded to develop the VIIRS instrument for the JPSS-2 project. Awards of the other instruments are on track.

As discussed above, Polar Free Flyer will be funded outside of the JPSS program and will provide spacecraft bus and launch for the Total Solar Irradiance Sensor-1 (TSIS-1), Advanced Data Collection System (ADCS)-1, and SARSAT-1.

In an effort to simplify NOAA's mission, the Budget proposes to transfer to NASA responsibility for climate sensors originally planned as follow-on missions to JPSS-1 and Free Flyer-1, including CERES, OMPS-Limb and TSIS.

The FY 2014 Budget request does not fund the FF-2 satellite mission. NOAA proposes to forgo the build and accommodation of SARSAT-2 in anticipation of U.S. Air Force GPS-3 satellites that are expected to serve the same purpose. NOAA will continue to seek a ride share launch opportunity for the ADCS-2 instrument. The FY 2014 Budget request also proposes to transfer TSIS-2 to NASA.

The following are significant program changes in the President's FY 2014 Budget request to reduce the life-cycle cost and improve the robustness of the constellation:

- Reduces program management costs
- Reduces science and algorithm requirements for lower priority data products
- Reduces Operations and Sustainment costs
- Reduces VIIRS and CrIS costs on JPSS-2
- Accelerates the planned launch of JPSS-2 to first Quarter of FY 2022 to reduce the risk of a gap between JPSS-1 and JPSS-2; this reduces the mission life by 3 years to year 2025

FY 2014 funds will be used to support:

- Completion and integration of JPSS-1 spacecraft bus; an integrated independent review of the spacecraft; and preparations for procurement of the JPSS-2 spacecraft bus;
- Completion and delivery of ATMS, CrIS, OMPS-N and VIIRS instruments; removal of CERES FM-6 from storage and execution of environmental and performance testing on all instruments by the Flight Vehicle Test Suite which supports verification of software products, system requirements validation, mission rehearsal and operations training and anomaly investigations during testing phase; beginning the development of instruments for JPSS-2;
- Continued ground system enhancements to operationalize JPSS-1, and upgrades of IT security and operational robustness to include completion of the Consolidated Backup Unit in Fairmont, West Virginia to the NOAA Satellite Operations Facility in Suitland, Maryland and sustainment of Suomi NPP;
- Continue with planning of launch vehicle and launch services for JPSS-1 launch in the second Quarter of FY 2017.

18. NOAA presently purchases lightning mapping data to supplement their weather information, and the proposed *Weather Forecasting Improvement Act of 2013* would direct NOAA to purchase commercial weather satellite data.

a. Beyond lightning mapping data, how does NOAA currently utilize or plan to utilize commercial weather data?

Response: NOAA currently purchases high-resolution imagery from the space-based commercial remote sensing industry and space-based synthetic aperture radar (SAR) data from commercial sources in Canada and Europe for ice detection and monitoring to meet the operational needs of the National Weather Service, and the joint NOAA - U.S. Coast Guard – U.S. Navy National Ice Center.

In the recent past, NOAA had purchased Sea-viewing Wide Field-of-view Sensor ocean color data from GeoEye Inc. until that satellite ceased to provide usable data. The commercial entity did not launch a successor satellite. NOAA relied on NASA EOS satellites to provide ocean color data until the Suomi NPP spacecraft started to provide ocean color measurements from the VIIRS instrument.

A 2010 Congressional report that NOAA provided to the Committee reported on the outcome of a series of Requests for Quotations from the commercial providers. At that time, NOAA indicated that pending the availability of funds and NOAA's data requirements, NOAA would continue to purchase commercially available Earth observation data to augment its existing datasets. Where feasible and appropriate, NOAA will develop contracts for purchasing commercial data. Based on our 2010 assessment, the following commercial solutions are potentially mature enough for further pursuit:

- Coronal Mass Ejection Imagery – commercial data purchase
- Total Solar Irradiance Monitoring – government developed payload on a commercial satellite
- Solar Wind Data – commercial data purchase
- GPS Radio Occultation – commercial data purchase or a government developed payload on a constellation of commercial satellites

For all four potential commercial approaches listed above, an independent cost estimate would be required to determine which acquisition approach provides the best overall value. Any future commercial approach would be subject to available resources.

b. How does NOAA currently evaluate the quality of commercial weather data prior to purchase?

Response: A NOAA program would need to demonstrate a requirement for data that could not be met by an existing source, but available from a commercial vendor. The NOAA program would then need to initiate a discussion with the provider, subject to the Federal Acquisition Regulation, to purchase the data.

NOAA is in the process of finalizing an agreement with NASA and the commercial suppliers and partners in the Sunjammer mission to acquire solar winds data to support operational space weather requirements at NWS's Space Weather Prediction Center. Although the primary purpose of this mission is to flight-test solar sail technology, the mission is also carrying prototype solar wind sensors and we will acquire the solar wind data for evaluation. We will also acquire the financial performance data from the commercial partners in the mission as part of this agreement. The mission is being run on a commercial model consistent with a long-term commercial mission.

c. Would it be possible for NOAA to evaluate weather data for potential commercial purchase if no data was currently available to evaluate (e.g. prior to a commercial weather satellite launch demonstrating data quality and utility)?

Response: It might be possible to evaluate test data from a sensor which a company either had in its possession or was in the process of building. The maturity of the sensor and test results (for example, thermal / vacuum tests) would need to be considered. Other relevant data needed for evaluation would include the financial data underpinning the likelihood that the business would succeed; the performance data from its proposed satellite carrier and from its potential launch services provider; and the company's overall experience in general.

Another approach could be to acquire, at a potentially modest price and for short duration, flight data from a commercial satellite that was rated less than operational. In other words, data acquired from a test flight asset, which is what we are doing for solar wind (question 18b). Test flight satellites are less expensive than operational satellites because they have much less redundancy and back up.

Finally, NOAA would need assurance that the commercial contractor's commitments with its suppliers were sufficiently concrete so as to minimize the risk of future cost growth. NOAA has experienced problems in the past with offered prices from potential suppliers which later changed subcontractors, resulting in much higher prices.

19. If JPSS-1 were to experience a launch vehicle failure, what would be the anticipated data gap between the launch failure of JPSS-1 and the launch of JPSS-2?

Response: The anticipated gap between JPSS-1 and JPSS-2 in the event of a JPSS-1 launch failure is 4 years and 9 months.

This is based on the JPSS-1 launch date, no later than the second Quarter of FY 2017, and the JPSS-2 launch date, the first Quarter of FY 2022.

a. What are the ramifications of a potential data gap?

Response: The ramifications of a loss of high quality sounder data in the afternoon orbit is an immediate degradation of the quality of the output from numerical weather prediction models which will have an immediate impact on the weather forecasts beyond 3 days. The sounder's primary role is to provide the critical global vertical information on temperature and water vapor needed for accurate medium to long-range weather forecasting. A medium-range forecast generally covers a period from to 3 to 7 days.

Assuming Suomi NPP is still operating, the ramification is that Suomi NPP would likely, at some point before JPSS-2 is launched, become the sole source of data in the afternoon orbit.

If Suomi NPP is not operating, we are solely reliant on the aging satellites in the afternoon orbit which have low probability of continuing to operate until JPSS-2 is launched.

We have agreements covering multiple orbits to ensure we have access to advanced sounder data from at least one orbit and to provide the improved forecasting that comes from having data from three orbits. Therefore, if we lose all data in the afternoon orbit, we will be reliant on European data from the mid-morning orbit, and less capable DoD data from the early morning orbit.

NOAA is the only entity (government or commercial) that flies the advanced sounders in the afternoon orbit that are the required for input into the numerical weather prediction models that provide the weather forecasts beyond 3 days. Our U.S. and international customers and partners rely on us for early-afternoon coverage to ensure they have advanced sounder data from at least one orbit and the improvements that come from having data from three orbits.

Currently we have NOAA-19, the primary operational polar-orbiting satellite is flying with operating AVHRR (imagery) and AMSU (microwave sounder) instruments. NOAA-19 is in the afternoon orbit and is past its design life. While NOAA is making use of secondary non-operational satellites, (NOAA-15,-16,-18), they are very much beyond their design life and cannot be relied upon to provide operational support. The NASA EOS research satellites Aqua is past its design life, however, as long as its AIRS and MODIS instruments continue to provide data, they will be used as input to NWS numerical weather forecast models.

Suomi NPP will provide the advanced sounder data from the polar-orbiting afternoon orbit until failure or until a JPSS satellite is launched and has completed its calibration and validation. The JPSS Program is on-track for a no later than second Quarter of FY 2017 JPSS-1launch date.

The European Organisation for the Exploitation of Meteorological Satellites (EUMETSAT) has their sustained mid-morning orbit, which now includes Metop-A and Metop -B. Metop -C is already completed with a launch expected in 2017. In the morning orbit, DoD's Defense Meteorological Satellite Program (DMSP) satellite provides a microwave sounder, although significantly less capable than the Advanced Microwave Sounding Unit (AMSU) microwave sounders which currently fly on the NOAA Polar Orbiting Environmental Satellite (POES) and Metop, and ATMS which flies on Suomi NPP and will fly on JPSS-1 and JPSS-2. If there were a gap between Suomi NPP and JPSS-2, the NWS would still continue to rely on sounder data from EUMETSAT and DMSP, as well as any existing polar-orbiting sounder data from older satellites such as the current POES and NASA EOS Aqua. However, as noted above, given the current age of those legacy satellites, it is conceivable that there will be fewer options available to rely on to fill the gap between Suomi NPP and JPSS-2.

NOAA and EUMETSAT will have a Joint Polar Satellite (JPS) agreement to continue the existing Initial JPS agreement. NOAA and DoD have an agreement from which NOAA operates the DMSP polar orbiting satellites. These agreements provide NOAA, DoD, and EUMETSAT with 24x7 real-time access to each other's polar satellite data. The EUMETSAT Metop satellite series have advanced sounding infrared and microwave instruments similar to JPSS. DMSP, an older generation system from the 1990s, does not have an advanced infrared sounder, and their microwave sounder is not as accurate as the microwave sounders on Suomi NPP, JPSS, and Metop.

With funds provided by the Public Law 113-2, "*Disaster Relief Appropriations Act of 2013,*" NOAA is implementing a number of strategic actions designed to make its weather forecasting enterprise more robust in the face of the possibility of a gap in polar-orbiting weather data. These activities seek to make better use of existing data, take advantage of new data sources planned in the future, improve operational high performance computing capacity, and improve the assimilation of data into weather prediction models, including hurricane models. The goal is to minimize the impact of a gap in coverage should it become a reality. While none of these activities, individually or collectively, can totally replace a lack of JPSS data, they represent the positive actions NOAA can take to mitigate the loss of these data. Should a data gap not occur, these investments will nonetheless improve NOAA's ability to use existing data, thus improving weather forecasts. These actions are being taken in addition to the steps NOAA is taking to ensure that JPSS and GOES-R Series satellite development continue as planned.

b. How is NOAA building robustness into the JPSS program to guard against data gaps and ensure continuity of this critical data?

Response: The JPSS Program has built in robustness by:

- Developing and maintaining a program baseline that has appropriate schedule margin, component spares, reserves, and a solid risk management process at all levels.
- Maintaining a top-notch management and technical team, with a strong organization that delivers proven execution.
- Supporting NASA launch and eventual NOAA operation of Suomi NPP All systems are operating nominally and with no failures.
- Continuing to meet milestones leading to the launch of JPSS-1 on schedule.
- Moving ahead with early steps needed for an on-schedule launch of JPSS-2 (see responses to Questions 16, and 17(a/b/c).
- Improving the understanding of the probability of a gap and potential mitigation options.
- Strategic thinking on a polar follow-on mission to ensure there are no gaps in the JPSS-2 and beyond timeframe.

With respect to preventing/mitigating potential data gaps, in addition to working to achieve the earliest possible JPSS-1 and JPSS-2 launches, the JPSS Program is conducting several other gap mitigation initiatives:

A. <u>Suomi NPP health and safety monitoring</u>

- Suomi NPP telemetry monitored continuously by Mission Operations Team (MOT) and reported monthly to JPSS Flight Project and Program.
    - Monitoring based on spacecraft and instrument vendor documented recommendations.
- Instrument performance continuously monitored by NOAA STAR and NASA Langley Research Center for the CERES instrument.
- JPSS Flight Project conducts semi-annual trending meetings to look at long-term trends and dig into specific issues.
- Conjunction Assessment Risk Analysis (CARA) conducted continuously by joint NASA /NOAA team.
    - Utilizes same Joint Space Operations Center based system used for NASA Goddard Space Flight Center (GSFC)-managed NASA missions.

B. Suomi NPP Life extension

- Mission Operational Lifetime Optimization Technical Interchange Meeting (TIM) conducted on May 23, 2013.

  The purpose was to gather lessons learned from long-life GSFC and NOAA missions to inform Suomi NPP planning. The following activities were reviewed:
  - Satellite trending and monitoring process.
  - Identification of life-limiting items and consumables.
  - Status of residual risk and operations watch items.
  - Robustness of operations in response to on-orbit component functional failure(s).
  - Feedback was translated into JPSS Program actions.

- Sustaining engineering contracts are in place for continued spacecraft and instrument technical support for Suomi NPP on-orbit operations.

C. Polar satellite constellation health monitoring

- JPSS maintains Monthly Health Status report on operational constellation systems that provide JPSS backup data for core sensors/products (imagery, microwave and infrared sounders).
  - One set for each of early-morning, mid-morning, and afternoon polar orbits.
  - Tracks key spacecraft system degradations or potential ground segment issues that may impact continuity of observations. See examples below:

Constellation Health Status
Early Morning Orbit as of July 2013

	AF Early Morning DMSP (F17)	AF Early Morning DMSP (S19)	AF Early Morning DMSP (S20)
Launch Date	11/04/2006	LRD 2014	LRD 2020
Design Life (years)	4	5	5
Instruments			
Sounding			
Infrared			
Microwave	SSMIS		
Imagery	OLS		
Spacecraft			
Command and Control			
Communications			
Data Handling			
Power			
Thermal			
Fuel	n/a		
Ground			

Constellation Health Status
Mid-Morning Orbit as of July 2013

	AM Secondary NOAA-15	[illegible]	AM Primary Mid-Morn. MetOp-A	AM MetOp-B (Eval Per.) Planned 4/24/2013 Operational	AF Mid-Morning DMSP (F18)	AF Mid-Morning DMSP (F16)	EPS-SG Definition Phase
Launch Date	5/13/1998	[illegible]	10/19/2006	9/17/2012	10/18/2009	10/18/2003	2020
Design Life (years)	>2Yrs	[illegible]	5	5	4	4	
Instruments							
Sounding							
Infrared	[illegible]	[illegible]	HIRS				IASI-AIRS Like
Microwave	AMSU-A1 (Y20)	[illegible]	AMSU-A1		SSMIS	SSMIS	AMSU-A MHS Like
	AMSU-A2	[illegible]	AMSU-A2				
	[illegible]	[illegible]	MHS				
Imagery	AVHRR (Y19)	[illegible]	AVHRR		OLS	OLS	AVHRR-MODIS Like
Spacecraft							
Command and Control							
Communications	(Y22)	[illegible]	Y1				
Attitude Control	(O10)	[illegible]					
Data Handling							
Power		[illegible]					
Thermal	(10)						
Fuel	n/a	[illegible]			n/a	n/a	
Ground	(G1)	[illegible]					

Constellation Health Status
PM Orbit July 2013

	PM Secondary NOAA-16	PM Secondary NOAA-18	PM Primary NOAA-19	Aqua 1330	SNPP 1330	GCOM-W
Launch Date	9/21/2000	5/20/2005	2/06/2009	5/4/2002	10/28/2011	5/17/2002
Design Life (years)	> 2	> 2	> 2	6	5	5
Instruments						
Sounding						
Infrared	HIRS (Y13)		HIRS	AIRS	CrIS	
Microwave	AMSU-A1(Y15)	AMSU-A1	AMSU-A1	AMSU-A(1)	ATMS	AMSR 2
	AMSU-A2	AMSU-A2	AMSU-A2	AMSU-A(2)		
	AMSU-B	MHS	MHS			
Imagery	AVHRR (Y12)	AVHRR	AVHRR	MODIS	VIIRS	
Spacecraft						
Command and Control						
Communications						
Attitude Control	(Q16)	Y(7)				
Data Handling	OTR 4B,5A, 5B R					
Power						
Thermal						
Fuel	n/a	n/a	n/a			
Ground	(S3)	(G3)	(S4)			

D. <u>Gap probability assessment</u>

- Collaboration between JPSS, NWS, The Aerospace Corporation's Reliability and Statistics Dept., NASA GSFC Reliability and Risk Analysis Branch.
- Identified all sources of Key Performance Parameter (KPP) and KPP-replacement data in polar satellite constellation currently used by NWS.
  - JPSS KPP: S-NPP, JPSS-1, JPSS-2.
  - KPP-replacement: NOAA-18, NOAA-19, Aqua, Metop-A, Metop-B.
  - Other potential sources exist (e.g., DMSP, Metop-C), future studies will incorporate additional potential data sources.

- Modeled reliability of each KPP and KPP-replacement sensor and supporting spacecraft.
  - Identified and used models of the flight system or the most similar available system.
  - Failure rates.
  - Component failure rates (MIL-HDBK-217) updated with time on-orbit.
  - Updated model with on-orbit failures using Weibull or Bayesian technique.
  - Incorporated wear-out item(s) as additional failure mode.

- Defined Constellation Data Availability scenarios (JPSS and other assets).
  - JPSS system only, Afternoon Orbit only, Polar Constellation (2-orbit) with JPSS-1 failure, Polar Constellation (2-orbit).

- Built fault tree for data availability scenarios that incorporated satellite/sensor reliability data for calculating data availability which will continue to refine models; update analysis semi-annually.

In summary, the JPSS Program is robust, with the necessary management and technical expertise, excellent processes, and a solid baseline. In addition, it has on-going activities to understand the probability of a gap as well the mitigating options to ensure critical data continuity.

THE HONORABLE DANA ROHRABACHER

20. After the cancellation of NPOESS the Department of Defense restructured its weather satellite program into the Defense Weather Satellite System (DWSS). In late 2011, Congress directed DWSS's cancellation. While DOD has stated the follow-on system will be named Weather Satellite Follow-on (WSF), it has not yet provided funding to begin building a system.

Given the critical importance of weather information to our warfighter and Intelligence Community, I am concerned by the lack of a request for FY14 funds for a DOD weather satellite follow-on program or for the program office necessary to ensure future launch schedule needs can be met.

I am also concerned about the potential for reliance on foreign, non-ally nations for critical global weather information, in both polar and geostationary orbits, that would be used for U.S. national security.

a. Dr. Sullivan, should DOD continue to fail to provide the needed funding for military polar weather capability, what options would they have for polar weather satellite information especially if JPSS-1 were to experience a delay or problem?

Response: DoD still has two DMSP satellites to launch, each with a six-year life expectancy. Their current plan has the first launch in 2014, and the second in 2020, providing coverage to 2026. DoD would need to explore all other options available within their available assets, to include space-based, aircraft based, land-based, ocean-based, and other observing systems either available or planned, similar to the tack that NOAA is taking to mitigate the potential loss of JPSS-1 data. And we will, of course, share all of the data we collect with our DoD partners, to help mitigate the same types of concerns that NOAA has, with respect to predicting and preparing for severe weather events.

b. What foreign weather satellite information does NOAA intend to utilize to support DOD needs and does NOAA have plans to utilize Chinese polar or geostationary weather satellite data?

Response: NOAA has no plans to use Chinese data unless authorized by Congress. Currently, NOAA has access to polar-orbing and geostationary satellite data from our strongest international partner, EUMETSAT. Through our partnership, we agree to share all of our data sources and back each other up in the event of long-lasting data outages. In addition, several NOAA satellite sensors are manifested on the current generation of EUMETSAT's polar-orbiting satellite series, Metop. NOAA also acquires geostationary satellite data to serve our needs over the Pacific Ocean, through a partnership with the Japanese Meteorological Agency (JMA). Similarly, NOAA and JMA have signed a backup agreement to meet our critical requirements for geostationary satellite data through the loan of any spare assets. NOAA has successfully exercised these agreements with both EUMETSAT and JMA in the past. And we continue to work on additional partnerships with other friendly nations, such as India, Canada, France, South Korea, and Taiwan, to acquire additional data sources as needed to improve our weather, ocean, and climate prediction enterprise. As noted above, NOAA does not access, nor do we have any concrete plans to access, weather satellite data from China. We have security concerns that must be worked out before exploring these potential opportunities.

Currently, Section 8 of the Committee's draft weather forecasting legislation would seek placement of weather satellite instruments on cohosted government or private payloads. There are some potential cost-effective options out there such as a hosted payload partnership between the U.S. and Canada. NOAA will continue to explore options to meet its data requirements in consultation with the Department of State and other U.S. government agencies.

THE HONORABLE SUZANNE BONAMICI

21. Please explain the weather research structure within NOAA. How does the current structure promote coordination between research initiatives and forecasters to ensure continuous improvement in weather forecasting? Are there specific coordinating mechanisms in place that guarantee cooperation and eliminate duplication between OAR and NWS?

Response: NWS is the Nation's first line of defense against severe weather. Its mission is to provide weather, water, and climate data, forecasts, and warnings for the protection of life and property and enhancement of the national economy. OAR is NOAA's central research line office and provides the Nation with critical environmental information through climate, weather, oceanic, and Great Lakes research, technology development, and related services that support informed decision-making and promote healthy, productive, and resilient ecosystems, communities, and economies. Together, NWS and OAR have partnered on objectives that will support the NOAA mission for decades. One of NOAA's major objectives is to advance weather forecasting. OAR contributes to this directly by conducting research to advance operational products and services, and by developing cutting-edge science and technology that will represent the next generation of weather service products and services.

NOAA conducts weather research primarily in OAR, NWS, and NESDIS. The high-level planning structure for weather research occurs within NOAA's strategy, execution, and evaluation budget process (see *www.gao.gov/products/GAO-13-649R* for a recent GAO review of the process for more information), which is informed by strategic planning activities within both NWS and OAR. These planning activities involve participation from all NOAA line offices. In addition, the latest NWS strategic plan involved significant input from OAR scientists. OAR is currently updating its strategic plan and will also solicit input from NWS.

Within OAR's organizational structure, weather research is conducted by many of their laboratories according to the hybrid research model, which relies on a federal research enterprise working closely with mission-driven extramural research. OAR's laboratories work primarily with their co-located Cooperative Institutes and, as appropriate with researchers and forecasters within NWS and NESDIS. OAR's Office of Weather and Air Quality funds and manages high-impact weather research that often involves extramural partnerships that lead to the transition of research into NOAA operations.

Because this relationship is so vital, the two Line Offices are continually looking for ways to improve their working relationship. OAR and NWS have implemented a number of ways to better their working relationship, such as:

- The NWS Assistant Administrator and the OAR Assistant Administrator meet monthly to discuss priority issues, including collaborations between the two Line Offices; research-to-operations transitions; and funding levels for joint Service Level Agreements between the two line offices.
- Beginning in FY 2013, OAR and NWS formalized a number of service level agreements for OAR services to be provided to NWS using NWS funds. This process has significantly helped both line offices better coordinate their collaborative work with program and budget planning.
- Government and academic researchers and forecasters work together through NOAA's testbeds (see *www.testbeds.noaa.gov*). These testbeds provide an environment for researchers and forecasters to work within an operational structure to test new research ideas collaboratively and to test the feasibility of using the research results within the constraints of the operational environment. These testbeds allow an ongoing exchange of ideas between researchers and forecasters.

22. During the hearing, you discussed NOAA's goal to provide more advanced notice of a tornado to citizens. However, you also stated that research into improving advanced notice needed to be coupled with social science research to find the best way to communicate severe weather warnings to communities. Could you briefly elaborate on what scientific questions need to be undertaken to enhance warning effectiveness?

Response: An NWS warning that is not received or heeded provides little benefit to its intended audience. Social scientists and meteorologists have only begun to understand how the public would react if the current approach to tornado warnings were extended to 30, 60, or more minutes in advance. Some early research in 2008[2] suggests that extending the lead-time of traditional tornado warnings beyond 15 minutes may have a negative effect on reducing fatalities and expected injuries, likely due to concern over false alarms. Simply extending warning lead times would necessarily decrease their accuracy without a commensurate increase in the science and technology behind the forecasts and warnings themselves.

NOAA sponsored two workshops that focused on building a Weather-Ready Nation, one in December 2011 in Norman, OK, and one in April 2012 in Birmingham, AL. These workshops brought social and physical scientists together to provide recommendations for building a Nation more resilient to high-impact weather. In addition to recommendations for improving the understanding, detection, and prediction of storms, these scientists posed many social science questions that NOAA and the entire weather enterprise need to address. Some of these questions include:

- What are the psychological processes by which people classify an outcome as a false alarm or a near miss?
- What are the acceptable error limits within which vulnerable populations will still effectively respond to warnings and alarms?

[2] K. M. Simmons, and D. Sutter. 2008. Tornado Warnings, Lead Times, and Tornado Casualties: An Empirical Investigation. *Weather and Forecasting* 23: 246-258.

- What are the effects of different warning frequencies (the number of warnings per year) on public response in different areas of the country?
- How are warning recipients likely to interpret and respond to the elements of warning messages, and how will the message elements affect perceptions of risk and resulting protective actions?
- What are the impediments that prevent the elderly, those who have disabilities, and other vulnerable populations, from achieving adequate levels of tornado preparedness, warning response, and disaster recovery?

23. The bill mandates that NOAA use OSSEs to evaluate any major acquisition or purchase of data from private parties to insure that the data be operationally effective.

a. Could you please comment on what kind of technical and scientific tools exist to allow NOAA to evaluate proposed acquisitions or purchases?

Response: NOAA uses computer models to estimate the impact of new observing systems -- or changes to existing systems -- to our operational forecasts. NOAA has recently expanded its use of tools to examine the benefit of potential future systems -- systems that don't currently exist. These tools are called Observing System Simulation Experiments or OSSEs. An OSSE is a type of observing system experiment aimed at assessing the impact of a hypothetical data type on a forecast system. OSSEs show how much improvement can be expected from a new observing subsystem that is being proposed. They can be used to evaluate the relative value to be gained from alternative concepts for observing systems, so that the maximum impact on NOAA operations can be obtained in the most cost-effective manner. OSSEs can also be used to improve the utilization of currently available data to maximize their impact on forecasting.

Another assessment used by NOAA to evaluate observing systems prior to acquisition is Analysis of Alternatives (AoA). AoA is a deliberate effort to explore multiple alternatives so agencies have a basis for funding the best possible projects in a rational, defensible manner considering risk and uncertainty. The general federal policy and practice is to ensure that at least three feasible alternatives are analyzed prior to making costly investment decisions. NOAA uses AoAs before beginning the acquisition and development of new observing systems to investigate potentially lower cost approaches to the Government-developed systems. The AoA establishes and benchmarks metrics for Cost, Schedule, Performance and Risk.

NOAA also uses quantitative economic analysis, which is a tool used for medium and long-range planning of observing systems. For example, to provide up to one-hour warnings for tornadoes and severe weather, there are several possible improvements to the national scale observing system. These include increasing the amount of surface data, new satellite sensors, and ground-based upper air sensors. A quantitative analysis starts with estimates of costs for the components, and uses the techniques of cost-minimization to determine the best mix of new sensors to meet the requirements.

b. To the degree you feel qualified to comment, please explain the strengths and weaknesses of OSSEs.

Response: Some pros and cons of using OSSEs are found below.

Strengths:

- OSSEs have the capability to assess the potential impact of proposed/future observing systems on numerical weather, ocean, and climate prediction systems and to inform decision-makers prior to acquisition or construction of the proposed observing system.
- The benefits of an observing system or type of observation can be estimated before it is designed, built, and launched into orbit.

Weaknesses:

- OSSEs do not assess the impact of a specific existing data point.
- If a future instrument requires new data assimilation, i.e. algorithms or techniques that do not currently exist, NOAA may not be able to fully assess the impacts of the instrument using the OSSE. The OSSE may underestimate or overestimate the impact.
- OSSEs cannot select which instruments would be the best to pursue out of several different options without testing each option individually.
- Conducting OSSEs on the global scale, such as would be required for a satellite system, would necessitate significant resources and can take as much as 1-3 years to complete.

c. What kind of evaluation techniques other meteorological organizations (such as the European Center for Medium-Range Weather Forecasting) use?

Response: Other meteorological organizations, such as the European Center for Medium range Weather Forecasting (ECMWF), have used OSEs (denying existing data to models to see the resulting forecast degradation) and other techniques to determine the contribution of various observing system components, and have participated in the OSSEs that we have conducted. The ECMWF, and other European centers, have worked closely with the U.S. on these observing system studies. For example, the current test ("nature") atmosphere used by the U.S. OSSE system was generated by ECMWF, and they are currently generating a new nature run (reference atmosphere) for the OSSEs that we will be performing. This is necessary, because when an OSSE is performed, it must use a different model than the U.S. forecast model used in the test.

Responses by Dr. Kelvin Droegemeier

Response by Dr. Kelvin K. Droegemeier
to Questions for the Record Posed by the Honorable Chris Stewart

Restoring U.S. Leadership in Weather Forecasting Part 2

2013 Hearing by the Subcommittee on Environment, US House of Representatives Committee on Science, Space and Technology

Question #1: What provisions in the Weather Forecasting Improvement Act will help us get closer to your suggested goal of achieving zero deaths from hazardous weather.

Response: First and foremost, I believe an appropriately *balanced portfolio* of research – across disciplines and across the weather/water/climate nexus – is essential for making progress toward improving weather prediction. To date, the bulk of research funding for severe weather has rightly been directed toward the physical science domain because, as we all recognize, statistically accurate forecasts are foundational to effective response and the protection of life and property. This research must continue, and the version of the bill considered at the hearing contained several provisions that should lead to advances necessary to achieve the goal of zero deaths from hazardous weather (e.g., better understanding of the atmosphere, advanced radars for both storm detection as well as data input to forecast models, more powerful computers, improvements in forecast models, more observations, especially at low levels, and more effective use of the observations we now have in terms of forecast model data assimilation). I believe most researchers agree on the importance of these items, though some no doubt would differ regarding relative priorities for investment and returns on investment.

However, the original text of the bill did not fully address [though it did make reference in SEC 5 (4) to] what I and many others believe is the most important issue for moving toward the goal of zero deaths: namely, understanding human behavior under conditions of extreme stress, understanding how to formulate information in ways the public can understand and utilize, and then actually use this knowledge and understanding to craft a threat notification system that effectively communicates weather risk information to those in harm's way. I would strongly urge that the bill speak more forcefully to the social science issue, particularly to avoid too great an emphasis on warning lead time (SEC 4) as a singular measure of success (see below). Tornado warning lead time has more than doubled since 1986 yet hundreds of people continue to die in tornadoes. *Physical science and technology alone cannot get us to the goal of zero deaths.*

Catastrophic loss of life continues to occur because severe weather is not being studied in a truly *integrative fashion*, that is, as a *weather-driven societal and human behavior* problem. That is the essence of the zero deaths argument. Physical scientists can produce the forecasts – but social scientists are needed to understand how to package and convey threat information, and anticipate and manage human response. And these two groups must work closely together, as is now the case at the NOAA Hazardous Weather Test Bed. Even extremely accurate forecasts, as were produced in Hurricane Katrina, for example, lose considerable value of they are not communicated effectively, and if response to them is not understood and accounted for in planning. *Weather predictions are like seat belts; even though they have the potential to save lives, they can do so only if used properly.*

Question #2: NOAA spent less than $70 million in 2013 on weather research. This legislation authorizes $100 million for weather research a year, and a dedicated stream of $20 million to facilitate research-to-operations. Do you oppose this investment? Are we spending enough on weather research?

Response: Neither the bill nor the testimony about it made clear to me how the $70 million in existing NOAA funding for weather research relates to or already contains elements of the proposed $100 million. I believe such an analysis, and the setting of priorities, is important to most effectively answer the important question you pose. Overall, I believe additional investment is needed to achieve the goal of zero deaths, though the sources of funding for it must be carefully considered in light of the need for a balanced portfolio, as noted in my response to Question #1.

I also believe greater progress could be made if NOAA, NSF, and NASA in particular would more effectively coordinate their investments in weather research. A great deal of unrealized opportunity exists for *leveraging* funding across agencies, and I realize doing so is difficult – as was made clear during the US Weather Research Program. Yet, in these days of substantial fiscal constraint, the only way to achieve bold goals is to *leverage and invest in a highly strategic manner*.

With regard to research-to-operations (R2O), as mentioned in my written testimony, I believe the concept should be re-fashioned as research-plus-operations (R+O). This is far more than a name change and gets to the heart of the challenge mentioned by Dr. Chen in her written and oral testimony. R2O represents an outdated concept in which researchers work in relative isolation and provide their outcomes to operations experts, without actually being informed by operational problems, constraints and issues. The R+O concept, which is utilized in the NOAA Hazardous Weather Test Bed (HWT) in Oklahoma, brings researchers and operational practitioners *together*, working hand in hand *continuously to jointly* uncover, understand and address meaningful problems. The success of the HWT is unquestioned, and the integration of social sciences in this framework is now underway and is a central part of the Weather Ready Nation concept. I am very supportive of the $20 million dedicated to research/operations engagement.

Question #3: Dr. Sullivan's testimony described an R&D effort at NOAA to increase tornado warning lead times, stating that "with advances in observing and modeling, we hope to extend warning lead times from the current average of less than 15 minutes to a period of up to an hour, to help save lives and property."

a. Would you agree that extending accurate tornado warning times is an appropriate goal that should be made both a management priority and a funding priority by NOAA?

I believe tornado warning lead time is an appropriate metric only if other metrics which stress the human dimension of warning and response likewise are included as priorities. This will prevent warning lead time from overshadowing many other important factors involved in severe weather situations. For example, I noted in my written testimony that a critical issue involves how people use whatever warning lead time is available to them. When lead time increases, people have more time not only to seek shelter, but to seek confirmation – which is a well-known characteristic of people acting under stress. Larger lead times may create actions such as fleeing one's location, which as evidenced in central

Oklahoma on May 31, 2013 could have been disastrous. This leads one to ask whether emphasis also should be placed on metrics such as increasing the time available from issuance of a warning to being sheltered in a survivable location. Social scientists can help identify those and other metrics, such as people's trust of information based upon source – an extremely important factor in how the public processes and acts upon weather threat notification. This issue is ever more important in our age of social media, where many use Facebook and Twitter posts from *friends* as their authoritative source of weather warnings.

b. What are some of the specific areas of research that might move us closer to this goal?

See response to part a above.

Question #4: By many measures, U.S. numerical weather prediction by NOAA has fallen behind models in Europe and elsewhere.

a. Is it possible that, in the next several years, the U.S. forecasting system can be restored to compete with the European model?

Yes, I believe that with planned investments to increase computing capacity, especially from "Sandy Supplemental" funds, the U.S. GLOBAL model, in terms of quantitative skill measures, will become statistically equivalent to that of the European Center for Medium Range Weather Forecasts (ECMWF) – the world's premier system today. Of course, ECMWF does one thing (medium-range weather forecasting, which extends to roughly 10 days) whereas NOAA runs a much larger suite of models (global, regional, local, hydrological, wave height, hurricane, space weather) reflecting a much broader mission. NOAA already exceeds the capability of other nations in many of these other areas, especially with regard to regional and specialized (e.g., hurricane) models. But NOAA presently is not the global leader in global model skill.

b. Are there provisions in this draft legislation that would help accomplish that goal?

The comparison mentioned concerns the ECMWF global model, so yes, SEC 3 (b)(D)(ii) addresses this specifically by speaking to "enhanced global models," though without much detail.

I would offer that consideration also be given to how and why ECMWF was able to achieve its position as the global leader in global medium range forecasting. Many reasons exist, of course, including a long history of utilizing the most powerful computers available and a laser-like focus on a single task (medium range weather forecasts). However, often overlooked is the fact that ECMWF comprises both permanent and visiting personnel, the latter representing the best and brightest researchers from academia who spend 3-5 years in "rotator" positions. In this manner, ECMWF has the world's foremost research experts <u>in house</u>, directly contributing via their research to operational activities while also publishing outstanding scholarly articles. In this manner, R2O is not a separate activity at ECMWF but is part and parcel of the organization's philosophy and structure. A similar capability for NOAA's National Centers for Environmental Prediction (NCEP) would, in my view, substantially increase U.S. competitiveness and possibly allow the U.S. to take the lead globally in numerical prediction at all scales.

Response by Dr. Kelvin K. Droegemeier
to Questions for the Record Posed by the Honorable Suzanne Bonamici

Restoring U.S. Leadership in Weather Forecasting Part 2

2013 Hearing by the Subcommittee on Environment, US House of Representatives Committee on Science, Space and Technology

Question: The bill mandates that NOAA use OSSEs to evaluate any major acquisition or purchase of data from private parties to ensure that the data be operationally effective. Could you please comment on what kind of technical and scientific tools exist to allow NOAA to evaluate proposed acquisitions and purchases? To the degree you feel qualified to comment, please explain the strengths and weaknesses of OSSEs and what kind of evaluation techniques other meteorological organizations (such as the European Center for Medium Range Weather Forecasts) use?

Response: Prior to addressing the specific question posed, it is useful to briefly describe OSSEs and their close cousin, OSEs.

OSSE is an acronym for Observing System Simulation Experiment. OSSEs involve the use of computer models of the atmosphere to evaluate potential designs for, and expected benefits of, data generated by observing systems that do not yet exist. As an example, suppose a satellite-borne instrument is being considered for development to observe hurricane winds as a means for improving computer hurricane forecasts. The OSSE concept would involve simulating a previous hurricane with a computer model and then sampling the output in a manner similar to that of the proposed satellite instrument. These simulated observations then would be fed into another computer model forecast of the same hurricane, with the intent of determining the impact of the simulated observations. The actual OSSE process is somewhat more complex, particularly with regard to calibration (see below for elaboration).

OSE is an acronym for Observing System Experiment. Whereas OSSEs use *simulated* observations from *future* observing systems, OSEs use *real* observations from *existing* observing systems, usually in operational forecast models. The most common type of OSE is the so called data denial experiment, wherein actual observational data are systematically withheld from a computer model to determine the associated impact on the forecast.

For both OSSEs and OSEs, it is important to recognize that adding observations to a computer model does not always yield a better forecast and in some cases can actually degrade it. Additionally, the question posed by the Ranking Member focuses on data to be provided from private parties. OSSEs are agnostic regarding the nature of the entity providing the data.

With regard to technical and scientific tools for evaluating the potential value of observations, others exist in addition to OSSEs. For example, the so-called adjoint sensitivity method has the capability of determining how a specific aspect of a forecast (e.g., hurricane intensity, amount of rainfall from a thunderstorm) is impacted by all observations simultaneously, real or simulated. If this sensitivity can be understood, then an observational system can be devised to drive the sensitivity in the desired direction (improving the forecast rather than degrading it). Although the adjoint method is very powerful, it requires the adjoint formulation of the forecast model computer code, or in other words, another model (that operates backward in time) of equivalent complexity and computational requirements. Many adjoint models exist in the research community and could be deployed to help address the observational requirements challenge.

Another technique is the Forecast Sensitivity to Observations (FSO) approach that can be applied to *operational* data assimilation and prediction systems. Given the huge number of observing systems associated with operational forecasts, performing OSE-type data denial experiments every day using every observing system is computationally infeasible. However, using the adjoint data assimilation approach, as is done at ECMWF, it is easily possible to evaluate the relative contribution of each and every observing system to the reduction of forecast error on a daily basis. NOAA currently cannot use this approach because it does not have an operational adjoint data assimilation system. However, it is possible, in principle, to create a real time FSO capability using ensemble Kalman filter data assimilation techniques currently employed by NCEP.

Turning to the strengths and weaknesses of OSSEs, this method of evaluating the potential of new observing systems has a long history of use and value, dating back to the 1970s. More recently, numerous OSSE studies have been performed, but it is unclear to what extent the results have been acted upon – particularly with regard to satellites, where functionality appears to be driven more by instrumentation capability and budgets than specific need as determined from numerical experimentation.

The principal value of OSSEs lies in their ability to *estimate* the impact of a *future* observing system. Ironically, this same attribute also represents one of OSSE's principal limitations in that OSSEs evaluate that impact within *today's* model and observations environment. More specifically, given the lack of information regarding the future mix of observations, by the time an instrument developed as an outcome of OSSEs becomes operational, its value added, relative to others also implemented during the same period, is impossible to assess and may in fact be diminished by redundancy.

Another important issue for OSSEs is the need for ***calibration.*** This is performed by first conducting an OSE data denial experiment for a selected *existing* observing system to determine the real impact of the observations on a forecast. Then, the experiment is repeated within the OSSE framework, which *estimates* the same information, for comparison. The differences between the actual and simulated results can be used to calibrate subsequent OSSEs so they more faithfully represent likely impacts from actual future observations.

Numerous OSSE studies have been performed with cloud resolving models (i.e., those which show promise of explicitly predicting tornadoes), with emphasis on the impact of radar data and quantities retrieved from them. However, because operational models are not yet run at sufficiently fine (e.g., 1 km and finer) grid spacings, the associated results have not yet been applied comprehensively to the development of future observing systems.

In my written testimony, I cited a report by the National Research Council (National Research Council, 2009: Observing Weather and Climate from the Ground Up: A Nationwide Network of Networks, 234 pp. http://www.nap.edu/catalog.php?record_id=12540), which discusses and makes recommendations for addressing the most compelling unmet observational needs of the weather and climate community. The strategies described in the current reply can serve as important tools for determining the optimal mix of observing systems and observational data. Ultimately, a multi-agency strategy is needed to utilize both research and operational models to address this important need for the nation.

Finally, it is important to recognize that the meteorological community has studied systematic approaches for evaluating public investments in observations for operational weather forecasting. Dr. Rebecca Morss, a scientist at the National Center for Atmospheric Research (NCAR), published a paper on this topic nearly a decade ago (Morss, R.E., K.A. Miller, and M.S. Vasil, 2005: A systematic economic approach to evaluating public investment in observations for weather forecast. Mon. Wea. Rev., **133**, 374-388). To my knowledge, neither her results, nor subsequent work stemming from them, have been adequately integrated into our nation's planning.

Responses by Dr. William Gail

GWC GLOBAL WEATHER CORPORATION

1 August 2013

Chairman Chris Stewart
Congress of the United States, House of Representatives
Committee on Science, Space, and Technology; Subcommittee on Environment
2321 Rayburn House Office Building
Washington, DC 20515-6301

Dear Chairman Stewart,

Thank you again for the invitation to participate in the June 26, 2013 hearing entitled *Restoring U.S. Leadership in Weather Forecasting Part 2.*

I am pleased to answer the follow-up question you have provided.

> *Question*
> The bill mandates that NOAA use OSSEs to evaluate any major acquisition or purchase of data from private parties to ensure that the data be operationally effective. Could you please comment on what kind of technical and scientific tools exist to allow NOAA to evaluate proposed acquisitions or purchases? To the degree you feel qualified to comment, please explain the strengths and weaknesses of OSSEs and what kind of evaluation techniques other meteorological organizations (such as the European Center for Medium-Range Weather Forecasting) use?
>
> *Answer*
> Routine evaluation of operational effectiveness for major acquisition or purchase of data from private parties is advisable for NOAA. OSSEs are one technique for doing this. OSSEs can be effective in some situations, but have shortcomings that undermine their use in all situations. Alternative techniques are available, such as ensemble data assimilation (EDA) used by the European Centre for Medium-Range Weather Forecasts, the U.S. Navy, NASA, and others. Each particular evaluation may have specific circumstances that lead to a preference for one technique over another. Recommending a specific technique prior to understanding the specific circumstances of each evaluation can lead to either incorrect results or costly efforts of limited value. Should the Subcommittee wish to provide additional guidance to NOAA on this topic, I would recommend instead an emphasis on using independent advice (such as an advisory board) to ensure that evaluation is being performed properly for each such acquisition or data purchase and that the most appropriate techniques are being used.

I have also reviewed the transcript and provided suggested edits on the following page.

Sincerely,

William B. Gail

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Suggested Edits to Testimony on "Restoring U.S. Leadership in Weather Forecasting, Part 2" held Wednesday, June 26, 2013.

Line 1210. Replace the word 'cavities' with 'activities'.

Line 1214. Replace the period after 'revolutionized' with a comma, and replace "Beginning" with 'beginning'.

Line 1215. Insert a comma after 'radars'.

Line 1223. Replace the comma after 'property' with a period and replace 'but' with 'But'.

Line 1235. Replace 'the' with 'their'.

Line 1264. Replace 'and' with 'at'.

Line 1265. Insert a comma after 'community'.

Line 1268. Insert a comma after 'interlinked'.

Line 1274. Insert a comma after 'legislation'.

Line 1277. Delete 'who have had –'.

Line 1279. Replace 'It' with 'That'.

Line 1496. Replace 'doesn't' with 'does'.

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Responses by Dr. Shuyi Chen

Subcommittee on Environment
Committee on Science, Space, and Technology
United States House of Representatives
A hearing on:
Restoring U.S. Leadership on Weather Forecasting, Part 2, **June 26, 2013**

Shuyi S. Chen, Ph.D.
Professor of Meteorology and Physical Oceanography
Rosenstiel School of Marine and Atmospheric Science, University of Miami

Response to Hearing Questions Posed by Chairman Stewart:

1. ***Q:*** *Dr. Chen, in the hearing you stated that, "a National Advisory Board would help to make that decision, transition from the research not only at OAR or NOAA but also a broad research community that is driven by users' needs, and at the same we would like that the body of oversight for this important effort to making decisions transition to the National Weather Service."*

a. Please elaborate on the need to create a separate oversight institution for weather. Where would such a proposed advisory board be located and who would comprise its membership?

A: One of the key challenges in restoring U.S. leadership in weather forecasting is the lack of a coherent and systematic approach to transition the best science and technology from research to operations. Basic research has played a vital role in advancing weather research and forecasting in the U.S. and worldwide. Much of the advancement today would have not been possible without broadly based research from the academic, government, and private research communities over the last several decades. However, the fruits of weather research have not been fully harvested by operations in NOAA. This issue has been the focus of several NRC studies and reports. Many have reached similar conclusions as those found in "*From Research to Operations in Weather Satellites and Numerical Weather Prediction: Crossing the Valley of Death*" (NRC 2000[1]) – a lack of a national strategy and leadership.

To develop a national strategy and a systematic approach to transition start-of-the-art weather research into operations, NOAA cannot do it alone. It needs to "***Engage the entire (weather) enterprise to develop and implement a national strategy for a systematic approach to research to operations and operations to research.***" – A key recommendation by NRC (2012[2]).

We must take a holistic approach to improving the transition from research to operations. Although I do not think "a separate oversight institution for weather" is a solution for this, we need a new, transformative, integrated system to transfer state-of-the-art weather research to operations. This system should be advised and overseen by a group of experts from the research, operations, and user communities of the weather enterprise. I believe that **Congress can help**

[1] NRC, 2000: *From Research to Operations in Weather Satellites and Numerical Weather Prediction: Crossing the Valley of Death.* National Academy Press, Washington, DC.

[2] NRC, 2012: *Weather Services for the Nation – Becoming Second to None.* National Academy Press, Washington, DC.

provide a mandate for a new National Advisory Committee for Transition Weather Research to Operations to develop a national strategy and a systematic approach as outlined here a two-step approach:

(a) First, under the proposed ***Weather Forecasting Improvement Act of 2013 (H.R. 2413)***, the Under Secretary of NOAA shall submit a plan for transition of research to operations to Congress. The plan should be based on NOAA's mission, users' needs, and recommendations published in recent NRC reports (2010[3], 2012).

(b) Second, the NOAA plan should be reviewed by an independent National Advisory Committee outside NOAA. The Advisory Committee, charged exclusively with providing ongoing scientific and technical advice to NOAA on transition from research to operations, can be organized by, for instance, the National Academy of Sciences. The Advisory Committee, under the proposed ***Weather Forecasting Improvement Act of 2013 (H.R. 2413)***, shall submit its review and recommendations to the Congress in addition to NOAA. The Congress can provide oversight through the budgetary process.

[3] NRC, 2010: *When Weather Matters – Science and Services to Meet Critical Societal Needs.* National Academy Press, Washington, DC.

Response to Questions Posed by Ranking Member Bonamici:

1. ***Q:*** *Please provide the Committee with your observations about how NOAA has limited its ability to use outside modeling or advice from the academic community? What impact has this situation had on moving science and technology from academics or research centers into NOAA's forecast modeling? Please include any insights you have into problems with the current innovation system at NOAA and ideas you have to address such problems.*

A: Improving current numerical weather prediction (NWP) models and developing the next-generation NWP models are key elements in weather forecasting. The weather research community, including academia, government, and even some private companies, have been developing various NWS models over the years. However, these models developed outside NOAA, no matter how good they are, have no pathway for transition to NOAA operations.

Within NOAA, the National Center for Environmental Prediction (NCEP)/National Weather Service (NWS) has been developing its own NWP models for operations, while the Office of Oceanic and Atmospheric Research (OAR) laboratories have developed separate NWP models. With limited resources (divided between OAR and NWS), NCEP is unable to replace its aging modeling system such as GFS and is unwilling to support extramural research and model development (UCAR, 2010[4]), which leads to intellectual isolation. This vicious cycle continues today. At the same time, the research community outside of NOAA continues to develop a number of next-generation high-resolution NWP models. Unfortunately, there is no pathway for these models to become operational at NCEP. Despite an awareness of the problem and recommendations from many entities, there has been little progress in improving the transition of research to operations, especially in terms of NWP models.

To restore U.S. leadership in weather forecasting, we must improve our ability to harness the best science and technology resources available. We must cease to perpetuate the destructive and unnecessary divide between research and operations. I firmly believe that Congress can help change the situation by providing a mandate for a new National Advisory Committee for Transition Weather Research to Operations to develop a national strategy and a systematic approach, as outlined above, a two-step approach:

(a) First, under the proposed ***Weather Forecasting Improvement Act of 2013 (H.R. 2413)***, the Under Secretary of NOAA shall submit a plan for transition of research to operations to Congress. The plan should be based on NOAA's mission, users' needs, and recommendations published in recent NRC reports (2010, 2012).

(b) Second, the NOAA plan should be reviewed by an <u>independent</u> National Advisory Committee <u>outside</u> NOAA. The Advisory Committee, charged exclusively with providing ongoing scientific and technical advice to NOAA on transition from research to operations, can be organized by, for instance, the National Academy of Sciences. The Advisory Committee,

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[4] UCAR, 2010: *2009 community review of the NCEP Office of the Director.* Boulder, CO.

under the proposed ***Weather Forecasting Improvement Act of 2013 (H.R. 2413)***, shall submit its review and recommendations to the Congress in addition to NOAA. The Congress can provide oversight through the budgetary process.

2. ***Q:*** *The bill mandates that NOAA use OSSEs to evaluate any major acquisition or purchase of data from private parties to insure that the data be operationally effective. Could you please comment on what kind of technical and scientific tools exist to allow NOAA to evaluate proposed acquisitions or purchases? To the degree you feel qualified to comment, please explain the strengths and weaknesses of OSSEs and what kind of evaluation techniques other meteorological organizations (such as the European Center for Medium-Range Weather Forecasting) use?*

A: An integrated model-data assimilation system for observing system assessment and planning will be a key going forward. The traditional approach has been using observing system experiments (OSEs) to assess impacts of existing observations on numerical model prediction, and observing system simulation experiments (OSSEs) for future observations. However, OSSEs, a model-based approach, are rarely used because of its large uncertainty due to model biases and a lack of independence between the model simulated "nature" state and its "synthetic" data assimilation system.

Because the shortcomings of OSSEs, some operational centers including the U.S. Navy, NASA, and the European Center for Medium-Range Weather Forecasts (ECMWF) have chosen to develop new alternative approaches using adjoint and/or ensemble data assimilation (EDA) system for observing system assessment and planning. These alternative methods used by U.S. Navy, NASA, and ECMWF allow for better integration of model and data assimilation system. New and better technologies are likely to continue to be developed in the future (NRC, 2012). For these reasons, I would strongly urge caution for legislating specific technologies for observing system assessment and planning (re. Section 7 in the proposed ***Weather Forecasting Improvement Act of 2013***). Instead, it will be best to encourage innovations and new technology development.