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THE FUTURE OF FORECASTING: BUILDING A STRONGER U.S. WEATHER ENTERPRISE

HEARING

BEFORE THE

SUBCOMMITTEE ON ENVIRONMENT

OF THE

COMMITTEE ON SCIENCE, SPACE, AND TECHNOLOGY

HOUSE OF REPRESENTATIVES

ONE HUNDRED SIXTEENTH CONGRESS

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C O N T E N T S

May 16, 2019

Appendix II: Additional Material for the Record

THE FUTURE OF FORECASTING: BUILDING A STRONGER U.S. WEATHER ENTERPRISE

THURSDAY, MAY 16, 2019

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

The Subcommittee met, pursuant to notice, at 2:04 p.m., in room 2318 of the Rayburn House Office Building, Hon. Lizzie Fletcher [Chairwoman of the Subcommittee] presiding.

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

"The Future of Forecasting: Building a Stronger U.S. Weather Enterprise"

Thursday, May 16, 2019
2:00 p.m.
2318 Rayburn House Office Building

PURPOSE

This hearing will provide an opportunity for a discussion on the state of the U.S. Weather Enterprise, which is comprised of public, private, and academic partners. The overarching goal of this hearing is to determine what next steps need to be taken to not only develop U.S. leadership in weather modeling and forecasting, but also to encourage coordination and collaboration between the three sectors to ensure a robust U.S. Weather Enterprise that can provide the most timely and accurate weather products and services.

WITNESSES

- **The Honorable Neil Jacobs, Ph.D.**, Assistant Secretary of Commerce for Environmental Observation and Prediction, performing the duties of Under Secretary of Commerce for Oceans and Atmosphere, National Oceanic and Atmospheric Administration (NOAA)
- **Dr. Louis Uccellini (Ooh-che-LEE-knee),** Assistant Administrator for Weather Services and Director of the National Weather Service, NOAA
- **Dr. Shuyi Chen**, Professor, Department of Atmospheric Sciences, University of Washington
- **Dr. Christopher Fiebrich (Fee-brick)**, Associate Director of the Oklahoma Climatological Survey and Executive Director of the Oklahoma Mesonet
- **Mr. Rich Sorkin**, CEO, Jupiter Intelligence

OVERARCHING QUESTIONS

- What is the current state of the U.S. Weather Enterprise, and how do we determine its future priorities?
- How do we improve the U.S.'s weather models and forecasting capabilities?
- What are the priorities, initiatives, and current weather infrastructure needs of the National Weather Service (NWS)?
- What are the workforce concerns for NOAA and NWS, as well as the broader Enterprise?
- How is the implementation of the Weather Research and Forecasting Innovation Act of 2017 progressing?
- What are the concerns surrounding the auction of 5G Spectrum in the 24 GHz band for weather forecasting capabilities?

BACKGROUND

In 2018, the U.S. experienced 14 separate billion-dollar weather and climate disasters, which is the fourth highest total number of events since 1980, only behind years 2017, 2011, and 2016. So far in 2019, the U.S. has already experienced two weather and climate disasters exceeding $1 billion each.[1] The need for accurate weather and climate predictions will continue to grow as we see more frequent and intense severe weather events across the country. However, accurate forecasts on their own have no value; forecasts gain value through their ability to influence decision-making. Fostering dialogue between all the sectors of the U.S. Weather Enterprise – public, private, and academic – will help us meet this challenge head-on.

U.S. Weather Enterprise

The U.S. Weather Enterprise (Enterprise) is an entity comprised of the public, private, and academic sectors that work collaboratively to provide timely and accurate weather products and services. The total value of weather data across all industries is approximately $13 billion.[2] A large part of the success of the Enterprise is due to open communication and collaboration between the three sectors, as each sector has a distinct and complementary role to play. The Enterprise is not static, but rather a dynamic entity where the roles of each sector continue to evolve and change. The Enterprise stands at a critical juncture as it is not considered the global leader in weather modeling and forecasting.

Nearly 30 years ago, weather data primarily came from public sector sources, but with the advancement of science and technology within the commercial sector of the Enterprise, non-federal sources of weather data have grown tremendously in recent years. While public sector sources of data continue to remain free and open to the public, some commercial data sources are proprietary. Given the rapid pace of technological advancement, the roles of each sector of the Enterprise have continued to advance as new user needs have emerged. Continued coordination and collaboration between the sectors is necessary to ensure that the entire Enterprise is working towards one common goal; improving the state of weather forecasting in the U.S. Instead of defining rigid roles for each sector, the key to successful partnerships thus far has been allowing flexibility in the interaction between the sectors with some delineation of core responsibilities for each.[3]

Public Sector NOAA's National Weather Service (NWS) is the operational face of weather forecasting in the U.S. The NWS provides long and short term terrestrial weather forecasts, operational forecasts and warnings for space weather, and issues warnings, watches, and advisories. The mission of the NWS is to "Provide weather, water, and climate data, forecasts and warnings for the protection of life and property and enhancement of the national economy."[4] NWS operations are made up of: NWS Headquarters, six Regional Headquarters, nine National

[1] https://www.ncdc.noaa.gov/billions/

[2] National Weather Service. 2017. *National Weather Service Enterprise Analysis Report: Findings on changes in the private weather industry.* https://www.weather.gov/media/about/Final_NWS%20Enterprise%20Analysis%20Report_June%202017.pdf

[3] National Research Council. 2003. *Fair Weather: Effective Partnership in Weather and Climate Services.* Washington, DC: The National Academies Press. https://doi.org/10.17226/10610.

[4] https://www.weather.gov/about/

Centers for Environmental Prediction (NCEP), 13 River Forecast Centers, 122 Weather Forecast Offices (WFOs), 21 Center Weather Service Units, 18 Weather Service Offices, two Tsunami Warning Centers, two Data Collection Offices, eight other National Centers, and the National Water Center. The WFOs provide specialized forecasts for their regions.

In April 2011, a tornado outbreak in Mississippi and Alabama resulted in significant loss of life and property damage, despite the NWS providing accurate forecasts with above average lead time for evacuation.[5] Following this event, NWS focused on its efforts to *Evolve* into a Weather-Ready Nation (WRN) to build "community resiliency in the face of increasing vulnerability to extreme weather, water, and climate events."[6] A key component of becoming a WRN is providing Impact-based Decision Support Services (IDSS) to local communities. The NWS works to provide forecasts and warnings to their partner decision-makers in state and local government, and the emergency management (EM) community through the WFOs. The partnership with the NWS has allowed the EM community to move from reacting to extreme weather events, to proactively preparing for weather events. NWS conducted an Operations and Workforce Analysis (OWA) from 2015-2016 to generate findings and recommendations to help the NWS move toward its vision to provide IDSS for a WRN. The OWA found that "the demand for IDSS [outstripped NWS's] ability to provide it across every county of the United States, and that [NWS's] current structure, workflow, and operational processes may not be ideally suited for providing the level of IDSS [NWS] partners need."[7]

The OWA made recommendations to help NWS make IDSS more widely available to its partners by freeing up forecaster time through the implementation of a Collaborative Forecast Process that would utilize the National Blend of Models (NBM). The NBM is a blend of NWS and non-NWS numerical weather prediction guidance that provides a nationally consistent starting point for forecasters in WFOs.[8] Additionally, the OWA recommended a General Schedule (GS) 5-12 career progression for meteorologists, which would put the field meteorologists onto a single career track and let them progress non-competitively from the GS-5 to GS-12 level based on the completion of certain core competencies. The NWS engages with the National Weather Service Employees Organization (NWSEO) on issues related to labor and staffing.

Other line offices within NOAA that support the mission of the NWS include the Office of Oceanic and Atmospheric Research (OAR) and the National Environmental Satellite, Data, and Information Service (NESDIS). OAR serves as the primary research arm of NOAA that provides the science needed for NOAA to achieve its strategic goals to: understand climate variability and change; serve society's needs for weather and water information; protect, restore and manage the use of coastal and ocean resources; and support the Nation's commerce with information for safe transportation. OAR administers collaborative long-term partnerships between NOAA and participating universities and other non-profit institutions. These partnerships include 16

[5] https://www.weather.gov/about/wrn
[6] https://www.weather.gov/wrn/force
[7] National Weather Service. 2017. *Operations and Workforce Analysis Catalog.* https://www.weather.gov/media/nws/OWA_Catalog_09072017.pdf
[8] https://www.weather.gov/mdl/nbm_home

Cooperative Research Institutes affiliated with NOAA Research Laboratories[9] and 33 Sea Grant Programs coordinated under the National Sea Grant College Program.[10]

NESDIS is responsible for providing observational data from NOAA's satellite constellation that feed into the NWS forecast models. The observations from polar and geostationary satellites is the backbone of numerical weather prediction at NWS. This satellite data is complemented through other observational technologies including radars, Argo buoys (free-drifting profiling floats that measure temperature and salinity in the oceans), and mesoscale data and networks. The National Academies found in a 2012 study that the NWS needs to leverage existing partnerships with the broader Enterprise to meet its mission and achieve the "greatest national good" beyond what the NWS budget alone would allow.[11] This hearing provides an opportunity to hear from all three sectors on how the NWS is doing to strengthen those partnerships.

Private Sector The private sector arm of the Enterprise is diverse and varied, with each individual business entity tailoring their unique products to their specific end-users. Due to fewer restraints, and the ability to take on more risk, than the federal government, the private sector of the Enterprise is on the cutting-edge of innovation and technology development. Much of the foundational data used by the private weather industry comes from NOAA and other federal agencies, and is used as a base to create new weather products and services for various end-users. This has developed into a lucrative secondary forecast market, with the U.S. private weather industry valued at approximately $7 billion.[12] However, private industry is also developing emerging space-based and ground-based observation technologies that could play a bigger role in providing observational weather data. Despite this potential paradigm shift in data collection, most private sector companies see the NWS as the authoritative voice for disseminating watches, warnings, and advisories to ensure public safety, [13] and work with the NWS to ensure the widest possible dissemination of these watches, warnings, and advisories.

Academia OAR research is supported by many outside academic entities such as research universities, cooperative institutes, and private research organizations. The University Corporation for Atmospheric Research and the National Center for Atmospheric Research (UCAR and NCAR) are two of the most visible manifestations of university-based weather research. Much of the research conducted by academic partners goes into the operational activities at the NWS. Many academic researchers conducting weather related research are funded by federal grants from the National Science Foundation (NSF), NOAA, and other federal agencies. In addition to conducting weather research, the academic sector is also responsible for training the next generation of meteorologists, scientists, and engineers that will make up the future Enterprise-wide workforce. The skills needed to be a successful part of the Enterprise have changed over time due to advances in science and technology, and emerging user needs.

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[9] https://ci.noaa.gov/Locations.aspx
[10] https://seagrant.noaa.gov/About
[11] National Research Council. 2012. *Weather Services for the Nation: Becoming Second to None*. Washington, DC: The National Academies Press. https://doi.org/10.17226/13429.
[12] National Weather Service Enterprise Analysis Report. 2017
[13] National Weather Service Enterprise Analysis Report. 2017

Research to Operations (R2O) and Operations to Research (O2R)
New innovations in science and technology can bring about significant improvement in operations and improve the effectiveness of an organization, but NOAA, and the federal government broadly, have not always been quick to adopt new technology. The National Academy of Public Administration noted that the NWS "does not have an efficient and effective means for identifying science and technology requirements, researching and developing them to maturity... and introducing them into operations." [14] NOAA's own Scientific Advisory Board (SAB) noted in 2013 that science is the foundation of NOAA's mission, but unless that science is successfully transitioned into operations, NOAA will fail in its mission.[15] The NOAA SAB recommended that an emphasis should be placed on a seamless transition in both Research to Operations (R2O) and Operations to Research (O2R) activities by developing strong partnerships between researchers and operational users at the beginning of a project to ensure the research conducted would meet operational needs.

Data Sharing
NOAA follows a free and open data policy by making all of its weather data available to the public. This freely available data has allowed academia access to thousands of data sets for meteorological research and has allowed the private weather industry to create value-added products and services that build upon NWS data. As more commercial entities develop the capability to collect their own proprietary environmental observations and weather data, the availability of these unique data sets to the public could potentially jeopardize not only academic research, but also the market for specialized weather products and services developed by the private sector.

NOAA Forecasting
The NWS uses numerical weather prediction (NWP) to develop forecasts by utilizing current data from space and ground based observation platforms. Ensemble predictions combine multiple runs of NWP models with different initial conditions or parameters, to better include information on the uncertainty of forecasts.[16] NOAA has been using the current NCEP Global Forecast System (GFS) weather forecast model for over 30 years as the basis of its weather models. NOAA is currently developing its next generation global prediction system which is based on the Finite Volume Cubed-Sphere dynamical core (FV3). The FV3 model was developed by NOAA's Geophysical Fluid Dynamics Laboratory, an OAR laboratory located in Princeton, NJ.[17] NOAA's phasing in of the GFS with the FV3 was delayed by the 35-day government shutdown and currently plans to make the FV3 operational sometime in 2019.

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[14] National Academy of Public Administration. 2013. *Forecast for the Future: Assuring the Capacity of the National Weather Service.* https://www.napawash.org/studies/academy-studies/forecast-for-the-future-assuring-the-capacity-of-the-national-weather-servi

[15] NOAA Science Advisory Board. 2013. *In the Nation's Best Interest: Making the Most of NOAA's Science Enterprise. A Report from the NOAA Science Advisory Board.* file:///C:/Users/pkh/Downloads/SAB%20R&D%20Portfolio%20Review%20Report%20to%20NOAA%20FINAL.pdf

[16] https://www.weather.gov/media/ajk/brochures/NumericalWeatherPrediction.pdf

[17] https://www.weather.gov/news/fv3

Congressional Activity

The Weather Forecasting and Innovation Act of 2017[18] (Weather Act) authorized research and development efforts at NOAA, primarily within OAR. It also prioritized the development of subseasonal (forecasts of two weeks to three months) to seasonal (forecasts of three months to two years) forecasts, and provided weather satellite and commercial weather data innovation and federal weather coordination. This legislation is currently being implemented by NOAA with a number of reports still due to Congress to track implementation. The reauthorization of the National Integrated Drought Information System (NIDIS) Act of 2018,[19] included the reauthorization of Title II of the Weather Act, and also authorized the Earth Prediction Innovation Center (EPIC), within OAR, to improve numerical weather prediction by creating a community global weather research modeling system.

Potential Impacts to Forecasting Due to 5G Spectrum Auctions

The Federal Communication Commission's (FCC) plans to have 5G operations share radiofrequency spectrum with Earth-observing satellites at the 24 GHz band would cause significant interference with federal weather data and forecasts. The 24 GHz band is adjacent to the band that is used by satellite-borne microwave sensors to measure water vapor, including NOAA's Joint Polar Satellite System (JPSS) Advanced Microwave Sounder (ATMS). Water vapor measurements are essential to numerical prediction of nearly every type of weather prediction, including rainfall, drought, sea surface temperature, soil moisture, and hurricane tracking. According to NOAA, water vapor data accounts for 85% of data that is used for weather forecast models. Due to the physical properties of water, water vapor can only be measured at the frequency bands currently allocated. The FCC's proposed radio frequency protection levels at 24 GHz (-20 dBW) would fail to safeguard water vapor measurements against interference. In a recent briefing to House Science Committee staff, NOAA said that this will cause an estimated 30% degradation in forecast error to operational numerical weather prediction models.

The FCC initiated an auction on March 14, 2019 for the 24 GHz band for commercial 5G services and applications, despite a bipartisan call from Chairwoman Johnson and Ranking Member Lucas to delay the auction until interagency concerns regarding weather data degradation were addressed.[20] On April 3, Chairwoman Johnson and Ranking Member Lucas sent a document request letter[21] to NOAA Acting Administrator Jacobs requesting the release of any studies NOAA has conducted that calculate a radio frequency protection level that would prevent interference with microwave sensor data. As of the time this hearing charter was sent, the Committee has not received a response from NOAA. On April 29, FCC Commissioner Ajit Pai responded to Chairwoman Johnson and Ranking Member Lucas's request to delay the 24 GHz Spectrum auction and said that the FCC had "not been presented with any evidence of harmful interference from these existing service nor a validated study suggesting operations in

[18] P.L. 115-25
[19] P.L. 115-423
[20] March 13, 2019. https://science.house.gov/letters-to-fcc-chairman-and-commissioners-arequesting-the-delay-of-5g-spectrum-auction
[21] April 3, 2019.
https://science.house.gov/imo/media/doc/4.3.19%20Jacobs%20NOAA%20impacts%20of%205G%20letter.pdf

accordance with these rules would adversely affect use of the 23.6-24 GHz allocation, including for weather forecasting."[22]

When asked about spectrum concerns at this Committee's Fiscal Year 2020 budget hearing for NASA earlier this year, Administrator Bridenstine said that the 24 GHz auction "could have an impact on NASA's missions" and bring the United States back to the 1970s when it comes to weather forecasting.[23] Similarly, NOAA Acting Administrator Jacobs expressed concern about interference with NOAA and NASA satellite-borne weather data at this Committee's Fiscal Year 2020 NOAA budget hearing on April 30, 2019.[24]

ADDITIONAL READING

Government Accountability Office. 2017. *National Weather Service – Actions Have Been Taken to Fill Increasing Vacancies but Opportunities Exist to Improve and Evaluate Hiring.* https://www.gao.gov/products/GAO-17-364

National Research Council. 2006. *Completing the Forecast: Characterizing and Communicating Uncertainty for Better Decisions Using Weather and Climate Forecasts.* Washington, DC: The National Academies Press. https://doi.org/10.17226/11699.

National Academies of Sciences, Engineering, and Medicine. 2018. *Integrating Social and Behavioral Sciences Within the Weather Enterprise*. Washington, DC: The National Academies Press. https://doi.org/10.17226/24865.

National Weather Service. 2013. *Weather-Ready Nation Roadmap.* https://www.weather.gov/media/wrn/nws_wrn_roadmap_final_april17.pdf

[22] April 29, 2019. https://science.house.gov/imo/media/doc/4.29.19%20Ajit%20Pai%20letter%20to%20EBJ.pdf
[23] House Committee on Science, Space, and Technology. April 2, 2019. *A Review of the NASA FY2020 Budget Request.* https://science.house.gov/hearings/a-review-of-the-nasa-fy2020-budget-request
[24] House Committee on Science, Space, and Technology. April 30, 2019. *A Review of the NOAA Fiscal Year 2020 Budget Request.* https://science.house.gov/hearings/a-review-of-the-noaa-fiscal-year-2020-budget-request

Chairwoman FLETCHER. This hearing will come to order. Without objection, the Chair is authorized to declare a recess at any time. Good afternoon, and welcome to today's hearing, entitled, "The Future of Forecasting: Building a Stronger U.S. Weather Enterprise". I would like to welcome and thank all of our witnesses for being here today to discuss the important topic of the U.S. weather enterprise, and how we can leverage the partnerships between the sectors to improve U.S. weather forecasting and modeling capabilities.

The U.S. weather enterprise is one of the most robust globally, with NOAA (National Oceanic and Atmospheric Administration) estimating the value of weather data across all industries in the U.S. at approximately $13 billion in 2012. This enterprise is built upon open communication and collaboration between its public, private, and academic sectors. Americans across the country rely on data and services NOAA and the National Weather Service (NWS) provide every single day. This freely available data serves as the basis of many of the consumer-facing weather products we regularly interact with, ranging from weather apps on our phones to the local forecasts on our TV news. This is a prime example of the strong existing partnerships between the public and private sectors of the enterprise.

This freely available data is also the foundation of much of the research conducted into the—in the academic sector that feeds into operations at the Weather Service. We've spoken in this Committee about the increased frequency of severe weather events that are impacting every part of the country. In fact, NOAA has found that, since 1980, the U.S. has experienced almost 250 weather and climate disasters in which the overall cost and damages have reached or exceeded $1 billion. A little over 2 weeks ago, Dr. Jacobs testified before this Committee on the NOAA Fiscal Year 2020 proposed budget, where he informed the Committee that the U.S. was not the global leader in weather forecasting. This is something that should be of concern for all Americans, given the need for accurate forecasts due to the wide range of severe weather events we experience as a Nation, and the increasing frequency of severe weather events due to climate change.

We've also discussed the need to accelerate research and operations at NOAA, but in no place is that more crucial than at the Weather Service, as it relates to improving U.S. weather models and forecasts. However, NOAA's budget request does not reflect this critical need, with more than 40 percent reduction in funding for the Office of Oceanic and Atmospheric Research, where much of NOAA's internal research is conducted, and extramural research is funded. I hope to better understand how NOAA and the Weather Service plan to address the significant research to operations challenge in light of the priorities articulated in this most recent budget request. I'm looking forward to this hearing starting the conversation about strengthening the enterprise, and I'm pleased to have representatives of all three sectors here today.

While the private sector is perhaps the most diverse of the three, we are fortunate to have Mr. Rich Sorkin, CEO of Jupiter Intelligence, testifying from the commercial perspective. Jupiter provides climate and weather risk analysis based on NOAA and other Federal and private sources of data. I would also like to welcome

Dr. Shuyi Chen, whose research at the University of Washington is focused on understanding extreme weather events, like hurricanes, and depends on Federal grants from agencies like NOAA. With the Atlantic hurricane season starting on June 1, I'm glad she's here to answer any questions about hurricane forecast improvement.

I'm also glad to have the opportunity to discuss an issue facing the enterprise, particularly NOAA, regarding the potential loss of our Nation's valuable weather data from interference from 5G operations at the 24 gigahertz band. I look forward to asking Dr. Jacobs for more clear cut answers to what these impacts will be, the cost to the American public, and how NOAA is working to mitigate these impacts. I am entering into the record a letter from the Aerospace Industries Association in support of this hearing, and the importance of addressing the 24 gigahertz issue. So ordered.

The weather enterprise is a dynamic entity that continues to evolve. Given how rapidly our technological capabilities are advancing, it is clear that we need to revisit the interaction between the sectors of the enterprise and understand how to best utilize these scientific and technological advancements for public good. That's why today's hearing should be a good opportunity to not only understand the current state of our weather enterprise, but how the three sectors of that enterprise can work together toward a common goal. Thank you.

[The prepared statement of Chairwoman Fletcher follows:]

Good afternoon. I would like to welcome and thank all of our witnesses for being here today to discuss the important topic of the U.S. Weather Enterprise and how we can leverage the partnerships between the sectors to improve U.S. weather forecasting and modeling capabilities.

The U.S. Weather Enterprise is one of the most robust globally, with NOAA estimating the value of weather data across all industries in the U.S. at approximately $13 billion in 2012. This Enterprise is built upon open communication and collaboration between its public, private, and academic sectors.

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A little over two weeks we ago, Dr. Jacobs testified before this Committee on the NOAA Fiscal Year 2020 Proposed Budget, where he informed the Committee that the U.S. was not the global leader in weather forecasting. This is something that should concern all Americans—given the need for accurate forecasts due to the wide range of severe weather events we experience as a nation and the increasing frequency of severe weather events due to climate change.

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I'm looking forward to this hearing starting the conversation about strengthening the Enterprise and am pleased to have representatives of all three sectors here today. While the private sector is perhaps the most diverse of the three, we are fortunate to have Mr. Rich Sorkin, CEO of Jupiter Intelligence, testifying from the commercial perspective. Jupiter provides climate and weather risk analysis based on NOAA and other federal and private sources of data. I would also like to welcome Dr. Shuyi Chen, whose research at the University of Washington is focused on understanding extreme weather events, like hurricanes, and depends on federal grants from agencies like NOAA. With the Atlantic hurricane season starting on June 1st, I am glad that she is here to answer any questions about hurricane forecast improvement.

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That's why today's hearing should be a good opportunity to not only understand the current state of our Weather Enterprise, but how the three sectors of that enterprise can work toward a common goal.

Thank you.

Chairwoman FLETCHER. I will now recognize Ranking Member Lucas of the Full Committee for his opening statement.

Mr. LUCAS. Thank you, Chairwoman Fletcher, for holding this hearing. As I stated in the NOAA budget hearing, weather forecasting is among the most important matters in this Committee's jurisdiction, and one of our top priorities in Congress. We rely on accurate weather forecasting for everything from efficient crop planting to protecting life and property. From hurricanes, to wildfires, to tornadoes, we have an obligation to provide our citizens the most accurate information on weather events so they can make informed decisions for their own wellbeing.

Weather forecasting is especially important in my home State. Two of Oklahoma's finest universities, Oklahoma State and the University of Oklahoma, have long histories of researching weather patterns. The National Weather Center is based in Norman, and is a national leader in researching climate and weather. This year marks the 25th anniversary of the creation of Oklahoma's Mesonet, founded as a partnership between the University of Oklahoma and Oklahoma State. The Mesonet consists of a series of environmental monitoring stations that provide data to customers across the State of Oklahoma. Our Mesonet is a valuable climate tool, and enjoys broad public support. I believe the Mesonet can serve as a model for improving forecasting across the Nation, and I look forward to discussing this with our witnesses.

This Committee has a bipartisan history of weather research and forecasting policy. During the 115th Congress, we passed the *Weather Research and Forecasting Innovation Act*. This legislation provided NOAA important tools to help address is sub-seasonal and seasonal forecasting abilities by partnering with the private sector to collect weather data and integrate it into the forecast. More recently Congress passed the National Integrated Drought Information System, known as NIDIS, the reauthorization built on pre-

vious efforts to help monitor and predict droughts, and attempt to mitigate those effects.

While Congress has taken steps to improve weather forecasting, we must be certain that other policies aren't undercutting our abilities. We've heard concerns from NASA and NOAA about the recent FCC (Federal Communications Commission) wireless spectrum auction could potentially undermine the quality of weather forecasts due to the overlap of frequencies used to detect moisture. We all support the many benefits of 5G, including faster and more reliable connections, but we must develop it in a way that doesn't lower the quality of our satellites' remote sensing abilities. I hope the FCC will work to address concerns raised by the science community.

I want to thank our witnesses for sharing their expertise today. We have a panel of government, private-sector, and academic witnesses whose perspectives should inform this Committee's actions moving forward. In closing, let me state that working toward improved weather forecasts will be a top priority for me in this Congress. While we have made progress in improving the accuracy of weather forecasting, many challenges remain. This Committee should be a leader in helping the Federal Government, the private sector, and the academic community pool its resources to take the next step in continuing American leadership in weather forecasting.

With that, Madam Chair, I yield back.

[The prepared statement of Mr. Lucas follows:]

Thank you, Chairwoman Fletcher, for holding this hearing. As I stated at the NOAA budget hearing, weather forecasting is among the most important matters in this Committee's jurisdiction and one of my top priorities this Congress.

We rely on accurate weather forecasting for everything from efficient crop planting to protecting life and property. From hurricanes to wildfires to tornadoes, we have an obligation to provide our citizens the most accurate information on weather events so that they can make informed decisions for their own well-being.

Weather forecasting is especially important in my home State. Two of Oklahoma's finest universities—Oklahoma State and the University of Oklahoma—have long histories of researching weather patterns. The National Weather Center is based in Norman and is a national leader in researching climate and weather.

This year marks the 25th anniversary of the creation of Oklahoma's Mesonet, founded as a partnership between the University of Oklahoma and Oklahoma State.

The Mesonet consists of a series of environmental monitoring stations which provide data to customers across the State of Oklahoma. Our Mesonet is a valuable climate tool and enjoys broad public support. I believe the Mesonet can serve as a model for improving forecasting across the nation and I look forward to discussing this with our witnesses.

This Committee has a bipartisan history of weather research and forecasting policy. During the 115th Congress, we passed the *Weather Research and Forecasting Innovation Act*. This legislation provided NOAA important tools to help address its sub-seasonal to seasonal forecasting abilities by partnering with the private sector to collect weather data and integrate it into its forecasts.

More recently, Congress passed the *National Integrated Drought Information System (Ny-dis) Reauthorization Act*. The NIDIS reauthorization built on previous efforts to help monitor and predict droughts and attempt to mitigate these effects.

While Congress has taken steps to improve weather forecasting, we must be certain that other policies aren't undercutting our abilities. We've heard concerns from NASA and NOAA that the recent FCC wireless spectrum auction could potentially undermine the quality of weather forecasts due to the overlap with frequencies used to detect moisture.

We all support the many benefits of 5G, including faster and more reliable connections. But we must deploy it in a way that doesn't lower the quality of our satellite's remote sensing abilities. I hope the FCC can work to address concerns raised by the science community.

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In closing, let me state that working toward improved weather forecasts will be a top priority for me this Congress. While we have made progress in improving the accuracy of weather forecasting, many challenges remain. This Committee should be a leader in helping the federal government, the private sector, and the academic community pool its resources to take the next step in continuing American leadership in weather forecasting.

Thank you, I yield back.

Chairwoman FLETCHER. Thank you, Mr. Lucas. If there are Members who wish to submit additional opening statements, your statements will be added to the record at this point.

[The prepared statement of Chairwoman Johnson follows:]

Thank you, Chair Fletcher. I would also like to thank our witnesses for joining us this afternoon.

The U.S. Weather Enterprise is comprised of academic, private, and public sectors. Our federally funded suite of environmental observations and weather and climate forecast models are complemented by a robust private sector. These private partners distribute National Weather Service watches, warnings, and advisories to ensure the widest dissemination of this information in order to adequately protect the public. The academic sector conducts cutting-edge research that feeds into our weather models and forecasts. They also train the next generation of scientists and engineers for the workforce of the Weather Enterprise.

Despite the strength and unique nature of our Weather Enterprise, our country is falling behind in weather forecasting.

Two years ago, Congress passed the *Weather Research and Forecasting Innovation Act*, which included, among other things, a focus on regaining U.S. leadership in weather modeling and forecasting. I hope our panel will touch upon the extent to which this legislation has moved the Weather Enterprise towards achieving this goal, and what remains to be done.

In order to keep up with other countries and be prepared for the weather risks associated with a changing climate, we need to optimize our investments in weather forecasting. It is vital that all sectors of the Weather Enterprise effectively coordinate to ensure efficiency and innovation. Setting clear, long-term, enterprise-wide goals can prevent duplication or gaps in capability.

The challenge of how to improve our weather models and forecasts will not be solved by the federal government alone. NOAA and the Weather Service must find ways to capitalize on the rapid development of new science, technology, observational capabilities, and high-performance computing both internally and within the private and academic sectors. Successfully making these innovative approaches operational is a key step to achieving this goal. Today's hearing will be a good starting point to understand the best path forward.

I look forward to hearing from our expert witness panel on how best to address this challenge and learn where we should prioritize federal investments in the Weather Enterprise to build upon the leadership and contributions of all three sectors. Thank you, and I yield back the balance of my time.

Chairwoman FLETCHER. At this time I'd like to introduce our witnesses. Our first witness, Dr. Neil Jacobs, was confirmed as the Assistant Secretary of Commerce for Environmental Observation and Prediction in February 2018. He's been performing the duties of Under Secretary of Commerce for Oceans and Atmosphere since February 2019. Prior to joining NOAA, Dr. Jacobs was Chief Atmospheric Scientist at Panasonic Avionics Corporation. He was also previously the chair of the American Meteorological Society's Forecast Improvement Group, and served on the World Meteorological Organization's aircraft-based observing team. Dr. Jacobs has a bachelor's degree in mathematics and physics from the University of South Carolina, and a master's and doctoral degrees in atmospheric science from North Carolina State University.

Our second witness from NOAA, Dr. Louis Uccellini, serves as the Assistant Administrator for Weather Services, and the Director

of the National Weather Service. Prior to this position, he served as the Director of the National Centers for Environmental Prediction (NCEP) for 14 years, where he directed the operations at nine NCEP centers. Before that, Dr. Uccellini has been the director of the National Weather Service's Office of Meteorology, chief of the National Weather Service's Meteorological Operations Division, and section head for the Mesoscale Analysis and Modeling Section of the Goddard Space Flight Center's Laboratory for Atmospheres. Dr. Uccellini received his Ph.D.,master's, and bachelor's of science degrees in meteorology from the University of Wisconsin, Madison.

Our third witness, Dr. Shuyi Chen, is a Professor of Atmospheric Sciences at the University of Washington. Her research focuses on understanding extreme weather, like hurricanes, and intraseasonal variability that affect the global weather and climate system, and improving their prediction. Dr. Chen has led national and international research programs in both field observations and coupled atmosphere ocean modeling. Currently she serves as the vice chair of National Academy's Board on the Atmospheric Science and Climate. She received her Ph.D. in meteorology from Penn State University, her master's in meteorology from the University of Oklahoma, and her B.S. in geophysics from Peking University.

The last witness that I will introduce is Mr. Rich Sorkin, the cofounder and CEO of Jupiter Intelligence. Jupiter provides data and analytic services to better predict and manage risks from weather and sea-level rise, storm intensification, and changing temperatures caused by medium- to long-term climate change. Mr. Sorkin has been involved in Silicon Valley startups for 3 decades, commercializing technologies in a wide variety of industries. Mr. Sorkin received his MBA from Stanford, and his bachelor's in economics from Yale.

The Chair will now recognize Ranking Member Lucas to introduce Dr. Christopher Fiebrich, who hails from his home State of Oklahoma.

Mr. LUCAS. Thank you, Chairwoman Fletcher, and I am pleased to welcome Dr. Fiebrich to our panel of witnesses today. Dr. Fiebrich is the Executive Director of the Oklahoma Mesonet and the Associate Director of the Oklahoma Climatology Survey of the University of Oklahoma. He oversees all activities of the Mesonet, ranging from sensor calibrations to research. Dr. Fiebrich has published 26 peer-reviewed articles on Mesonet activities and research in his career. His Oklahoma roots run deep. He has a bachelor's degree, a master's degree, and a Ph.D. from the University of Oklahoma, so thank you for being here today, Doctor. Yield back.

Chairwoman FLETCHER. Thank you, Mr. Lucas. Each witness will have 5 minutes for their spoken testimony. Your written testimony will be included in the record for the hearing. When you've completed your testimony, we'll begin with questions. Each Member will have 5 minutes to question the panel. We'll begin with Dr. Jacobs.

TESTIMONY OF HON. NEIL JACOBS, ASSISTANT SECRETARY OF COMMERCE FOR ENVIRONMENTAL OBSERVATION AND PREDICTION, PERFORMING THE DUTIES OF UNDER SECRETARY OF COMMERCE FOR OCEANS AND ATMOSPHERE, NOAA

Dr. JACOBS. Chairwoman Fletcher, Ranking Member Lucas, and Members of the Committee, thank you for the opportunity to testify today. Accelerated advancements in NOAA's global forecast system is a top priority. The future of forecasting in the U.S. weather enterprise is dependent on the success of this program, as this model serves as the underpinning for the majority of products and services offered by the National Weather Service and our industry partners.

A skillful global weather prediction system is based on three main components: Observations, code, and high-performance computing (HPC). NOAA is embracing new and novel in situ observing systems, such as smartphone pressure, as well as commercial aircraft and ship data. Many of these valuable observations are obtained from industry, academia, and State partners through the national Mesonet program. The commercial weather data pilot has proven successful, and NOAA is now planning to acquire GPS RO (radio occultation) data for operational use. Satellite data are the most critical inputs we have, and the polar orbiting passive microwave sounders account for 90 percent of the data used in the global model, and provide up to 30 percent of the forecast scale. How the observations are used in the model is based on the code. The upgrade to the FV3 GFS is tentatively planned for mid-June. Future critical advancements are focused on model physics and data assimilation. As part of the input quality control, as well as enhancing sub-grid scale output, NOAA is exploring cutting-edge artificial intelligence techniques.

To meet these objectives, NOAA plans to harness external expertise across the weather enterprise, from industry software engineers to university faculty and students. By standing up an outward-facing community model development program through the Earth Prediction Innovation Center (EPIC), which was authorized in the *National Integrated Drought Information Systems Reauthorization Act of 2018*. Based on the *Weather Research Forecasting Innovation Act of 2017*, EPIC will serve as the hub for building and maintaining a true community model. EPIC will significantly enhance our ability to access external expertise across the weather enterprise, and place the global modeling program on a path to regain U.S. leadership, as directed by the *NIDIS Reauthorization ACT of 2018*.

None of this sophisticated code can be developed, tested, or run without substantial HPC resources. On the operational forecasting side, NOAA has a 99.9 percent uptime availability requirement, with mirrored parallel systems that can fail over seamlessly to meet mission critical needs of severe weather forecasts. The National Weather Service is often compared to the European Center of Medium Range Weather Forecast when it comes to models, skill, and HPC resources. While we do have comparable systems, the European center only focuses on a single global modeling system,

whereas the National Weather Service runs dozens of models to address a wide range of issues, from weather and climate, to short range convection, hurricanes, ocean waves, air quality, storm surge, inland flooding, solar activity, and space weather.

Transitioning research to operations requires a significant amount of HPC. One option NOAA is exploring is cloud-based virtual HPC provided by commercial cloud vendors. The potential public-private partnerships can solve a wide range of problems, from limited availability of internal research compute, to providing systems that are accessible to the external model development community throughout the weather enterprise. Pilot programs within NOAA's satellite division, or NSDIS, have shown that the pre-processing of critical satellite data can be performed securely and reliably within these cloud-based architectures. By moving the processing to the location of the data, the potential exists to extract more value from existing satellite observations. Likewise, initial testings show that running the global model code in the cloud can offer a technically feasible and cost-effective alternative to internal HPC needed for research and development.

Finally, NOAA's Big Data Project has proven that commercial cloud-based storage is an extremely cost-effective solution for hosting and disseminating petabytes of environmental data. Making NOAA's data more easily accessible to the American public will create a substantial untapped opportunity for academic research and economic growth. Thank you again for the opportunity to testify today. I would be pleased to answer any questions you may have.

[The prepared joint statement of Dr. Jacobs and Dr. Uccellini follows:]

Dr. Neil Jacobs,
Assistant Secretary of Commerce for Environmental Observation and Prediction,
performing the duties of Under Secretary of Commerce for Oceans and Atmosphere

Dr. Louis Uccellini,
Assistant Administrator for Weather Services and
Director of the National Weather Service,
National Oceanic and Atmospheric Administration,
U.S. Department of Commerce

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

The Future of Forecasting: Building a Stronger U.S. Weather Enterprise
May 16, 2019

Introduction

It is our honor to testify before you today on the current status of and future opportunities for U.S. weather forecasting capabilities. The Department of Commerce's National Oceanic and Atmospheric Administration (NOAA) welcomes the opportunity to discuss this important topic. As a mission-driven, operational agency, NOAA's work spans observations and research to the delivery of critical forecasting products and services. NOAA's National Weather Service (NWS) works with NOAA's other line offices to realize our mission and implement the Weather Research and Forecasting Innovation Act of 2017 (Weather Act, Public Law 115-25), as passed by Congress in 2017 and reauthorized in part by Public Law 115-423 late last year.

NOAA is entrusted with the responsibility to provide environmental information and forecasts to the public, businesses, and governments to enable informed decisions on a range of issues and scales—local to global and short-term to long-term. The NWS provides a suite of products and services to the public, including the reliable and timely delivery of public weather and water forecasts and warnings. To do so, we work closely with the larger community of federal, state, local, tribal, and territorial emergency management officials, other federal agencies, the larger academic and research communities, and the commercial weather sector to deliver the best possible information. Put simply, NWS provides critical information that saves lives and property and enhances our national economy.

Evolving to Build a Weather-Ready Nation

The Department, NOAA, and NWS are strongly committed to ensuring that the United States is a Weather-Ready Nation[1] (WRN) in the face of threats related to extreme events. In 2010, Congress recognized that NWS' current operations were based on tools, workflows, and structures that are not designed to meet today's demands. Seeing the need for NWS to change, Congress directed that two studies be conducted.[2] The first examined the NWS Modernization and Restructuring of the 1990s as a background for moving forward and addressed "lessons learned to support future improvements to NWS capabilities." The follow-on study was directed by Congress in 2012 to focus on NWS operations and addressing user needs. The studies, completed in 2012 and 2013, reaffirmed NOAA's Weather-Ready Nation concept.

In response to these studies, NWS restructured its budget and headquarters to better align resources to function, enhance transparency, and link programmatic management structure to performance outcomes. This portfolio-based structure now reflects our core competencies – observations; central processing; analytics, forecast and support; dissemination; science and technology infusion; and facilities. Based on recommendations from the above Congressional studies, the NWS also contracted with a leading management and organization consultant to perform the Operations and Workforce Analysis (or OWA, 2017)[3,4].

The OWA focused on the NWS strategic vision to provide Impact-based Decision Support Services (IDSS) to build a Weather-Ready Nation, as codified in the Weather Act, and generated findings and ideas to implement that vision. In general, the analysis noted the high level of partner support for the NWS, its products and services, and the concept of IDSS. It found the NWS professional workforce is highly skilled, trained, and motivated in their mission delivery. The OWA also highlighted the previous contention from Congressional studies that the NWS structure, workflow, and operational processes should continue to be improved.

The OWA formed the basis for our ongoing "Evolve NWS" initiatives. A subset of these OWA recommendations have been transitioned to a testing and evaluation phase, including the GS-5-12 Career Progression, Weather Balloon Auto-launchers, and the Collaborative Forecast

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[1] https://www.noaa.gov/wrn

[2] "Weather Services for the Nation: Becoming Second to None," August 2012, National Academy of Sciences (NAS), https://www.nap.edu/catalog/13429/weather-services-for-the-nation-becoming-second-to-none ;
"Forecast for the Future: Assuring the Capacity of the National Weather Service" 2013, National Academy of Public Administration (NAPA), https://www.napawash.org/studies/academy-studies/forecast-for-the-future-assuring-the-capacity-of-the-national-weather-servi..

[3] https://www.weather.gov/owa-catalog

[4] Congress funded this initiative starting in Fiscal Year 2014, stating its "[support for] efforts by NWS to develop a framework for continuous improvement." Congress reiterated that support in the NWS fiscal 2016 and 2017 budgets, and codified it in the Weather Act (April 2017):SEC. 409. NATIONAL WEATHER SERVICE; OPERATIONS AND WORKFORCE ANALYSIS. The Under Secretary shall contract or continue to partner with an external organization to conduct a baseline analysis of National Weather Service operations and workforce.

Process/National Blend of Models. We have briefed Congress previously on these Evolve NWS[2] initiatives, and we look forward to continuing to provide updates to Congress.

The NWS is excited about the ideas and actions generated by the OWA that will inform our Evolve initiatives, implement the directives within the Weather Act, and improve the NWS as we connect our forecasts and warnings to decision makers at every government level and work with our partners to build a Weather-Ready Nation. The new NWS Strategic Plan[5], issued in April 2019, continues to focus on ensuring the U.S. is a Weather-Ready Nation and enabling the NWS to provide IDSS for extreme weather events. Moving forward, the NWS is committed to ensuring the NWS keeps pace with stakeholder and societal needs for forecasting that protects life and property and enhances the national economy

Improving Forecasts for Extreme Weather

In order to achieve a Weather-Ready Nation and implement the vision set forth by Congress in the Weather Act, the NWS is focused on making improvements to our science and technology, services, workforce, and partnership relations. We are working to sustain our observations database, including observations from geostationary and polar orbiting satellites. NOAA's weather satellites are critical for providing data that feeds numerical weather prediction models that must meet the increasing demands for more accurate and reliable forecasts and warnings. We are refocusing the NWS workforce to meet the needs for IDSS for our core partners in the emergency management community. We need to streamline, while ensuring the robustness of, the multiple pathways of disseminating our forecasts, watches, and warnings. We are improving an integrated weather-water approach to advance environmental predictions, especially along our coasts. We are supporting an active and engaged collaboration across the entire weather, water, and climate enterprise.

In order to advance weather forecasting, NOAA will pull from advances across all of the interdisciplinary fields of earth science, research, technology, and observations. We must leverage partnerships within government, academia, and the commercial sector, and we must actively pursue, in concert, a balanced program to advance all of the factors critical to success.

NWS strives to integrate the best advances in science and technology in order to provide the most accurate and timely forecasts possible. Much of our success comes from scientific and technological breakthroughs made by research that spans across disciplines, time, and space scales. The dynamic systems of this planet are interconnected in rich and complex ways, and success in forecast improvement comes by looking broadly across those linkages.

[5] https://www.weather.gov/news/192203-strategic-plan

Furthermore, NWS has evolved to provide more than just short-term weather forecasts and warnings. This work is focused on the IDSS concept, especially for federal, state, local, tribal, and territorial emergency managers. Our prediction capabilities are becoming a fusion point that emergency managers, broadcasters, federal agencies, and the public increasingly turn to as a trusted source that distills scientific information into a focus on weather-related impacts. This is done by embracing a number of interrelated fields of physical and social sciences, examining the atmosphere, oceans, land, ice, and space, and determining the best ways to communicate forecasts and warnings to ensure preparedness and response that can save lives and protect property. Emergency managers have told us that our forecasts have changed the way they do their work. Emergency managers are becoming more proactive and IDSS allows decision makers at all levels of government to make more informed decisions in the face of extreme events.

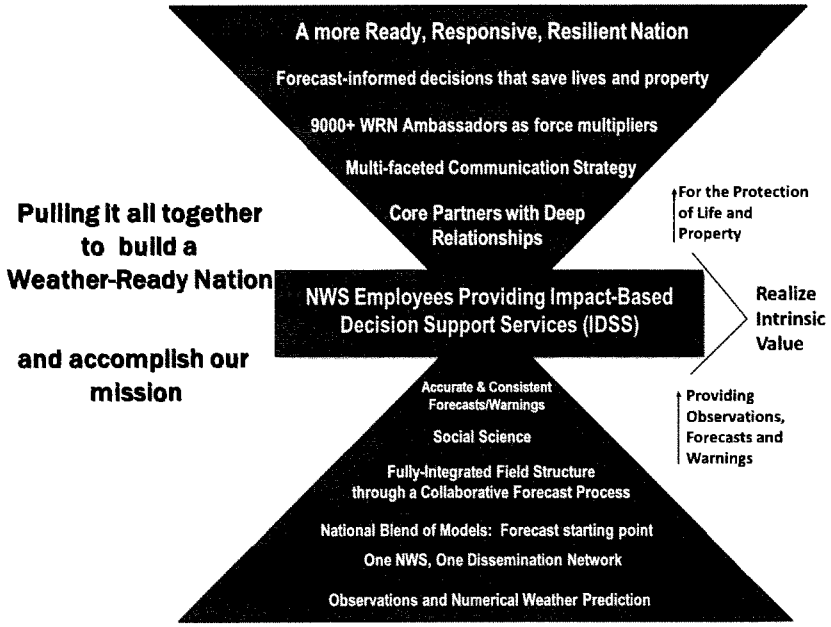
Several weather events over the past year have demonstrated the value of IDSS. In January of 2016, based on NWS forecasts and IDSS, New York City essentially closed ahead of a predicted major snowstorm. This allowed much quicker recovery efforts to bring the NYC area back to normal operations. This type of rapid recovery did not happen 10 or even 5 years ago. It's the confidence in the forecasts that are enabling these types of decisions.

We are constantly striving to better predict extreme weather events. Our forecasts of track, rainfall, and flooding for major hurricanes, Harvey, Maria, Michael, and Florence were excellent and our IDSS for the emergency managers proved critical. Hurricane Harvey was a particularly catastrophic storm for Texas. As the storm was making landfall near Corpus Christi, TX, the local fire chief was in constant dialogue with our local NWS office. There were people stranded on the barrier island. Our forecasters accurately predicted the timing of the eye's passage, allowing the fire chief to prepare and execute an evacuation. The fire chief credits the NWS decision support with saving over 200 lives. Also, for Harvey, the NWS predicted over 40 inches of rain that would cause catastrophic, record-setting flooding. Emergency managers in Houston took that extreme, unprecedented forecast to heart, making the decision to essentially close the city in advance of the heaviest rainfall.

This spring, the record floods in our Nation's heartland and northern plains were also accurately predicted by the NWS. NWS IDSS for key decision makers enabled them to make life and property saving decisions. In one example, after a meeting on March 7, 2019 the Grand Forks emergency manager immediately briefed Grand Forks city hall that he was planning to prepare for levee closures and contingencies for up to and including a Flood of Record based on NWS probabilistic outlooks updated that day. The Fargo, ND Metro area leaders took initial steps on March 18 to prepare for a community-wide fight against a potential Red River flood (almost two weeks before flooding began in the Fargo area). Fargo Mayor, Tim Mahoney, declared a state of

emergency[6] that day to initiate essential flood-fighting efforts as the city prepared for a possibility of a 40.3-foot crest.

The figure below captures the whole NWS forecasting process, from observations and numerical weather prediction and culminating with the final decision making. The lynchpin is NWS IDSS:



Designing the World's Best Weather Modeling Program

The backbone of NWS forecasts and warnings are the numerical weather prediction - or computer weather models. NWS forecasts and warnings are only as good as the infrastructure supporting them—from the *in situ* and remotely-sensed observations, to the computer weather models and high-performance supercomputers on which they run, to the dissemination network, to the actual facilities themselves. All weather forecasts start with observations from around the globe: satellites, upper air (weather balloon) soundings, surface, aircraft, and others. These data, used to best-eapture the current state of our environment, feed into our computer forecast

[6] https://www.valleynewslive.com/content/news/Mayor-Mahoney-declares-State-of-Emergency-sets-goal-of-one-million-sandbags-for-Flood-2019-507312361.html

models, which, using the best science and knowledge of atmospheric physics, generate "guidance" our forecasters use to issue their forecasts.

At the heart of the effort to improve this guidance is advancing NOAA's Next-Generation Global Prediction System (NGGPS). As we advance the NGGPS, we continue to advance NGGPS ensemble forecasts. While more observational data is typically better, no matter how much data we obtain, we still have gaps and errors in the initial conditions for numerical models. Furthermore, we cannot "model" the exact wind field everywhere or the exact temperature everywhere. Since we know that the best depiction we have is not perfect, we approximate these "initial conditions" and then rerun the models, based on our best estimated spread on this operational database. We do this dozens of times creating an "ensemble" of our model forecasts. This is done for many of our models, the global model, the regional models, and the short-term high-resolution models. Many of the solutions aligning within an envelope increases the confidence that the model solutions are pointing toward a specific event. If this does not happen, then most often there is more uncertainty in the forecast. A great example of "ensembles" is the hurricane spaghetti plots– with the tracks sometimes going every which way, and other times aligned within a narrow area.

NOAA is developing its next generation global prediction system, and at its heart is the Finite-Volume Cubed-Sphere dynamical core (FV3) modernizing NWS's approach to weather modelling. A dynamical core consists of a system of equations that can predict changes in temperature and movement in the atmosphere, such as moisture traveling through the water cycle, all the ingredients needed to describe changes in the weather. We expect the new model will be more accurate and more reliable, and be the global model that is used as a basis for all weather forecasts in the U.S. The FV3 core enables the model to provide localized forecasts for several weather events simultaneously, all while generating a global forecast every six hours. Looking 10 years ahead, the "American" Global Forecast System (or GFS) model with the FV3 core will run in higher resolution and be able to zoom in on smaller and smaller storm systems to provide forecasters better pictures of how storms will evolve.

NOAA is working toward a Unified Forecasting System which will facilitate the federal, academic, and private sectors to all work on the research version of the operational forecast model. NOAA's Earth Prediction Innovation Center (EPIC)—as codified by Congress in December 2018's reauthorization of the Weather Act—will advance U.S. weather modeling and reclaim international leadership in the area of numerical weather prediction. While strides have been made recently, in the past it has been difficult for the NWS to incorporate model developments from non-NOAA sources. EPIC will provide the framework for a "community modeling" effort to provide outside research partners the ability to test, evaluate and provide feedback on the American modeling system. This is expected to minimize the barrier between NOAA's modeling and the outside world and accelerate model development and improvements. EPIC will use cloud computing so multiple users could run the model simultaneously. As proposed, EPIC will be a center with no single physical location, but operated from within existing NOAA modeling groups and other institutions serving the larger research and academic

community. Where appropriate, NOAA will look to partner with other Federal agencies and institutions of higher learning/academia to further this initiative. The President's FY 2020 Budget proposes $15.0 million for EPIC (which includes $12.3 million in new appropriations and a $2.7 million transfer from the National Environmental Satellite, Data, and Information Service).

Building the Next-Generation Global Prediction System will take a tremendous amount of testing, analysis and verification. Model components, including the physics package, data assimilation, and post processing—all parts of the existing architecture—will be rebuilt and improved to work with new software as part of EPIC.

Another innovative forecasting tool available to NWS forecasters is NOAA's National Water Model (NWM). The NWM provided accurate flood forecast information for the catastrophic flood levels experienced in North Carolina during Hurricane Florence. NWS forecasts of record precipitation fed extremely accurate river flood level forecasts and duration, which helped emergency managers and responders plan for and respond to the flooding. The NWM simulates conditions for 2.7 million stream reaches across the continental U.S. and Hawaii every hour, and improves NOAA's ability to provide more frequent, accurate, and expanded water information used to save lives and protect property. The NWM is not yet fully operational and is being updated to incorporate the latest research and development that is occurring in the academic sector. The goal is to provide predictions of inundation from river and stream flooding for emergency managers and other decision makers for them to make informed decisions about potential impaets.

Collaborative Forecast Process & the National Blend of Models

The OWA reports also point to weather forecast *process* improvements necessary for building a Weather-Ready Nation. While working with emergency managers, our forecasters often hear about the need to have consistent forecast information from one Weather Forecast Office to the next, and from national centers to the local level. One way to achieve this goal—as recommended by the OWA—is the NWS's development of a Collaborative Forecast Process (CFP). This process ensures NWS provides weather and water data, forecasts, and warnings for the protection of life and property and the enhancement of the national economy in the most efficient, effective, and consistent way possible. The CFP develops a single authoritative source for forecasts by layering national and local expertise onto a common starting point. By making the best use of models and technology described above, this process can reduce duplication and increase consistency. A central tool the NWS is developing to facilitate consistency and allow forecasters to work more with decision makers is the National Blend of Models (NBM).

Before diving into the process in selecting this approach, understanding what makes up a "blend of models" is important. As previously noted, NOAA runs ensembles of weather models on our high-performance supercomputing system and non-NOAA entities also run weather models. The output of all of these models individually provide guidance to issue weather forecasts. Research

has shown that by averaging the output of various model parameters (i.e. temperature, wind, pressure, etc.) the "blended" or ensemble forecast guidance provides increased skill and accuracy.

The use of blends has been around for more than a decade and some NWS regions have adopted regional blends and policies that encourage the use of the blend as a common starting point for the forecast. While a regional blended model approach has improved forecasts locally, forecast inconsistencies between regions can still occur. In response to these inconsistencies, the development of a national blended model output is required and is nearing operational implementation In the aftermath of Hurricane Sandy, Congress recognized the potential benefits of this approach and funded NOAA to develop and implement a national blend of models through the Disaster Relief Supplemental Appropriations Act of 2013.

In response to various recommendations and assessments, the NBM Project was officially launched in 2013. This project is an effort to develop a nationally consistent set of foundational gridded guidance products based on well-calibrated NWS and non-NWS model information. Today, the NBM is currently operating in an experimental status in accordance with the approval memo for the Experimental Implementation of Guidance from the National Blend of Models in August 2016. On October 3, 2018, NBM v3.1 was successfully implemented on NOAA's operational high-performance weather supercomputing system. The model is supported operationally for experimental use by NWS offices.

The NBM includes all operational numerical weather prediction models including GFS, Navy, Canadian, European Center for Medium Range Weather Forecasting (ECMWF or "Euro"), including both deterministic global models as well as global ensembles. In addition, regional ensembles including High Resolution Rapid Refresh (HRRR) and High Resolution Ensemble Forecast (HREF), also are included in the NBM.

Ensuring a Robust Weather Observations and Infrastructure Backbone

Observations

Observations are critical to effective forecasts. Observations integrated into the models and NWS forecast operations range from surface observing stations (including mesonet data), ocean, coastal, and Great Lakes buoys, radars, weather balloon (radiosonde) launches, aircraft-collected readings, and satellite remotely-sensed data.

The bellwether observation tool for tornado, flash flood, and severe weather warnings is the Next Generation Doppler Weather Radar (NEXRAD). The Federal NEXRAD program is a tri-agency effort among the Department of Defense, Federal Aviation Administration, and the Department of Commerce/NOAA. The NEXRADs were deployed in the early-mid 1990s and recently reached their designed 20-year service life. The three agencies are close on schedule and about three years away from completing a Service Life Extension Program (SLEP) for the NEXRADs

providing a technology refresh and overhaul of necessary parts and subsystems to ensure the system can perform reliably for another 20 years. The SLEP replaces the signal processor, the transmitter, the pedestal and the shelter.

Of the data actually assimilated into NWS numerical weather prediction models that are used to produce the longer-term weather forecasts three days and beyond, over 93 percent comes from satellites, of which over 80 percent are from polar-orbiting satellites. Polar orbiting satellites that feed these models include: NOAA's Joint Polar Satellite System program satellite (NOAA-20), which became operational on May 30, 2018 and the National Aeronautics and Space Administration (NASA)/NOAA Suomi National Polar-orbiting Partnership (Suomi NPP) satellite, both in the afternoon orbit, and EUMETSAT's Metop satellites in the mid-morning orbit. This data is supplemented by legacy satellite data from NOAA's Polar-orbiting Operational Environmental Satellites (POES), the NASA Earth Observing Satellites (EOS), and the Department of Defense's Defense Meteorological Satellite Program (DMSP). Satellites from the Geostationary Operational Environmental Satellites-R Series program (GOES-R Series) are providing valuable data in the GOES East and West positions, along with the NEXRAD, to assist operational weather forecasters with monitoring existing conditions and providing essential information over data-sparse areas, including the oceans. NOAA is committed to providing high quality satellite data through the Joint Polar Satellite System and GOES-R Series programs. The FY20 President's Budget requests funds to begin the multi-year process of developing NOAA's satellite observing systems architecture, which will lead to a more cost-effective and resilient satellite architecture.

Dissemination

Fulfilling the NWS mission depends on transmitting critical data to forecasters within NWS, as well as delivering forecast products and services to the public and the Weather Enterprise. The NWS mission will not be met if the information is not delivered in a reliable and timely manner. In FY 2014, the NWS established the Integrated Dissemination Program (IDP). The goal of the IDP is to transform the organization's dissemination capabilities from a collection of independent communications stovepipes to an integrated, common, operational dissemination service.

NWS defined the scope of IDP focusing on a set of the most critical systems needed to deliver NWS watches and warnings. The goals for IDP included 100 percent primary and backup dissemination services with a geographically-diverse footprint for NWS critical systems; improved communications bandwidth, resilience, scalability, and security; and an increased access to environmental data using diverse methods and data formats.

The technology infrastructure created through the IDP is deployed at two distinct and geographically diverse locations. This 100 percent backup capability for delivery of NWS reliable and timely critical observations, model guidance, forecast, and watches and warning

information was achieved for the first time in history. The OneNWS Network[7] is operationally used at all local, regional, and national NWS forecast units (including all Weather Forecast Offices, River Forecast Centers, Regional Headquarters, and National Centers for Environmental Prediction) to support mission-critical coordination. Data delivery services were upgraded and the bandwidth was increased tenfold.

IDP has proven to be a powerful resource for the NWS. This was evident during the 2017 and 2018 hurricane seasons, when the IDP infrastructure, upgraded OneNWS Network, and a newly implemented video-enabled hurricane hotline communication system performed flawlessly during the most critical times. However, the level of demand the NWS anticipated on the system has been far exceeded. The IDP infrastructure—planned and developed just five years ago—is reaching its maximum capacity and user demands continue to grow. NWS is exploring the potential of using public cloud-based computing services to meet the demands for IDP.

Facilities

The NWS Office of Facilities is responsible for maintaining adequate physical infrastructure across all NWS offices. There are approximately 190 complexes that are maintained through upgrades or physical improvements, system replacements, or considered for relocation. Many of the NWS-owned facilities were constructed during the Modernization and Restructuring of the NWS in 1990s and are beginning to show their wear. The Joint Explanatory Statement Report accompanying the Consolidated Appropriations Act, 2018 (Public Law 115-141) included language requiring NWS to submit a report prioritizing NWS deferred facilities maintenance needs based on condition assessments, as well as estimated costs associated with these facilities.

This report was delivered to Congress in July 2018. NOAA is currently updating the report for FY 2019. This update will address NWS' prioritized approach to deferred maintenance requests and infrastructure improvements. However, NOAA is also doing a NOAA-wide assessment of all of its facilities, which will allow us to make informed decisions regarding our facilities portfolio that improve agency operations overall, including for NWS.

Improving Staffing and Labor Relations

Hiring staff for critical, operational positions remains a top priority of the NWS. Vacancies in operational units cause significant strain on our ability to consistently operate 24/7/365 and deliver the life-safety services the public and our partners expect.

After several years of a downward trend, we have begun to turn the corner by addressing deficiencies in NOAA and DOC's workforce management and security clearance process.

[7] https://www.weather.gov/news/181207-one-nws-network

Staffing levels are currently at approximately 91.5 percent of our appropriated level. Working with the NOAA Office of Human Capital Services (OHCS, formerly the NOAA Workforce Management Office), NWS is hiring staff as quickly as possible within appropriated funding levels. Per Congressional direction in recent Appropriations bills, NWS has focused on expediting new hires, and our efforts are bearing fruit. During calendar year 2018, NWS hires exceeded attrition for the first time since 2011. While the NWS continues to demonstrate significant improvement in hiring staff for FY18 (544 hiring actions) and the beginning of FY 2019 (194 hired to date), hiring activity was stalled during the lapse in appropriations earlier this year and recovery will take time. There are currently 434 funded vacancies in the NWS and there are 252 hiring actions in progress at this time, with those actions expected to rise. Concurrently, we are analyzing the vacant positions and determining how the associated resources would best benefit NOAA.

However, the NWS and NOAA's OHCS, combined with oversight, assistance, and innovations from DOC Enterprise Services, are working hard to improve hiring performance. To assist with NWS hiring, DOC has hired a contractor (YRCI), which has demonstrated excellent customer service and a quick turnaround time for hiring actions. YRCI's worked with NWS to implement hiring process efficiencies that drove NWS's "time- to- hire" to the lowest time among NOAA line offices. These OHCS-approved efficiencies included use of a nationwide 120-day open announcement for lead forecasters, standardized position descriptions across the agency, bundled junior meteorologist announcements, and released nationwide vacancy announcements three times per year. These actions will enable vacancies to be more quickly filled from a qualified applicant pool.

GS 5-12 Career Progression

NWS has been working for several years on initiatives to increase the agility of the workforce within forecast offices as we provide improved IDSS to our key partners. We have briefed congressional staff previously on this component of the Evolve initiative. In coordination with the National Weather Service Employees Organization (NWSEO), we are now implementing a General Schedule (GS) 5-12 career progression. This will place our field meteorologists into a single career track and allows them to progress non-competitively from the GS -5 level to the GS-12 level, based on completing competencies at each progressive level.

Moving to a single career progression for meteorologists provide staff with a clear career path, and opportunity to advance, and the ability to contribute to the office operations based on their competencies. Having all meteorologists in one career progression will provide more flexibility to field units when assigning work, allowing offices more resources to provide IDSS to the communities and partners they support. We expect this initiative will also reduce the administrative burden involved with hiring and promoting field staff and lower the yearly relocation costs NWS pays for internal promotions.

Many employees throughout the NWS have expressed support for this initiative. With this change, all 1340-series NWS employees will be called 'Meteorologists' instead of 'Interns.,' In the past, the "Intern" designation was very confusing to those outside the NWS given that employees in those positions typically possess years of training (and sometimes decades of previous experience with the military). All will have new promotion potential to a higher grade, and a clear pathway on how to achieve it.

Throughout the remainder of FY2019, we expect to transition over 1,000 employees into new position descriptions and performance plans and begin competency training and assessments for the new career progression. We have initiated management training on the new career progression that the 5-12 initiative offers and on their responsibilities related to managing the transition process for the workforce.

NWS management will continue to provide direct communications to NWSEO and our employees on this effort as well as engage with our employees through regular announcements, a dedicated webpage, and internal feedback mechanisms.

NWS management and NWSEO had success agreeing to move forward with the GS 5-12 Career Progression initiative and we continue to work with the union on this and other issues pertaining to the workforce. We are continuing to negotiate with NWSEO on a new Collective Bargaining Agreement that will modernize the current, outdated agreement.

Implementing the Weather Research and Forecasting and Innovation Act

Weather Research and Forecasting Innovation Act of 2017 (Public Law 115-25), and its recent reauthorization and extension in December 2018, provides excellent direction for NOAA and the NWS, as noted throughout this testimony. The Weather Act will continue to drive innovation, enhanced research-to-operations coordination, and NOAA's efforts to build a weather-ready nation. Implementing the Act is one of NOAA's highest priorities, and we look forward to continuing to work with Congress to execute its vision to the fullest extent.

Conclusion

NWS 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, to our people—forecasters, modelers, technicians and managers and it 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. We are proud of the NWS, especially our people who are on the front lines delivering critical products and services every day to help keep our citizens safe.

The protection of the people of the United States from the devastation that weather can bring is a duty given to NOAA. Together, we must ensure NWS services and operations lives up to this duty. We have come a long way, but there is more we need to do to become a Weather-Ready Nation—to be ready for the event, to be responsive, and to be resilient

National Oceanic and Atmospheric Administration
U.S. Department of Commerce

Dr. Neil Jacobs

Assistant Secretary of Commerce for Environmental Observation and Prediction, performing the duties of Under Secretary of Commerce for Oceans and Atmosphere

Dr. Neil Jacobs is the Assistant Secretary of Commerce for Environmental Observation and Prediction, performing the duties of Under Secretary of Commerce for Oceans and Atmosphere. Dr. Jacobs is responsible for the strategic direction and oversight of over $5.54 billion in annual spending, including key investments in developing a community model framework to advance U.S. weather modeling and prediction, space innovation, streamlining unmanned systems research to provide critical data across NOAA's mission areas, and unlocking the partnership potential of non-governmental and private organizations to study our nation's oceans and promote a blue economy.

Previously as the Chief Atmospheric Scientist at Panasonic Avionics Corporation, he directed the research and development of both the aviation weather observing platform and weather forecast model programs. He was previously the Chair of the American Meteorological Society's Forecast Improvement Group, and also served on the World Meteorological Organization's aircraft-based observing systems expert team.

Dr. Jacobs holds a bachelor degree in mathematics and physics from the University of South Carolina and masters and doctoral degrees in atmospheric science from North Carolina State University.

NATIONAL WEATHER SERVICE
NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION

Dr. Louis W. Uccellini

National Weather Service Organization
National Program

Dr. Louis W. Uccellini
Assistant Administrator for Weather Services,
National Oceanic and Atmospheric Administration (NOAA),
and Director, National Weather Service
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Dr. Louis W. Uccellini is the National Oceanic and Atmospheric Administration's Assistant Administrator for Weather Services, and Director of the National Weather Service. In this role, he is responsible for the day-to-day civilian weather operations for the United States, its territories, adjacent waters, and ocean areas.

Prior to this position, he served as the Director of the National Centers for Environmental Prediction (NCEP) for 14 years. He was responsible for directing and planning the science, technology, and operations related to NCEP's nine centers: Central Operations, Environmental Modeling Center, Ocean Prediction Center, Hydrometeorological Prediction Center, Climate Prediction Center, all in Camp Springs, MD; the National Hurricane Center in Miami, FL; Storm Prediction Center in Norman, OK; Space Weather Prediction Center in Boulder, CO; and the Aviation Weather Center in Kansas City, MO. With his leadership, the 13 year effort to plan, develop and build the new NOAA Center for Weather and Climate Prediction (the NCWCP Building) at the University of Maryland M Squared Research Center was completed; as was the implementation of a Seamless Suite of Models from the S2S to Mesoscale modeling systems based on the principle of multi model ensembles.

Dr. Uccellini was the Director of the National Weather Service's Office of Meteorology from 1994 to 1999, Chief of the National Weather Service's Meteorological Operations Division from 1989 to 1994, and section head for the Mesoscale Analysis and Modeling Section at the Goddard Space Flight Center's Laboratory for Atmospheres from 1978 to 1989.

Dr. Uccellini received his Ph.D. (1977), Master (1972) and Bachelor of Science (1971) degrees in meteorology from the University of Wisconsin-Madison. He has published more than 70+ peer-reviewed articles and chapters in books on subjects including analysis of severe weather outbreaks, snowstorms, gravity waves, jet streaks, cyclones, and the use of satellite data in analysis and modeling applications and more recently the basis for the Joint Center for Satellite Data Assimilation, the WMO based Grand Challenge for Seamless Prediction and the Restructuring of the NWS to Build a Weather Ready Nation. He is the co-author of a widely acclaimed two-volume American Meteorological Society (AMS) monograph Northeast Snowstorms, published in 2004, and authored chapters in the 1990 AMS publication Extratropical Cyclones, the 1999 AMS publication The Life Cycles of Extratropical Cyclones, and the 2008 AMS publication Synoptic Dynamic Meteorology and Weather Analysis and Forecasting.

Dr. Uccellini is the Permanent US Representative at the World Meteorological Organization, and has served on many national and international research and field experiment programs. He has received many awards in recognition of his research and operational achievements including the Maryland Academy of Sciences Distinguished Young Scientist Award (1981), the NASA Medal for Exceptional Scientific Achievement (1985), the AMS's prestigious Clarence Leroy Meisinger Award (1985), the Cleveland Abbe Award (2016), and the National Weather Association's Research Achievement Awards for Significant Contributions to Operational Meteorology (1996). He was elected as President of the AMS in 2012- 2013 and served as Co-Chief Editor of Weather and Forecasting from 1988-1992. In 2001 he received the U.S. Presidential Meritorious Executive Rank Award and in 2006 he received the U.S. Presidential Distinguished Rank Award.

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Chairwoman FLETCHER. Thank you, Dr. Jacobs. Dr. Uccellini?

TESTIMONY OF DR. LOUIS UCCELLINI, ASSISTANT ADMINISTRATOR FOR WEATHER SERVICES AND DIRECTOR OF THE NATIONAL WEATHER SERVICE, NOAA

Dr. UCCELLINI. Good afternoon, Chairwoman Fletcher, Ranking Member Lucas, and Members of the Subcommittee, and—for—and thank you for inviting me to this very important hearing. It's come at a—at the right time. Our Nation is experiencing an increase in, and impacts from, extreme weather events, such as devastating wildfires and floods, heat spells, snow and ice storms, tornado outbreaks, and catastrophic hurricanes. All of these events are well forecast, and have been well forecast, days in advance by the best forecasters in the world, the men and women of the National Weather Service. Weather Service forecasts execute their daily mission by working with emergency managers and other decisionmakers at all levels of government. They do this through a process called impact-based decision support services, that connects our forecasters directly to decisionmakers, communicating critical information so they can prepare a community in advance of extreme weather and water events to save lives and mitigate property loss.

Decision support is a major component of our updated strategic plan, that envisions building a weather-ready nation to ensure communities are ready, responsive, and resilient in the face of upcoming extreme events. This plan is embraced by our workforce, who now incorporate decision support into their daily work. The vision is also embraced by a large component of academic, research, and private-sector components of the weatherprise, as reflected by the growing list of 9,300 plus Weather-Ready Nation Ambassadors, organizations all working with the National Weather Service to achieve this formidable goal.

Executing our mission requires a comprehensive forecast process that begins with global observations, as you've just heard. Processing those data, running weather, water, and seasonal climate computer models on supercomputers, forecasters applying their expertise and training to use that information to develop accurate forecasts and warnings, disseminating the information, and then supporting critical decisions made by our core partners. Underpinning all of this work are many research and development activities, and the critical facility infrastructures that support advancing the Weather Service to stay at the top of our operational capabilities, for we are only as strong as our weakest link.

We are pushing the limits of scientific understanding of the interactions of space, atmosphere, oceans, land, hydrology, and ice. More research needs to be done to understand how these Earth system elements interact to enable us to improve our model-based predictive capabilities of weather and water from the short term to the seasonal timeframe. Our partners have told us that communicating and delivering consistent and accurate forecasts to them is key. To facilitate consistency and allow our forecasters to work more with decisionmakers, we are developing a new tool called the National Blend of Models (NBMs). This tool will combine the best aspect of over 170 national and international forecast model members at any one time to produce a blended 7-day forecast. The goal

of the NBM is to serve as a scientifically valid common starting point to drive more accurate and consistent forecasts across the Nation.

Disseminating our environmental information internally and externally is critical to making the entire weather and water enterprise function. We established the Integrated Dissemination Program to transfer the organization's communication capabilities into an integrated, common operational service, with 100-percent backup capability for the first time in the history of the Weather Service. Data delivery services were upgraded, and the bandwidth to all Weather Service officers and external users increased tenfold.

The level of demand on this system has far exceeded what was anticipated, and is now reaching its maximum capacity as user demands continue to grow. We need to continue system and infrastructure enhancements to ensure future capacity and reliability meet these additional user requirements. Hiring expert forecasters and other critical operational positions is a top priority for us. Through a focused program of policy and programmatic innovations, we have turned a corner. Calendar year 2018 was the first year in nearly a decade that hiring outpaced attrition for that year.

In summary, moving forward depends on fundamental advancements across a full spectrum of activities, including our forecasts—our forecasters embracing decision support, the Weather Service engaging the private sector across the entire value chain, advancements in science and technology, improved partnerships with academic research and the broader research communities that reach across many disciplines in the physical and social sciences, transitioning these research activities into operations. As directed by the *2017/2019 Weather Act*, the Weather Service is evolving to provide more than just weather and water forecasts and warnings. It is also providing decision support services for Federal, State, local, tribal, territorial, emergency managers, and water resource managers. Emergency managers have told us that their partnership with us has revolutionized the emergency management community from one that reacts to events to one that proactively prepares and stays ahead of extreme events.

I am proud of the National Weather Service, especially our people, who are on the front lines delivering critical products and services every day to help keep our citizens safe. We have come a long way, but there's more we need to do for communities to be ready, responsive, resilient for the next event, to be a weather-ready nation. Thank you.

Chairwoman FLETCHER. Thank you, Dr. Uccellini. Dr. Chen?

TESTIMONY OF DR. SHUYI S. CHEN,
PROFESSOR, DEPARTMENT OF ATMOSPHERIC SCIENCES,
UNIVERSITY OF WASHINGTON

Dr. CHEN. Chairwoman Fletcher, Ranking Member Lucas, and all other Committee Members, thank you for the opportunity to testify today. Based on the questions from the Committee in my invitation to testify, I organized my testimony around four topics: Building a stronger U.S. weather enterprise and working toward a common goal, enhanced national forecast capability and meeting workforce need to support national forecasting capabilities, and, fi-

nally, we would like to chart a way forward for the U.S. weather enterprise.

Accurate, actionable weather forecasts and warnings can help save lives and reduce economic loss. Over the past 2 decades, weather research has enabled tremendous progress in better understanding weather process and our ability to observe and predict weather. Atmospheric scientists of the United States are among the best in the world. However, the United States no longer leads the field of numerical weather prediction, as documented clearly by a number of National Academies reports. I believe that we have the ability to fully realize our potential in weather forecasting, be the best in the world. We must first understand the challenges we're facing so we can identify our weakness, find a solution, making progress. We need to build a strong U.S. weather enterprise working toward a common goal. I applaud the Committee for taking such an important initiative to address this issue in today's hearing.

So I projected on the screen—you can see the weather enterprise is complex, has changed significantly over the past 15 years, and continues to evolve rapidly. We're facing challenges to meet the growing need for weather and climate information in society. To address these challenges, we first should recognize we have some specific things we need to do, for instance, model development. We need weather forecasts with long lead time. Weather knows no boundaries. What happens over the Indian Ocean and the Pacific Ocean can influence rainfall and flooding, heat wave, drought, and the potential for wildfires in the United States on a time scale of weeks to months, so to—predicting these phenomena, we will need to represent the slow varying part of the Earth's system, ocean, land, and sea ice in our weather forecasting model. On the other hand, impact of weather is all very local. Hurricanes Harvey, Irma, and Maria showed us very clearly we need the level of forecast detail down to the street level for storm surge and flooding, and that aid for the decisionmaking, like in emergency management, and the electrical grids, and the infrastructure, and for recovery process as well.

The other challenge we have is the research-to-operation, which is an unmet challenge. We have tried to communicate it for many years now. That remains to be a problem because many of the research product has no pathway—go into operation as we know today. Advancement in technology, such as high-performance computing, cloud-based computing, artificial intelligence, new observing capability, and communication capability present a number of opportunities for us to really meet these challenges of the system. So, in order to move forward, I would like to see the uncoordinated enterprise, as we see in the top left (on the slide), move toward enterprise that works toward a common goal. To do that transition, from my perspective, I would have a few recommendations.

One, we would like to launch a study by the National Academies on the future of the weather enterprise. This study can help us to assess the current state of enterprise, and the way forward with experts from all different areas. Second, we need to develop a national unified modeling system to address the entire timescale, cross-scale—from the longer lead time to the high-resolution local

forecast. To do this, we need a consolidated national center, with participation from the entire weather enterprise, and multi-agency support. Third, we would also like to establish for a sustained resource to support research, observation, communication, modeling, computing, forecasting, and workforce development.

So, in closing, I think there's no doubt that improving weather forecast to save lives and reduce economic loss should be a national priority. Restoring U.S. leadership in weather forecasts for the benefit of society is a great challenge. No single Federal agency, no single private industry, no single university, can do it alone. It will take the entire weather enterprise. Thank you for inviting me, and I would welcome any questions you may have.

[The prepared statement of Dr. Chen follows:]

STATEMENT OF

Shuyi S. Chen, Ph.D.
Professor of Atmospheric Sciences
University of Washington

On

"The Future of Forecasting: Building a Stronger U.S. Weather Enterprise"

Before the
Subcommittee on Environment
U.S. House of Representatives Committee on Science, Space, and Technology

May 16, 2019

I wish to thank Chairwoman Fletcher, Ranking Member Marshall, and other Members of the Subcommittee for the opportunity to testify on the need to build a stronger weather enterprise and improve weather forecasts for the Nation. I am a Professor of the Atmospheric Sciences at the University of Washington. I serve as the Vice Chair of the National Academies' Board on Atmospheric Sciences and Climate (BASC). I am a Fellow of the American Meteorological Society (AMS).

My research and professional service have centered on understanding and improving prediction of weather systems, especially high-impact weather. I served as an Editor for *Weather and Forecasting* of the AMS. I currently serve on the Advisory Board for the Weather Research and Forecast (WRF) modeling community. I was on the National Academies' Committee on Progress and Priorities of U.S. Weather Research and Research-to-Operations Activities, which produced the 2010 report *When Weather Matters: Science and Services to Meet Critical Societal Needs.* I was appointed to oversee the review of the National Academies' report *Weather Services for the Nation: Becoming Second to None* (2012). I also chaired the Workshop Planning Committee for *The Future of Atmospheric Boundary Layer: Observing, Understanding, and Modeling* (2017). Most recently, I served on the steering committee that authored the National Academies' report *Thriving on our Changing Planet: A Decadal Strategy for Earth Observation from Space* (2018). While I have not been invited to testify on behalf of the National Academies, my testimony is deeply informed by their reports and my involvement in their activities to convene stakeholders from across the Weather Enterprise.

In the past 25 years, I have conducted research focusing on understanding extreme weather events (e.g., hurricanes) and intraseasonal variability that affect the global weather and climate system, and improving their prediction. I take interdisciplinary approaches to study coupled atmosphere-ocean systems in the tropics and coastal environment using satellite and airborne observations and atmosphere-ocean coupled numerical models. I have led national and international research programs in both field observations and coupled atmosphere-ocean modeling. My research group at the University of Washington has developed a first-generation high-resolution coupled atmosphere-wave-ocean model to better understand and predict high-impact weather such as hurricanes. I was a lead scientist of the National Oceanography Partnership Program 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 the transition of research to operations.

Accurate and actionable weather forecasts and warnings can help prevent natural hazards from becoming disasters by saving lives and reducing economic loss. Continuation and acceleration of improving weather forecasts and warnings must be a national priority. Over the past two decades, weather research in the U.S. has enabled 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.

Despite leading the field of numerical weather prediction (NWP) since its inception in the 1950's and 1960's, the United States no longer leads the field. Our operational weather prediction skill has fallen behind those of some other nations, as found by three National Academies' reports (2010a[1]; 2010b[2]; 2012[3]). I believe we can fully realize our potential in weather forecasting and be the best in the world. This requires us to first identify the weaknesses and the challenges we are facing, so we can find solutions to them and make anticipated progress. I applaud the Committee for taking the leadership to address this important issue of building a stronger U.S. Weather Enterprise for the Nation's future of weather forecasting.

Following the suggestion in the Subcommittee's letter inviting me to testify, I organized my testimony around the following four topics:

1. Building a stronger U.S. Weather Enterprise and working towards a common goal
2. Enhancing national forecast capability
3. Meeting workforce needs to support national forecast capability
4. Charting a way forward for the U.S. Weather Enterprise

1. Building a stronger U.S. Weather Enterprise and working towards a common goal

Recognizing the importance of weather forecasting for the Nation, Congress passed the Weather Research and Forecasting Innovation Act of 2017 (H.R. 353) with bipartisan support. The law defines the Weather Enterprise as the "individuals and organizations from public, private, and academic sectors that contribute to the research, development, and production of weather forecast products, and primary consumers of these weather forecast products." The 2003 National Academies' report *Fair Weather: Effective Partnerships in Weather and Climate Services* recognized the important contributions of all sectors of the enterprise and defined the roles and responsibilities of each. This guidance has served the weather community well, but changes in the

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

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

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

U.S. Weather Enterprise in the intervening years mean that the guidance no longer fully or accurately addresses how the sectors are interacting.

The U.S. Weather Enterprise has changed significantly over the past 15 years and is evolving rapidly. Advances in technology currently underway and anticipated in the coming decade will present a number of opportunities and challenges for the Weather Enterprise. Foremost among these opportunities are advances in high performance computing, cloud-based computing, and artificial intelligence; new observing technology and curation; and new communication technology and practice. The Weather Enterprise is also facing a number of challenges, such as

- a shifting balance between the traditional government responsibility and increasing roles of the private sector in collecting data, developing forecasting capabilities, making forecasts, and disseminating forecast products;
- regulating and facilitating the fast-growing use of robotic devices in both air and water for data collection;
- extending traditional weather forecast models to Earth System forecast models to meet broad societal needs;
- international collaboration and coordination; and
- particularly transitioning from research by broad academic and private communities to operations by NOAA.

Building a stronger U.S. Weather Enterprise critically depends how we seize these opportunities and meet these challenges.

Our greatest asset is the integrated capability of the three sectors—government, academia, private industries—each bringing complementary capabilities. However, the three sectors often have complex disjointed goals, and the need for specialization can lead to undesirable stovepipes. The relative roles of the three sectors are evolving more rapidly than simple coordination can accommodate. The process for extending these roles to an ever-expanding community has been unclear and inconsistent. To overcome these barriers, we must establish a shared vision and work together towards a common goal of serving the growing need of society for accurate and actionable weather forecasts.

2. Enhancing national forecasting capability

Making U.S. operational weather forecasting capability the best in the world again will require both research investments to improve modeling capability and enhanced efforts to transition research to operations.

a. Model development

Weather knows no boundaries. Traditional weather forecast models represent regional atmospheric processes without interacting with the ocean, surface waves, and land processes. We need to develop Earth System models that can accurately represent the global atmosphere, ocean, land, and sea ice, processes that not only affect weather but also are an important part of holistic environment prediction. Within NOAA, the National Weather Service (NWS) and National Ocean Service (NOS) use separate models for operational weather and ocean forecasts. A unified coupled atmosphere-ocean model will benefit forecasting for the blue economy (fisheries,

shipping) as well as forecasting weather with a longer lead time, as the ocean and land evolve slower than the atmosphere. The inclusion of these more slowly varying components of the Earth system is one reason for the improved performance of the UK Met Office weather model. They first developed their Unified Model with seamless prediction capability across scales in the atmosphere in the 1990's and continued to develop it into a coupled Earth System model that allows for both fine detailed, high-impact weather forecasts at short timescales and climate forecasts on long timescales.[4] This is perhaps the best example in the global Weather Enterprise of accomplishing an ambitious goal with a well-thought-out strategic plan.

Impacts of weather are local. The impacts are determined not only by the weather conditions, but also by the local landscape. A paradigm shift has already started from weather to explicit impact forecasting to inform decisions related to many sorts of systems, such as electric grids, transportation, and increased coastal flooding due to sea level rise. These are particularly active research topics by academics in geosciences and civil and environment engineering, and applications by private companies. Very high-resolution (down to the street level) impact modeling and forecasting systems are needed, which are driven by the global Earth System model. However, development of storm surge, land, and inland water models are uncoordinated at the national level.

Impacts of weather span many timescales. On the one hand, there are growing societal needs for accurate and actionable weather forecasts with increased lead times for severe weather events that occur over minutes to days (e.g., tornadoes, hurricanes) to support emergency management. On the other hand, decision makers desire seasonal probabilistic prediction of wildfires, heat waves, drought and flooding for long-term planning. To maximize the socio-economic benefits to society, we need predicative capability across a wide range of timescales.

Accurate weather forecasts beyond two weeks would be highly valuable. There is a growing need for extending weather forecasts beyond two weeks to subseasonal-to-seasonal (S2S) timescales (four weeks to two years) for long-term planning. This has been documented in the World Weather Research Program (WWRP) Implementation Plan[5] and two National Academies' reports (2010b, 2016). The Weather Research and Forecasting Innovation Act (H.R. 353) clearly identifies S2S prediction as part of the goal of improving the U.S. weather forecast capability.

NOAA's National Center for Environmental Prediction (NCEP) and other operational centers have demonstrated measurable but limited success with operational S2S forecasts. Yet, demands for these forecasts outpace its provision. S2S forecast products are still limited, their errors and uncertainties often large. With focused research-operation integration, substantial improvement of S2S forecasts and elevated societal benefit are within our grasp.

Now we have the will; what we need is a well-thought-out plan. However, as we speak, on the national level, we have only recommendations from the National Academies (2016) on a framework to develop a U.S. S2S prediction capability. There is no national strategy that enables the public, private, and academic sectors to work together to achieve this common goal.

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[4] https://www.metoffice.gov.uk/binaries/content/assets/mohippo/pdf/research/met_office_science_strategy_2016-2021.compressed.pdf

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

NOAA's NCEP has pioneered atmosphere-ocean operational Coupled Forecast System (CFS) and led the field of seasonal forecasting for a decade or so. This coupled system could have served as a basis to develop a coupled forecast model for S2S prediction. However, this leading edge is being eroded as NOAA is focused on developing a new atmosphere model (FV3 based NGGPS) for short-range (within two weeks) forecasts while other operational centers (e.g., European Centre for Medium-Range Weather Forecasts [ECMWF] and UK Met Office [UKMO]) are quickly developing coupled models for S2S prediction. This happened partially because there is no national strategy for developing the U.S. S2S prediction capability.

The capability to observe the state of the atmosphere, land, ocean, and sea ice is absolutely essential to weather research and prediction. It is critical for us to understand how cutting-edge technologies should help improve the current observing systems and also build new observing systems for better weather forecasts. The private sector is playing an increased role in collecting environmental data for their own applications and to fill gaps in the current observation systems developed and maintained by governments. Data sharing between private and public sectors is an unmet challenge. At the national level, numerical models and observing systems must be advanced jointly.

Adaptability of current models to future exascale high-performance computing facilities is key to ensure continued progress in model development. We should invest in scientific software engineering so that we are ready for future computing capabilities. With increased computing capability comes increasing volumes of data. Extracting scientific value from those data will require improved data management, archiving, and sharing capabilities, especially with our science partners. Academic and public research institutes and private companies are using the latest data analytics, artificial intelligence, and machine learning for both model development and innovative application of complex forecast information.

b. Research-to-Operation Transition

U.S. weather research has been on the leading edge in terms of innovation and breadth in basic research that has led to improvement in weather forecasting, especially in the area of high-impact weather forecasting and warnings by NOAA. Much of the advancement today would have not been possible without basic research by the academic, government, and private research community funded by the National Science Foundation (NSF), the Office of Naval Research of DoD, DoE, NASA, NOAA, and others over the past 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 National Academies' studies and reports. Many have reached similar conclusions, namely a lack of national strategy and strong leadership are the main reasons for the lapse, as found in *From Research to Operations in Weather Satellites and Numerical Weather Prediction: Crossing the Valley of Death* (NRC 2000[6]). A similar view was expressed in a provocative article entitled "The Uncoordinated Giant: Why U.S. Weather Research and

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

Prediction Are Not Achieving Their Potential" by Mass (2006)[7]. 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.

For decades, NCEP/NWS has been developing its NWP models for operations in isolation, while the Office of Oceanic and Atmospheric Research (OAR) laboratories have developed separate NWP models. Under the Weather Research and Forecasting Innovation Act 2017, there have been efforts to consolidate modeling activities within NOAA. Engagement with the broader academic community has been limited, which leads to intellectual segregation.

To develop a national strategy and a systematic approach to transition state-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 the National Academies (2012). Without a well-defined national strategy, a systematic approach, and sufficient infrastructure to support and facilitate continual adaptations of new research results to operations, the goodwill from research community outside NOAA cannot meet the ultimate challenge of research-to-operation transition at the national level.

To restore the U.S. leadership in weather forecasting, I believe that we need a new, transformative, integrated system to connect state-of-the-art weather research to operations. This system should be overseen by a consortium of experts from research, operations, and user communities of the Weather Enterprise. The consortium should design the pathway to ensure success in reaching the capability of:

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

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

- Communicating with federal and local governments to optimize the utility of the forecasts and assessment products in public response;
- Training the next-generation of scientists and forecasters with innovative tools for prediction and impact mitigation;

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[7] 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.

- Educating vulnerable residents on the application value of the new information coming out of the integrated forecast system on short and long lead times.

The rapid advancement of science and technology presents us with an unprecedented capabilities and opportunities to develop an 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 a critical need for the involvement of NSF to support the ambitious and risky interdisciplinary basic 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 research, operations, and management. Further, successful implementation of such a system requires education of a new generation of scientists, engineers, forecasters, managers, and will guarantee a smooth transition from research to NOAA operations.

3. Meeting workforce needs to support national forecast capability

Workforce development and training is essential for future weather forecasting. A significant challenge will be the increasingly diverse knowledge and skills that are needed to advance modeling and forecasting. Many new and emerging job markets require interdisciplinary and multidisciplinary education. The desired skill sets range from emerging science (meteorology and its coupling to other Earth systems on multiple timescales) and technologies (e.g., computing, data analytics, machine learning), to a host of disciplines and skills related to decision support (e.g., impacts, communication, social and behavioral science).

A new generation of scientists and forecasters are needed to communicate high-impact weather in a changing climate to support effective decision making. Indeed, a recent National Academies' report (2018[6]) emphasized an urgent need for better integration of physical science and social and behavioral sciences within the Weather Enterprise.

Another area of growing concern is the difficulty in attracting and retaining talented computer scientists to apply their skills to building the next generation of weather models, data analytics, and forecasting systems. This problem will become even more acute as efforts proceed to move current models to future exascale high-performance computing facilities.

The atmospheric science education in universities has not changed significantly over the last a few decades. It still mostly follows the traditional disciplinary curricula, which cannot meet the needs for more broadly trained professionals in the Weather Enterprise. Universities need to modernize their curricula to meet the growing needs for an interdisciplinary and multidisciplinary workforce. There are opportunities for working partnerships and collaborations across public, private, and academic sectors in workforce development and training.

4. Charting a way forward for the U.S. Weather Enterprise

The challenges facing the U.S. Weather Enterprise can be addressed with bold action to harness and coordinate the capabilities that span the public, private, and academic sectors. Here I provide three ambitious recommendations that I believe are particularly promising. The views I share are

my own, shaped by my 25 years of research in the field, by the authoritative work of the National Academies, and by extensive engagement with multiple stakeholders across the public, private, and academic sectors.

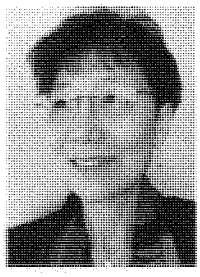
Launch a National Academies study on the Future of the U.S. Weather Enterprise. Over the last several years, I have participated in numerous conversations with a wide range of public, private, and academic stakeholders on how best to foster U.S. leadership in weather forecasting, modeling, and communication. One common theme that has emerged is the need for a comprehensive study to engage the broad weather community to develop a shared vision for the next generation U.S. weather enterprise. to the National Academies' Board on Atmospheric Sciences and Climate (BASC) has developed a proposal for such a study. The proposed study would gather experts in the physical, natural, social and behavioral sciences, technology, and weather operations, from academia, public agencies (including NOAA, NSF, NASA, DoD, DOE, DoT), and the private sector, to assess the current state of the U.S. Weather Enterprise and recommend priority investments and coordination mechanisms needed to achieve this vision. I personally believe that this proposed National Academies' study would be a highly effective way to bring the community together in a structured process that can provide guidance for all the sectors.

Establish a unified modeling and forecasting system for the United States. I believe that the multiple national investments and capabilities in weather forecasting could yield much improved performance if planning and implementation of these multiple components was approached as an integrated system. A first step will be to develop a vision and strategic plan for a unified modeling and forecasting system (including coupled atmosphere-ocean-land-ice modeling, data assimilation, and ensemble predictions) and a supporting observing system that facilitates innovation, research-to-operation, operation products that in turn support and demand further research. This strategic plan should be developed by experts from all three sectors of the Weather Enterprise. In my view, implementation of this holistic approach will require a consolidated national center—similar to that of ECMWF and the UK Met Office—with the participation from all relevant government agencies, academia, and private industries that can effectively use the best possible new technologies for computing, data analytics, and continued scientific innovations in modeling, observations, and data assimilation.

Create mechanisms for sustained resources and ongoing accountability. Restoring and maintaining U.S. leadership in weather forecasting will require a sustained commitment and coordination among multiple federal agencies and other partners, which are each balancing other competing priorities. The efforts described above to develop a community vision and unified modeling and forecasting system will put the nation on the right track. I believe that Congress should also act to ensure the outcome of these community efforts will be implemented and supported through sustained resources commensurate with the scale of the challenge and with the expected value to the nation. It also will be important to establish clear mechanisms for ongoing accountability, develop and track metrics of success, and provide incentives for collaborations among government agencies and their partnerships with academia and the private sector. Many in the community have suggested that a "decadal survey" model of Congressionally mandated National Academies studies that provide community-driven priorities every 10 years, combined with interim reports to assess progress, could address these needs for ongoing accountability. As

this Committee knows well, this approach has worked well for other science areas that require significant resources to achieve long-term community-driven goals (such as astronomy, earth science and applications from space). It is my personal opinion, based on my experience with other decadal surveys, that this Committee should establish a similar ongoing mechanism for the Weather Enterprise.

There is no doubt that improving the weather forecasts and response to save lives and reduce economic loss should be a national priority. Restoring U.S. leadership in weather forecasting for the benefit of society should be a national priority. No single federal government agency can do it alone. It will take the entire Weather Enterprise.



Dr. Shuyi S. Chen is a professor of Atmospheric Sciences at the University of Washington. Her research focuses on understanding extreme weather like hurricanes and intraseasonal variability that affect the global weather and climate system and improving their prediction. She studies air-sea interaction and precipitation in the tropics and coastal environment using satellite and airborne observations and coupled atmosphere-wave-ocean models. Dr. Chen has led national and international research programs in both field observations and coupled atmosphere-ocean modeling. Her research group at the University of Washington has developed a first-generation high-resolution Unified Wave Interface – Coupled Model (UWIN-CM) to better understand and predict high-impact weather such as hurricanes and winter storms, and ocean transport in events of oil spill and other hazards. Professor Chen is a lead scientist for several major field campagins including Coupled Boundary Layer Air-Sea Transfer (CBLAST) in 2003-04, Hurricane Rainbands and Intensity Change Experiment (RAINEX) in 2005, Dynamics of the MJO (DYNAMO) in 2011-12, and Convective Process Experiment (CPEX) in 2017. She was an editor of *Weather and Forecasting* of the American Meteorological Society. Currently she serves as the Vice Chair of the National Academis' Board on the Atmospheric Science and Climate (BASC). She served on the University Corporation for Atmospheric Research (UCAR) Board of Trustees in 2017-18. Dr. Chen is a Fellow of American Meteorological Society. She received her Ph.D. in meteorology from Penn State University.

Chairwoman FLETCHER. Thank you, Dr. Chen. Dr. Fiebrich?

TESTIMONY OF DR. CHRISTOPHER FIEBRICH, ASSOCIATE DIRECTOR OF THE OKLAHOMA CLIMATOLOGICAL SURVEY AND EXECUTIVE DIRECTOR OF THE OKLAHOMA MESONET

Dr. FIEBRICH. My name is Chris Fiebrich, and I'm the Executive Director of the Oklahoma Mesonet, and I'm also adjunct faculty in the University of Oklahoma School of Meteorology, and I want to thank Chairwoman Fletcher, and Ranking Member Lucas, and the Members of the Committee for the invitation to speak to you today. The Oklahoma Mesonet was established 25 years ago, both to address the needs for improved severe weather warnings, and to improve our ability to research and better understand the weather. We have one or more stations in each of our 77 counties so that no matter where you are in Oklahoma, we have local, real-time observations within about 10 miles of your location. The power of any Mesonet is driven by the high spatial density of its observations, and the goal of our Mesonet is to provide timely and useful weather information to Oklahoma citizens and decisionmakers.

The Mesonet is a unique partnership between our State's two largest universities, the University of Oklahoma in Norman and the Oklahoma State University in Stillwater. Our operational home is at the National Weather Center on the OU campus, where we share space with OU School of Meteorology and five NOAA facilities. This gives our students the opportunity to work side by side with NOAA's storm prediction center, the National Weather Service, and the National Severe Storms Lab, providing unique benefits to both the students and the Weather Service. Two additional OU research centers that stand out, with regard to their engagement with the Weather Service, are the Advanced Radar Research Center and the Center for the Analysis and Prediction of Storms. These centers are actively developing the prototypes for the next generation of weather radar systems and testing new weather models and forecast delivery systems, and NOAA's hazardous weather test bed.

My primary expertise is the Oklahoma Mesonet, which I oversee at OU. When the Mesonet began 25 years ago, we knew we'd fall short of our potential if all we did was collect the weather observations. We knew we needed to synthesize the data into useful tools for our citizens, first responders, and the State's key economic sectors. In the area of fire forecasting, we've trained more than 1,600 wildland fire managers on weather's impact on wildfire suppression, prescribed burning, and smoke management. Many aspects of wildland fire behavior can be modeled with real-time Mesonet observations, including predicting the likelihood a fire will ignite, how fast it will spread if it ignites, and how high the flames will be, given the observed winds, temperature, solar radiation, and moisture.

Mesonet data are also used to improve production and optimize inputs for crops and livestock. The occurrence of many plant pests and diseases can be successfully predicted given observations and Mesoscale weather conditions. Using the latest agricultural research, coupled with real time Mesonet observations, allows grow-

ers and producers to make efficient decisions on spraying for pests and diseases, as well as smart irrigation decisions.

While Mesonets like the one we have in Oklahoma provide significant value to numerous economic sectors, the greatest value that weather observations and prediction systems provide is for protecting lives and livelihoods. We've trained over 1,400 emergency preparedness managers, police, fire, and public-health professionals to use our data to keep Oklahomans safe.

Oklahoma, as you know, is subjected to many forms of destructive weather, most of which occur on the very short timescales of minutes to hours. These are threats that include damaging winds from thunderstorms, flooding rains, and crippling ice storms. The Oklahoma Mesonet has proven its worth in this role by significantly advancing a special form of forecasting known as Nowcasting. Nowcasting is the prediction of critical weather details in the next 0 to 6 hours that are often difficult to resolve through numerical weather prediction models. Subtle atmospheric features revealed by the Mesonet show the locations of fronts, dry lines, and moisture plumes that allow Weather Service forecasters to pinpoint areas most likely for convective initiation.

On the national scale, the Oklahoma Mesonet is part of NOAA's national Mesonet program, comprising 30-such university and State Mesonets and additional partners. The national Mesonet program has proven to be a successful public-private partnership model, in which the Federal Government can leverage tens of thousands of additional real time weather observations from across the Nation without having to maintain and operate them. This allows forecasters to use these additional data to improve weather models, and thus every community's weather forecast.

It's essential that Congress and the Administration support and expand the national Mesonet to ensure that local forecasters have access to these highly localized weather data. The University is proud to play a role in these programs, and I look forward to answering any questions you have about our efforts in Oklahoma.

[The prepared statement of Dr. Fiebrich follows:]

The UNIVERSITY of OKLAHOMA

COMMITTEE ON SCIENCE, SPACE, AND TECHNOLOGY

SUBCOMMITTEE ON THE ENVIRONMENT

Christopher A. Fiebrich, Ph. D.

Executive Director, Oklahoma Mesonet

Associate Director, Oklahoma Climatological Survey

The University of Oklahoma

Norman, OK 73072

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16 May 2019

My name is Christopher Fiebrich and I am the Executive Director of the Oklahoma Mesonet. I am also Adjunct Faculty in the University of Oklahoma's School of Meteorology. I want to thank Chair Fletcher, Ranking Member Lucas, and Members of the Committee for the invitation to speak to you today.

The Oklahoma Mesonet was established 25 years ago, both to address the needs of our state's citizens to have improved warnings when severe weather strikes, and to improve our ability to research and better understand the weather. It is our state's network of 120 environmental monitoring stations that transmit atmospheric and soil observations every five minutes around the clock. We have one or more stations in each of our 77 counties so that no matter where you are in Oklahoma, we have local, real-time observations within ten miles of your location. The "power" of any Mesonet is driven by the high spatial density of its observations, and the goal of our Mesonet is to provide timely and useful weather information to Oklahoma's citizens and decision makers.

The Mesonet is a unique partnership between our state's two largest Universities - the University of Oklahoma in Norman and the Oklahoma State University in Stillwater. Our operational home is at the National Weather Center on the OU campus where we share both intellectual and physical space with OU's School of Meteorology and five NOAA facilities. This gives our students the opportunity to work side-by-side with NOAA's Storm Prediction Center, the National Weather Service (NWS), and the National Severe Storms Laboratory, providing unique benefits to both the students and the NWS. Our OU School of Meteorology is the largest

program in the nation and has produced hundreds of graduates that work in the National Weather Service. Two additional OU Research Centers that stand out with regard to their engagement with the NWS are the Advanced Radar Research Center (ARRC) and the Center for the Analysis and Prediction of Storms (CAPS). The ARRC and CAPS are actively developing the prototypes for the next generation of weather radar systems and testing new weather models, forecast techniques, and forecast delivery systems in NOAA's Hazardous Weather Testbed.

My primary expertise is the Oklahoma Mesonet, which I oversee at OU. When the Mesonet began 25 years ago, we knew we'd fall short of our potential if all we did was collect weather observations. We knew we needed to synthesize the data into useful products and tools for citizens, first responders, and the state's key economic sectors.

Over the years, we've worked with over 250 K-12 schools and over 390 teachers to enhance science and math curriculum in Oklahoma schools, and we've hosted hundreds of students at meteorology summer camps. Mesonet data have been used to advance the scientific understanding of the atmosphere as detailed in over 1000 peer reviewed journal articles and over 400 theses and dissertations.

In the area of fire forecasting and preparedness, we've trained more than 1600 wildland fire managers on weather's impact on wildfire suppression, prescribed burning, and smoke management. Many aspects of wildland fire behavior can be modeled with real-time Mesonet observations. We use the Mesonet's observations to predict the likelihood a fire will ignite, how

fast it will spread if ignited, and how high the flames will be given the observed winds, temperatures, solar radiation, and moisture. Since a large fraction of the state's agriculture sector relies on prescribed burning, we help those folks burn in the safest manner given accurate observations of wind and humidity to ensure the burn is successful and effective.

Mesonet data are also used to improve production and optimize inputs for crops and livestock. The occurrence of many plant pests and diseases can be successfully predicted given observations of mesoscale weather conditions. The number of cumulative hours above a certain temperature readily predicts the prospect of alfalfa weevil, likewise the number of hours above a certain humidity can ascertain the growth of scab on pecan trees or black rot on grapes. Using the latest agricultural scientific research coupled with real-time Mesonet observations allow growers and producers to make efficient decisions on spraying for pests and diseases, as well as smart irrigation decisions to get moisture to critical root zones while at the same time conserving water resources. The cumulative economic benefits for agricultural production in Oklahoma from utilizing Mesonet information are estimated at $20 million each year[1].

While Mesonets like the one we have in Oklahoma provide significant value to numerous economic sectors such as agriculture, tourism and renewable energy, the greatest value that weather observation and prediction systems provides is for protecting lives and livelihoods.

[1] ‡ *Journal of the Science of Food and Agriculture* 98(13): 4945-4954

We've trained over 1450 emergency preparedness managers, police, fire, and public health professionals to use our products and critical tools to keep Oklahomans safe. Oklahoma, as you know, is subjected to many forms of destructive weather, most of which occur on the very short time scale of minutes to hours. These are threats that include damaging winds from tornadoes and thunderstorms, flooding rains, and crippling ice storms. The Oklahoma Mesonet has proven its worth in this role by significantly advancing the special form of forecasting known as nowcasting. Nowcasting is the prediction of critical weather details in the next 0 to 6 hours that are often difficult to resolve through numerical weather prediction models. Subtle atmospheric features revealed by the Mesonet in real-time show the location of fronts, drylines, and moisture plumes that allow forecasters to pinpoint areas most likely for convective initiation. These local, real-time data are critical for National Weather Service forecasts and warnings.

On the national scale, the Oklahoma Mesonet is part of NOAA's National Mesonet Program, comprising 30 such university/state Mesonets and additional partners. The National Mesonet Program has proven to be a successful public/private partnership model in which the federal government can leverage tens of thousands of additional real time weather observations from across the nation without having to maintain and operate them. The National Mesonet Program ensures that all observations are quality controlled and in the correct format for the NWS's Meteorological Assimilation Data Ingest System (MADIS). This allows forecasters to use these additional data to improve weather models and every community's weather forecast. Therefore, it is essential that this Congress and the Administration vigorously support and

expand funding for the National Mesonet to insure that local forecasters and the communities in which they serve have access to this highly localized weather data so they can continue to protect lives and enhance the livelihood of communities that are heavily dependent upon stewardship of our precious natural resources. The University is proud to play a role in providing scientific credibility and fundamental research on weather forecast models via these programs, and I look forward to answering any questions you have about our efforts in Oklahoma.

Dr. Christopher A. Fiebrich (pronounced Fee-brick)

Bio

Christopher A. Fiebrich is the Executive Director of the Oklahoma Mesonet and Associate Director of the Oklahoma Climatological Survey at the University of Oklahoma (OU). He is also Adjunct Faculty with the School of Meteorology at OU. He has published 26 peer reviewed articles on mesoscale meteorology and climatology, meteorological instrumentation, and applied meteorology and climatology. He oversee all activities of the Oklahoma Mesonet, including sensor calibrations, field operations, technology and software development, data and climate services, research, and outreach to emergency managers, fire fighters, farmers, and K-20 educators.

He earned his B.S. in 1998, M.S. in 2000, and Ph.D. in Meteorology in 2007 from the University of Oklahoma. His dissertation was awarded the Dissertation Medal for 2009 from the American Association of State Climatologists (AASC). He is a Steering Committee member of the AASC Mesonet committee and a Certified Consulting Meteorologist of the American Meteorological Society.

Chairwoman FLETCHER. Thank you, Dr. Fiebrich. Mr. Sorkin?

TESTIMONY OF RICH SORKIN,
CEO, JUPITER INTELLIGENCE

Mr. SORKIN. Chairwoman Fletcher, Ranking Member Lucas, and Members of the Subcommittee, I am Rich Sorkin, CEO of Jupiter Intelligence. Jupiter predicts risks from weather and climate change. We work with some of the country's and world's largest insurance, mortgage, power, and resource companies, responsible for roughly $1 trillion in assets, showing them the risks to their assets in their language and relevant timeframes. I appreciate the opportunity to testify before you today.

I understand the Committee is broadly interested in the weather enterprise, leadership in forecasting, the role of the private sector, and all of this against the backdrop of increasingly severe weather and impacts due to climate change. I have three core points. First, broad sectors of U.S. society are increasingly concerned about the growing risks to life, well-being, and property caused by climate change. The Federal Government should, among other things, do more on preparedness, especially in programs related to infrastructure investment and the Department of Defense (DOD).

Events such as Hurricane Katrina, Superstorm Sandy, Hurricane Harvey, Midwest flooding, and the California wildfires dramatically illustrate the need for improvement in planning for, predicting, communicating, and reducing the risks from extreme weather. Costs for emergency response and disaster recovery, especially from FEMA (Federal Emergency Management Agency), are increasing much faster than GDP or government revenues. Recently the Air Force requested that Congress allocate $4.9 billion for repairs at just two bases, Tyndall in Florida, and Offutt in Nebraska, from damages due to severe weather, and this is just the tip of the iceberg. The impacts of climate change are not just in the future. They are upon us, and getting worse, and the risks are resonating in corporate boardrooms.

Second, while NOAA and the National Weather Service do an excellent job of forecasting, they could do even better by using technologies widely adopted in the private sector, particularly artificial intelligence, or AI, and cloud computing. Jupiter, for example, is seeing enormous acceleration in transitioning research to operations through the use of cloud computing. These technologies assist in global collaboration, both inside the company and with our university partners, and in rapid prototyping and accelerated-performance testing. AI is also benefiting Jupiter in the spatial and temporal resolution of our predictions, the speed of developing new services, and reductions in costs for computing. China, by the way, is making enormous progress in AI. We need to ensure that we are not leapfrogged by China, both in the weather enterprise, and more generally. The Earth Prediction Innovation Center, or EPIC, is an excellent first step in NOAA adopting AI and cloud computing.

Third, the path to renewed U.S. leadership across the weather enterprise depends upon stronger collaboration between the three sectors of the enterprise. A vibrant private sector is emerging for solutions to help customers understand, plan for, and mitigate the impacts of severe and worsening weather. Investors have deployed

billions of dollars in satellites, other observations, and analytics, including work like ours, and will invest more, especially if the collaborative relationship is right, with the Federal Government focusing on the core modeling that the private sector can build upon. At Jupiter, we have followed a collaborative philosophy from the beginning, working with the Federal Government and university partners. Going forward, I recommend enhanced investment in NOAA's capabilities to produce better weather forecasts, as well as expanded observations, to help produce actionable climate risk services.

While NOAA's role in saving lives and property is paramount, the private sector can supply hyperlocal climate information to our colleagues in the private sector, as well as local governments. I also recommend easing the way for public-private collaborations, as well as improved mechanisms for allowing pilot projects with NOAA, which could provide favorable returns on investment for the government and its agencies. I look forward to your questions. Thank you.

[The prepared statement of Mr. Sorkin follows:]

Testimony of
Rich Sorkin
Chief Executive Officer of Jupiter Intelligence

Before the Subcommittee on Environment of the
House Committee on Science, Space, and Technology
Hearing: "The Future of Forecasting: Building a Stronger U.S. Weather Enterprise"

May 16, 2019

Chairwoman Fletcher, Ranking Member Marshall, and Members of the Subcommittee, I am Rich Sorkin, CEO of Jupiter Intelligence. Jupiter predicts risks from weather and climate change. I appreciate the opportunity to testify before you today.

Executive summary

Jupiter predicts risks from weather and climate change.

We understand the Committee is broadly interested in the Weather Enterprise, leadership in forecasting, and the role of the private sector, against the backdrop of increasingly severe weather due to climate change.

We would like to emphasize three core points:

First, broad sectors of U.S. society are increasingly concerned about the growing risks to life, well-being, and property caused by climate change. The federal government should, among other things, do more on preparedness, especially in programs related to infrastructure investment and the Department of Defense.

Events such as Hurricane Katrina, Superstorm Sandy, Hurricane Harvey, Midwest flooding, and the California wildfires dramatically illustrate the need for improvement in planning for, predicting, communicating, and reducing the risks of impacts from extreme weather that touch nearly every urban and rural area of the nation.

Costs for emergency response and disaster recovery, especially from FEMA, are increasing much faster than GDP or government revenues.

Recently, the Air Force requested that Congress allocate $4.9 billion for repairs at just two bases — Tyndall in Florida and Offutt in Nebraska — from damages due to severe weather. And this is just the tip of the iceberg.

For many years, climate change was viewed as a problem for future generations. But recent events demonstrate that the impacts of climate change are upon us and getting worse.

And the risks of climate change are resonating in corporate boardrooms. Last month, the Governor of the Bank of England stated: "The majority of banks...are already seriously considering the financial risks that arise from climate change. We expect regulated firms to manage these risks strategically."

Second, while NOAA and the National Weather Service do an excellent job of forecasting, they could do even better by using technologies widely adopted in the private sector, particularly Artificial Intelligence (or AI) and Cloud Computing. Jupiter, for example, is seeing enormous acceleration in transitioning research to operations through the use of cloud computing. It assists in global collaboration both inside the company and with our university partners, and in rapid prototyping and accelerated performance testing.

Another technology, AI, is delivering significant benefits to Jupiter in the spatial and temporal resolution of our predictions, the speed of developing new services, and reductions in costs for computing.

It is also worth highlighting that China is making enormous progress in AI across their entire society. We should be much more aggressive in ensuring that we are not leapfrogged by China, both in the Weather Enterprise and more generally.

The Earth Prediction Innovation Center, or EPIC, is an excellent first step in NOAA adopting AI and cloud computing.

Third, the path to continued and renewed U.S. leadership across the Weather Enterprise depends upon stronger collaboration between the three sectors of the Enterprise.

A vibrant private sector is emerging for solutions to help customers understand, plan for, and mitigate the impacts of severe weather, especially as they continue to worsen.

Investors have deployed billions of dollars in satellites, other observations, and analytics including work like ours and will continue to invest more, especially if we can get the collaborative relationship right, with the federal government focusing on the core modeling that the private sector can build upon.

At Jupiter, we have followed a collaborative philosophy from the beginning, working with both the federal government and university partners.

Going forward, we recommend enhanced investment in NOAA's capabilities to produce better weather forecasts, near-term and seasonal, as well as expanded observations to support the production of actionable climate risk services. While NOAA's role in saving lives and property is paramount, the private sector can supply hyper-local climate information to municipalities and the private sector.

We also recommend easing the way for public-private collaborations as well as improved mechanisms for allowing pilot projects with NOAA, some of which could provide favorable returns on investment for the U.S. Government and its agencies.

The following written statement includes more detail on these and related issues.

Background

Weather and climate have a powerful impact on the health, safety, security, and prosperity of the United States and the world. During the 20th century, the U.S. Weather Enterprise, including federal agencies, academia, and private industry, led the world in providing information that drove enormous improvements in agricultural productivity, transportation safety, warnings for extreme events such as tornadoes and hurricanes, the everyday quality of citizen's lives, and a broad range of other social and economic benefits. Advances in the U.S. Weather Enterprise also informed key Department of Defense strategic basing and deployment decisions.

Historically, the public, private, and academic sectors have worked together to provide forecast products of unequalled accuracy, specificity, and availability. As the need for better, more precise weather and climate information expands, the enterprise cannot fully meet the challenges of the 21st century without deeper collaboration. Innovation and advances in technology, from AI to cloud computing, are occurring more rapidly in the private sector. Many aspects of forecast accuracy have been significantly enhanced and produced life-saving improvements in the lead time for warnings of severe weather, and in improved track forecasts of hurricanes, as well as in the timing and spatial extent of winter weather.

However, the potent impact of events such as Hurricane Katrina, Superstorm Sandy, Hurricane Harvey, Midwest flooding, and the stunning fires in California and the west over the last several years dramatically illustrates the need for improvement in planning for, predicting, and communicating the risks of impacts of extreme weather that touch nearly every urban and rural area of the nation. Costs for emergency response and disaster recovery, especially from FEMA, are increasing much faster than GDP or government revenues. Between FY 2013 and FY 2018, FEMA Disaster Relief Fund spending grew from $11.1 billion to $26.4 billion, 140% growth, outpacing U.S. GDP growth from $16.7 trillion to $20.5 trillion, 23% growth during the same time frame.[1]

The Air Force alone recently requested that Congress allocate $4.9 billion for repairs at just two bases — Tyndall in Florida as a result of Hurricane Michael, and Offutt in Nebraska on account of Midwest flooding. And this is just the tip of the iceberg.

[1] FEMA, *Disaster Relief Monthly Report*, updated May 8, 2019. https://www.fema.gov/media-library/assets/documents/31789

Jupiter Intelligence

Jupiter is a private sector company addressing many of these challenges. Our customers own, insure, lend to, and govern roughly $1 trillion in physical and financial assets, and use Jupiter's products for a broad range of risk-oriented decisions. Jupiter's customers include some of the world's largest insurance companies and mortgage firms, power providers, resource companies and ports, large cities, and state Departments of Environmental Protection. One customer is funded by the U.S. Department of Housing and Urban Development (HUD) Rebuild by Design Program. We increasingly operate all over the world, including having offices in New York, California, and Colorado, and provide our risk prediction services in Texas, Florida, New York and other states and countries. Today, we provide projections of future flooding, wind, and extreme heat tailored to the decision-making processes of our customers. Later this year, we will add fire. Jupiter's hyper-local probabilistic estimates of hazards are on the time scales that matter to our customers, hours or decades, and go far beyond what is available from any government or university. Our success is based on using dynamic modeling combined with Artificial Intelligence (AI), cloud computing, and risk analytics, and designing a great, easy-to-use customer (user) experience. The Company's scientists test their forecasts against the best available observations — to see, for instance, how well they predict flooding from major storms using reports of calls to emergency management.

If a customer wants a full picture of flooding risk, for example, they need expertise in weather, and also in climate, hydrology, engineering, risk, and running complex models on the latest computer hardware. Within the public sector and the scientific community, teams focusing on these very different areas do not necessarily coordinate sufficiently closely, or at least not to the degree which occurs at Jupiter.

Jupiter's predictive tools, with simple interactive visuals that look much like Google Maps, allow our customers to zoom down to the city block or asset level to get a better sense of the potential risks they face from storms, heat waves, wildfires, or other climate-change effects in the coming decades.

WIRED recently wrote: "If you run a business, or maintain a city, or plan power plants or highways or bridges, you'd like to know how bad things are, and how bad they're going to get. That's what Jupiter ... sells. Jupiter explicitly incorporates climate change into its models for catastroph[ic] risk, both proprietary and public, and then offers that knowledge to the kind of people who might lose money when the floods, fires, storms, and heat waves really kick in."

Jupiter has a strong interest in a vibrant Weather Enterprise

Jupiter uses weather predictions and climate models as inputs to these risk predictions. To create flood maps, Jupiter uses public data, including satellite-based observations of rainfall and gage measurements of waves and storm surge. We integrate this with information from other sources, including how changes in the urban landscape affect how water flows through cities. We harness recent advances in cloud-based elastic computing to combine all the data sources, models, and analytics in a single solution.

Jupiter relies on NOAA and other federally funded efforts to supply global climate models and their projections, as well as critical observations, including the ocean buoys and river gages, while working with customers in ways that, while complementary, are beyond the mandate of the federal government.

The frequency and severity of extreme weather events are increasing due to climate change

As the U.S. National Climate Assessment (NCA) makes clear, many of the extreme impacts we are seeing are driven by the changes that have already occurred in the global climate. U.S. average temperature has increased by 1.3°F to 1.9°F since record-keeping began in 1895; most of this increase has occurred since about 1970. Since 1950, the number of heavy precipitation events for the U.S. has increased by 40 percent.[2]

For a long time, the issue of climate change and its impacts seemed to be something to be addressed in the distant future, a problem for our children and grandchildren. No longer. Events of recent years demonstrate that the impacts of climate change are upon us. And they are getting worse.

Not surprisingly, the risks of climate change, including the risks of liability, are resonating in corporate boardrooms, and the private sector is taking on new leadership in addressing the severe and growing impacts of severe weather events. Shareholders are increasingly demanding it. Banks are starting to pay attention, as Bank of England Governor Mark Carney recently stated: "We will expect our regulated firms to anticipate and manage the risks ... "The majority of banks recognise this and are already seriously considering the financial risks that arise from climate change. We expect regulated firms to manage these risks strategically."[3]

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[2]USGCRP, 2018: *Impacts, Risks, and Adaptation in the United States: Fourth National Climate Assessment,* Volume II [D.R. Reidmiller, C.W. Avery, D.R. Easterling, K.E. Kunkel, K.L.M. Lewis, T.K. Maycock, and B.C. Stewart (eds.)]. U.S. Global Change Research Program, Washington, DC, USA, 1515 pp. doi: 10.7930/NCA4.2018.

[3]The Bank of England, *PRA Review Finds That 70% of Banks Recognise That Climate Change Poses Financial Risk,* 26 September 2018.

Current challenges have broad impacts, including for national security

The intensifying impacts of climate change poses significant challenges for our society. The truth is, we live in a world designed for an environment that no longer exists. The public and private sectors must design, implement, and operate assets based on realistic expectations of future weather and climate conditions. Otherwise, critical infrastructure such as hospitals, power plants, and roads may be unavailable at times when most urgently needed. The public and private sectors must have better warning systems for floods and fires. Look at the consequences of extreme events in just two places — the destruction to Tyndall Air Force Base in Florida caused by Hurricane Michael, and the ravages of the California fires that killed at least 88 people and wiped out PG&E shareholders. Both the insurance industry and NOAA estimated that the economic costs of severe weather events in the U.S. were nearly $1 trillion in the last ten years. Those costs are growing significantly faster than GDP,[4] as in the case of the 2013-2018 toll for FEMA disaster recovery and emergency services cited earlier.

Asset owners, planners, developers, investors, and government agencies are increasingly recognizing the need to incorporate climate impact data into risk modeling for specific assets. Catastrophic risk modeling most often projects the future based on past statistics with the assumption that the climate is not changing. This approach is flawed in today's dynamic environment, which is continually shaped by changes to built and natural landscapes. Similarly, climate panels at the international, national, state, and metropolitan levels use inconsistent methodologies, validation approaches, and metrics that make it nearly impossible for the private sector to use them without extensive custom work.

Today's decision-makers need data that reflect ongoing change and provide consistent approaches to quantifying physical risk in a changing climate. With the right information, they can make more informed decisions for site selection and design, critical infrastructure planning, equipment ratings, capital investment and portfolio planning, insurance, alternative investment decisions, zoning, and building code development, among other things. The right decisions improve safety and reduce risks to critical infrastructure and business operations.

Climate change poses an especially noteworthy threat to our military readiness due to its effect on frequency and intensity of extreme weather events and sea level rise. This has implications for our ability to project power and influence around the world, and can constrain our capacity to effectively advance our interests abroad.

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[4] NOAA, National Centers for Environmental Information.
https://www.ncdc.noaa.gov/billions/summary-stats
https://www.ncei.noaa.gov/news/calculating-cost-weather-and-climate-disasters

Military leaders have concluded that climate change now contributes to unprecedented security threats for the United States – and the world. In 2017, Secretary of Defense James Mattis stated that the effects of a changing climate "impact our security situation," and that "we are prepared to address the effects of a changing climate on our threat assessments, resources, and readiness." In 2016, the Climate Security Consensus Project stated that "the effects of climate change present a strategically significant risk to U.S. national security." In 2018, the National Defense Authorization Act stated that "climate change presents a direct threat to national security." During this Administration alone, at least 23 senior military leaders have publicly expressed serious concerns about the security threats of a changing climate.

Research supported by USAID, and published in September of last year, further demonstrates the effects of climate change on state fragility around the world. In written testimony on the Worldwide Threat Assessment in January 2019, the Director of National Intelligence, Daniel Coats, emphasized that the United States will have to manage the negative effects of a changing climate. The Director of National Intelligence has issued such concerns in 11 straight Worldwide Threat Assessments.

The Weather Enterprise cannot cure climate change. But it must diagnose the problem and treat the ever-worsening symptoms. As storms, fires, floods, heat waves, and other weather events and impacts continue to become more frequent and severe, especially in larger and denser concentrations of people and assets, the country needs to better plan for and respond to these events.

State of the U.S. Weather Enterprise: public, private and academic partners

As the Committee well knows, the federal agency members of the U.S. Weather Enterprise are responsible for much of the advances in science and technology that lead to increasing skill in weather forecasting. For example, investments in technology led to the new generation of weather satellites that increase warning times, and provide unprecedented data for ingest to weather forecasting models. Investments in basic science led to increased understanding of complex interactions between a hurricane and its environment to increase skill in hurricane track forecasting. The U.S. Weather and Climate Enterprise is the most active and productive enterprise in the world, providing innovation and products to the U.S.

And yet we are seeing governments and private sector entities demanding more actionable information on weather (and climate) risks. The *New York Times* wrote "[D]etailed information about the city's climate risks proved surprisingly hard to find ... Scientific reports on global warming, such as the National Climate Assessment, can tell you that heavy rainstorms are

expected to increase in the Southeast ... Federal flood maps are based on historical data, and won't tell you how sea-level rise could exacerbate flooding in the years ahead."[5]

As a result, the public and private sectors must continue to evolve. Fortunately, the technology is here today to make this happen. As the needs for weather and climate information expand, as well as innovations both from technological observations and analytical approaches to producing products, the natural roles for the public, private and academic sectors will need to continue to evolve. For instance, in the past, all weather forecasts came from the National Weather Service (NWS), then increasingly over the radio or television; now, forecasts often come to us on our phones and from commercial weather providers. Coincident with these changes, our forecasts are more targeted, accurate and useful than ever before.

The private sector provides products with localized detail designed to customers' specifications while these products are built on foundational models and observations that NOAA currently provides. Thus, public-private partnerships are crucial.

Private sector in weather products and services

Companies like Jupiter rely on NOAA to provide state-of-the-art weather prediction and consistent, long-term observations, and rely on the academic sector to continue with world class research which is the foundation of our products. This collaborative relationship is at the heart of the American Weather and Climate Enterprise.

While the conversations as to how NOAA and the private sector should interact on issues of weather and climate are evolving, many more questions need to be addressed, including critical observations, climate modeling priorities, and appropriate roles for hyper-local information.

These hyper-local products, for the most part, are best supplied by private sector entities including Jupiter. Addressing these needs may require NOAA to produce different observations, or share in the development of shorter-term climate information. For example, funding from NOAA and the Departments of Defense and Transportation supported university development of prototypes for short-term flood prediction by the team now at Jupiter. These are currently used in New York by the Port Authority, Transit Agency, city, and state to anticipate impacts one hour to five days ahead of storms. Yet, large commercial entities prefer to buy these services from private companies with service level commitments, regular upgrade plans and modern user interfaces.

In particular, risk analytics are often best provided by the private sector which has dramatically outpaced the public sector in probabilistic analytics tailored for different sectors — consumers,

[5]Plumer, Brad, "Will Land be Underwater in 20 Years? Figuring It Out Could be Lucrative," *The New York Times,* February 23, 2018.
https://www.nytimes.com/2018/02/23/climate/mapping-future-climate-risk.html

insurance, banking, infrastructure, tourism, real estate etc. We believe the federal government should defer to the private sector in this area, except as it relates to public safety and national security, where the public sector can also leverage private sector investments across the planet and multiple industries.

In data analytics, the private sector is increasingly moving to a model of buying data and analytics rather than owning the infrastructure to create and deliver the data and analytics. It is worth exploring how the Federal government can leverage similar models for observations for faster deployments and lower taxpayer expense, while maintaining U.S. companies' access to observations.

And, just as the weather has changed, so too has the technology landscape. The private sector now accounts for a very large percentage of basic R&D. Supercomputing has not only evolved from monolithic systems to distributed parallel servers but increasingly is performed in the cloud at Amazon, Microsoft and Google. New, nimble private-sector space companies like SpaceX, Rocket, Planet, Capella, and Spire are designing, launching, and running satellites, and AI-based predictions are seeping into every sector of the economy. Increasingly Americans get their information from their phones and social media, not TV and radio. In nearly every case, the private sector is leading the adoption of these new technologies, driven by brutal competition for profits in industries like advertising, commerce, finance, and natural resources.

Similarly, the business community is increasingly attentive to the need to plan for and respond to weather and climate risks, working with but not waiting for the U.S. public sector. For example, the power sector is gradually starting to plan for heat stress on industrial infrastructure and doing a better job planning for ongoing reliability as billions of dollars of equipment becomes less reliable and needs to be replaced sooner.

Steps to foster U.S. leadership in weather forecasting, modeling and communication

The weather forecasting capability of the Federal government today is overwhelmingly based in dynamic modeling to simulate the character of the atmosphere to predict its evolution over a variety of space and time scales. These models require vasts amount of observations from a multitude of national, international, and private sources. Additionally, the models run on large, government-owned supercomputers.

The Weather Enterprise needs to re-examine how observations, models and data-sharing should change in the future. And the needs of the private sector for climate information requires a similar examination or re-examination. The National Academy stands poised to conduct this type of examination.

While the private sector and local municipalities appreciate NOAA and other federal products, and the substantial contributions to this field, these users are seeking tailored products that can address their needs at a local level. Estimates of risks to specific assets are best provided by

the private sector. As *The New York Times* wrote, current public sector models and forecasts: "won't tell you whether specific roads leading to a given warehouse might be unusable during ... storms." Private sector entities, including Jupiter, are ready to fill this gap, particularly because the government does not offer comparable services free of charge, and is not expected to do so.

Operational modeling is the core of the Weather Enterprise and it is critically important that the U.S. be a global leader in this area. I largely defer to Dr. Jacobs and Dr. Uccellini on the steps required to accelerate the progress in this area, with two suggestions:

AI and China

AI is delivering significant benefits to Jupiter in the spatial and temporal resolution of our predictions, speed of developing new services, and reductions in costs for computing.

China, our number one geopolitical rival, is making enormous progress in AI across their entire society. While this issue is certainly much broader than the Weather Enterprise, even in the Weather Enterprise, the federal government should be much more aggressive in ensuring that the United States is not leapfrogged by developments in China.

Cloud computing

Jupiter runs its services in the cloud and our team have been pioneers in this area for a decade.

Cloud computing is an excellent option for prototyping scientific advancements; assessing the relative performance of different approaches and data sources; beginning to develop operational capabilities in advance of wide-scale implementation of cloud computing for hourly forecasts; and providing elastic resources when the forecast really matters and in data production workloads aimed at climate impacts.

Many weather forecasting problems, such as tropical cyclones or convective weather outbreaks, lend themselves to elastic computing. Heavy computing is less critical when those types of events are not expected to occur in a given state or region. But when weather threats arise, computer power can be quickly spun up and dedicated to providing the highest resolution and fidelity forecasts possible.

Jupiter's climate products leverage the cloud by using up to 100 thousand processors at a time to gain massive probabilistic data sets for our analytics. Those can be quickly updated when new science or models are available, on a pace of quarterly to biannually rather than every day.

Cloud computing ***should*** rapidly become an integral part of the U.S. Weather Enterprise, including for predictions that are not yet operational, non-core or intermittent.

The scale and complexity of the National Weather Service are such that it is probably years away from moving operational weather forecasts to the cloud because making this transition at scale is difficult. Scaling existing operational weather systems on the cloud is beyond Jupiter's current scope of business and NOAA should consider turning to other private sector companies, such as Microsoft, Amazon or Goldman Sachs to identify best practices in this area.

Accelerating research to operations and the role of the private sector

At Jupiter we have seen dramatic acceleration in moving science from the research to operations, largely enabled by cloud computing. In one case, the Jupiter scientists reported that running a new model in the cloud took them a day, versus what previously took months due to dependency on scarce internal information technology (IT) resources at universities and government laboratories. On an experimental basis, not-yet-mature research models can be run in the cloud and integrated as components with other already operationally mature models to assess the integration of models and impact on system-wide performance and skill.

The cloud is also well-suited to collaboration among people and across the planet. When operational environments can be replicated in the cloud, it provides immediate access among collaborators and contributors in a way not possible on dedicated machines behind firewalls. Cloud environments can be made every bit as secure as any dedicated machine that is connected to the internet.

Next steps to develop U.S. leadership in weather modeling and forecasting

Extreme and high-impact events will become ever more important threats to the U.S. in the coming years. Currently, it can be argued that private and public investments in science and technology related to understanding and predicting extreme events are far below what is needed to properly address the risks. Given adequate support, the sectors which comprise the U.S. Weather Enterprise can and will address these threats to the benefit and protection of the nation's infrastructure, society, and people. Three sets of actions can help create a more resilient future that includes improved forecasts of extreme and high-impact events on time scales that range from hours to seasons and beyond. The actions should focus on improved observing systems; improved science and forecast systems; and improved delivery of forecast information. Specifically:

1) Enhanced investment in basic science and modeling to increase understanding and simulation of extreme and high-impact events to feed NOAA's capabilities to produce weather forecasts with increased skill in both near-term and seasonal forecasts. Specific actions to support this include:

a) Greater collaboration between public-private and academic agents, such as proposed by the Earth Prediction Innovation Center.[6]
b) Increased ease in allowing for public-private collaborations, allowing private sector innovation to leverage and enhance government investments.
c) Improved mechanisms for allowing and enabling pilot projects within NOAA to evolve into established programs, and to be deployed when pilots show value to the science and nation.

2) Expanded observations from remotely sensed and *in situ* systems for NOAA to support the production of actionable weather and climate risk services for the protection of life and property, and assessment of risk.
   a) Continued, and in some areas enhanced, technology advances to bolster aging satellite systems and ocean buoy systems that will allow companies such as Jupiter to continue to serve its customers with state-of-the-art, actionable information.
   b) Expedited testing and expansion of new technologies for *in situ* observing systems of the most important aspects of severe weather, including UAS (unmanned aerial surveillance), private satellites, and new forms of citizen science.
3) National Academies
   a) Utilize the National Academy to identify the national needs and capabilities to achieve and maintain a capability that provides the nation with the most detailed, timely, and accurate information for the protection of life and property, and allows for economic prosperity.
   b) Mandate a decadal-survey approach to ensure that the Academy survey of needs and capabilities is current and prioritized.

Next steps to encourage collaboration between the three sectors

1) Increased opportunities and collaboration in public-private collectives to allow efficient, timely, and expanding delivery of weather and climate information, especially on issues of extreme weather and climate.

2) Exploration of the role of the private sector in supplying key forecasts — including harbor forecasts — to NOAA, improving efficiencies and accuracies because of the innovation private sector can offer.

3) Support for new and existing pathways to collaboration between public and private entities enabling a highly favorable return on investment for the U.S. Government and its agencies.

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[6] NOAA, *NOAA and NCAR Partner on New, State-of-the-Art Modeling Framework*, February 7, 2019. https://www.noaa.gov/media-release/noaa-and-ncar-partner-on-new-state-of-art-us-modeling-framework

4) Encouragement for NOAA to adopt and increase usage of funding mechanisms that accelerate Research to Operations using Other Transaction Authority (OTA) and similar contracts.

Silicon Valley and other technology focused regions across the nation deploy large sums of venture capital and investment dollars for the purposes of developing innovative and compelling technologies that have applications and utility in the public sector. Pathways such as the Congressionally approved OTA and Small Business Innovation Research (SBIR) vehicles allow for private-sector companies to move at the speed needed to leverage private capital sources. Success on these pilot and contract vehicles is a boon to both private industry, which gains a validated revenue source from the government, and to the public sector, which leverages substantial amounts of research and development money with none of the risk of undertaking privately funded investments internally.

Closing statement

As the weather and climate enterprise goes forward, we at Jupiter want to be clear we rely on and value what NOAA contributes to observing and modeling the Earth System. A continued commitment from the NWS, NOAA, DOE, and other federal entities to provide open access to model output and observational data is critical to enabling the private sector to do what it does best: provide consumable and actionable information to broad economic sectors. We look forward to continuing the conversation and contributing to the decisions which will help shape the Weather and Climate Enterprise of the future, whether this be a set of conversations organized by Department of Commerce or by the National Academies. We understand many of the needs of the private community with respect to risk and climate information and can be helpful in identifying new roles for the public, private, and academic sectors.

Jupiter and other innovative technology companies can offer tremendous additional services to the United States with significant return on investment to the U.S. economy. The innovation that the private sector has demonstrated in technology, efficiencies, and advanced analytical techniques has not yet been fully applied to the weather and climate communities. Enhanced and thoughtful collaborations between the public and private sectors are likely to allow for unprecedented advances that will help secure the infrastructure, economy and people of the United States. Jupiter looks forward to Congressional support of these public private collaborations to secure America's future.

Rich Sorkin is the Chairman, CEO and cofounder of Jupiter Intelligence, based in Silicon Valley. Jupiter provides data analysis through predictive modeling to help governments, organizations and society manage risks from climate change, natural disasters, and sea level rise. Led by veterans of Fortune 100 companies, machine learning pioneers, a Nobel Prize winner, and scientists from NOAA and the National Science Foundation, the firm offers services to predict weather risks from one hour to 50+ years in the future.

In his three-decade-long career as a serial entrepreneur, executive, advisor, board member and investor, he has led breakthrough companies in numerous industries. Sorkin focuses on commercializing transformative technologies, with a significant concentration on financial services, energy, media, politics, and the environment. A founder of multiple startups, his companies have pioneered the use of satellite data and scalable cloud computing to predict weather events for commodity traders and applied analytics to detect identity theft.

Sorkin is the former Chairman and Chief Executive Officer of Zip2, an Internet 1.0 company best known for analytics and visualization of geospatial data. He served as president of Kaggle prior to its acquisition by Google, leading the introduction of big data predictive analytics into the enterprise market and serving as the company's premier industry strategist.

Sorkin began his career as a consultant at Bain & Company. Before moving to Silicon Valley to focus on leading technology companies, he helped initiate research of the supercomputer industry at Goldman Sachs. After graduating business school, he ran the Sound Blaster business at Creative Labs during the time it gained market dominance, growing revenues from under $100M to close to $1 billion.

Sorkin is an alumnus of Yale University and Stanford Graduate School of Business, where he was a Lockheed Scholar. He has served as a Board Member at publicly-traded companies, private firms, the Yale University Development Board, and several non-profit organizations.

Chairwoman FLETCHER. Thank you, Mr. Sorkin. At this point we will begin our first round of questions. I'll recognize myself first for 5 minutes, and I'd like to start with Dr. Jacobs.

When you previously testified before this Subcommittee on April 30, you said that the subject-matter experts at your agency, NASA, and the FCC are collaborating on a study to set out-of-band emissions limits on the 5G spectrum use at the 24 gigahertz band to prevent interference with weather data. You said on the record that the results of the study would be decided upon on May 15. When will—a few questions, if you can just touch on these—When will the study be released publicly; what is the answer on an acceptable out-of-band emission limit to protect valuable Federal weather data; and can you explain NOAA and NASA's analyses, including how much weather data would be lost, and what would be the impact on forecast accuracy from emissions bleed over?

Dr. JACOBS. Thank you for the questions. I don't have an answer as to when the actual study will be released. I would like to say that NOAA and the Department of Commerce support 5G. We are dependent on 5G to be very successful in a way to distribute our tornado warnings faster to the public, and I'm optimistic that we can come up with an elegant solution where passive microwave-sensitive 5G can coexist.

That said, right now the input parameters that we are using in the study were provided by the International Telecommunications Union, with input from industry. We—subject-matter experts at the FCC, NASA, and NOAA are going back and forth still, debating the input parameters. I don't think there's any debate in the actual algorithms in the code itself, it's the input parameters. From what I've seen, any change to the assumptions in the input parameters proposed by the FCC that have some type of scientific basis produce a negligible change to the NOAA/NASA number.

The number currently proposed by the FCC, minus 20 decibel watts per 200 megahertz, according to the study would result in roughly a 77 percent data loss from our passive microwave sounders. This would degrade the forecast skill by up to 30 percent, so, if you look back in time to see when our forecast skill was roughly 30 percent less than it was today, it's somewhere around 1980. This would result in the reduction of hurricane track forecast lead time by roughly 2 to 3 days. A good example of this is a data denial study that the European Center did where they withheld the microwave sounder data during the forecast for Superstorm Sandy, and a model, which is the most accurate model in the world right now, kept the storm out to sea. So it's incredibly important—it's a critical data set for us.

The number that we've been dancing around is in the upper 40s, lower 50s, depending on when—whether you're discussing base stations or user hand-held devices. This number would result in roughly zero data loss, and then anywhere in between there we are looking at data loss possibly large enough to prevent us from meeting our mission requirements with the future JPSS (Joint Polar Satellite System).

Chairwoman FLETCHER. Thank you, Dr. Jacobs. I have just a short amount of time, so I want to ask just more broadly to anyone who wants to answer this on the panel, as you all know, our econ-

omy is becoming increasingly reliant on accurate weather data for decisionmaking. Every American consumes weather data in their everyday life, and it's in the interest of the entire country to understand how the weather enterprise plans to move forward in improving the short-, medium-, and long-range forecasts, and adapting the forecasts to best serve all Americans in trying to understand how the weather will impact them.

So can you—can—whoever wants to touch on this briefly, about the current mechanisms, can you talk about the current mechanisms for collaboration and communication between the members of the weather enterprise, and how they could be improved? Anybody wants to take that up? Dr. Uccellini?

Dr. UCCELLINI. So I probably had a long history in this, goes way back—in trying to get agencies working together on this. I think we're in a good spot right now, with respect to agencies recognizing that they have to work together to advance. This wasn't always the case. There was this divide between research, who didn't want to adopt, let's say, the operational goals or be hung—have their results hung by an operational success when their success is measured by, you know, papers they publish, and the research that they—in fact, the Academy did a study on this, and they entitled the study The Research to Operations Valley of Death. So—and I've tried reaching across that many times.

I think there has to be some kind of programmatic advances that a research organization, operational organization, see value in the outcome to both. What's happening in the research community now, as Dr. Chen has, I think, illustrated quite nicely, is that they are interested in how we're moving forward to serve society. So now's the time, from a programmatic point of view, to—whether it's focused on types of events, broad scale from maybe seasonal down to the Mesoscale, how we can move forward in that arena, this whole seamless suite of products that the research community has put forward, as a basis for getting researchers and operational people to work together that, I believe, are out there, and want to do it.

Chairwoman FLETCHER. Thank you, Dr. Uccellini. And I've exceeded my time, so I'm going to go ahead and recognize Ranking Member Lucas for 5 minutes.

Mr. LUCAS. Thank you, Madam Chairman. Dr. Jacobs, following up on the first part of the Chair's series of questions, in regards to spectrum and those resources, if NOAA is forced to stop work on its polar satellites, is there another type of observation that can offset that loss?

Dr. JACOBS. The—not today. I can't say that one wouldn't exist in the future, but there's not an existing capability to mitigate that data loss that exists today.

Mr. LUCAS. So this really matters?

Dr. JACOBS. Yes.

Mr. LUCAS. Dr. Jacobs, I understand NOAA is still conducting the Commercial Weather Data Pilot Program. Can you give us an update on the program, and is NOAA still considering purchasing commercial data?

Dr. JACOBS. Yes. With respect to the testing of the GPS RO data in our models, we're seeing a very promising impact. We've

transitioned this over to—actually, in the proposed budget, to acquire this data as an operational data source. The Commercial Weather Data Pilot Program will actually look at additional instruments beyond GPS RO, perhaps hyperspectral sounders, or other instruments.

Mr. LUCAS. Turning to you, Dr. Fiebrich, the Mesonet is a valuable resource which assists Oklahomans across the State in decisions ranging from farmers deciding when to plant, that soil temperature key being very important, to emergency personnel preparing for weather events. Can you describe to the Committee what makes the Oklahoma Mesonet unique?

Dr. FIEBRICH. Thank you for the question, Representative Lucas. I think one of the big things that makes Oklahoma's Mesonet unique is that we have survived 25 years, because it is a great challenge for the State networks to find the funding to keep these networks going from year to year.

Mr. LUCAS. At least twice in my tenure in Congress I've made calls home, I'm a former State legislator, to my old friends about how important this is over the course of the last decade, absolutely. Do you think we could replicate this model on a larger scale to provide the kind of weather forecast thing that we do in Oklahoma?

Dr. FIEBRICH. Certainly. Once we developed the Mesonet in Oklahoma, others took notice. They saw the dividends we were bringing to Oklahoma. And over the years we've worked with 25 States and countries to help them plan and operate Mesonets in their regions across the U.S. Because, as Dr. Chen mentioned, the weather doesn't stop at boundaries—at State boundaries. We need those observations in neighboring States like Texas, and Kansas, and Colorado to help make predictions in Oklahoma also.

Mr. LUCAS. In my home community, we're, of course, on the side of the Rockies—Southern Plains, the western part of the State, as you well know, prescribed burns are a very important part of maintaining the ecology of the national grasslands. My colleagues here who have not had a chance to look at your website would be amazed at the information that the Mesonet provides, and literally no prescribed burn plan in Oklahoma starts without a requirement to examine, on a moment-by-moment basis, the Mesonet sites before you can move on.

That said, in your role as Executive Director of the Mesonet, and a faculty member at the University of Oklahoma School of Meteorology, you're uniquely positioned to offer testimony to this Committee about the collaboration between Federal, academic, and industry. In your experience, is there enough collaboration between the different components of the weather enterprise? And, for that matter, what actions could this Committee take to promote a more effective collaboration, Doctor?

Dr. FIEBRICH. Well, as I mentioned, the national Mesonet program that I've been able to witness I think is a perfect example of that public-private partnership, that cost-sharing model, where you can take the expertise of the universities at the State level, work with the private sector, and provide the Federal Government tens of thousands of additional observations at a fraction of the cost. I think specifically this Committee could help promote that collaboration by, you know, steady growth to the program, supporting the

program, because, as we have more observations, the forecasts will improve. As there's more support, it'll give researchers the opportunity to look into new technologies in Mesonets. I think a really exciting one is using UAVs. We've launched over 1,000 UAVs at our Mesonet sites in prototype mode to look at how that could provide observations of the lower boundary layer to provide to Weather Service forecasters.

Mr. LUCAS. Thank you, Doctor. Just one more time, Dr. Jacobs, let's go back for a moment to the polar satellites. At the present time, if we lose the ability to use those, there's not another resource of that nature, at the present time, available to replace them with that——

Dr. JACOBS. No. We have no other capability to passively observe water vapor.

Mr. LUCAS. Thank you. Yield back, Madam Chair.

Chairwoman FLETCHER. Thank you, Mr. Lucas. I'll now recognize Mr. Tonko for 5 minutes.

Mr. TONKO. Thank you, Chairwoman Fletcher, and thank you to the witnesses for being here today. I am deeply concerned about the reorganization of the National Weather Service forecast offices. My questions about EVOLVE have faced delays, misinformation, and many questions remain unanswered. I've been requesting some of this information since May 2017, so let me state the obvious, that was 2 years ago. These delays have only added to my concern about what's really going on at the National Weather Service. At various times I have been given contradictory, and sometimes clearly incorrect information and reasoning for the delays, and, at times, I have received no answer at all.

Lacking a consistent credible response, I have to think that, where there's smoke, there is indeed fire, and there has been an awful lot of smoke these past few years. This prolonged pattern of misinformation and evasion leaves me wondering, what is the agency hiding? So, Dr. Uccellini and Dr. Jacobs, I'm looking for a straightforward yes or no. Will you commit to providing Members of this Committee with all of the materials that have been requested?

Dr. UCCELLINI. Yes.

Mr. TONKO. And Dr. Jacobs?

Dr. JACOBS. Yes.

Mr. TONKO. And can I ask what date would be a reasonable date by which to receive that information?

Dr. JACOBS. We'll have to get back with you on the exact date, because that depends on the actual materials that we have to gather, but it'll be as soon as possible, I can promise you that.

Mr. TONKO. Well, if you could get back to the Committee, and at least give us a date in the very, very near future——

Dr. JACOBS. Certainly.

Mr. TONKO [continuing]. So that we can understand what that threshold date is. Section 410 of the *Weather Research and Forecasting Innovation Act of 2017* required the agency to submit a report on contractor use and the number of civil service vacancies at the NWS by October 2017 and to publish an annual report on the Internet within 6 months of the end of every fiscal year thereafter.

Your agency has missed both deadlines. Why have you not submitted and published this report, and when will you do so?

Dr. UCCELLINI. So we keep track of the level of positions we have that are appropriated for, and the number of positions that we have on a biweekly basis, so I'm not—I'm a little bit confused as to why those numbers haven't gotten out. But, as of right now, we are appropriated for 4,623, onboard is 4,194, which is 429 vacancies, and we have over 300 hiring actions in place right now.

Mr. TONKO. Thank you. And, Dr. Jacobs, I expressed to you the last time you were here that I also have some major concerns about National Weather Service understaffing. I'm especially concerned that any reorganization or reduction of hours not result in any degradation of service. For example, I recently learned that the proposed changes to how you categorize field meteorologist will, in fact, result in fewer forecasters in each office. That is not acceptable. The rush to implementation of the national blend model, with the purported goal of freeing up forecaster time, is concerning. Background of all this makes matters even worse. NWS is not filing critical—filling critical vacancies.

Let me be very clear. If you are defying Congress and the American people by using this process to diminish the capacity and number of our forecasters, Congress will not be silent. Any major transition of this kind needs to follow a process backed by research and evidence that show the change will not degrade service. Some of the new innovations here are great forecasting tools, but they cannot replace having enough experienced forecasters on the ground. I have heard from many forecasters who are worried about the hasty changes being made, and about the resulting negative effect that this will have on public safety. Their concerns are credible, and deeply disturbing. Based on what we already know, the Committee needs to hear directly from forecasters on the ground, as well as emergency service providers who rely on them.

I am nearly out of my time here, Madam Chair, but, again, I would hope that we can work together on this going forward, because there are important constituents—constituencies who we should hear from, including the people who work as forecasters at the National Weather Service, and from the State and local workers, and emergency workers, who work closely with NWS to keep our constituents safe. This is a critical service. As a person who chairs the Subcommittee on Environment and Climate Change, there's a direct link, and I want to make certain that we're utilizing professionalism to the nth degree, and—in the most effective and efficient manner. So, with that, I'll yield back.

Chairwoman FLETCHER. Thank you very much, Mr. Tonko, and I would just like to underscore the importance of providing the documents that Mr. Tonko has requested, and, of course, providing all documents as they are requested by Members of Congress. Thank you very much. I will now recognize Mr. Gonzalez for 5 minutes.

Mr. GONZALEZ. Thank you, Madam Chair. Thank you to the witnesses for being here today, and for your attention and testimony. In my home State of Ohio we have tremendous research institutions that are always at the forefront of innovation, and I want to turn my question to the role academic institutions play in weather forecasting.

Dr. Chen, what role, in your opinion, should academic researchers play in helping the U.S. to improve its poor position in weather modeling, and can you tell us a bit more about how the institution should play more broadly?

Dr. CHEN. Thank you, that's a great question. We have been—really wrestled with this question for a long time. Academia play an important role on several fronts. First, the innovative research has been done at the university level, and academia, broadly speaking. That's always been the forefront in the world, and a lot of research products we're very proud of, eager to put them into useful tools for operations. This has been an unmet challenge, that I had mentioned.

Second, academics have played a key role in training the future workforce. The need for impact forecast and how people respond to forecast, it's very much interdisciplinary and multidisciplinary research, and this requires our current workforce to be up to date, in terms of both computing, management, and there's a lot of interface between physical science and the social science. We are very active in terms of promoting that multidisciplinary research and education to prepare for the workforce to meet the challenge, so the academic community really taking this very seriously. Although we still have a challenge, we would like to reform our system to meet the current technology and science advances.

Mr. GONZALEZ. Thank you. And, Dr. Uccellini, given we're on the cusp of new technologies being implemented across different applications and parts of our economy, I'm curious to know what you see the future role of artificial intelligence and machine learning at the National Weather Service. And, Mr. Sorkin, if you could talk about it more related to your industry after he's done?

Dr. UCCELLINI. Well, I think it's going to have a major role, and there's a lot of potential in utilizing that to assist decisionmaking, both in terms of accessing the data and quality control, extracting information from numerical models, whether they're the single runs or the ensemble runs. In fact, it's no way possible for any human being to extract the—all the information out of the myriad of ensemble model runs that we access today. And then in the probability aspects, in terms of how you affect a decision at key decision points, I think it'll be helpful there as well. I do want to emphasize that all these systems are better utilized as they're assisting decisionmaking by a human being, and that's something that I think sometimes gets lost in the enthusiasm for artificial intelligence.

Mr. GONZALEZ. Absolutely. Mr. Sorkin?

Mr. SORKIN. Yes. Jupiter uses a combination of dynamical modeling, as is prevalent in the weather enterprise, AI, and other forms of modeling. One of the benefits of our cloud-based architecture—or infrastructure is the ability to compare the results of a dynamical modeling and AI approaches side by side in the same modeling chain. We essentially can substitute one, see how it performs, versus the other, in terms of the accuracy of the predictions, when tested against ground truth data, the overall compute load, and the explainability of the results, which, in certain regulated industries, is also critical. And I would say that overall the private sector, in most other domains, is much further ahead primarily because of

the amount of investment in AI than the weather enterprise generally.

Mr. GONZALEZ. Got it. And then, if you could, how do you feel we're doing relative to China on this particular front?

Mr. SORKIN. Specifically within the weather enterprise?

Mr. GONZALEZ. Specifically AI machine learning. So generally.

Mr. SORKIN. Historically the United States has been a leader in AI and machine learning. The Chinese are catching up very rapidly. They have fewer constraints on the use of consumer data, which in some cases is an advantage in further progress on the whole. I think the United States is still ahead, however, it's an area that definitely requires very careful attention by the Federal Government and the private sector on an ongoing basis. And, in addition to that, I would emphasize the importance of protecting the country's intellectual property, something the President has given substantial attention to recently, and that is a critical issue for Silicon Valley and the country generally.

Mr. GONZALEZ. Excellent. Thank you, and I yield back.

Chairwoman FLETCHER. Thank you, Mr. Gonzalez. I'll now recognize Mr. Crist for 5 minutes.

Mr. CRIST. Thank you, Madam Chair, and thank you for the witnesses being here today. We appreciate your attendance. Dr. Jacobs, great to see you again, and to have another opportunity to discuss the very critical work that NOAA does.

Today's topic certainly is an important one, Madam Chair, and timely as well. We're only 16 days away from the start of the hurricane season, so when I heard weather forecasting would be the subject of today's hearing, my mind immediately went to Hurricane Irma, which, as you know, hit my home State of Florida in 2017. Leading up to that storm, the track kept shifting. First it was up the East Coast, then up the West Coast, and then finally straight up the middle of Florida. The entire State of Florida was inside the prediction cone, making it difficult for emergency managers to make evaluation decisions, and prompting a mass exodus of seven million people from the State that clogged our roadways and stressed fuel supplies. And while I'm thankful that so many Floridians took the storm as seriously as that, some would argue that over-evacuation can prompt under-evacuation the next time a storm may hit, and that's something I'm extremely concerned about.

Dr. Uccellini, how can we improve track forecasts for hurricanes to shrink the cone, perhaps, and provide the most accurate information to the public ahead of a large hurricane like Irma was?

Dr. UCCELLINI. So a couple of points on that. First of all, with Irma, we were actually amazed that the government of Florida actually declared a state of emergency 6-1/2 days before landfall, recognizing, A, the uncertainty in the track forecast, and we try to communicate that, and—especially with our users who are embedded in the emergency operation centers and the like.

Mr. CRIST. For the record, that was not me.

Dr. UCCELLINI. I know.

Mr. CRIST. OK.

Dr. UCCELLINI. I know. But it was an amazing event for us as well, to have that happen, given the uncertainties between the

tracks up the East Coast of Florida and the tracks up the West Coast of Florida. What we saw was that, on either track, there was going to be significant impact to the entire State.

But you're pointing to a really major problem, that decisions are made earlier to try to hit that sweet spot for the evacuations. And, given that earlier need for decisionmaking, it puts extra emphasis on the need for model forecasts, because that's the only thing we have in those timeframes to base any kind of decisions at 3, 4, 5, 6, 7 days in advance. To improve the models, it's all the things we're talking about here. You need the global observing network. So Dr. Jacobs spoke to the need for the passive microwave sounders that any value study of observations into models that I've seen rates that as the number one observation for the accuracy of the models.

The—so you have observations, you have—we have to improve the models in terms of resolution, the data assimilation to ingest the information for those models, and the physics, all of the above. And we need—we continually need to press the computer industry. For running models operationally we have a primary system and a backup system so that it's always there, and we're always pushing the envelope on the computational capacity that we need to run an operational model system to ensure you're getting the best forecast on a timely manner all the time. So those three components are there, and we're working all three of them. Again, like I said before, we're only as strong as our weakest link. We're pressing ahead on all three.

Mr. CRIST. Great. Thank you very much. And, Dr. Chen, I'm curious, would you have anything to add to this?

Dr. CHEN. Yes. I think Irma taught us lessons for current capability. We're not quite—met the challenge of forecasting impact. So in hurricane forecasts, we not only need the track to be correct, intensity correct, and also the tool to forecast storm surge. For instance, Irma—18 hours ahead of Irma, the forecast for Tampa Bay area is greater than several foot of water, so you know what happened. Tampa Bay not only didn't get storm surge, actually water drained out of Tampa Bay. We saw the bottom of Tampa Bay, because—wind offshore, and water being pulled out of Tampa Bay by ocean currents. This is a demonstration that we need a coupled model with ocean, and atmosphere, and storm surge capability to make that level—forecast. So that is the lessons we needed to learn.

And, at the same time, I do want to tell you that that morning the BBC called me about explaining this, because we have a publication already describing the full coupling impact on storm surge. So the academic community does have research results. We're—currently have no direct paths to have that function in the National Weather Service at this stage. So I want to emphasize the point we need a mechanism to make research to operation transition.

Mr. CRIST. OK. Thank you very much. Thank you, Madam Chair.

Chairwoman FLETCHER. Thank you. I'll now recognize Dr. Baird for 5 minutes.

Mr. BAIRD. Thank you, Madam Chair, and thank you, witnesses, for your testimony and discussion of these issues about weather.

Dr. Chen, you mentioned the changing landscape of the U.S. weather enterprise, and the challenges that's presenting. You also mentioned, just as kind of an example, that these include the shifting balance between government and private sector, so I guess my question deals with this. What do you foresee, and could you prioritize those for the future needs of the U.S. weather enterprise, and how and what Congress might do to be able to facilitate that?

Dr. CHEN. Thank you for the question. That's a great question. We've been—wrestled with this for—long time. The weather enterprise is broad. We have both—we have three sectors, the government, and the private, and the academic. So, in fact, I want to go back to an example we just discussed, the 5G. The weather enterprise is broad. A lot of times our challenge is even broader because the 5G, that actually showed us an example, the weather enterprise interface with other sectors. So I think National Academies have the capability to bring in all three sectors, and, outside of weather enterprise, to really make this assessment—currently.

For instance, this 5G issue, it is complex. We interface with a different part of the technology and economy, so the National Academy now is planning to bring the board radio frequency, which is not within our current weather enterprise, but we are expanding that because—the need for the society. So, if I may, I would like to comment on how should we go forward for making this enterprise is so broad, and excellent on each individual point—parts, but the total is not making up the sum of each component. The total should be better than the sum.

So, in order to do that, I really think we have an opportunity to bring this into a new operating model that brings in the academic, private, with the government agencies. Not only one agency, but the multi agencies. National Science Foundation, NASA, Department of Energy, Transportation. Many of them can bring their expertise to the table to develop models, observing capabilities, computing assessment. That's another complex field that we have not been able to do full assessment. Whether it's the high-performance computing, or cloud-based computing, or a combination of many things.

So our horizon really is looking down the road 10 years, 20 years from now, so we need to be totally open, bring all the sectors coming to the table to design the system. And, in order to do that, we need to have a national center to bring the entire community in, and developing this unified model can address this complex issue we just discussed, because we're facing the weather impacts, local and global prediction—increase our lead time. These are huge challenges. Our current modeling systems are not capable of doing this for the time being.

If I may, I want to add one more component. So we all have our phones in front of us. The phone—I have my first iPhone 2007. Only—little more than 10 years, this technology has changed our entire society. We are looking in the weather enterprise, in terms of next decade or 2 decades, we have to be completely open minded, embracing all possible sectors to think broad and bold, and thinking that we may really need assessment now, and how do we anticipate what's happening next. Thank you.

Mr. BAIRD. You timed that very well. You used all my time, so thank you very much. What a great answer, and we appreciate it. I yield back.

Chairwoman FLETCHER. Thank you, Dr. Baird. I'll now recognize Mr. Beyer for 5 minutes.

Mr. BEYER. Thank you, Madam Chair, very much. Dr. Chen's clearly a seasoned testifier before Congress. Dr. Jacobs and Dr. Uccellini, it's often been the role of this Committee to play defense on behalf of the staff, the workers of the National Weather Service, and I just want to make sure to echo Mr. Tonko's remarks that we want to make sure that any reorganization or the reduction of hours don't result in a degradation of service. We'd like to work closely with you to make sure that that workforce that's so essential is treated fairly, and is part of the solution.

Moving on—and I—again to Dr. Jacobs, Dr. Uccellini, I read really carefully your testimony about 85 percent of the data is water vapor data that you use for weather forecasts, and that, due to the physical properties of water, water vapor can only be measured at the frequency bands currently allocated, the FCC's proposed radio frequency, etc.—we have apparently heard a great deal from the digital community, the AT&Ts and others, saying, no, no, this is not going to interfere with NOAA. Where's the science on this, and how do we respond to the FCC chairman's notion that there's no science to back up this idea there's a conflict with this 24 band and NOAA's need for the data?

Dr. JACOBS. Well, we've been working together with NASA and the FCC for the last couple years on this study, and actually, at the request of the FCC, we've reconducted this study multiple times, in fact, wholesale rewriting the software in Matlab for a second time. I really don't think anyone's debating the actual algorithms in the study. The debate tends to be around the assumptions of the input parameters. And right now we're using the input parameters that were provided from industry that meet the recommendations by ITU. So, if there's other parameters beyond that, you know, we would have to determine whether there's any scientific basis for that or not. Again——

Mr. BEYER. Is——

Dr. JACOBS. Go ahead.

Mr. BEYER. Is this the kind of thing that you would encourage Congress to take an active role in protecting the weather data, and therefore pushing back on the FCC's intent to go forward?

Dr. JACOBS. Well, I, you know, I haven't seen any scientific evidence to support the minus 20 decibel watt per 200 megahertz number, so right now the only scientific studies I've seen out there are the ones produced by NOAA/NASA which have been concurred with by the Navy, as well as an independent European Space Agency study, which actually concluded a more restrictive number than we came up with.

Mr. BEYER. OK. Thank you very much. Mr. Sorkin, in Dr. Davis—Dr. Uccellini's testimony, they also talked about the availability of the unique data sets developed by the commercial sector, the private sector, could potentially jeopardize not only academic research, but also the market for specialized weather products and services. So I think they were trying to do the yin and the yang.

On the one hand, we want to have all this data available to the researchers, on the other hand, what do you have left to sell? What's the private sector's perspective on the data sharing?

Mr. SORKIN. The private sector is a diverse and complicated entity. It's not one particular viewpoint. So, for someone like Jupiter, we are consumers of the data from the Federal Government, and in particular NOAA and NWS, and it would be substantially disruptive to our business if some of that data and the modeling that NOAA does, based on that data, were no longer available. On the other hand, like Dr. Jacobs, we see that technologies, like GPS RO, are quite promising in improving the skill, or overall performance, of the weather forecasts, and so I would take a blended approach. It's kind of case by case. Certain data is of great value add to both NOAA and the private sector. Other data might be directly competitive. From our perspective, we kind of sit on top of that, and will use whatever the best available data is, whether it's coming from the Federal Government or the private sector. And that then translates into the best available services for citizens in places like New York, and Houston, and Puerto Rico, and throughout the country, in terms of understanding these risks, and we're really agnostic as to where the data comes from.

Mr. BEYER. Great, thank you. And later, Dr. Jacobs, I'd love—explain to me cubing the sphere, and how parallel that is to squaring the circle, but my time is up, so——

Chairwoman FLETCHER. Thank you, Mr. Beyer. I'll now recognize Ms. González-Colón for 5 minutes.

Ms. GONZÁLEZ-COLÓN. Thank you, Madam Chair, and thank you, all the witnesses here. And, coming from an island that suffered two hurricanes in a row, Irma and then Maria, I'm really grateful for all the help NOAA and the rest of the agencies gave to the island. Not just to the reconstruction—we lost our power, we lost our communication, we lost our radars. And we actually lost our Doppler, and the airport as well, with the radars at the airport. So it was because of the U.S. Marines Corps radar units and the Department of Defense that were lended to us on a temporary basis for a few months, I think 9 months until you repaired the Doppler and the radar. And we allocated funds for that during the bipartisan bill, plenty in different areas for repairing new technology, and the sensors.

My first question will be, all the Dopplers and the radars are repaired using new technology, or they were just repaired as they were before the hurricane?

Dr. UCCELLINI. So, first of all, you know, thank you for your comments. We actually worked with the Department of Defense, and we're very thankful for the interaction of bringing their X-band radars to you, and it was more than one, and—remind everyone you were still in the middle of the hurricane season when we were able to do that. And we got the Doppler reconstituted.

In that process, we actually improved the receivers and the transmitter components of the radars. That was part of an ongoing effort for the Service Life Extension Program for all the radars in the United States. So we built that new technology in, but still operating on the same principles, including the inclusion of the dual pole, so——

Ms. GONZÁLEZ-COLÓN. Yes. The reason I'm asking this question is I remember working with you guys, and the rest of the Federal agencies, to make that happen, and remembering when you used military planes to have the pieces to work that out. And when you've got no radars, no commercial planes flying to the island, no water, no electricity, and no telecom, it was a complete theater of war, what we experienced at that time.

So my next question to you will be in terms of making all the funds that were assigned for the marine debris assessment and removal, the repair and replacement of certain assets, the physical property mitigation, improved weather forecasting, all those funds that were allocated to the repairs across, you know, not just Puerto Rico, Virgin Islands, Florida, and the rest of the States, all those repairs have been done?

Dr. UCCELLINI. Yes. We're working according to the spend plans that were submitted to Congress.

Ms. GONZÁLEZ-COLÓN. So we don't need any more funds for that?

Dr. UCCELLINI. That I can't answer right now.

Ms. GONZÁLEZ-COLÓN. OK. That was the point of one of the question directly. My second question will be, then, how can we—if we can elaborate on any other new improvements that we may need in order to have a better position to withstand similar hurricanes affecting the same structures, do we have any other new way to maintain those units on the island?

Dr. UCCELLINI. I'm sorry, are you talking about—the means for measuring and providing the information, we are working to build—we, you know, the capacity of that is always something that we're trying to improve.

Ms. GONZÁLEZ-COLÓN. Let me better explain what I meant——

Dr. UCCELLINI. OK.

Ms. GONZÁLEZ-COLÓN [continuing]. In my question, maybe. We are part of the Caribbean belt, we are in the hurricane area, so this is something that, every year, we will have our hurricane seasons. My question is, the units, the radar, the Doppler, and all the equipment that we've got on the island can withstand another hurricane of the same magnitude. Do we improve the way they were built, or that's something that, of course, may happen?

Dr. UCCELLINI. I'll have to get back to you on the specific specifications for that, but a Cat Five hurricane——

Ms. GONZÁLEZ-COLÓN. Is complete destruction.

Dr. UCCELLINI [continuing]. Will still have its destructive capabilities, I'm afraid.

Ms. GONZÁLEZ-COLÓN. Actually, I agree with you. My question will be if there are any other opportunities that we may have to improve the location of the radars? I know that when you brought one of the radars, you established a pilot program in Aguadilla, and you can come back to me on that. I know my time is expired, so I will submit the rest of my questions for the record. Thank you, and I yield back. Thank you.

Chairwoman FLETCHER. Thank you. I will now recognize Mr. Casten for 5 minutes.

Mr. CASTEN. Thank you, Madam Chair. Thank you to our panel. So when I was starting my career as a young chemical engineer, I had a colleague who used to like to tell a story that—about a boy

who walks by a cave, and he sees a dragon, and he taps the dragon with a pencil, and the dragon stays asleep. And he said, only the dumbest kid on the planet would say, you know what, I can linearly extrapolate that I can probably safely punch the dragon in the nose. I tell that story because over the course of my lifetime, atmospheric CO_2 concentrations have gone from 325 to 415, almost 30 percent, and we have behaved like that dumb little kid. We have linearly extrapolated that first 10 ppm, 20 ppm, didn't seem to do anything, and so we've just kept burping CO_2 into the atmosphere, and we have now woken up the dragon. The nerd version of this is do not perturb volatile systems.

Fourteen billion-dollar weather events last year, wildfires on the West Coast, the bomb vortex in the Midwest, which followed shortly the polar vortex in the Midwest, Midwest flooding. Every year is the hottest year on record. And in an increasingly volatile system, we depend increasingly on having accurate weather forecasting for our farmers, for folks on the coast, folks in—like my daughter wondering how to seal the door when the bomb vortex was coming in.

I am really concerned, in light of that history, that the Trump FY 2020 budget request slashes our ability to do weather forecasting. I think it's a 7 percent total cut. It's a $12.5 million cut in Mesonet funding, sorry, Dr. Fiebrich. I believe it's a halt in HPC resources for hydrological prediction, which is a concern about Midwest flooding, and almost a 10 percent cut in full-time employees at the National Weather Service. Dr. Jacobs and Dr. Uccellini, were you consulted on that budget request?

Dr. JACOBS. So we spent a lot of time working very hard trying to put this budget together, and, in a situation that required really tough choices, and trying to balance priorities, we made the decision to implement these cuts primarily on external grants. So we are going to——

Mr. CASTEN. But hang on, you say hard choices. You—did you make a decision programmatically to cut those services, or were you told to meet a dollar value?

Dr. JACOBS. So we have a number that we have to work within——

Mr. CASTEN. No, excuse me, you don't. You can propose whatever budget you want. We're going to decide whether you like it. Did you request—did you formally request that budget, or were you told by the Trump Administration this was the budget you had to manage to?

Dr. JACOBS. So this budget was our formal request——

Mr. CASTEN. OK. So you requested those cuts in programmatic resources?

Dr. JACOBS [continuing]. But these cuts do not pertain to our actual operational capabilities. There's not going to be any degradation in our forecasting capability.

Mr. CASTEN. Did you formally model that?

Dr. JACOBS. Well, there will probably be a delay in some of the research capability, but that was the reason why we implemented the Earth Prediction Innovation Center. That was an additional $15 million to harness the external development——

Mr. CASTEN. No, but hang on, you just said this is not a diminution in the—I mean, I heard you talk about the importance of the HPC program, which is being cut. I heard a lot about Mesonet, which is being cut. You're saying that there will be no diminution of our modeling resources. How did you come to that conclusion?

Dr. JACOBS. Well, a lot of the research side of the compute we can actually work in the cloud. There's also another thing that we're looking at, in the interest of doing acquisition of HPC, is a cancellation liability fee. So that's something that's actually——

Mr. CASTEN. OK, but we're tight on time. I'm asking a quantitative question, and you're giving me a qualitative answer. How do we—you know—how do we know, on this side of the dais, how does the American public know that in a world with more and more volatile weather, that these draconian cuts to the system are, in fact, going to maintain accuracy of weather forecasting in an increasingly volatile weather world?

Dr. JACOBS. We would not make any cuts that are going to decrease our forecasting skill. How we prove that to you, I suppose you would have to look at our model verification scores.

Mr. CASTEN. Can you share the—that analysis with the Committee?

Dr. JACOBS. They're posted online. I can share the link.

Mr. CASTEN. If you are wrong, how quick is it to restore those programs?

Dr. JACOBS. Well, I'm confident I'm not going to be wrong, so that's a question that I can't answer.

Mr. CASTEN. I don't think any of us should be that hubristic, sir. I'm not that confident in my own abilities.

Dr. JACOBS. Well——

Mr. CASTEN. If we cut 110 people, how much institutional knowledge is lost? If we are no longer funding the HPC program, and all of a sudden a flood comes through that we didn't predict, it's a little late to say, well, Dr. Jacobs said he was confident he wasn't going to be wrong. How do we get that confidence, as we sit here and decide what the budget should be?

Dr. JACOBS. So these cuts were to extramural grant programs with cooperative institutes and programs like that. We're not making any cuts to our operational capability.

Mr. CASTEN. Well——

Dr. JACOBS. It's not going to get worse.

Mr. CASTEN [continuing]. My time is up, but 110 employees is a concern. I yield back my time. Thank you.

Chairwoman FLETCHER. Thank you, Mr. Casten. I'll now recognize Mr. Lamb for 5 minutes.

Mr. LAMB. If I could just follow up on that same line of questioning, I would just like to clarify, because I don't know—I also was concerned that there are such serious cuts in the 2020 budget request. I have a National Weather Service forecast office in my district, with excellent employees who just went through a government shutdown and worked without being paid this same year, doing, you know, work that we all know needs to be done. So under—let me just make it a simple question. Under your budget request, as you see it now, do you believe that there would be any

staff positions cut from the National Weather Service office in my district, in the 17th District of Pennsylvania?

Dr. JACOBS. No. We're not planning to cut any staff offices or personnel there. We're actually—so this last year was the first year since 2011 that hiring has actually outpaced attrition. If there was a decrease in actual staff, it was because the shutdown happened at the end of the year, and typically people retire at the end of the year, so we have to cover that gap, and we're still in the process of digging out of that hole, but we are certainly headed in a positive direction.

Mr. LAMB. I appreciate that clarification. So you believe that the cuts you have requested would not apply to actual personnel, but would apply to some of these other research programs that you're talking about?

Dr. JACOBS. It's on the research side. And I would like to take this opportunity to also highlight the national blend of models. I want to make sure everyone's aware that this is not meant to replace forecasters at all. It's meant to be a tool to help them.

Mr. LAMB. I appreciate that. Thank you. Dr. Uccellini, do you agree with that same assessment by Dr. Jacobs, that there will not be a personnel impact from the budget cuts you are proposing?

Dr. UCCELLINI. The budget states that they recognize our desire to apply personnel to this decision support services, but some of those resources will be redirected to other administration priorities.

Mr. LAMB. Would you mind just answering my question with a yes or no? His assessment is that it will not affect staff or personnel in the weather forecasting offices. Do you agree with that?

Dr. UCCELLINI. The—there is a decrease in the Weather Service that are—that's applied to the particular part of the budget that does involve personnel. There is still a question as to whether we can absorb that or not, with respect to the current staffing levels.

Mr. LAMB. And which personnel would be affected that you're referring to? Which portion of the budget is that?

Dr. UCCELLINI. That's the analyze forecast support. It's the—in the forecast area. So that—it's not a large cut, but it's something that we have to look at and apply within that particular portfolio.

Mr. LAMB. OK. And there are about 434 vacancies at the National Weather Service already?

Dr. UCCELLINI. 429.

Mr. LAMB. 429? All right. It's moving in the right direction, I guess. My point is this. I've met these people. They live and work in my district. They do excellent work. They absorbed a very difficult shock in their own personal lives, when they had to work through the shutdown this year, doing work that the country needs them to do. I think they deserve a little bit of clarity on whether they're getting help inside their agency or not. Many of these people feel overworked. They're working additional hours. Now they realize that, you know, the administration that oversees them is proposing cuts to their agency, and we're getting two different stories on whether those cuts are going to affect the personnel situation at that office. So I would request that the two of you communicate over exactly what's happening here, and if you can follow up with us on exactly what the personnel impact of these budget cuts would be, I think we all want to know that before, you know, we

render a decision on what we think of the budget request. And with that, Madam Chairwoman, I yield back the balance of my time.

Chairwoman FLETCHER. Thank you very much, Mr. Lamb. And I—again, I want to thank all of the witnesses. This has been such a good panel that your prize is a second round of questions from Members of Congress. So we agreed up here that this is something—we all would like to follow up on a few other things, and so I'm going to first yield myself an additional 5 minutes to ask questions, and I want to do a quick follow up on the budget.

We've already had a budget hearing, but I did want to follow up, as we talk about funding levels, about making sure that our communities are equipped with an accurate hurricane forecast. As we head into hurricane season, that is the number one concern in my district. I represent Houston, and we, of course, were impacted by Hurricane Harvey. So, on the budget question, I just want to ask you, Dr. Jacobs, to follow up, can NOAA ensure that our communities are equipped with the best possible hurricane forecast, given the funding cuts in these areas?

Dr. JACOBS. There's not going to be any degradation to the forecast skill.

Mr. LAMB. OK. And then my other follow up question, before I was asking, and Dr. Uccellini had a chance to answer my question, but would anyone else like to comment on mechanisms for collaboration and communication between the members of the weather enterprise? I think I cutoff some potential answers in the last round, so I would love to hear from you, Dr. Chen, from Mr. Sorkin, anyone who wants to weigh in on this.

Dr. CHEN. Thank you for the question. If I may, I would like to address—several questions came up during this hearing specifically addressing to, Chairwoman, your question about how we best go forward. One of the difficulties right now is our enterprise has this very broad, complex needs for the society service. So currently we have—like NOAA and some other agencies, the budgetary priority is set year to year, and sometimes we are put in this reactive position, which—something that National Academy has been proposing the study to look long-term at how we best predict these weather extremes, and—in the changing climate that will benefit society in the long term how do we best position ourself—forecast weather to—from the very high-resolution model, like resolving Harvey, flooding, if you probably recall, during Harvey much of the flooding was due to rain. Storm surge blocked drainage. Also, the built environment that actually blocked the drainage to the ground. So these are very challenging.

In my third part of the written testimony, we—asking Congress to help. So I think you can really help to organize this enterprise, look 10 years, 20 years down the road. We had very successful models to do this before. The decadal survey from the Earth—observing from space just published last year, that map out very long-term plan—200 scientists involved in developing that plan, and take a long-term vision. So this way, if we have something like that in the weather enterprise, we can best organize our entire country to take a long-term plan. We do not have to do this reactive thing that—year to year that put us in this very difficult position.

I'm pretty sure the whole country will be saying, well if we have weather like the decadal survey we can start acting now, and continue to meet our challenges.

Chairwoman FLETCHER. Thank you, Dr. Chen. Mr. Sorkin?

Mr. SORKIN. Thank you. Jupiter looks at this question from several perspectives. First, our current product, second, our product road map, and third, the difference between universities and the public sector. With regard to our existing products, the company is 2-1/2 years old. We deployed our first service in under a year, and part of that was through collaborations with university partners in New York that included Columbia University and Brooklyn College, where we identified very specific scientific expertise that we wanted to leverage into our commercial services. We've done the same thing with Rice in Houston, and similarly in Florida and around the world.

Second, from the perspective of our long term product road map, so say 3 to 10 years, we identify emerging science that we believe will have a positive impact on the predictive quality of our services for protecting life, and infrastructure, and continuity of mission for things like hospitals, and roads, and hotels, and power plants, and the like. And there—we talked earlier about cloud computing. One of the things that we're working quite aggressively on is helping our university partners access cloud compute resource, integrate it into our operational infrastructure, and test the models even before they're ready for operations to accelerate the research to operations process. We can do that because we're very targeted on a specific set of customer solutions, and work backward from that to the short-term and medium-term science that's required.

From a government perspective, we have a very good dialog with our colleagues at NOAA, and I think they're—the best, most useful thing, from a NOAA perspective, is transparency on the existing scientific priorities, as well as what's coming down the pike, both internally within NOAA, and from a scientific funding perspective. I think they do a good job on that, and we'll continue to work closely with them to better understand what's coming down the road to deliver these risk services in places like Houston and Texas generally.

Chairwoman FLETCHER. Thank you, Mr. Sorkin. And I've once again gone over my time. I'm going to recognize Ranking Member Lucas for 5 minutes.

Mr. LUCAS. Thank you, Madam Chair. Dr. Jacobs, let's talk for a moment more about the spectrum issue, and at the conclusion I'd like to offer an observation or two about the budget process.

And while—question to you, sir. While we wait for the public release of the NOAA/NASA study, can you explain the process you used to validate the study?

Dr. JACOBS. So typically we would take these algorithms, we would use a baseline set of assumptions, first testing things that are known quantities, and reproducing outputs that are known. That's how we actually verify the code. The actual subject-matter experts—this was validated with NOAA subject-matter experts. It was concurred with the Navy, and then, most importantly, validated by the subject-matter experts at NASA, and this is an agency that sent a man to the moon 50 years ago using calculators, so I

would certainly trust their input. But just to convince myself, I actually got a copy of the Matlab code myself, and I can tell you it's fairly straightforward. You don't even need to compile it. You just have to have Matlab and the right toolboxes.

Mr. LUCAS. So you don't even need a slide rule to do that?

Dr. JACOBS. Or an abacus.

Mr. LUCAS. Thank you. Dr. Jacobs, also would you describe the timeframe of NOAA's interaction with the FCC leading up to the March spectrum auction?

Dr. JACOBS. So we had assembled subject-matter experts from NOAA, NASA, and the FCC as far back as 2017, going back and forth on the studies. There was an original study, there was a lot of questions about the assumptions that went into the software, which was a pre-packaged software, which is relatively black box. You couldn't look at the source code to determine anything from it. So the FCC requested that we reconduct the study with code that you could actually see, and you could actually change the input parameters, which was a valid request. So we redid that. That began, I believe, somewhere last fall, November/December timeframe. Then we had the shutdown. On the heels of the shutdown we reconvened, and, at that point, had output, and have been going back and forth with the FCC ever since, where their subject-matter experts are proposing new assumptions, and questioning the inputs, and then we re-run the study with those inputs, and come back with the results, and we're still sort of stuck in that do loop, so to speak.

Mr. LUCAS. The public would call it running the time out, so to speak.

Dr. JACOBS. Well, we haven't seen anything that has been proposed by the FCC as far as assumptions that have changed the results of the study thus far.

Mr. LUCAS. So you're comfortable in saying that NOAA has dotted all the I's and crossed all the T's in preparing this information?

Dr. JACOBS. I'm confident that the study is acceptable.

Mr. LUCAS. Thank you, Doctor. And let me touch, for the benefit of my colleagues, a little bit on the budgeting process. Having been around a little while, I've discovered that, generally, when an executive budget comes down, the only thing that's ever recognized by people is when on the rare, rare occasion an Administration asks for additional spending, then we tend to respond to that in Congress. That was a weak attempt at humor, but a factual statement nonetheless.

Typically Presidential budgets, executive budgets, are something that are required in the *1974 Budget Act*, and are examined, and set aside. The *1974 Budget Act* gives the U.S. House, the U.S. Senate the responsibility, yes, to look at the President's executive budget, but to craft our own, and to reconcile that final document, and use that as the product for the appropriation process to move forward. While we have an executive budget that many of us find fascinating, I think the focus of this body should be how do we persuade on the Budget Committee to do their work so that we'll have a real document that the appropriators can move forward with, and fulfill all the responsibilities of the *1974 Budget Act*?

So while I, like many Members, have typically been underwhelmed by the executive branch budget, whichever Administration offered it up, the real onus is on us to do our work, and we should try harder to do our work and fulfill our responsibilities. With that, I yield back, Madam Chair.

Chairwoman FLETCHER. Thank you, Mr. Lucas. I'll now recognize Mr. Tonko for 5 minutes.

Mr. TONKO. Thank you, Chairwoman Fletcher. The—in May 2017 a Government Accountability Office (GAO) study confirmed the vacancy rate in NWS operational units has already reached a point where NWS employees are, and I quote, "unable at times to perform key tasks." According to the GAO, NWS managers admit, and again, quote, "that employees are fatigued, and morale is low," and that employees, quote, "were demoralized because they had to cover the workload for multiple vacancies."

Service assessments, which the NWS itself conducted following 12 major storms that occurred between 2008 and 2017 found that the ability of the NWS to protect lives during these major events was compromised due to already inadequate staffing at critical forecast offices, or river forecast centers. Yet the Administration has now proposed to cut 20 percent of all the forecasters at the Nation's 122 forecast offices, as well as close an unspecified number of forecast offices at night and on weekends as a result. The President's NOAA budget request admits that these closures are a potential risk to the public and partners. How do we reconcile these cuts with the stated reality that we're hearing from forecasters?

Dr. UCCELLINI. Well, since May 2017 we've actually focused our hiring on entry level meteorologists and hydrologists, and we track every forecast office in terms of the availability to cover shifts and do the other tasks. And we—we're in a better place now with respect to that than we were in May 2017. I—not aware of any plans to part time offices, as it's called, nor—or shut down any offices, so I'm not sure where that's coming from, but it's certainly not in any of our plans.

Mr. TONKO. And in terms of vacancies, the number again?

Dr. UCCELLINI. The vacancies we have right now are 429, compared to the appropriated level. In other words, we just heard about the budget process, and we actually staff according to what is appropriated. So that's 4,623, and right now we are looking at 429 vacancies, and we have about 301 hiring actions going. I should also note, for this year, having that 5-week shutdown has had a major impact on our abilities to sustain the momentum that we had going into December of last year, so we are concerned about what—you just—there's not just a light switch that you turn this process back on, and the same people are waiting in the—are waiting there to be brought on. A lot of the people don't stay within that process once it's shut down.

So we do have concerns for the very near term because of that, but we were on an upward trend, and that focus that we had was on the entry-level meteorologists to account for what you reported on from the May 2017 report.

Mr. TONKO. Right. And I know that the executive budget is something that we need to work away at, but a starting point is always an important factor. And, with all of these vacancies, it

would've been good if we had an executive that believes in climate change so that the numbers in a budget presented from the executive branch would reflect that in the budget planning that is envisioned for the agency.

I've also heard concerns that NWS forecast offices may be reduced, and these offices may no longer operate 24 hours a day, or 7 days a week. Are any such plans being studied, developed, or implemented by NWS to reduce the hours of operations at our NWS forecast offices?

Dr. UCCELLINI. So what we have seen in analysis and experience over the past 2 years is that in meeting the needs—increased needs, as specified in the *Weather Act*, of the impact-based decision support services, the forecast offices are taking on increased importance in our ability to do that. So I'll tell you that, within the Weather Service and NOAA, that we are working toward actually supporting those forecasters to meet those increased needs, and we've listened to the emergency managers, who have expressed the same concerns over the last several years, that we're working with them, and they're asking for 24 by 7 with respect to those local offices. But how we manage the resources within those offices is something that we have to do within what's appropriated to us.

Mr. TONKO. Well, in yielding back, I would just ask that you indicate which sites are—if they are going to be considered for reductions, if you could share that information with the Subcommittee, that would be important. And with that, I yield back, Madam Chair.

Chairwoman FLETCHER. Thank you, Mr. Tonko. I'll now recognize Ms. González-Colón for 5 minutes.

Ms. GONZÁLEZ-COLÓN. Thank you, Madam Chair. And, again, I couldn't finish to say thank you to the agencies that helped us out in the moment of need. And, I mean, all of your agencies went beyond and above to put us in place after the hurricane. And one of the lessons that I want you to tell me about is about incorporating relationship within the Federal agencies and the private sector to making this happen after the hurricane. Because without communication, without the radars, without a lot of the assets on the ground, I know you came together with Department of Defense and Marines, the agencies themselves, and even the private sector, could make things happen.

My question will be, are there any lessons that we need to put into law, or in an agreement with the private sector as well, in order to face this kind of emergency situation from now on?

Dr. UCCELLINI. Well, one of the lessons—first of all, we're working in partnerships with the Federal agencies. We recognize that to—in terms of making a forecast, and providing it for decision-making, we can't do that alone, and clearly there are other agencies that are actually on the ground, either preparing a location for an extreme event, or responding to it, or working after to restore. So a component of NOAA, the National Ocean Service, spends a lot of time working to restore the coastal areas and the harbors, as an example.

With respect to the private sector and the non-profits, which are playing an increasingly important role, many of those people and organizations are part of the Weather-Ready Nation Ambassador

number that I spoke to, and we work with them from a public safety perspective throughout the year. So there's a basis there to be working from, and there's a lot to learn.

One of the learning experiences from that hurricane season, as many of us prepare for a worst case scenario of one Category 5 storm, what if you have two Category 5 storms? So one of the tragedies with respect to Puerto Rico was the aid that was on its way had to turn back because there was even another storm coming in after the destructive storms that hit that area. So we're always there to learn from these events, but we are working together in a much better place than we were 5, 6, 7 years ago.

Ms. GONZÁLEZ-COLÓN. My second question will be, and we saw that in the happening, we got FEMA and the Federal agencies on the island before, during, and after the hurricane. That never happened before, so I thought that was better coordination before the hurricane could hit us, and better information. People knew what was happening because we got the data in time, and that's, I think, the most important thing, in terms of that forecast, the weather forecast, not just for Puerto Rico and the Caribbean, the whole Nation. And, in our case, the system that you installed helped us out, not just Puerto Rico, the Virgin Islands, and the rest of the small countries in the Caribbean that were using, actually, that data when they were cutoff from their communications.

During the last Congress we approved $120 million for operations, research, and facilities of those—more than $40 million for charting, mapping, improved weather forecasting, $79 million for procurement and construction, specifically 29 for repairs in many areas. Before this turn, I ask the question, if we need more resources in those areas, if we fall short in making those repairs at that time, and if there's anything else that Congress can do, and I completely agree with Mr. Lucas, and actually I want to thank him for making the legislation possible of the *Weather Act*—more than 25 years without having a comprehensive law that can permit—forecasting these kind of issues. Is there—anything else that you can recommend to us? And thank you, Dr. Jacobs, for your work in the agency as well. Dr. Chen?

Dr. CHEN. Yes. If I may add a point to that? So former FEMA director Craig Fugate always pointed out that, with all the heroic response to emergency, we, you know, are really grateful for these, but on the other hand, he will always remind us, we got to that situation tells us we haven't prepared ourselves. We should try to prevent these things to happen in the first place. So this brings me back to this long-term planning, in terms of future climate change. With the sea level rises, hurricanes are only going to be much more destructive. So how do we prepare ourselves for the situation that—avoiding the current situation, reacting to each storm the way we are? So that is the goal of the national priority, and I think Congress can help us do—to take a long-term approach. We don't want to put our society in that vulnerable position year after year. Thank you.

Ms. GONZÁLEZ-COLÓN. Thank you.

Chairwoman FLETCHER. Thank you, Ms. González-Colón. I will now recognize Mr. Babin for 5 minutes.

Mr. BABIN. All right. Thank you so much, Madam Chair. I'm sorry I'm running a little bit late today. And thank you, witnesses, for being here. Dr. Jacobs, I'd like to ask you the first question. In addition to serving on this Subcommittee, I'm the Ranking Member and former Chairman of the Space Subcommittee. NASA manages the development and launch of the reimbursable satellite programs, projects, and instruments for NOAA through the Joint Agency Satellite Division. One of the programs they developed is the Joint Polar Satellite System. JPSS is an $11 billion investment from taxpayers in our weather observation capabilities that protect lives and property. These satellites provide the bulk of the observations needed to make our medium- and long-range weather forecasting successful. Eighty-five to 95—to 90 percent of all data that's used in numerical weather prediction models come from polar orbiting satellite data.

One of the most important measurements that JPSS makes is microwave sounding. Recent reports indicated that the FCC's 24 gigahertz auction would effectively jam NOAA's use of that spectrum for microwave sounding that serves as the very backbone of our weather prediction capabilities that protect lives and property. If appropriate protection limits are not placed on the use of the spectrum sold at auction by the FCC, should NASA and NOAA issue stop work notices to contractors on JPSS?

Dr. JACOBS. Well, we're still in the process of working with NOAA, NASA, and the FCC to hopefully reach a solution that we can all live with, but with the ATMS instrument on the current JPSS, as well as the proposed JPSS 2, 3, and 4, the mission requirements are 98 percent data, so if we see a projected loss of 2 percent or more, then it's highly likely we would issue a stop work order.

Mr. BABIN. OK. And if NASA and NOAA continued to fund the development of JPSS that are effectively unusable as a result of the FCC auction, could this constitute a misappropriation of funds by these agencies?

Dr. JACOBS. Well, it probably would not be the best use of taxpayer money if we were paying for instruments we couldn't use.

Mr. BABIN. Right. OK. Thank you very much. And also, again, Dr. Jacobs, listening to the testimony from our panel, it seems that NOAA has a lot to do in order to take the next step in improving weather forecasting. From my vantage point, this should be among the agency's very top priorities in the coming years. Years ago the Office of Space Commerce and Office of Commercial Regulatory Affairs were buried in NOAA. Do you support consolidating them, and moving them back to the Department of Commerce, where they were originally placed by statute, in order to allow NOAA to focus on its core mission?

Dr. JACOBS. Yes. There's a lot of different bureaus within the Department of Commerce that would equally share and be very benefited by this being at the DOC level, so yes.

Mr. BABIN. Excellent, thank you. And, Dr. Uccellini, is that it? OK. Thank you. As you are aware, the Congress appropriated a great deal of additional funding to the National Weather Service after Hurricane Sandy. This money was intended to help the Weather Service improve its hurricane models for future cycles. As

a Member representing a district that was hit hard, very hard, by Hurricane Harvey, can you explain how this additional funding made a difference in forecasting, and what should the Congress do to improve severe weather prediction capabilities for future hurricane seasons?

Dr. UCCELLINI. So, first of all, thank you for the support after Sandy. That covered a whole spectrum of activities, including numerical modeling for the Hurricane Forecast Improvement Program, and an operational computer that allowed us the capacity to actually run the model operationally that the research community could transition as part of the R2O.

When it came to Harvey, Harvey was a tricky storm up front, when it was developing near the Mexican coast, east of the Yucatan Peninsula, but—first of all, the global models starting picking up on—that this storm would not only be moving toward the northwest, toward Texas, but also intensifying, but it was the new hurricane—the—what we call the HWRF, the new finer scale hurricane model, that picked up that this storm would rapidly intensify as it approached the coast. And it was one of these nightmare scenarios that that storm actually intensified from a Category 2 to a Category 4 as it was approaching the coastline. And we were ready for that, and—up to a certain amount. I don't think we quite had the 4, but we had that it was intensifying as it approached the coast.

The reason this was important was that we were co-located—we were embedded with the emergency management community in Corpus Christi, and we were briefing them on when they would be able to go out and rescue people, and when they would not, because this was not going to be a storm that they wanted to be out on the outer islands for. So we actually worked with them, and when—between the satellite data—first of all, the model, satellite data, and radars, they actually went out during the eye, when the eye wall passed over the coast, and went out and rescued over 250 people, and brought them back before the back wall came in. So, all things mapped out, the modeling component of that sequence was actually the benefit of Sandy's supplemental funding.

Mr. BABIN. Great. I really appreciate that, and I'll yield back my negative amount of time. Thank you very much. Thank you.

Chairwoman FLETCHER. Thank you, Mr. Babin, and thank you to all of our witnesses for coming today, and hearing us out, and answering not one, but two rounds of questions. You have a special distinction now in this Committee. But I really appreciate the testimony. It was very helpful, and this is a critically important issue.

The record will remain open for 2 weeks for additional statements from Members, and for any additional questions from the Committee to the witnesses. With that, the witnesses are excused, and the hearing is now adjourned.

[Whereupon, at 4:06 p.m., the Subcommittee was adjourned.]

Appendix I

Answers to Post-Hearing Questions

ANSWERS TO POST-HEARING QUESTIONS

Responses by Hon. Neil Jacobs and Dr. Louis Uccellini

HOUSE COMMITTEE ON SCIENCE, SPACE, AND TECHNOLOGY

SUBCOMMITTEE ON ENVIRONMENT

"The Future of Forecasting: Building a Stronger U.S. Weather Enterprise"

Questions for the Record to:
The Honorable Neil Jacobs
Assistant Secretary of Commerce for Environmental Observation and Prediction and
Acting Under Secretary of Commerce for Oceans and Atmosphere
-and-
Dr. Louis W. Uccellini, Ph.D.
Assistant Administrator for Weather Services,
National Oceanic and Atmospheric Administration (NOAA)
And Director, National Weather Service (NWS)

Submitted by Chairwoman Eddie Bernice Johnson

1. **The success of the National Weather Service (NWS) relies on cutting-edge scientific research conducted in all three sectors that is transitioned to meet operational needs.**
   a. **What steps is the Weather Service taking internally at NOAA, and externally with the other sectors, to accelerate research to operations (R2O) and operations to research (O2R) activities?**

Answer: Internally, the National Oceanic and Atmospheric Administration (NOAA) has a strong plan to accelerate our already robust research-to-operations transition. Internal research is focused on requirements from the National Weather Service (NWS), and integration into operations is included in the program plan. Within NOAA, there are already strong collaborations on modeling between the NWS (which is focused on implementation) and the Office of Oceanic and Atmospheric Research (OAR) (which is focused on research) to support the development of the Unified Forecast System (UFS) – an effort which will eventually be led by the Earth Prediction Innovation Center (EPIC) and will allow for community model development; the offices collaborate within the same model systems in order to accelerate research to operations. Across agencies there are many examples of important coordination focused on the operations to research (O2R) process, including the Joint Center for Data Assimilation (NOAA National Aeronautics and Space Administration (NASA), the United States Navy (USN), and the United States Air Force (USAF)); the Earth System Modeling Framework (ESMF), which enhances exchange of codes (NOAA, NASA, USN, and the National Center for Atmospheric Research (NCAR)). There also are numerous model component codes shared between research and NOAA's next-generation operational system, including for atmosphere dynamics, ocean, sea-ice, and waves. With the academic community, NOAA's 17 Cooperative Institutes (CI) are an integral piece of the R2O2R pipeline as they bring together academic researchers with NOAA laboratories. NOAA and CI partners work together from the initial phase of envisioning a product, through research and development, and into the final stages of operationalization.

Incorporating research from external entities falls into two basic categories: research funded by NOAA to meet NOAA requirements, and research done by the other entities with the goal that it will be integrated into NWS operations. The former is being done to meet NOAA requirements, and the latter will be included if it meets an operational need and funding can be obtained to implement the research. For example, NOAA is moving to a Unified Forecast System (UFS) approach, where operational models are based on community models rooted in U.S. and international academic efforts. The interest of U.S. academia in partnering with NOAA in developing tools applicable to both research and operations is evident in the recently signed Memorandum of Agreement (MoA) among the NCAR, NWS and OAR, which commits academia and research to jointly develop the infrastructure for such an UFS. Finally, the NWS led NOAA's effort to establish a formal R2O process for space weather prediction through a Memorandum of Understanding signed by NOAA, NSF, and NASA as part of the Space Weather Operation Research Mitigation (SWORM) Working Group overseen by the White House Office of Science and Technology Policy. This partnership has accelerated the operational transition of the environmental model from George Mason University and the Geospace Model from the University of Michigan to provide the U.S. space weather prediction of solar flares up to 3.5 days before a potential impact. This R2O process involves the larger research community and has also allowed the U.S. to take a leadership position in operational space weather prediction, well above other countries.

NOAA is continuing robust R2O activity not only with computer models, but also with improvements to observations, with social sciences, and new forecast tools. Many of these new research tools are incorporated into operations through NOAA joint testbeds, where research concepts are tested and refined based on input from operations. In these testbeds, the researchers and the forecasters sit side by side, ensuring full spectrum of R2O and operations to research (O2R) coordination. These testbed proving grounds are a critical pathway for proven, demonstrated research to be incorporated into operations.

b. What role can Congress play in facilitating these relationships?

Answer: Congress should encourage the continued interagency collaboration on common code elements, and applying them for various agency-specific missions, and support the necessary resources to transition and sustain research into operations. Continued support of NOAA's Earth Prediction Innovation Center EPIC will be critical in this regard.

2. In 2017, *the Weather Research and Forecasting Innovation Act* was signed into law and provided NOAA and the NWS direction on advancing observational, computing, and modeling capabilities to support improvements in forecasting and prediction of high impact weather events, expanding opportunities for procuring commercial weather data, among other things.

a. Can you speak to how the Congressional priorities in the Weather Act have directed the research and other work done at the NWS?

Answer: The Weather Act has provided renewed focus, within the resources appropriated by Congress, on the research activities that were ongoing in NOAA, including such programs as the Hurricane Forecast Improvement Program (HFIP), advances in the Global Forecast System modeling suite, the Commercial Weather Data Pilot, tornado and tsunami prediction research, and advancing sub-seasonal to seasonal temperature and precipitation forecasts. In addition, our efforts to simplify and strengthen the NWS Watch, Warning and Advisory system, a goal of the Weather Act, is making great strides as we improve and clarify hazard communications for weather, water, space, fire, and climate predictions.

b. Can you describe some of the new research initiatives within NWS that have been a direct result of the Weather Act?

Answer: The Weather Act has led to: 1) increased NWS-OAR coordination, ensuring linkages between the research activity and operational needs within NOAA, which includes coordination to identify critical research, and transition plans for research dedicated to improving operations; 2) moving to a Unified Forecast System (UFS)/Next Generation Global Prediction System (NGGPS), including acceleration of this development through EPIC and the associated outreach to the larger research community; and 3) increased research focused on subseasonal to seasonal prediction. A key element in the UFS development is a recent MoA between NOAA and NCAR, which expands the input of U.S. academia in operational model development. NOAA has made great strides in establishing EPIC, made possible by the recent reauthorization of the Weather and Research Forecasting Innovation Act of 2017. This virtual Center will enable the research community to develop new and emerging model technology that can be quickly transitioned into forecast operations. The operational global Earth system models will be made available to the research community to support scientific and research work. The Weather Act also supports the ongoing efforts to improve our communication of risk (e.g. new winter products, advancing day three extreme rain outlooks, etc.) and application of social science to improve the way people receive our forecasts and warnings with Impact-based Decision Support Service (IDSS).

c. Is NWS on track for implementing the Weather Act? When can Congress expect to receive any outstanding reports detailed in the Weather Act?

Answer: Implementing the Weather Act is one of NOAA's top priorities, driving the entire agency, along with supporting the Nation's Blue Economy. NOAA has made great strides over the past three years since the Weather Act was signed into law in 2017, and it continues, within the resources appropriated by Congress, to drive NOAA programs and priorities across many disciplines. As of January 2020, NOAA has completed and delivered to Congress more than half of the reports and studies required by the Act (14 of 22). The remaining reports are in various stages of development, review, and clearance, and NOAA is committed to updating the Committee on a routine basis.

Submitted by Chair of Subcommittee on Environment
Lizzie Fletcher

1. **NOAA's data is freely available to the public, which has allowed for robust engagement with the private sector to develop specialized weather products and for academia to conduct research. Given this new frontier of weather data that could be collected outside of the public sector, there are new possibilities and challenges for non-industry stakeholders.**
   a. **How will NOAA go about ensuring access to data it purchases from private sources?**

Answer: NOAA's activities related to the commercial satellite data sector will be guided by the NOAA Commercial Space Policy,[1] the National Environmental Satellite, Data, and Information Service (NESDIS) Commercial Space Process,[2] the Federal Acquisition Regulations, and NOAA Administrative Order 212-15 on Environmental Data Management and Information.[3] Access to non-satellite data is also governed by NOAA Administrative Order 216-112, Policy on Partnerships in the Provision of Environmental Information.[4]

NOAA's current policy, consistent with Federal statute and regulation (e.g., the recent Foundations of Evidence Based Policymaking Act of 2018, and OMB Circular A130), is to make NOAA data available for open and unrestricted use whenever possible, given legal, intellectual property, privacy, security, and regulatory restrictions. Data availability to non-NOAA users will be governed by the specific business agreements and contracts that were made when NOAA agreed to purchase those data from the provider.

NOAA works with each private data provider to seek mutually-acceptable and economically-responsible terms that are respectful of their business concerns, allow the data to be used for NOAA's life and property-saving mission, are obtained at reasonable cost to the US taxpayer, and – whenever possible and practical – allow those data to be used to meet international data exchange agreements (such as World Meteorological Organization (WMO) Resolution 40), enable research, and be shared openly with others.

All of these activities will support, not negate, acquiring and making data available for NOAA's lifesaving missions and meeting international data exchange agreements.

2. **Private industry is quickly increasing its ability to collect weather data through observation. This includes core infrastructure like satellites, as well as new sources like smart devices, personal weather stations, LIDAR, drones and unmanned vehicles. This data can both supplement data that the National Weather Service (NWS) already collects and fill important gaps in the data, such as observations in the planetary boundary layer.**

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[1] https://www.space.commerce.gov/policy/noaa-commercial-space-policy/

[2] https://www.space.commerce.gov/business-with-noaa/nesdis-commercial-space-activities-assessment-process/

[3] https://www.corporateservices.noaa.gov/~ames/administrative_orders/chapter_212/212-15.html

[4] https://www.noaa.gov/work-with-us/partnership-policy

a. Is NWS planning to create rules or standards governing NOAA's purchase of commercial data? Specifically, how will NWS determine who gets access to proprietary data, and how it can be used?

Answer: NOAA will be guided by the NOAA Commercial Space Policy and the NOAA Policy on the Provision of Environmental Information when assessing these new sources of non-federal data. NWS will also leverage lessons learned from NESDIS Commercial Weather Data Pilot activities to inform its own commercial data purchases, including a careful assessment related to the quality of the data and its availability in real-time forecast application.

NOAA works to make acquired data as openly accessible and available for non-NOAA users as possible. In most cases, there are no restrictions to the redistribution of data procured from commercial sources. In other cases, it depends on the company's business model and the terms of use agreements that are made. NOAA is working with industry to develop a model that supports their business, while still making the data available for NOAA's life-saving mission, international data exchange agreements, and for further use by academia and the general public.

The NOAA Procedure for Scientific Records Appraisal and Archive Approval, and the NOAA Data Access, and Data Sharing Procedural Directives will help inform these deliberations.

b. How can the needs for proprietary data by corporations be best balanced with the value that can be extracted from industry data for public safety and improving NWS forecasts?

Answer: In some cases, companies have no data redistribution restrictions. In other cases where the companies have a business model to sell observational data, such as the contracts NOAA manages for the purchase of mesonet data or lightning data, contractual conditions are established by which NOAA can use the data without compromising the integrity and business model of the corporations and companies providing that data for NOAA's use for public safety and improving NWS forecasts.

c. In your experience, to what extent are companies willing to share data with NWS?

Answer: Industry has often made their data available to NWS forecasters for them to use in their public safety mission and for improving forecasts. The main restriction was that, in many cases, the data were for NWS use only and NWS could not redistribute the unprocessed data immediately, but could offer a delayed release of those data.

3. The rapidly evolving Weather Enterprise has created new technologies and led to the advent of new user communities. The training needed to be a successful meteorologist or scientist in today's Weather Enterprise differs greatly from 20 years ago.

a. What do you see as the biggest workforce needs for the Weather Enterprise?

Answer: The greatest workforce needs are training in the latest advancements in science and technology, as well as retooling the workforce to deliver critical weather information to our core

partners and the weather enterprise in a manner so they can make critical decisions to aid the NWS in meeting its mission of saving lives and property. These needs include: 1) satellites; 2) numerical weather prediction; 3) engineering; 4) communicating Impact-based Decision Support Services; 5) social science; 6) leadership and partnership building skills; and 7) project management.

b. What qualities and skills would you like to see in the next generation of meteorologists and weather scientists, and are we currently training our students to meet the new challenges we face?

Answer: The qualities required in the next generation of meteorologists include a balance of core meteorological science with the ability to effectively communicate risk and the impacts of weather and water hazards. This means that meteorologists will have to expand their knowledge of social science and related risk assessments related to extreme weather, water, and climate events, all while sustaining a solid foundation in the physical, mathematical, and computer sciences, which are the basis for the modern observations and forecast process. Through the American Meteorological Society and the University Corporation for Atmospheric Research (UCAR), we are working with the meteorology-teaching universities to produce students that have a multi-disciplinary background, combining physical science with social science, GIS, computer science, or business, as examples.

c. How does having a well-trained workforce impact the success of the broader enterprise?

Answer: A well trained workforce is critical to the success of the weather enterprise. World class forecasts and services from the NWS skilled in a more collaborative approach, will only lead to a stronger weather enterprise as a whole.

d. How can we go about having the best trained scientists and engineers in the Weather Enterprise?

Answer: With respect to the Federal Government, we believe attaining the best trained scientists and engineers will take time, investment, and critical partnerships. The NWS has deep relationships in the weather education and training communities, including major universities and research and training organizations, such as University Corporation for Atmospheric Research (UCAR). The training needs to be focused both on new hires as well as continuing education for existing scientists, engineers, and leaders throughout all components of the enterprise.

4. The last comprehensive report on the state of the U.S. Weather Enterprise was the National Academies' seminal "Fair Weather Report" published in 2003. The report outlined the roles of the three sectors and made a number of important recommendations to the National Weather Service, which helped shape the direction of the Enterprise. 16 years later, some are saying it is time for another forward-looking set of recommendations for the Enterprise.

a. **Where do you see the state of the U.S. Weather Enterprise in 10 to 20 years, and would it benefit from another set of independent recommendations? What should serve as the guiding principles for improving partnerships between the sectors going forward?**

Answer: We envision continued growth of the U.S. Weather Enterprise to meet ever increasing and changing demands for weather, water, and climate information and forecasts. In its 2013 Report, the National Academy of Public Administration (NAPA) strongly supported the strategic outcome of a Weather-Ready Nation (WRN), while also emphasizing that NWS cannot build a WRN alone and provided a roadmap for the future. We rely heavily on the 2013 NAPA and 2012 National Academies study *Weather Services for the Nation: Becoming Second to None* ("Second to None") reports that were mandated by Congress. The NWS also uses the 2003 NAS "Fair Weather Report" as a basis for its interactions with the Private Sector, a success story the NWS Director has touted around the globe, including at the World Meteorological Organization, which recently approved a "Geneva Declaration" that raises the profile of the Private Sector across the entire value chain around its entire "Global Enterprise" for the first time. In the next 10 to 20 years, academic institutions and other federal agencies will continue to provide critical scientific and technological innovations, as well as observations and forecast products. America's growing weather, water, and climate industry will play an increasingly important role contributing observations, models, and new tools and technologies to the Enterprise. Through this public-private partnership, the NWS will continue to stimulate growth by providing foundational data and forecasts for the Enterprise, while also increasing the economic resilience of the nation. Food security, energy production, supply chains, water availability, ecosystem health, and transportation systems are just some of the sectors that will continue to benefit from the Enterprise.

We believe the *Weather Research and Forecasting Innovation Act of 2017* and its 2018 reauthorization provide clear guidance and direction to the NWS about how the NWS should partner with the Enterprise (i.e., Title IV – Federal Weather Coordination). The Act built upon strong cues from the 2012 NAS *"Second to None"* report, as well as the 2013 NAPA study. Furthermore, NWS has sufficient information from internal and external reviews and analyses to guide the path forward. These critical inputs are incorporated into the new 2019-2022 NWS Strategic Plan, which, through specific goals and objectives, emphasizes the importance of partnerships to accomplish the mission of the NWS. These partnership discussions occur through NWS Partners Meetings, Environmental Information Services Working Group of the NOAA Science Advisory Board meetings, American Meteorological Society meetings, National Weather Association meetings, and other routine interactions with Enterprise members.

Submitted by Congresswoman Suzanne Bonamici

Thank you, Chair Fletcher and Ranking Member Marshall, and thank you to our witnesses.

The climate crisis, including human activities that have induced warming temperatures, is affecting weather patterns around the world. According to the Fourth National Climate Assessment, the number of extreme weather events per year has increased significantly since 1980. The total cost of these extreme weather events for the United States since 1980 has exceeded $1.1 trillion and is expected to increase. The need for accurate weather and climate predictions is essential for resiliency efforts in vulnerable communities subject to extreme weather, water, and climate events.

In Northwest Oregon, the communities I am honored to represent rely on timely and accurate weather forecasts to decide when to harvest their crops, when to go to sea to fish, how to navigate the roads safely when there is freezing rain or snow, and when to prepare for possible flood conditions.

Question 1: Last Congress, I was proud to work with Ranking Member Lucas on the Weather Research and Forecasting Innovation Act. In addition to including my Tsunami Warning, Education, and Research Act, the bill took important steps to connect the research-to-operations pipeline to improve our weather forecasting enterprise.

Dr. Jacobs and Dr. Uccellini, in your testimony you state that implementing the Weather Research and Forecasting Innovation Act is one of NOAA's "highest priorities." The bill requires a number of reports to Congress to track its implementation, but they are overdue.

What information can you provide today about tangible steps NOAA and the NWS have taken to implement the bill? When will we receive overdue reports like the gaps in the coverage of the National Weather Service's Next Generation Weather Radar?

Answer: Implementing the Weather Act is among the National Oceanic and Atmospheric Administration's (NOAA) top priorities, along with supporting the Nation's Blue Economy. NOAA has made great strides over the past two years since the Weather Act was signed into law in 2017, and it continues, within the resources appropriated by Congress, to drive NOAA programs and priorities across many disciplines. As of January 2020, NOAA has completed and delivered to Congress more than half (14 of 22) of the reports and studies required by the Act. The remaining reports are in various stages of development, review, and clearance, and NOAA is committed to updating the Committee on a routine basis.

With respect to the Radar Gap study and subsequent report, a significant amount of work has gone into this effort, which is now going through review, coordination, and clearance. The study has been exhaustive, examining over 12,000 tornado events from 2006-2016, and over 30,000 flash flood events from 2008-2016. We are mapping these 42,000+ use cases against the very specific criteria directed in the Act. This is no small task, and was not possible within the

deadlines established in the Act. NOAA will continue to update the Committee as the report progresses.

Question 2: I am particularly concerned about a potential reorganization of National Weather Service Forecast Offices that would degrade the quality of service and forecasts. Last year, I joined Chairwoman Johnson and Reps. Tonko and Crist in calling on Secretary Ross for information about the implementation of the National Blend of Models in Evolve activities, and an operations workforce analysis contracted with the consulting firm McKinsey & Company. We subsequently requested a GAO report.

Dr. Jacobs and Dr. Uccellini, does the National Weather Service currently have any plans to reduce hours of operation or staff levels at any Forecast Offices? If so, what is the basis for this decision and is there scientific analysis to establish that modeled forecasts are as accurate as those developed by staff?

Answer: The National Weather Service (NWS) currently has no plans to reduce hours of operation or staff levels at any Weather Forecast Offices, River Forecast Centers, or National Centers.

Questions for the Record to:
The Honorable Neil Jacobs
Assistant Secretary of Commerce for Environmental Observation and Prediction and
Acting Under Secretary of Commerce for Oceans and Atmosphere

Submitted by Chair of Subcommittee on Environment
Lizzie Fletcher

1. **In December 2018, the NIDIS Reauthorization Act included an authorization of NOAA's Earth Prediction Innovation Center, or EPIC, within the Office of Oceanic and Atmospheric Research. The EPIC program is meant to enhance collaboration to improve numerical weather prediction.**

   a. **How was the concept for EPIC developed? Given that its goal is to encourage community model development, was the community consulted in the development of this concept?**

Answer: Advancing weather modeling skill, reclaiming and maintaining international leadership in the area of numerical weather prediction, and improving the transition of research into operations have long been priorities of the National Oceanic and Atmospheric Administration (NOAA), and our domestic partners in the U.S. Weather Enterprise. Thus, the essence of Earth Prediction Innovation Center (EPIC) is not new. NOAA also recognizes the need to extend research into operations and operations into research in all disciplines within the agency and with our external partners. Thus, EPIC will serve as NOAA's core research-to-operations (R2O) center and NOAA's pipeline for numerical weather prediction model development. EPIC is the means by which we will make current and future model code available to the public, and will be the conduit between the operational modeling community and the research communities (user support, verification and validation, software engineers for code compatibility). It will provide the framework to support community model development of the Unified Forecasting System (UFS). .

NOAA is making every effort to engage federal partners, the academic community and the private sector during this implementation phase of EPIC to help ensure it is constructed in a way that facilitates continued community involvement. NOAA released a RFI in July 2019[5], held the EPIC Community Workshop in August 2019,[6]and held an Industry Day with vendor meetings in September 2019. All were successful and have helped to refine our vision and strategy for the program.

[5] https://www.fbo.gov/index?id=8b0c2a02d42355c4238470d5aa5faeae
[6] https://owaq.noaa.gov/Programs/EPIC

b. What is the governance structure for EPIC?

Answer: The structure of the center is still under development as we determine the optimal implementation strategy to achieve the goals in the authorizing legislation. Our initial focus will be on software engineering that NOAA needs to build the infrastructure that would support co-development of the Unified Forecast System (UFS) on the cloud and partner institution HPC systems.

c. Will other federal agencies have a role to play in EPIC? Does this include funding support?

Answer: Yes. EPIC will coordinate with NOAA's established testbeds and proving grounds to facilitate the orderly transition of research capabilities to operational implementation through development testing in testbeds, and pre-deployment testing and operational readiness/suitability evaluation in operational proving grounds. NOAA works on NWP and has interagency agreements with, among others, the National Aeronautics and Space Administration, the United States Air Force, the United States Navy, and the National Center for Atmospheric Research. Funding support will be determined by each agency and partner through the annual budget process.

Submitted by Congressman Paul Tonko

During your testimony, you stated that they are not planning to cut any staff or personnel who are forecasters. You said the proposed cuts were on the research side and not to actual personnel. However, in the FY2020 Budget Justification NOAA requested authority to eliminate funding for 355 operational positions in the NWS. The personnel cuts included the elimination of 74 positions by eliminating the Information Technology Officer at each one of the 122 NWS Forecast Offices and replacing them with smaller regional IT support teams, elimination of 248 forecasters at the nation's 122 forecast offices, elimination of 25 positions by closing one of the nation's two Tsunami Warning Centers, and the elimination of 8 positions by consolidating the NWS Climate Prediction Center into another NWS unit. This proposal represents a 20 percent reduction of all the forecasters in NWS forecast offices nationwide. So to clarify, are you planning to reduce staff positions for forecasters? And do you have plans to close any NWS Forecast Offices or reduce the hours?

Answer: NOAA currently has no plans to reduce hours of operation or staff levels at any Weather Forecast Offices, River Forecast Centers, or National Centers.

During your testimony you stated adamantly that there would not be a degradation of service from proposed budget cuts. However, in the FY2020 Budget Justification which NOAA submitted to Congress, it concedes that "operation times at various offices will be reduced" as a result of these staffing reductions, and that this will present "potential risk to the public and partners." The specific personnel cuts are identified including closing one of the two tsunami warning centers. The budget proposes to eliminate 20% of the 1,250 or so forecasters who issue these forecasts, warnings and advisories from the nation's 122 Weather Forecast Offices. Do you consider this potential risk to the public and partners a degradation of service? Are there other potential risks to the public from these changes?

Answer: At the hearing on May 16, I stated that there would not be a decrease or degradation to our forecasting skill. With respect to services, if certain proposed position reductions are accepted by Congress, NOAA would implement operational reforms through staffing flexibilities, to best match service demands with available resources. NOAA prefers to eliminate positions through attrition, to minimize the impact on existing staff. Testing and implementation could present some short-term risks that will need to be managed effectively to minimize any impact to operations.

Submitted by Ranking Member of the Subcommittee on Environment
Representative Roger Marshall

1. **I understand that NOAA and NASA have conducted technical studies to assess appropriate power levels for 5G deployments in spectrum adjacent to the weather satellites operating near the 24GHZ Band to protect their weather systems. Are you aware of this study and was this study conducted in coordination with industry?**

Answer: Yes, the National Oceanic and Atmospheric Administration (NOAA) was a coauthor of the study, which was delivered to Congress in late June. NOAA and the National Aeronautics and Space Administration (NASA) conducted preliminary impact assessments and determined that if sufficient protection limits for these passive bands are not maintained, it could significantly deteriorate the accuracy of weather forecasts. The interference levels have been the topic of intense discussion in national meteorological agencies worldwide.

2. **Is it true that the suitability of the 24GHz Band for 5G deployment in the United States is something that has been debated for over 3 years in the global and domestic policy arenas? Further, are you aware that this spectrum is currently being auctioned and has garnered $2B in bids from interested parties? How do we change the rules on spectrum we've already sold?**

Answer: NOAA, NASA, the Department of Defense, and the Federal Communications Commission (FCC) have been in discussions for years over the need to protect the Nation's weather prediction capabilities. The intent of the discussions among the agencies and the FCC is to preserve our ability to observe the atmospheric components required for weather forecasting

while also supporting and facilitating the Administration's priority to be a global leader in 5G technology.

Questions for the Record to:
Dr. Louis W. Uccellini, Ph.D.
Assistant Administrator for Weather Services,
National Oceanic and Atmospheric Administration (NOAA)
And Director, National Weather Service (NWS)

Submitted by Chairwoman Eddie Bernice Johnson

3. **We've heard concerns for several years about high NWS vacancy rates and slow progress in filling these vacancies with personnel. Your written testimony indicates that NOAA has begun to turn the corner on this. Can you clarify where the NWS currently stands in filling vacancies, and what progress has been made?**

Answer: Over many years, due to multiple factors both internal and external, the national Oceanic and Atmospheric Administration's (NOAA) National Weather Service (NWS) on-board staffing levels significantly diminished. Staffing levels are currently at approximately 91% percent of our appropriated level. We are working with the NOAA Office of Human Capital Services (OHCS, formerly the NOAA Workforce Management Office), to hire staff as quickly as possible within appropriated funding levels. NWS showed significant hiring improvement in FY2018 (544 hiring actions) and the beginning of FY 2019, reversing the seven-year trend of attrition exceeding hiring. Unfortunately, much of those gains were lost in January 2019 where no new hiring actions were initiated due to the lapse in appropriations and a surge of retirements lowered overall staffing numbers. At the conclusion of FY2019, NWS hiring had roughly equaled attrition. The past inability to hire new staff efficiently was due primarily to critical deficiencies in NOAA and the Department of Commerce's (DOC) workforce management and security clearance processes. This has improved as shown by the increase in hiring for FY2018 and pre-shutdown FY2019. However, there are other issues as well. For example, a large number of NWS vacancies have historically been filled by internal candidates (through promotions or reassignments), meaning that the number of hiring actions required to add staff is much higher than the level of attrition.

The NWS and NOAA's OHCS, combined with oversight, assistance and innovations from DOC Enterprise Services, are working hard to improve hiring performance. DOC hired a contractor (YRCI) to assist with NWS hiring. NWS and OHCS have also released a nationwide standing announcement for lead forecasters, bundled meteorologist intern announcements, and released nationwide vacancy announcements three times per year, which should allow vacancies to be

quickly filled from a qualified applicant pool. In addition, in 2019 NWS implemented a GS 5-through-12 Meteorologist Career Progression Program, which has streamlined the administrative processes for hiring entry level meteorologists and also allowed internal promotion of qualified meteorologists, reducing the number of personnel actions as well as employee relocations. NWS continues to make progress filling vacancies, but continued improvement efforts are still needed.

Submitted by Congressman Paul Tonko

During the hearing you stated that you were not aware of any plans to part-time offices as it is called nor shut down any offices. However, the NOAA Budget Justification states that as a result of the proposed elimination of 248 forecasters, "operation times at various offices will be reduced" and that these shuttered offices "will collaborate with other NWS offices for met watch and services during off hours . . . allowing for certain offices to reduce operation times." The Budget Justification concedes that this reduction in hours poses "a potential risk to the public and partners." Are you aware of these plans? Again, are any such plans being studied, developed or implemented by NWS to reduce the hours of operations at NWS Forecast Offices? If so, please indicate which sites are being considered for reductions.

Answer: The National Weather Service (NWS) currently has no plans to reduce hours of operation or staff levels at any Weather Forecast Offices, River Forecast Centers, or (or National Centers).

These are outstanding Committee requests for information:

- **We have asked who is the original author of the slide decks they shared. Can they confirm that these are McKinsey work product or are they something else?**

Answer: The slides are a McKinsey work product. They are available here: https://www.weather.gov/owa-catalog

- **Who is the author of the NWS OWA Catalog dated September 2017? Was this a product produced by NWS in response to our June 28 letter? If so, can you please provide the final materials provided to NWS by McKinsey in their original form?**

Answer: The Operations and Workforce Analysis (OWA) Catalog was produced by the National Weather Service, using McKinsey inputs. The final report from McKinsey that contained their summaries at the end of the project is known as the OWA White Paper. It was provided to Congress and made public at the same time as the Catalog, in September 2017 and remains available here: https://www.weather.gov/owa-catalog. These products were well underway at the time of the June request from Congress, and were expected to be released much earlier, but took longer than anticipated to be released due to their extensive length, and need for internal review.

- **The contract states that a report was due. Can we see that report written by McKinsey?**

Answer: The slide package and the OWA White Paper together are the final McKinsey product. There is no other report.

- **In the past I have joined the committee in asking why some slides have been redacted in their entirety from the production. How is total redaction dissimilar from the pre-decisional watermark? Furthermore, if these slides are McKinsey work product, how was the decision made to redact these slides in their entirety from the production request?**

Answer: The redactions were made to ensure the anonymity of the participants who provided the information to McKinsey. These slides contain Personally-Identifiable-Information. A pre-decisional watermark is used to indicate a work product that is informational or deliberative in nature, so as not to be confused with a decision or plan of the NWS or the National Oceanic and Atmospheric Administration.

- **Can you provide the statistical analysis that has been conducted or commissioned indicating that computer models are as reliable as the experienced human forecaster with local knowledge?**

Answer: To clarify, there is no intention or plan to replace forecasters with a computer model forecast. The National Blend of Models (NBM) was introduced by the field before 2012, was included in the Sandy Supplemental spend plan for 2013, and is intended to be a common forecast guidance starting point for all forecasts. Some NWS Regions have been using regional blends as an initial starting point for forecast guidance for years. The NBM is simply the next step in this process, one that would provide for national consistency, reliability, and consolidate development resources on the central operations computer to provide the best product to forecasters. With the NBM output as a common starting point, we expect forecasts to display greater consistency and accuracy across the Nation by using more information from the large number of ensemble models run around the world. NWS forecasters will have at their disposal a uniform forecast support system providing a common operating picture across the forecast area and the ability to use their local expertise to make improvements to the guidance, and to focus that expertise on the most difficult and critical parts of the forecast.

The NWS is conducting continued validation and verification of NBM forecasts compared with the National Digital Forecast Database, which is the official NWS digital forecast. We would be pleased to provide a detailed briefing describing the processes involved in verifying the NBM.

- **Specifically, we have not received any information related to the justification for proposed changes to forecaster duties, specifically blend verification statistics, nor have we received the statistical analysis that has been conducted or commissioned to indicate that computer models are as reliable as the experienced human forecaster with local knowledge. When can we expect to receive that information?**

Answer: There are no proposed changes to forecaster duties. Local offices have freedom to reallocate staff resources based on the highest priorities of the day. The NBM is intended to be a common forecast guidance starting point for all forecasts. With the NBM output as a common starting point, we expect forecasts of greater consistency and accuracy across the Nation. The NBM is expected to be fully operational in 2022. Until then it is simply another tool to be used by the forecasters to assist them in creating their forecasts. Validation and verification of the NBM is an ongoing process. We can provide statistical analysis and information for any parameters currently provided by the NBM (temperature, dew point, wind, and precipitation).

Responses by Dr. Shuyi Chen

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

A hearing on:
***The Future of Forecasting: Building a Stronger U.S. Weather Enterprise*, May 16, 2019**

Shuyi S. Chen, Ph.D.
Professor of Atmospheric Sciences
University of Washington

Response to Hearing Questions Posed by Chairwoman Johnson:

1. ***Q:*** *The success of the National Weather Service (NWS) relies on cutting-edge scientific research conducted in all three sectors that is transitioned to meet operational needs.*
   a. What can be the federal government do to fully leverage the partnership with academia to meet the research to operations challenge in weather forecasting?
   b. What role can Congress play in facilitating these relationships?

A: ***a.*** The lack of a coherent and systematic approach to transition the cutting-edge science and technology from research to operations is a key and unmet challenge. 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 basic research and innovation in computer modeling and technologies in satellite observation over many decades since 1970-1980's. The societal needs for accurate forecast with longer lead time, and specific/detailed impact forecasts have grown significantly in recent years. However, our current operational forecasting tools have evolved at a slower paste and has fall behind the other weather forecast centers around world, especially that of the European Center. We need the leadership from the Federal government to establish a national strategy with multi-agencies support for research to operations, not only in computer modeling but also new observing technologies and workforce development.

b. Research to operations have not succeeded, which many consider it as a systematic failure. Restoring U.S. leadership in weather forecasting for the benefit of society should be a national priority. No single federal government agency can do it alone. It will take the entire Weather Enterprise. Congress can help direct Federal agencies (including NOAA, NASA, NSF, and others) to act and take a systematic approach:

1. Launch a **National Academies' study on the Future of the U.S. Weather Enterprise**, which can provide an urgently need guidance with Congressional mandate,
2. Develop a **national unified modeling and forecasting system**: a consolidated National center with participation from the entire Weather Enterprise (academia, industries, government) and multi-agency support, and
3. Establish mechanisms for **sustained resources to support research to operations** and accountability with metrics to measure of success.

2. ***Q:*** *In 2017, the Weather Research and Forecasting Innovation Act was signed into law and provided NOAA and the NWS direction on advancing observational, computing, and modeling capabilities to support improvements in forecasting and prediction of high impact weather events, expanding opportunities for procuring commercial weather data among other things.*
    a. *Can you discuss how the research priorities articulated in the Weather Act have affected the research conducted within the academic community?*

A: Outside of NOAA, the priorities articulated in the *Weather Act* have not yet had a broad impact on research community. For example, the *Weather Research and Forecasting Innovation Act (H.R. 353)* clearly identifies subseasonal-to-seasonal (S2S) prediction as a goal of improving the U.S. weather forecast capability. Basic research on S2S in the U.S. is leading the world. The Earth system (coupled atmosphere-ocean-ice-land) modeling capability needed for S2S prediction is rapidly increasing outside of the NOAA operations. However, there is no national strategy that enables the public, private, and academic sectors to work together to achieve this common goal.

NOAA's National Center for Environmental Prediction (NCEP) had pioneered atmosphere-ocean operational Coupled Forecast System (CFS) and led the field of seasonal forecasting for a decade or so in the past. This coupled system could have served as a basis to develop a coupled forecast model for S2S prediction. However, this leading edge is being eroded as NOAA is focused on developing a new atmosphere model (FV3 based NGGPS) for short-range (within two weeks) forecasts while other operational centers (e.g., European Centre for Medium-Range Weather Forecasts [ECMWF] and UK Met Office [UKMO]) are quickly developing coupled Earth system models for S2S prediction. This happened partially because there is no national strategy for developing the U.S. S2S modeling and prediction capability.

The **Recommendation 4.2 from the recent Decadal Survey by the National Academies**[1] is a good example how we can move forward: "*NOAA should develop a close partnership with NASA and other agencies to lead the Next-Generation Global Prediction System (NGGPS) effort in developing the next-generation cloud-permitting, fully coupled ESMs (Earth System Models) with advanced data assimilation and NOAA's sustained global ocean observing system for enabling subseasonal-to-seasonal (S2S) forecasting and seamless weather-climate prediction.*" The research community can contribute effectively to this national effort.

NOAA's NCEP and other operational centers have demonstrated measurable but limited success with operational S2S forecasts. Yet, demands for these forecasts outpace its provision. S2S forecast products are still very limited, their errors and uncertainties often large. With focused research-operation integration, substantial improvement of S2S forecasts and elevated societal benefit are within our grasp.

[1]National Academies of Sciences, Engineering, and Medicine (NASEM), 2018: Thriving on our changing planet: A decadal strategy for Earth observation from space, *The National Academies Press*, https://doi.org/10.17226/24938.

Response to Hearing Questions Posed by Chairwoman Fletcher:

1. ***Q:*** *In December 2018, The NIDIS Reauthorization Act included an authorization of NOAA's Earth Prediction Innovation Center, or EPIC, within the Office of Oceanic and Atmospheric Research. The EPIC program is meant to enhance collaboration to improve numerical weather prediction.*
    a. *Can you comment on the value of a true community driven model development? What are your thoughts on NOAA's new EPIC initiative?*

A: A **true** community driven model development will be extremely valuable and is urgently needed for restoring U.S. leadership in weather forecasting. The EPIC Vision paper developed and released by NOAA recently listed a number of important items for supporting a new community-based model. However, it has not addressed the following key questions regarding the new generation, community-based model development:

- What are **science drivers**?
- What are **requirements**?
- What are **metrics of measuring success**?

A clearly articulated vision and science drivers are critical for attracting young scientists and diverse community to participate in EPIC. Here are some **examples** of the science drivers for the community driven model development:

- High impact weather (e.g., hurricanes, tornadoes, heat waves, flooding, etc.)
- Increase forecast lead time beyond 7-10 days (need to focus on source of predictability on weeks-S2S time scales such as the Madden-Julian Oscillation, jet streams, tropics-high latitude teleconnection, etc.)
- Coastal prediction in a changing climate and rising seas (need to focus on sea, land, urban, rivers and water shields, storm surge, etc.)

2. ***Q:*** *NOAA's data is freely available to the public which has allowed for robust engagement with the private sector to develop specialized weather products and for academia to conduct research. Given this new frontier of weather data that could be collected outside of the public sector, there are new possibilities of and challenges for non-industry stakeholders.*
    a. *What impact to academic research would a greater prevalence of private weather data have?*

A: It could have a great, positive impact on academic research, especially in areas of cutting-edge technologies and specialized observations that are not available in the public sectors. There will be new challenges such as business model for sustainability and transparency required for open publications on weather research by the academic community.

3. ***Q:*** *The rapidly evolving Weather Enterprise has created new technologies and led to the advent of new user communities. The training needed to be a successful meteorologist or scientist in today's Weather Enterprise differs from 20 years ago.*
    a. *What do you see as the biggest workforce needs for the Weather Enterprise?*

b. What qualities and skills would you like to see in the next generation of meteorologists and weather scientists, and are we currently training our students to meet the new challenges we face?

c. How does having a well-trained workforce impact the success of the broader enterprise?

d. How can we go about having the best trained scientists and engineers in the Weather Enterprise?

A:

a. A new generation of scientists and forecasters are needed to communicate high-impact weather in a changing climate to support effective decision making. Indeed, a recent National Academies' report (2018) emphasized an urgent need for better integration of physical science and social and behavioral sciences within the Weather Enterprise.

b. Interdisciplinary training and capability are critical.

c. Workforce development and training is essential for future weather forecasting. A significant challenge will be the increasingly diverse knowledge and skills that are needed to advance modeling and forecasting. Many new and emerging job markets require interdisciplinary and multidisciplinary education. The desired skill sets range from emerging science (meteorology and its coupling to other Earth systems on multiple timescales) and technologies (e.g., computing, data analytics, machine learning), to a host of disciplines and skills related to decision support (e.g., impacts, communication, social and behavioral science).

d. The atmospheric science education in universities has not changed significantly over the last a few decades. It still mostly follows the traditional disciplinary curricula, which cannot meet the needs for more broadly trained professionals in the Weather Enterprise. Universities need to modernize their curricula to meet the growing needs for an interdisciplinary and multidisciplinary workforce. We need to create opportunities for working partnerships and collaborations across public, private, and academic sectors in workforce development and training.

Responses by Dr. Christopher Fiebrich

HOUSE COMMITTEE ON SCIENCE, SPACE, AND TECHNOLOGY

SUBCOMMITTEE ON ENVIRONMENT

"The Future of Forecasting: Building a Stronger U.S. Weather Enterprise"

Questions for the Record to:
Dr. Christopher Fiebrich Executive Director,
Oklahoma Mesonet
And Associate Director, Oklahoma Climatological Survey

Submitted by Chairwoman Eddie Bernice Johnson

I. The success of the National Weather Service (NWS) relies on cutting-edge scientific research conducted in all three sectors that is transitioned to meet operational needs.
   a. What can the federal government do to fully leverage the partnership with academia to meet the research to operations challenge in weather forecasting?

Response from Fiebrich: The academic sector must be encouraged and supported by Congress to provide the rigorous and unbiased scientific foundation for our understanding of the atmosphere. The federal government plays a key role in the research to operations process. It must be persistently engaged in facilitating the coordination and collaboration of the three sectors in supporting advances in the National Weather Service. There are several specific opportunities for federal agencies to leverage academic contributions to the research to operations challenge:

- **i. Make it easier for the academic community to use NOAA models in their research through the creation of community models. This will allow the academic community to improve NOAA's models. This can be facilitated by providing access to the model code and its documentation, tutorials and workshops on using the model code, and user support.**
- **ii. Increase access to federal high-performance computing facilities, including cloud vendors that support the community models.**
- **iii. The academic community plays a large role in the collection of atmospheric observations across the United States (e.g., through state and regional Mesonets). These Mesonets are largely funded through state and local funds but continue to struggle to remain operational due to unstable funding. Through the federal government's continued support of the National Mesonet program, NOAA can gain access to thousands of additional weather observations from across the country for use in research and operations at a fraction of the cost it would require for the government to operate them on their own. The supplemental funding through the National Mesonet program often makes the difference between a state Mesonet surviving or not.**
- **iv. While NOAA/NWS now provides short-term (1-2 year) grants to universities to help NWS implement the new Unified Forecast System (UFS), they need to provide longer-term funding (3-5 years) so that academia can have a more**

stable source of funding to support faculty and Ph.D. students to work on UFS improvements.

v. **While NSF properly devotes its resources to leading-edge basic research, there are also great needs in the field of numerical weather prediction. NSF should partner with NOAA to support basic research that will benefit the UFS 6-10 years from now.**

vi. **Ensure that major projects have both operational/governmental *and* academic leads. These collaborations between NOAA and the universities can be incentivized through co-supervised postdocs and funding calls that encourage operational/academic interaction.**

b. What role can Congress play in facilitating these relationships?

Response from Fiebrich: It is important for Congress to recognize that improving weather forecasting requires equal attention to four unique components including (1) improving the observational datasets that provide the initial conditions for forecast models, (2) improving the modeling systems, (3) providing increased high-performance computing capacity to take advantage of new data and improved models, and (4) extending research on the sources of predictability (e.g., El Nino-Southern Oscillation, Arctic sea ice breakup, Madden-Julian Oscillation). Congress can facilitate these needs and federal-academic partnerships by:

i. **Assessing today's operational observing systems to identify the greatest observational needs required to improve forecasts, especially on short-term storm scales and longer-term ocean scales.**

ii. **Continuing to support and expand the National Mesonet program whereby the federal government can leverage tens of thousands of additional real-time weather observations from across the nation to aid operational forecasts at the National Weather Service.**

iii. **Supporting the new EPIC (Environmental Prediction Innovation Center). EPIC was created to achieve the goals outlined in *a. (i) and (ii)* above. EPIC's progress should be monitored, and, if successful, funding for it should increase over time.**

iv. **Increasing high-performance computing for weather forecasting via a more stable, reliable path. High-performance computing requirements for data assimilation (i.e., processing the billions of input observations), modeling for both storm and seasonal scales, and ensembles (multiple model runs that increase the reliability of the forecasts) are all increasing simultaneously, thus necessitating large annual increases in high-performance computing capacity. A long term (e.g., 10-year) plan for increasing high performance computing infrastructure is needed.**

2. In 2017, *the Weather Research and Forecasting Innovation Act* was signed into law and provided NOAA and the NWS direction on advancing observational, computing, and modeling capabilities to support improvements in forecasting and prediction of high impact weather events, expanding opportunities for procuring commercial weather data, among other things.

a. Can you discuss how the research priorities articulated in the Weather Act have affected the research conducted within the academic community?

Response from Fiebrich: First, let me state that my colleagues at the National Weather Center (NWC) are very supportive of this important authorizing legislation. In particular, this bill requires NOAA's Office of Oceanic and Atmospheric Research (OAR) to conduct a program aimed at developing "an improved understanding of forecast capabilities for atmospheric events and their impacts, with priority given to the development of more accurate, timely, and effective warnings and forecasts of high impact weather events that endanger life and property." The bill also asks for the National Weather Service to "collect and utilize information to make reliable and timely foundational forecasts of sub-seasonal and seasonal temperature and precipitation". Sub-seasonal forecasting is forecasting weather between two weeks and three months and seasonal forecasting is between three months and two years.

The educational, research and operational centers within the NWC have a distinguished history of addressing high impact weather events that endanger life and property. The past month has seen record outbreaks of tornadoes and floods across the U.S. The severity of these events requires us all to do more—especially in enhancing our observational capabilities such as the National Mesonet and ground-based radars and in accelerating improvements in numerical weather prediction models.

The prioritization of sub-seasonal forecasting is relatively new, and it will become a focus of the NWC. We recognize that predictions at these time scales are critical for many practical applications, such as water management (e.g., drought vs. pluvial years), prevention of vector borne diseases like malaria or West Nile Virus, energy management (e.g., heating and cooling needs), and agriculture. We note that the 2016 National academies report (https://doi.org/10.17226/21873) presented strategies for how to move towards the next generation earth system prediction models that can provide more accurate predictions for the sub-seasonal to seasonal time scales, that fall in between the range of skills of classic weather prediction models (i.e., less than 10 days) and climate models (i.e., several decades). This report concluded that in a decade from now, intermediate range forecasts are expected to be as widely used as weather forecasts today. To achieve this vision, it is critical to connect advancements in forecasting with applications (e.g., pre-deploying resources in advance of significant weather events). Programs such as NOAA RISA that fund the Southern Climate Impact Planning Program are working with stakeholders to identify such needs. Additionally, OU's School of Meteorology (SoM) faculty members and NWC scientists have expertise in many research areas outlined in the NAS report, but the challenge is significant and will require investment of significant federal dollars.

HOUSE COMMITTEE ON SCIENCE, SPACE, AND TECHNOLOGY

SUBCOMMITTEE ON ENVIRONMENT

"The Future of Forecasting: Building a Stronger U.S. Weather Enterprise"

Questions for the Record to:
Dr. Christopher Fiebrich
Executive Director, Oklahoma Mesonet
And Associate Director, Oklahoma Climatological Survey

Submitted by Chair of Subcommittee on Environment
Lizzie Fletcher

1. In December 2018, the NIDIS Reauthorization Act included an authorization of NOAA's Earth Prediction Innovation Center, or EPIC, within the Office of Oceanic and Atmospheric Research. The EPIC program is meant to enhance collaboration to improve numerical weather prediction.
    a. Can you comment on the value of a true community driven model development? What are your thoughts on NOAA's new EPIC initiative?

Response from Fiebrich: We at the OU National Weather Center (NWC) are well aware of the new EPIC initiative, and we plan to participate actively in the EPIC Community Workshop in August in Boulder. For EPIC to be successful, it must engage the university community. For years, NWC scientists have contributed significantly to the development of NOAA's Finite Volume Cubed-Sphere Dynamical Core (FV3), which is likely to be an important part of the path forward for improved NWP models. NWC scientists have also been heavily involved with assisting the Next Generation Global Prediction System (*NGGPS*) and Hurricane Forecast Improvement Project (HFIP). There is a great deal of other capabilities within the OU School of Meteorology including the NOAA/OU Cooperative Institute for Mesoscale Meteorological Studies (CIMMS) and the Center for the Analysis and Prediction of Storms (CAPS) with our history of collaboration with the Global Systems Division (GSD) of the Earth System Research Laboratory (ESRL) and Geophysical Fluid Dynamics Laboratory (GFDL). Additionally, NWC scientists actively engage in research to operations activities on an ongoing basis via many programs within the Hazardous Weather Testbed.

If managed properly, the combined intellectual resources of the federal, academic, and private sector should, in principle, be able to develop a community model whose performance is superior to the European Model, currently considered to be the world's best. However, harnessing and coordinating these intellectual resources will be a challenge. An effective governance and code management structure is needed. Stable research funding, high-performance computing resources, and user-support software infrastructure will be needed by the external community. The mission of EPIC is

to address and solve these issues. NOAA's Vision Paper for EPIC addresses many of the critical issues needed for success. It is still not clear how the full spectrum of user support needs will be addressed and if there will be a small central physical location for experts and beginners to convene to share knowledge.

EPIC has great promise to finally enable the federal and academic sectors to collaborate effectively on community model development. I hope the EPIC infrastructure is created quickly so that these collaborations can begin.

2. NOAA's data is freely available to the public, which has allowed for robust engagement with the private sector to develop specialized weather products and for academia to conduct research. Given this new frontier of weather data that could be collected outside of the public sector, there are new possibilities and challenges for non-industry stakeholders.
    a. What impact to academic research would a greater prevalence of private weather data have?

Response from Fiebrich: Although significant progress has been made in the sharing and distribution of private weather data with the academic sector, there are likely important, yet unrealized opportunities. The National Academy of Sciences seminal study in 2009, "Observing Weather and Climate from the Ground Up: A Nationwide Network of Networks", identified there was no national network tying together the growing data systems provided by businesses, state and local governments. As a result, the collection methods were inconsistent and public accessibility was limited. The 2009 report identified short-term and long-term goals for federal government sponsors and other public and private partners to establish a coordinated nationwide network of networks. As a result, Congress acted, and we now have the National Mesonet Program, which is answering this identified issue. Increased funding is needed, but we now have the foundation of a national program. As the National Mesonet continues to grow, it is important to maintain the quality and reliability of the observations. Proliferation of observations is important, but quality of the data are equally important. For the data to be trusted and reliable, funding mechanisms through the federal government are essential. Many universities and state governments have made significant investments in these networks, but they alone cannot be expected to support the broader national needs of the data without funding support.

3. The rapidly evolving Weather Enterprise has created new technologies and led to the advent of new user communities. The training needed to be a successful meteorologist or scientist in today's Weather Enterprise differs greatly from 20 years ago.
    a. What do you see as the biggest workforce needs for the Weather Enterprise?

Response from Fiebrich: It has become readily apparent that the private sector workforce is growing faster than the public or academic sectors. Jobs in the private sector are rarely *pure* forecasting positions. Instead, they require a workforce with a blend of skills including communications, software development, and business management. Thus, the biggest workforce need will be for graduates with a blend of education and training that extends beyond the typical meteorology curriculum.

b. What qualities and skills would you like to see in the next generation of meteorologists and weather scientists, and are we currently training our students to meet the new challenges we face?

Response from Fiebrich: As an Adjunct Faculty member of the OU School of Meteorology, I am aware of and involved in efforts to understand work force needs and how these needs relate to the educational system. The OU School of Meteorology recently surveyed alumni to gain their impression of what skills they found to be important for today's work force. This survey was followed up with discussions with the departments and agencies within the National Weather Center and employers who participated in our College's Career Day and in other venues such as the meeting of our College's Board of Visitors and the UCAR Members meeting. The School of Meteorology's Director also participated in an NSF-sponsored effort to examine the future of graduate education in the geosciences and efforts under the World Bank- World Meteorological Organization-Hydrometeorological Equipment Industry sponsored effort called the Global Weather Enterprise Forum to look at the needs of employers. The findings were that employers desired that the core curriculum and expertise in the atmospheric sciences not be trimmed back or compromised, but noted the importance of greater proficiency in programming, oral and written communication, critical thinking and problem solving, and team work. Given the growth of positions in the private sector, the recommendation was also made to provide students with the opportunity to learn business skills.

Many academic programs are adapting to the new challenges, some more quickly than others. The OU School of Meteorology is revising our undergraduate curriculum to include additional programming/IT skills, communication, and critical thinking to better meet employer needs. It is also creating a broader spectrum of classes across the atmospheric sciences. We created two new degree programs denoted as "4+1", which are accelerated programs that allow students to earn both a Bachelor's and Master's degree in just five years. For one of the new programs, we collaborated with the OU Price College of Business to create a 4+1 program that provides students with a B.S. in Meteorology and an M.B.A. In the second program, we collaborated with the Data Science and Analytics department within the OU Schools of Computer Science and Industrial and Systems Engineering to create a 4+1 that provides students with a B.S. in Meteorology and an M.S. in Data Science and Analytics.

c. How does having a well-trained workforce impact the success of the broader enterprise?

Response from Fiebrich: A well-trained workforce enables students to start benefitting their employers immediately upon hire, giving them the desired skills right from the start. Of course, employers should still be expected to provide training on applications specific to their company. Additionally, recent graduates bring new technology and approaches directly into the workplace.

d. How can we go about having the best trained scientists and engineers in the Weather Enterprise?

Response from Fiebrich: As mentioned above, it's important for Universities to revise their curricula to stay relevant for the skills required of the current and future workforce. With the rising cost of higher education, it is important to strive to make college affordable to all applicants. Cost should not be a factor in preventing talented individuals from obtaining a STEM education. Federal resources for research should increase, thereby giving both undergraduate and graduate students in the sciences and engineering the opportunity for training in relevant and real-world research.

4, The last comprehensive report on the state of the U.S. Weather Enterprise was the National Academies' seminal "Fair Weather Report" published in 2003. The report outlined the roles of the three sectors and made a number of important recommendations to the National Weather Service (NWS), which helped shape the direction of the Enterprise. 16 years later, some are saying it is time for another forward-looking set of recommendations for the Enterprise.

a. What should serve as the guiding principles for improving partnerships between the sectors going forward?

Response from Fiebrich: One relatively new aspect not accounted for in the 2003 report is the prospect of the private sector providing enormous amounts of important weather data. Thus, this issue alone warrants an updated study of some kind. As a guiding principle, the new report should not be overly restrictive in its recommendations but more "aspirational" or "guiding". Additionally, since the American Meteorological Society played a major role in facilitating the recommendations in the "Fair Weather Report", it could play a major role again. The American Meteorological Society membership spans expertise across academia, corporations, and the public sector. The Office of Science and Technology Policy could also play a role.

Responses by Mr. Rich Sorkin

Response to Questions on Testimony by
Rich Sorkin
Chief Executive Officer of Jupiter Intelligence

Before the Subcommittee on Environment of the
House Committee on Science, Space, and Technology
Hearing on May 16, 2019
"The Future of Forecasting: Building a Stronger U.S. Weather Enterprise"

June 13, 2019

Questions Submitted by U.S. Representative Eddie Bernice Johnson
Chair of the Science, Space, & Technology Committee

The success of the National Weather Service (NWS) relies on cutting-edge scientific research conducted in all three sectors that is transitioned to meet operational needs.

Question: In your testimony, you spoke about the acceleration of research to operations within the private sector and the role of cloud computing technology in this transition. Do you see potential to replicate this process in the public sector?

Response: *I believe that the private sector has developed a variety of approaches which could help NWS. One of the strongest tenets within the private sector is to move quickly in both developing and testing innovations. Cloud computing is one of the approaches that allows for this rapid development, testing and deployment. This could help NWS in at least three ways:*

1) *Cloud computing is useful for research and testing on subcomponents of weather forecasting models.*

2) *Cloud computing is scalable and economical, which is particularly important for developing and testing advancements in weather forecasting.*

3) *Cloud computing is particularly useful for allowing the larger research community to collaborate in a safe environment; it's much more effective than allowing researchers access to NOAA's supercomputing hardware.*

There are a number of additional approaches used in the private sector which could help NWS, if the appropriate resources are available to allow for this innovation.

Question: What role can Congress play in facilitating these relationships?

Response: *NOAA needs to embrace a cultural shift toward a more focused goal of fundamental forecasts, more rapid deployment of new approaches, and a stronger relationship with the academic and private sectors. Congress can facilitate this shift with additional resources to develop more innovative and cost-effective approaches, and much greater flexibility in how NOAA spends its current resources. Innovation is currently constrained with historical spending approaches which can limit leadership driven by potential advances in methodology, technology, and effectiveness. For example, to adopt cloud computing, NOAA will need training as well as a dedicated cloud computing budget that includes associated administrative costs. This will give NOAA the resources to plan, collaborate, and process the results of collaborative cloud computing activities. While this cultural shift requires initial investment, it will save money and support innovation in the long run.*

In 2017, the Weather Research and Forecasting Innovation Act was signed into law and provided NOAA and NWS direction on advancing observational, computing, and modeling capabilities to support improvements in forecasting and prediction of high impact weather events, expanding opportunities for procuring commercial weather data, among other things.

Question: How, if at all, did the Weather Act impact research and development activities at Jupiter, or at other private weather companies?

Response: *The 2017 Weather Research and Forecasting Innovation Act opened the door to a wide variety of private sector activities. Jupiter actively uses NOAA's observational data, while other commercial sector entities are able to develop private sector observations in a collaborative way. Jupiter is currently working together with NOAA to provide state-of-the-art operational forecasts for major harbors in the U.S. This level of collaboration between NOAA and the private sector on forecasts did not previously exist.*

Questions Submitted by U.S. Representative Lizzie Fletcher
Chair of the Subcommittee on Environment
Member of the Science, Space, & Technology Committee

In December 2018, the NIDIS Reauthorization Act included an authorization of NOAA's Earth Prediction Innovation Center, or EPIC, within the Office of Oceanic and Atmospheric Research. The EPIC program is meant to enhance collaboration to improve numerical weather prediction.

Question: You made reference to the Earth Prediction Innovation Center in your testimony. Can you elaborate on why you think it is a good first step toward helping NOAA adopt Artificial Intelligence and Cloud computing?

Response: *Jupiter has been collaborating with NOAA's Office of Oceanic and Atmospheric Research since I started the company in 2017. Our scientists have briefed NOAA scientists on the use of Artificial Intelligence and cloud computing. The establishment of EPIC enables more structured and direct collaboration on both Artificial Intelligence and cloud computing by allowing greater and more fluid collaboration between NOAA and both the academic and private sectors. Currently, the private sector both drives the vast majority of innovation in Artificial Intelligence and cloud computing and has led the way in applying these analytical approaches to weather, water, and climate issues.*

EPIC, as a first effort towards collaboration, provides an opportunity for growth in the private sector, along with more rapid exchange of ideas with closer public-private relationships. NOAA would benefit from a greater involvement by the private sector at the advisory level for EPIC, as well as the greater involvement of academia. The volume of environmental information is growing rapidly, particularly in areas related to specialized weather forecasts and hyper-local climate risk information. EPIC will allow the public, private and academic sectors to address critical challenges while maintaining appropriate roles for each of the sectors. By supporting communication and collaboration across the sectors, EPIC will help ensure the most cost-effective use of taxpayer investments.

Private industry is quickly increasing its ability to collect weather data through observation. This includes core infrastructure like satellites, as well as new sources like smart devices, personal weather stations, LIDAR, drones and unmanned vehicles. This data can both supplement data that the National Weather Service (NWS) already collects and fill important gaps in the data, such as observations in the planetary boundary layer.

Question: In your experience, to what extent are companies willing to share data with NWS?

Response: *Historically, most instruments have been built by the private sector; however, we are now seeing an evolution in which the private sector is expanding its role and both deploys and operates the instruments in innovative ways. All private sector efforts to gather observations are motivated by profit and have clear business models developed to regain their investment and earn a profit. This motivation has spurred some of the most innovative, cost-effective solutions for monitoring the environment in the history of Earth observations. All private sector companies we are familiar with welcome the opportunity to sell their data to NWS. We strongly encourage NOAA to consider new models of buying services rather than building and deploying satellites because of the cost effectiveness of this approach, and its ability to allow NOAA to embrace innovation more rapidly. This model has been successful for the U.S. Department of Defense and is rapidly being adopted around the world. I am aware of organizations, including EDF, willing to give their observations away. For many companies, the collected observations can serve a variety of purposes, and sharing of data to support weather forecasts may be possible at minimal costs. Private sector companies are working with WMO to find ways to improve global weather and climate prediction capabilities, while supporting a sustainable business model. I strongly suggest that NWS become more active in exploring ways it can buy observations as well as model output to supply U.S. interests with the best possible forecasts in a cost-effective manner.*

The rapidly evolving Weather Enterprise has created new technologies and led to the advent of new user communities. The training needed to be a successful meteorologist or scientist in today's Weather Enterprise differs greatly from 20 years ago.

Question: What do you see as the biggest workforce needs for the Weather Enterprise?

Response: *Modern technologies and the applications of weather science have evolved much more rapidly than the actual practice of weather science, particularly in the last decade or so. As a result, the workforce needs:*

1) *Updated training on methods and technologies being developed outside of meteorology but with applications in weather science, particularly in modern computational methods and emerging techniques like Artificial Intelligence;*

2) *Increased instruction on the application of weather information in the broader economy and how to communicate that information to different users of that intelligence; and*

3) *Exposure to non-academic career tracks to better disseminate critical weather knowledge and skills outside of academia.*

Question: What qualities and skills would you like to see in the next generation of meteorologists and weather scientists, and are we currently training our students to meet the new challenges we face?

Response: *The next generation of meteorologists and weather scientists will need to leverage evolving data and computational methods to synthesize insights from the vast amounts of environmental information we are collecting and producing. They will need the tools to confront big-data problems, programs for distributed large-scale computing, the ability to condense and summarize information, and the skills to communicate this value to a wide spectrum of end users. Current training programs in this field rarely offer a comprehensive exposure to all of these areas. At Jupiter, we pull as much from the innovative computing areas as we do from the traditional meteorological and climatological areas.*

Question: How does having a well-trained workforce impact the success of the broader enterprise?

Response: *Insight and information about weather analysis and prediction are valuable to a large and diverse audience of end users across economic sectors. As this science matures and grows in complexity, members of the weather science workforce who can both leverage evolving technologies and effectively communicate weather information to consumers will, in turn, be able to enrich the Weather Enterprise itself and promote innovation in promising, useful directions. Without the kinds of skills outlined above, the Enterprise remains isolated and its growth stagnates.*

Question: How can we go about having the best trained scientists and engineers in the Weather Enterprise?

Response: *Some specific suggestions could include:*

1) *Encouraging greater interaction between academia, government, and the private sector, allowing meteorology students to be exposed to a broader spectrum of users and technologies;*

2) *Promoting job opportunities for meteorologists outside of the academic or forecaster track;*

3) *Supporting applied research programs to address specific needs that can be informed by weather science; and*

4) *Ensuring access to the latest technology and training in that technology for collecting and analyzing weather information and data.*

The last comprehensive report on the state of the U.S. Weather Enterprise was the National Academies' seminal "Fair Weather Report" published in 2003. The report outlined the roles of the three sectors and made a number of important recommendations to the NWS, which helped shape the direction of the Enterprise. Sixteen years later, some are saying it is time for another forward-looking set of recommendations for the Enterprise.

Question: Where do you see the state of the U.S. Weather Enterprise in 10 to 20 years, and would it benefit from another set of independent recommendations? What should serve as the guiding principles for improving partnerships between the sectors going forward?

Response: *I expect that the U.S. Weather Enterprise in 10 to 20 years will continue to be the world leader in providing a wide range of forecasts globally. The structure of the Enterprise is changing and likely will continue to change to include a much larger role for the private sector, including observations, modeling, and communication of forecasts. This greater role of the private sector will result in more accuracy, efficiency, and specialization of forecasts. The use of estimates of severe weather risks, as produced by Jupiter, will be a part of every business plan globally, and will help drive planning for private companies as well as local and national governments. Week-ahead forecasts will be almost as accurate as our current day-ahead forecasts. Many of these advances will come from the private sector. The public sector can support this ambitious vision by continuing to support an advanced observational system, providing foundational global forecasts, and assuring a healthy academic research sector.*

The Weather Enterprise will definitely benefit from a re-examination of the roles of each sector moving forward, as may be accomplished with a new National Academies Report. A healthy Enterprise requires clear guidance of appropriate roles so that long-term planning and investments can build toward a more effective and collaborative enterprise. In general, Congress should expect that some services that NOAA provides for free will see greatly limited private sector investment. NOAA should avoid providing barely minimal services in areas the private sector could support with private capital, especially where the private sector is open to mutually beneficial collaboration with NOAA. More specifically, a scenario in which the federal government produces inferior or insufficient forecasts or estimates of future flooding exerts a downward force on the private sector; it keeps innovators from stepping in and doing a much better job while at the same time depriving end users of state-of-the-art products.

A guiding principle going forward is that end users receive forecasts that are both accurate and actionable. This can best be achieved by all three sectors flourishing and collaborating to address the emerging challenges for weather and climate. A further guiding principle will be a growing focus on the economic value of useful weather and climate information.

Appendix II

Additional Material for the Record

LETTER SUBMITTED BY REPRESENTATIVE LIZZIE FLETCHER

AIA AEROSPACE INDUSTRIES ASSOCIATION

STATEMENT FOR THE RECORD PROVIDED BY THE AEROSPACE INDUSTRIES ASSOCIATION TO THE HOUSE SCIENCE, SPACE AND TECHNOLOGY SUBCOMMITTEE ON THE ENVIRONMENT
MAY 16, 2019

The Aerospace Industries Association (AIA) appreciates the opportunity to submit our position on the importance of the future of our nation's weather enterprise. AIA also thanks the House Science, Space and Technology Committee Subcommittee on the Environment for holding today's hearing, "The Future of Forecasting: Building a Stronger U.S. Weather Enterprise." We are pleased to see that this Committee is prioritizing weather and comes at a time when the future of accurate weather forecasts faces uncertainty moving forward.

AIA is the voice of the American aerospace and defense industry. AIA represents nearly 340 leading aerospace and defense manufacturers and suppliers, supporting 2.4 million jobs and over $800 billion in annual exports. Our members and companies like them build the satellites used by the federal government to ensure that weather forecasts are accurate and available in real time.

The average American takes accurate weather readings for granted. You can be almost anywhere in the world and look at your phone to receive accurate weather data. The federal government also relies heavily on these readings. Natural disaster situations like Hurricane Sandy prove that accurate weather readings help with disaster preparedness and recovery efforts.[1] Interference-free radiofrequency spectrum communications that allow for accurate readings make these applications possible.

Unfortunately, today's spectrum reality could directly impact the future of accurate weather readings. Spectrum is a finite resource and as the Federal Communications Commission (FCC) looks to free up spectrum for emerging technologies like 5G, the risk of interference with existing users rises, in both the incumbent band and the adjacent bands.

This risk has come into the spotlight recently as a result of the FCC's 24 GHz auction plan. While it was a multi-year process to get to the auction itself, it is unclear if the proper testing to ensure that harmful interference with weather equipment in the directly adjacent band would not take place had been conducted fully. As NASA Administrator Jim Bridenstine and U.S. Department of Commerce Secretary Wilbur Ross highlighted in their letter to FCC Chairman Ajit Pai on February 28, 2019:

> "[this] would have a significant negative impact on the transmission of critical Earth science data — an American taxpayer investment spanning decades and billions of

[1] https://spacenews.com/5g-trumps-weather-in-spectrum-debate/

> dollars with data supporting public safety, natural disaster and weather forecasting... As the U.S. government continues to investigate additional spectrum for future commercial broadband use, it is essential that protections are established for the critical operations of NASA, the Department of Commerce and our international partners in the 23.6 to 24 GHz spectrum band."

AIA and our members are excited about the promise of new technologies like 5G, but believe it is critical that the proper testing takes place prior to any FCC auction, to protect the existing users of both the specific and adjacent spectrum bands. This will allow spectrum band sharing to take place where appropriate and allow for existing services to continue without harm if the risk of interference is too great.

We thank the Subcommittee for holding this hearing and bringing attention to this critical matter and look forward to working with both Congress and the regulatory bodies to ensure that 5G can be rolled out in both a timely and safe manner for all spectrum users.