A TASK OF EPIC PROPORTIONS: RECLAIMING U.S. LEADERSHIP IN WEATHER MODELING AND PREDICTION

HEARING

BEFORE THE

SUBCOMMITTEE ON ENVIRONMENT

OF THE

COMMITTEE ON SCIENCE, SPACE, AND TECHNOLOGY

HOUSE OF REPRESENTATIVES

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C O N T E N T S

November 20, 2019

Appendix II: Additional Material for the Record

A TASK OF EPIC PROPORTIONS: RECLAIMING U.S. LEADERSHIP IN WEATHER MODELING AND PREDICTION

WEDNESDAY, NOVEMBER 20, 2019

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

The Subcommittee met, pursuant to notice, at 1:58 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

"A Task of EPIC Proportions: Reclaiming U.S. Leadership in Weather Modeling and Prediction"

Wednesday, November 20, 2019
2:00 P.M.
2318 Rayburn House Office Building

PURPOSE

The purpose of this hearing is to assess the development and implementation of the Earth Prediction Innovation Center (EPIC), which was recently authorized under the National Oceanic and Atmospheric Administration (NOAA) in the National Integrated Drought Information System Reauthorization Act of 2018, P.L. 115-423. It will be an opportunity to discuss the origins of EPIC, NOAA's short and long-term goals for the program, and its organization, management, and governance. It will focus on the challenges and opportunities of a community approach to numerical weather prediction and modeling, and include perspectives from NOAA, academia, the private sector, and other key members of the weather community.

WITNESSES

- **Dr. Neil Jacobs**, 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. Cliff Mass**, Professor of Atmospheric Sciences, University of Washington
- **Dr. Peter P. Neilley (Knee-Lee),** IBM Distinguished Engineer and Director of Weather Forecasting Sciences and Technologies, The Weather Company, An IBM Business
- **Dr. Thomas Auligné (Oh-Leen-Yay),** Director of the Joint Center for Satellite Data Assimilation, University Corporation for Atmospheric Research (UCAR)

OVERARCHING QUESTIONS

- What is EPIC, and how was it developed?
- What are NOAA's and the broader weather community's vision for EPIC, and what are the short and long-term goals to get us there?
- How will EPIC restore U.S. leadership in weather forecasting?
- What should EPIC's organization, structure, and governance look like?
- How is NOAA engaging with the broader weather community in developing and implementing EPIC and how is it taking recommendations into consideration?
- What is the timeline for next steps in implementing EPIC?

- What should the roles of the federal, academic, private industry, and other members of the U.S. weather enterprise be in EPIC?
- Where should EPIC be hosted; should it be a virtual or physical center?
- How will EPIC attract the best talent to address forecasting and modeling challenges, and how will it support workforce development?
- What additional resources (i.e. computing needs) does NOAA need to successfully implement EPIC?

BACKGROUND

In 2012, Hurricane Sandy made it clear that American weather forecasting abilities lagged those of Europe. The European model[1] accurately predicted the sharp left turn the hurricane would take, making landfall and wreaking havoc on the U.S. East coast. The American model failed to predict this, instead estimating that Sandy would fade out over the Atlantic.[2]

Post-Sandy, Congress allocated significantly more funding to improve forecasting and research to operations (R2O) at NOAA; however, the U.S. still ranks third or fourth in the world in terms of forecast accuracy.[3] In order to bolster the accuracy of U.S. models and reclaim global leadership in weather forecasting, Congress has directed NOAA to establish the Earth Prediction Innovation Center (EPIC). The goal of EPIC is to foster collaboration within the broader U.S. weather community to address the longstanding gaps in R2O and forecasting accuracy.[4]

To accomplish the stated goal of "creating a community global weather research modeling system," NOAA aims to utilize cloud computing to enable wider access to data and code, reduce computing bottlenecks, and allow for research activities to be scaled across various computational systems.[5]

EPIC Timeline

The Weather Research and Forecasting Innovation Act (Weather Act) of 2017 (P.L. 115-25) directs NOAA to "prioritize improving weather data, modeling, computing, forecasting, and warnings for the protection of life and property, and for the enhancement of the national economy."[6] The National Integrated Drought Information System (NIDIS) Reauthorization Act of 2018 (P.L. 115-423) amends the Weather Act and directs NOAA to establish EPIC to enhance community efforts to develop and translate scientific and technological advancements into numerical weather prediction (NWP) and forecast operations. Section 4 of NIDIS outlines the following responsibilities for the EPIC program:

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[1] Developed by the European Center for Medium-Range Weather Forecasts
[2] https://www.aip.org/fyi/2019/noaa-betting-%E2%80%98epic%E2%80%99-drive-us-weather-forecast-innovation
[3] https://arstechnica.com/science/2016/06/the-us-weather-model-is-now-the-fourth-best-in-the-world/
[4] Ibid.
[5] P.L. 115-423, January 7 ,2019.
[6] P.L 115-25, April 18, 2017.

"(4) Advancing weather modeling skill, reclaiming and maintaining international leadership in the area of numerical weather prediction, and improving the transition of research into operations by—

A. leveraging the weather enterprise to provide expertise on removing barriers to improving numerical weather prediction;
B. enabling scientists and engineers to effectively collaborate in areas important for improving operational global numerical weather prediction skill, including model development, data assimilation techniques, systems architecture integration, and computational efficiencies;
C. strengthening the National Oceanic and Atmospheric Administration's ability to undertake research projects in pursuit of substantial advancements in weather forecast skill;
D. utilizing and leverage existing resources across the National Oceanic and Atmospheric Administration enterprise; and
E. creating a community global weather research modeling system that—
i. is accessible by the public;
ii. meets basic end-user requirements for running on public computers and networks located outside of secure National Oceanic and Atmospheric Administration information and technology systems; and
iii. utilizes, whenever appropriate and cost-effective, innovative strategies and methods, including cloud-based computing capabilities, for hosting and management of part or all of the system described in this subsection"[7]

In January 2019, NOAA and the National Center for Atmospheric Research (NCAR) signed a Memorandum of Agreement (MOA) establishing a partnership to create a common modeling infrastructure. The goal is for this infrastructure to be transparent, easily accessible, and used by both public and private researchers.[8] The MOA provides that NOAA and NCAR utilize existing investments to prioritize collaboration and is a step towards realizing EPIC's goal of community modeling.

On March 6-7, 2019, NOAA held an internal workshop with twenty employees to begin planning EPIC. There was a consensus from attendees that EPIC must provide a mechanism through which R2O can be advanced through community-developed improvements.[9]

In June 2019, NOAA distributed a Request for Information (RFI) to "gather ideas, recommendations, and best practices from industry on how to develop, meet the goals of and support a virtual" EPIC.[10] They specifically solicited advice on how to develop and execute the following seven areas of EPIC: software engineering, software infrastructure, user support services, cloud-based high performance computing, scientific innovation, management and planning, and external engagement and community modeling.

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[7] P.L. 115-423, January 7 ,2019.
[8] https://www.noaa.gov/media-release/noaa-and-ncar-partner-on-new-state-of-art-us-modeling-framework
[9] https://owaq.noaa.gov/portals/0/EPIC_Vision_paper_V5.0.pdf?ver=2019-06-04-103244-717
[10] https://www.fbo.gov/index?s=opportunity&mode=form&id=1c7429877ff32fa8c21a97985114e344&tab=core&_cview=0

On August 6-8, 2019, NOAA's Office of Weather and Air Quality (OWAQ), within Oceanic and Atmospheric Research (OAR), hosted a Community Workshop in Boulder, Colorado to engage the broader weather community and plan out the next steps for EPIC's development. More than 300 participants from government, academia, and industry participated to co-create a vision for the program and discuss pathways to advance community modeling and research to operations.[11] A report on the workshop is expected to be released in the near future.

The Future of EPIC

To make EPIC successful, the Environmental Information Services Working Group (EISWG) recommends that NOAA act quickly to implement EPIC's governance structure and processes, and to make EPIC's vision and values clear to the community.[12] EISWG recommends that NOAA engage the broader community in EPIC's development, including multiple agencies, the Cooperative Institutes, and other stakeholder groups. The group also notes that NOAA should invest immediately in cloud computing in order to bolster R2O and community involvement.[13]

The President's FY 2020 budget for NOAA requests an increase of $12,320,000 to support EPIC at a total of $15 million.[14] The Senate's FY 2020 Commerce, Justice, Science (CJS) appropriations bill sets aside no less than $7 million for NOAA to establish EPIC.[15] The House-passed FY 2020 CJS appropriations bill does not specifically call out EPIC but provides $10 million in High Performance Computing Initiatives to support NOAA research.[16]

Key Terms

Cloud-Based Computing Needs

EPIC will need to establish the first operational end-to-end NWP system that will be accessible to scientists and researchers in and outside of NOAA as part of the its high-performance computing (HPC) strategy.[17] As HPC is a limited resource, a cloud-based computing network could be the way forward to develop a system that can be scaled up and made accessible to those in and outside of NOAA, without requiring an increase in the "big iron" HPC machinery that is currently being used.[18] Cloud computing refers to the availability of computing services over the

[11] https://owaq.noaa.gov/Resources/News/ArtMID/446/ArticleID/54

[12] https://sab.noaa.gov/sites/SAB/Documents/Meetings/SAB%20Meetings%202019/September%202019/EISWG-EPIC%20Letter%20Report%20to%20the%20SAB%20FINAL.pdf?ver=2019-09-03-130727-177

[13] https://sab.noaa.gov/sites/SAB/Documents/Meetings/SAB%20Meetings%202019/September%202019/EISWG-EPIC%20Letter%20Report%20to%20the%20SAB%20FINAL.pdf?ver=2019-09-03-130727-177

[14] https://www.corporateservices.noaa.gov/nbo/fy20_bluebook/NOAA-FY20-Congressional-Justification.pdf

[15] https://www.congress.gov/116/crpt/srpt127/CRPT-116srpt127.pdf

[16] https://www.congress.gov/116/crpt/hrpt101/CRPT-116hrpt101.pdf

[17] https://owaq.noaa.gov/portals/0/EPIC_Vision_paper_V5.0.pdf?ver=2019-06-04-103244-717

[18] Ibid.

Internet ("the cloud"), and can potentially offer faster processing and more data storage than traditional computing machinery.

At the EPIC Community Workshop in August 2019, there was a consensus that far more computer resources are required to succeed in world class weather prediction. Moreover, participants recognized the potential that cloud computing offers for NOAA and the community to co-develop a common modeling system. They stressed the importance of ensuring EPIC be readily adaptable to an evolving computing landscape.[19]

Community Modeling

Central to EPIC's vision of improving U.S. NWP and forecasting is building a community-based model that involves NOAA internal and external partners to increase the rate of knowledge transfer from research to an operational system. To accomplish the goal, NOAA is looking to design a community modeling infrastructure that public and private researchers can access and use.[20] To leverage the modeling skills that exist within the broader weather community, a common model is needed. At present, those in academia, the private sector, and any other non-federal entities face many barriers to accessing the models that NOAA uses for U.S. weather forecasts. These barriers prevent expertise that exists outside of NOAA to be incorporated into NWP models and forecasts, which hinders U.S. weather forecasting abilities. NOAA aims to remedy this by creating EPIC as a community-developed modeling center.[21]

Numerical Weather Prediction (NWP)

Numerical Weather Prediction (NWP) uses current observations of weather characteristics and processes them with computer models to forecast future weather conditions.[22] Numerical computer models process weather observations utilizing data assimilation to produce outputs such as temperature, precipitation, wind, and others. As outlined in the NIDIS Reauthorization Act of 2018, EPIC's purpose is to accelerate scientific and technological enhancements into the operational applications for numerical weather prediction. As outlined in NOAA's vision paper for EPIC, the initial focus is on improving NOAA's currently operational global medium range NWP application, called the Global Forecast System (GPS).[23]

Recommended Reading

NOAA's "A Vision Paper for the Earth Prediction Innovation Center (EPIC)" (updated 5/28/19)[24]

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[19] https://owaq.noaa.gov/Programs/EPIC
[20] https://www.noaa.gov/media-release/noaa-and-ncar-partner-on-new-state-of-art-us-modeling-framework
[21] https://www.noaa.gov/media-release/noaa-and-ncar-partner-on-new-state-of-art-us-modeling-framework
[22] https://www.ncdc.noaa.gov/data-access/model-data/model-datasets/numerical-weather-prediction
[23] Ibid.
[24] https://owaq.noaa.gov/portals/0/EPIC%20Vision%20paper%20V5.0.pdf?ver=2019-06-11-064803-163

Mr. CASTEN [presiding]. This hearing will come to order. Without objection, the Chair is authorized to declare recess at any time. As some of you know, due to caucus votes at 3 p.m., I'm going to try to keep my introductory remarks brief, and ask to submit the rest for the record, in order to get witness testimonies in as quickly as possible. The Chairwoman and Ranking Member of the full Committee have also agreed to submit their statements for the record.

As we have previously discussed in this Subcommittee. Americans depend on the data and services provided by the National Oceanic and Atmospheric Administration, or NOAA, and the National Weather Service every day. Earlier this Congress, in this Subcommittee's hearing on the NOAA Fiscal Year 2020 proposed budget, we heard from Acting Administrator Dr. Jacobs that the U.S. is not currently the global leader in weather forecasting. Considering how important accurate weather forecasting is to all Americans, this is extremely concerning.

The *National Integrated Drought Information System Reauthorization Act*, NIDIS,which was signed into law in January 2019, directed NOAA to establish the Earth Prediction Innovation Center, or EPIC. EPIC is tasked with creating a collaborative, community-driven, global weather research modeling system. The system will be publicly accessible, allowing those outside of NOAA to access and contribute to a community developed model. At today's hearing I look forward to a discussion with our distinguished panel of experts about how EPIC will leverage the skills and expertise across the public, private, and academic sectors of the United States weather community to bolster modeling and forecasting. Since EPIC is still in its infancy, this hearing will provide a timely opportunity to discuss the future of its organization, management, and governance, and examine each sector's vision and short- and long-term goals for EPIC.

I cannot overstate the importance of improving U.S. weather modeling and prediction capabilities. EPIC represents what some experts in the weather community have claimed as America's last chance to get this right, and restore our leadership in global weather prediction. I look forward to today's discussion about how EPIC is going to accomplish this. Thank you.

The Chair now recognizes Ranking Member Marshall for an opening statement.

Mr. MARSHALL. Thank you for holding this hearing. I want to thank our witnesses for appearing before the Subcommittee, especially Dr. Jacobs, who is in front of all of us now for the third time this year in Congress. And thanks for all of you on the panel for sharing your perspectives.

Weather prediction is something that affects the constituents of every Member up here, from the fields of Kansas to the Outer Banks of North Carolina. Anticipating the strength and conditions of the next weather event can save lives and property, as well as be the difference between a profitable year for a farmer or a catastrophic loss. I'm proud to say the Science Committee acted decisively last Congress by passing the *Weather Research and Forecasting Innovation Act*, the *Weather Act*, and the *National Integrated Drought Information System Reauthorization Act*. The *Weather Act* was the first authorizing legislation to address weather forecasting in 25 years, and prioritized improving weather data, modeling, computing, and forecasting. I'd like to extend to my gratitude to Ranking Member Lucas for introducing what is now a law, and for his continued leadership on this issue.

The *NIDIS Reauthorization Act* established the Earth Predication Innovation Center, EPIC, the topic of our hearing today. EPIC, when completed, will crowdsource the expertise of the private sector and the research communities to improve our forecasting models. This aligns with Congress' vision for the program by leveraging the weather enterprise to provide knowledge and skill on numerical weather prediction. The Federal Government should be doing more to utilize resources of private companies and university researchers, who are often the leading sources of innovations. In addition to having world class facilities and minds, private companies and academics are extremely flexible in research and development and cost effective in their methods. It is in the best interest of Kansas farmers, ranchers, emergency personnel, and everyday residents to have more accurate forecasts, and EPIC is an important step in the improvement of our forecasting ability.

In 2012 Hurricane Sandy caused nearly $70 billion in damage as it made landfall in Cuba and the Northeast Coast of the United States. This was the catalyzing weather event which caused Congress to examine how we could improve weather forecasting. We don't know when the next superstorm will be, but it's my hope that, through EPIC, NOAA and the National Weather Service will be fully prepared to predict, respond, and recover from the next severe weather event. While NOAA has taken the initial steps to implement EPIC, we must see a stronger sense of urgency moving forward. Because it's designed as a community approach to weather prediction and modeling. I look forward to hearing how Dr. Mass and others have been involved in implementing the center, and getting their feedbacks on how to ensure a successful and timely completion.

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

[The prepared statement of Mr. Marshall follows:]

Thank you for holding this hearing, Chairwoman Fletcher. I want to thank our witnesses for appearing before the subcommittee, especially Dr. Jacobs who is in front of the Committee for the third time this Congress, and all of you on the panel for sharing your perspectives.

Weather prediction is something that affects the constituents of every Member up here. From the fields of Kansas to the Outer Banks of North Carolina, anticipating the strength and conditions of the next weather event can save lives and property.

I'm proud to say the Science Committee acted decisively last Congress by passing the *Weather Research and Forecasting Innovation Act* (the *Weather Act*) and the *National Integrated Drought Information System (NIDIS) Reauthorization Act*.

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Thank you, Madam Chair. I yield back.

Mr. CASTEN. 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 Fletcher follows:]

Good afternoon, and welcome to the Subcommittee on Environment's hearing entitled ″A Task of EPIC Proportions: Reclaiming U.S. Leadership in Weather Modeling and Prediction.″ I would like to thank all of our witnesses for being here today to discuss the current state and future of the Earth Prediction Innovation Center, or EPIC, and its role in improving U.S. weather forecasting capabilities.

As we've previously discussed in this Subcommittee, Americans depend on the data and services provided by the National Oceanic and Atmospheric Administration (NOAA) and the National Weather Service every day. Much of these data are utilized in the weather products offered by private companies, such as weather apps on our cell phones or local news forecasts. Earlier this Congress, in this Subcommittee's hearing on the NOAA Fiscal Year 2020 Proposed Budget, we heard from Dr. Jacobs that the U.S. is not currently the global leader in weather forecasting. Considering how important weather forecasting is to all Americans, this is extremely concerning.

A devastating display of this was in 2012, when the U.S. model failed to predict Hurricane Sandy's sharp left turn and landfall over the East Coast. The European model got it right, demonstrating to the nation that U.S. weather forecasting abilities were far behind those of Europe. As we've discussed in this Committee, severe storms like Sandy are increasing in frequency and intensity due to climate change, making accurate forecasts even more critical.

A major difference between the U.S. and the European systems is that in Europe, the entire weather community contributes to a single model. In the U.S., the public, private, and academic sectors operate in isolation from each other, each working on their own weather prediction research and contributing to their own models. Even within the federal government, multiple agencies work on their own models in an uncoordinated way, and resources and expertise are fragmented. As a result, the U.S. Air Force abandoned the U.S. global weather model in 2015, preferring the United Kingdom's Unified Model. It is of the utmost importance that the U.S. weather community immediately act to catch up with its European counterpart.

Congress recognized the need to better leverage the skills and expertise across the public, private, and academic sectors of the U.S. weather community to create a single global model that is stronger than any of the individual models. The *National Integrated Drought Information System Reauthorization Act*, which was signed into law in January 2019, directed NOAA to establish the Earth Prediction Innovation Center, or EPIC. EPIC is tasked with creating a collaborative, community-driven global weather research modeling system. The system will be publicly accessible, allowing those outside of NOAA to access and contribute to a community-developed model.

On top of improvements to global weather prediction, EPIC could also serve as a vehicle to improve other, specialized modeling systems, such as rainfall and flooding prediction. This has implications for places like my district, Texas's 7th Congressional District in Houston, that has been experiencing increasingly frequent and intense precipitation events in recent years. Leveraging the capabilities of the community to improve precipitation modeling could provide my constituents, and others who live in flood-prone areas, more precise information about the timing and intensity of forecasted rainfall, thus protecting lives and property. I know all of our constituents look to the Weather Service as the national authority in issuing life-saving forecasts, watches, and warnings. While EPIC is intended to leverage the expertise of the non-federal weather community, the provision of official watches, warnings, and forecasts should remain with the National Weather Service.

At today's hearing, I look forward to a discussion with our distinguished panel of experts from across the U.S. weather community about how EPIC will combine each sector's expertise to bolster U.S. modeling. Since EPIC is still in its infancy, this hearing will provide a timely opportunity to discuss the future of its organization, management, and governance and examine each sector's vision and short and long-term goals for EPIC.

I cannot overstate the importance of improving U.S. modeling and prediction capabilities. EPIC represents what some experts in the weather community have called America's last chance to get this right and reclaim our leadership in global weather prediction. I look forward to today's discussion about how EPIC is going to accomplish this.

Thank you.

[The prepared statement of Chairwoman Johnson follows:]

Thank you, Chair Fletcher.

We have had many discussions this Congress, and Congresses in the past, about the importance of accurate and timely weather forecasts.

Weather forecasting is complex and relies on first collecting as many observations and data as possible that are then assimilated into cutting edge weather models that are tested and verified. NOAA, the lead civilian agency for operational weather forecasting, participates in all aspects of this process, including the development of our weather models. Despite being at the forefront of the development of numerical weather prediction, the accuracy of U.S. forecasts and numerical weather prediction has fallen behind that of other countries. But this isn't just a matter of pride; accurate weather forecasts save lives and protect property.

We recently had a devastating tornado touch down in Dallas that ripped through densely populated areas of the Metroplex in and near my district. Fortunately, there were no deaths or severe injuries related to this outbreak, but the tornadoes did cause an estimated $2 billion in property damage.

Timely forecasts, watches, and warnings from the National Weather Service were instrumental to keeping Texans safe during this tornado outbreak. Thank you to Dr. Jacobs and the dedicated employees at NOAA and the National Weather Service for their great work in protecting Americans every day.

As Texans, Chair Fletcher and I are very familiar with extreme weather events, as are Ranking Members Lucas and Marshall. This Committee held a hearing earlier this year on how to improve the understanding and forecasting of extreme weather events in a changing climate. Many of the witnesses at that hearing shared that leveraging the capabilities and resources of our robust weather enterprise through a community approach would be critical to addressing extreme weather forecasting challenges. NOAA's Earth Prediction Innovation Center, or EPIC, has thepotential to support the goal of regaining U.S. leadership in global weather forecasting through a community driven approach.

The *Weather Research and Forecasting and Innovation Act of 2017* was a significant step toward improving weather forecasting. This was followed by the National Integrated Drought Information System, or *NIDIS Reauthorization Act of 2018* that amended the *Weather Act* and authorized EPIC at NOAA.

It is vital for Congress to conduct oversight of federal programs that we have authorized to ensure they are being implemented as Congress intended. Hearings like this are important if we are to be good stewards of taxpayer dollars. I am looking forward to hearing from a broad group of stakeholders from the weather community this afternoon on how we can leverage a program like EPIC to achieve a common goal of improving our weather forecasts to better protect our constituents.Thank you and I yield back.

[The prepared statement of Mr. Lucas follows:]

Thank you, Chairwoman Fletcher, for holding today's hearing. I've said before that the continued improvement of weather forecasting is one of the most important topics in this committee's jurisdiction. Accurate forecasting not only helps our businesses make strategic plans, but it helps us to protect lives and properties during severe weather events. We need an accurate and trustworthy system.

The United States was once the world's leader in numerical weather prediction, but we can't credibly make that claim today. This was apparent in 2012, when

American forecasts predicted Hurricane Sandy would weaken over the Atlantic, while the European forecast model correctly saw Sandy making landfall.

Congress saw the need for rapid improvement in U.S. weather forecasts. In the supplemental appropriations package passed in response to Sandy in early 2013, Congress provided more than $20 million to NOAA to help improve forecast modeling and computing resource needs. While this assistance resulted in some improvements to our forecasting abilities, we needed to do more.

This committee passed the *Weather Act* during the 115th Congress, which was signed into law in April 2017. The *Weather Act*, the most significant weather legislation passed by Congress in more than 25 years, provided authorities and direction for NOAA in its weather research and forecasting efforts. One of the most consequential provisions in the bill was direction for NOAA to begin purchasing more commercial data in creating forecasts. This came in response to a recognized need for NOAA to better utilize the knowledge and expertise of the private sector and the research community.

An extension of the *Weather Act* was signed into law earlier this year. Included in this legislation was an authorization of the Earth Prediction Innovation Center - known as EPIC. This center represents a new way of weather modeling for NOAA by utilizing the computing resources and expertise of the academic community, private enterprise, and others who want to help the U.S. regain leadership. It will also utilize new computing resources, a significant reason why the U.S. has lagged in its forecasting abilities.

The authorizing legislation for EPIC became law in January. While NOAA has taken initial steps to implement EPIC, progress has been slow. We must move forward quickly to implement this legislation and begin closing the gap with the Europeans, Canadians, and others who have surpassed us. Our panel of witnesses will help us identify potential bottlenecks in implementing EPIC and what we can do to help the process move forward quickly.

Dr. Neil Jacobs is no stranger to our committee, and I want to thank him for again appearing before us today. He has made the quick and effective implementation of EPIC a personal priority. His education and professional background will be invaluable as we continue to improve the accuracy of our weather forecasts and I look forward to working with him on this effort.

I again want to thank Chairwoman Fletcher for conducting today's hearing and I also want to thank Chairwoman Johnson for her shared commitment to helping the U.S. again be the world leader in weather forecasting.

Thank you and I yield back.

Mr. CASTEN. At this time I would like to introduce our witnesses.

Our first witness is Dr. Neil Jacobs. He is the Assistant Secretary of Commerce for Environmental Observation and Prediction, performing the duties of Under Secretary of Commerce for Oceans and Atmosphere. Prior to joining NOAA, Dr. Jacobs was the Chief Atmospheric Scientist at Panasonic Avionics Corporation. He was also 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 master's and doctoral Degree in atmospheric science from North Carolina State University.

Our second witness, Dr. Cliff Mass, is a Professor of Atmospheric Sciences at the University of Washington. His specialty is numerical weather and climate prediction, and the meteorology of the western United States. Previously Dr. Mass was a faculty member at the University of Maryland's Meteorology Department. Dr. Mass is a Fellow of the American Meteorological Society, a member of the Washington State Academy of Sciences, and has published over 120 papers. Dr. Mass received his Ph.D. in atmospheric sciences from the University of Washington. Welcome.

Our third witness, Dr. Peter Neilley, is an IBM Distinguished Engineer, and Director of Weather Forecasting Sciences and Technologies for The Weather Company. He specializes in developing state-of-the-science technologies in weather forecasting for public use and weather-dependent markets. Dr. Neilley worked as a scientist at the National Center for Atmospheric Research, and the Chief Scientist at Weather Services International Corporation. Dr. Neilley recently served on NOAA's Science Advisory Board's Environmental Information Services Working Group. He was a longtime member and Chair of the American Meteorological Society's Committee on Weather and Forecasting. Dr. Neilley holds a master's degree and a Ph.D. in meteorology from MIT. Welcome.

Our final witness, Dr. Thomas Auligné, thank you, is the Director of the Joint Center for Satellite Data Assimilation, a research center based on a multi-agency partnership between NOAA, NASA (National Aeronautics and Space Administration), the U.S. Navy, and Air Force. He is responsible for the mission to accelerate and improve the quantitative use of satellite data in weather, ocean, climate, and environmental analysis and prediction systems. Dr. Auligné has held research positions at the National Center for Atmospheric Research, the European Center for Medium-Range Weather Forecasting, and Meteo-France. Dr. Auligné earned a master's in meteorology and a Ph.D. in atmospheric physics in France.

As our witnesses should know, you will each have 5 minutes for your spoken testimony. Your written testimony will be included in the record for the hearing. When you all have completed your spoken testimony, we will begin with questions. Each Member will have 5 minutes to question the panel. We will start with Dr. Jacobs.

TESTIMONY OF DR. 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. Good afternoon, Chairman Casten, Ranking Member Marshall, and Ranking Member Lucas. Thank you for the opportunity to testify at this hearing. NOAA is entrusted with the responsibility to provide environmental information and prediction to the public to enable informed decisions on a range of phenomenon spanning a broad spectrum of temporal and spatial scales. Part of NOAA's core mission is to protect lives and property, and to safeguard the national economy. With such an important task, it is imperative that NOAA provide accurate and timely weather information. We strive to produce the best weather forecast in the world, underpinned by cutting edge research, collaborative external partnerships, and thousands of dedicated scientists.

Following Hurricane Sandy, Congress provided supplemental funding for NOAA to take the first large step toward increasing computing capacity and improving its global forecast models. The desire to improve NOAA's weather mission culminated in congressional interest, and the passage of the *Weather Research and Forecasting Innovation Act of 2017*. This groundbreaking legislation contains a number of important directives for NOAA, including focusing transitioning research to operations, sub-seasonal and seasonal weather forecast improvement, and satellite data innovation.

Since coming to NOAA, implementing the *Weather Act* has been my top priority.

One section in the *Weather Act* I would like to draw attention to is the mandate to make NOAA's numerical weather prediction code publicly available. While NOAA complied with this directive in spirit, it has been unable to fully implement it. The existing version of the code is unique to NOAA computers. This means that, while the public would have access to the code, without access to NOAA's internal computers, they would not be able to actually run the model.

To solve this problem, NOAA needs a strategy to allow for greater accessibility by the public. To achieve this NOAA, will need to port its weather model code to commercial cloud, where it can be hosted by one or more providers. Making NOAA's model code available to the public will allow external world class scientists and researchers the opportunity to collaborate on new improvements, and this is a new way of thinking. Instead of keeping research and development inside of NOAA, the entire weather enterprise will be able to work with us to improve our modeling system, thereby accelerating advancements to our mission of protecting life and property. This strategy is the core principle of NOAA's new Earth Prediction Innovation Center.

Building on the tenets of the *Weather Act*, and recently authorized in the *National Integrated Drought Information System Reauthorization Act of 2018*, EPIC will serve as the core research to operations to research hub for building and maintaining a community modeling framework. EPIC's innovative structure will link scientists and software engineers in academia, the private sector, and partner agencies with research, development, and operational activities inside the agency. Doing so will help accelerate model improvements, enhancing NOAA's ability to provide accurate warnings of weather-based threats, and helping to re-establish the U.S. preeminence in numerical weather prediction.

Once integrated into the infrastructure of NOAA, EPIC will be used with the Unified Forecast System to improve the forecast skill of NOAA and other modeling initiatives, such as climate and ocean models. EPIC's public accessibility through highly scalable commercial cloud-based HPC (high-performance computing) architecture will enable external research partners to develop, test, and provide feedback on the American modeling system. Structured as a virtual center, EPIC will also manage model evaluation, source code, and user training. Where appropriate, NOAA will look to partner with other Federal agencies and academia to further this initiative.

The President's Fiscal Year 2020 budget proposed $15 million for EPIC. NOAA recognizes that importance of the EPIC program and has already started implementing several steps to plan for its future. Last month NOAA held an industry day to engage outside collaborators, ranging from universities to cloud vendors. NOAA has also issued a request for information on governance structure of the program itself, and has conducted extensive market research with external stakeholders. With adequate funding, NOAA looks forward to issuing a request for proposals, and moving forward with this critical program.

Chairman Casten, Ranking Member Marshall, Ranking Member Lucas, and Members of the Subcommittee, thank you again for inviting me to participate today, and I would be pleased to answer any questions you may have.

[The prepared statement of Dr. Jacobs follows:]

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

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

Earth Prediction Innovation Center

November 20, 2019

Good afternoon Chairwoman Fletcher, Ranking Member Marshall, and Members of the Subcommittee. Thank you for the opportunity to testify at this hearing. The National Oceanic and Atmospheric Administration (NOAA) is entrusted with the responsibility to provide environmental information and predictions to the public to enable informed decisions on a broad range of phenomena. Part of NOAA's core mission is to protect lives and property, and to safeguard the national economy. NOAA does this by issuing weather forecasts and warnings to American citizens every day.

With such an important task, it is imperative that NOAA provide accurate and timely weather information. We strive to produce the best weather forecast in the world, underpinned by cutting-edge research, collaborative external partnerships, and thousands of dedicated scientists. The quest to improve our ability to predict extreme weather events is ongoing.

Following Hurricane Sandy, Congress provided supplemental funding for NOAA to take its first large step towards increasing computing capacity and improving its global forecast models. Congress's desire to improve NOAA's weather mission culminated in the passage of the *Weather Research and Forecasting Innovation Act of 2017* (the Weather Act). This groundbreaking legislation contains a number of important directives for NOAA, including transitioning research to operations, sub-seasonal to seasonal weather forecast improvement, and satellite data innovation. Since starting at NOAA, implementing the Weather Act has been my top priority.

One section in the Weather Act that I would like to draw attention to is the mandate to create a community global weather research modeling system. While NOAA has complied with the letter of this directive by making the global weather modeling code available, we have been unable to fully honor the spirit of the statutory requirement. The existing version of this code was unique to NOAA computers. This means that while the public has access to the source code, without access to NOAA's internal computers, they encounter significant and time-consuming difficulties in actually running the model themselves.

To solve this problem, NOAA needed to rewrite millions of lines of code to run on non-NOAA computers that were publicly accessible. Likewise, NOAA needed a strategy to allow for greater accessibility by the public. To achieve this, NOAA will need to port its weather model code to the commercial cloud, where it can be hosted by one or more providers.

Making NOAA's model code available to the public will allow external world-class scientists and researchers the opportunity to collaborate on new improvements. This is a new way of thinking. Instead of keeping research and development inside of NOAA, the entire weather enterprise will be able to work with us to improve our modeling system, thereby accelerating advancements to our mission of protecting life and property. This strategy is the core principle of NOAA's new Earth Prediction Innovation Center (EPIC).

Building on the tenets of the Weather Act, and recently authorized in the National Integrated Drought Information System Reauthorization Act of 2018, EPIC will serve as the core research-to-operations-to-research hub for building and maintaining a community modeling framework. EPIC's innovative structure will link scientists and software engineers in academia, the private sector, and partner agencies with the research, development, and operational activities inside the agency. Doing so will help accelerate model improvement, enhancing NOAA's ability to provide accurate warnings of weather-based threats, and helping to re-establish the preeminence of U.S. operational forecast skill.

While EPIC is initially focused on making short and medium range weather forecast model code publicly available, other areas of NOAA will see benefits as well. Once integrated into the infrastructure of NOAA, which is currently anticipated to occur by Fiscal Year (FY) 2023, EPIC will be used with the Unified Forecast System to improve the forecast skill of NOAA's other modelling initiatives, such as climate and ocean models. NOAA's coastal ocean and wave models have been community-based for years and serve as a proof of concept for EPIC.

Public accessibility of model codes, data and supporting infrastructure through scalable, commercial cloud-based High-Performance Computing architecture will enable external research partners to develop, test and provide feedback on the American modeling system. This platform will support underlying research required to improve the model forecasts, especially of extreme events such as hurricanes, floods, tornadoes, winter storms, and wildfires.

To this end, at the White House Summit on Partnerships in Ocean Science and Technology on November 14, we announced the draft NOAA Cloud Strategy and released the draft for public comment. Structured as a virtual center, EPIC will also manage model evaluation, source code versions, and user training. Where appropriate, NOAA will also look to partner with other federal agencies and academia to further this initiative.

The President's FY20 Budget proposed $15.0 million for EPIC. NOAA recognizes the importance of the EPIC program and has already started implementing several steps to plan for its future. Last month, NOAA held an industry day to engage outside collaborators ranging from universities to commercial cloud vendors. NOAA has also issued a Request for Information (RFI) for the governance structure of the program, and has conducted extensive market research via the RFI, EPIC Community Workshop, and the Industry Day/Vendor Meetings. NOAA looks forward to the next step of issuing a Request for Proposals and the other integral activities that will advance this critical program.

Chairwoman Fletcher, Ranking Member Marshall, and Members of the Subcommittee, thank you again for inviting me to participate today. I would be pleased to answer any questions you may have about NOAA's EPIC program.

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.

Mr. CASTEN. Thank you. Dr. Mass, you're recognized.

TESTIMONY OF DR. CLIFFORD MASS, PROFESSOR OF ATMOSPHERIC SCIENCES, UNIVERSITY OF WASHINGTON

Dr. MASS. Thank you. Good afternoon, Chairman Casten, Ranking Member Marshall, Members of the Subcommittee. My name is Cliff Mass, and I am a Professor of Atmospheric Sciences at the University of Washington. The U.S. is behind in numerical weather prediction, and we are not catching up. NOAA's global model is either third or fourth in skill, behind the European Center, the U.K. Met Office, and often the Canadian model. The U.S. has the leading weather research community in the world, and our Nation invests heavily in weather prediction. We should be far ahead, consistent with the state of the science, but we are not, and our global model is not the only problem. U.S. weather prediction trails in other crucial aspects, including high-resolution ensembles, and model post-processing.

In 2012 the Nation became aware of the problem during Hurricane Sandy, and Congress responded with additional funds. Seven years later objective numbers show that we are not catching up, and the cost to the American people of the stagnation is huge. State of the science forecasting will save lives, greatly aid the U.S. economy, and serve as the first line of defense for severe weather. So why is the U.S. failing in this crucial arena? The causes are duplication of effort, poor organization, and lack of leadership, plus insufficient computer resources.

The enormous weather research resources of the United States are spread over too many modeling systems. NOAA has three groups working on such models, the Environmental Modeling Center, and NOAA's ESRL (Earth System Research Laboratory) and GFDL (Geophysical Fluid Dynamics Laboratory) labs. NASA and the Navy have both developed both global and regional models. The Air Force has acquired a foreign modeling system, and the National Center for Atmospheric Research, which encompasses the academic community, has developed another global modeling system, in addition to the well-known WRF (Weather Research and Forecasting) model.

The U.S. research community has mainly worked with NCAR's (National Center for Atmospheric Research's) weather models, and NOAA has used its own. They are not generally working together, and thus NOAA has been cut off from the innovations and energy of the U.S. academic community. Such a division of effort has undermined U.S. weather prediction, resulting in a large number of subcritical, inferior efforts. But there's more. NOAA has been starved for computer resources, crippling research and testing, and blocking the operational application of promising approaches. My analysis, supported by colleagues at NOAA, is that the National Weather Service could effectively use 100 times its current computer allocation.

All of these problems can be turned around quickly if our Nation reorganizes how we develop, test, and run numerical weather prediction models. And the key to it all is bringing resources and personnel together in one national effort. EPIC can be a big part of the solution. EPIC must become the center of U.S. model development and testing, and resources should be concentrated there. It must be a physical center located outside of NOAA, and serve all agencies and groups in the Nation.

EPIC needs resources, independence, autonomy, stability, and, most importantly, responsibility to deliver the best modeling system in the world. It must be an exciting center of discovery, science, and technology that will attract the best scientists, and our best students. EPIC needs sufficient computer resources for development and testing. It must entrain the efforts and capabilities of the U.S. research community, most importantly that of the National Center for Atmospheric Research. Finally, EPIC must develop and support a national community model that is freely available to the Nation. EPIC can easily fail if it is not given primary responsibility and resources to create the best weather prediction system in the world. It will fail if its goals are too narrow, or designated to serve a single agency.

Our nation was the first in numerical weather prediction, but we threw away leadership by dividing our efforts. It is time, through EPIC, to combine the national resources, and rationalize how we develop forecast models with extraordinary benefits to the American people. Thank you very much.

[The prepared statement of Dr. Mass follows:]

Professor Clifford F Mass
Department of Atmospheric Sciences
University of Washington

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

A Task of EPIC Proportions: Reclaiming U.S. Leadership in Weather Modeling and Prediction
November 20, 2019

Good afternoon Chairwoman Fletcher, Ranking Member Marshall, and Members of the Subcommittee. My name is Cliff Mass and I am a professor of atmospheric sciences at the University of Washington.

The U.S. is behind in numerical weather prediction and we are *not* catching up. NOAA's global model is either third or fourth in skill, behind the European Center, the UKMET office, and the often the Canadian model. The U.S. has the leading weather research community in the world, and our nation invests heavily in weather prediction. We should be far ahead. But we are not. And our global model is not the only problem: U.S. weather prediction capabilities trail in other crucial aspects, including high-resolution ensembles and model post-processing.

In 2012, the nation became aware of the problem during Hurricane Sandy, and Congress responded with additional funds. Seven years later, objective numbers show we are not catching up. And the cost to the American people of this stagnation is huge. State-of-the-science forecasting will save lives, greatly aid the U.S. economy and serve as the first line of defense for extreme weather.

So why is the U.S. failing in this crucial arena?

Duplication of effort, poor organization, and lack of leadership, plus a profound deficiency in computer resources.

The enormous resources of the U.S. are spread over too many modeling systems. NOAA has at least three groups working on such models: the NWS Environmental Modeling Center, and NOAA's ESRL and GFDL labs. NASA has developed a global model and its own version of the regional WRF model. The Navy has developed both global and regional models. The Air Force acquired a foreign weather modeling system, and the National Center for Atmospheric Research, which encompasses the academic community, has developed *another* global modeling system,, in addition to its well-known WRF model.

The U.S. research community has mainly worked with NCAR weather models and NOAA has used their own. They are not working together, and thus NOAA is cut off from the innovations and energy of the academic community.

Such division of effort has undermined U.S. weather prediction, resulting in a large number of subcritical, inferior efforts.

But there is more. NOAA has been starved for computer resources, crippling research and testing, and blocking the operational application of promising approaches. My analysis, supported by colleagues in NOAA, is that the NWS could effectively use at least 100 times its current computer allocation.

All of these problems could be turned around quickly if our nation would reorganize how we develop, test, and run numerical weather prediction models. And the centerpiece must be bringing resources and personnel together in one national effort.

EPIC can be a big part of the solution.

EPIC must become the center of U.S. model development and testing, and resources should be concentrated there.

It must be a physical center, located outside of NOAA, and serve all agencies and groups in the U.S. government.

EPIC needs resources, independence, autonomy, stability and, most importantly, responsibility to deliver the best weather modeling system in the world.

It must be an exciting center of discovery, science and technology, that will attract our best scientists.

EPIC needs sufficient computer resources for development and testing.

It must entrain the capabilities and efforts of the U.S. Research Community, including the National Center for Atmospheric Research. And the participation of the National Science Foundation is crucial.

Finally, EPIC must develop and support a national community model, freely available to the nation.

EPIC can easily fail if it not given the primary responsibility and resources for creating the best weather prediction system in the world. It will fail if its goals are too narrow or designed as a service organization for a single agency.

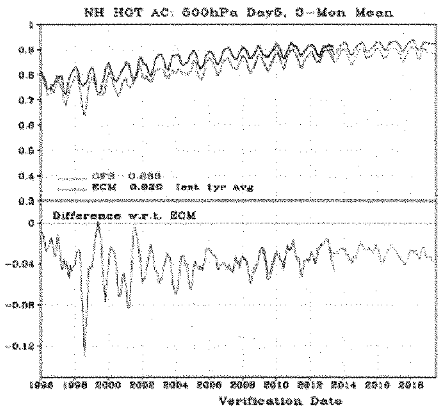
Our nation was the first in numerical weather prediction, but threw away leadership by dividing our efforts. It is time, through EPIC, to combine and rationalize how we develop our forecast models, with extraordinary benefits to the American people.

Cliff Mass Blog: August 2, 2019

EPIC: The Last Chance for National Weather Service Weather Modeling to Regain Leadership?

I have written at least a dozen blogs, a peer-reviewed paper, and given tens of conference talks on the unfortunate state of numerical weather prediction in the National Weather Service (which is part of NOAA the National Oceanographic and Atmospheric Administration).

The bottom line: U.S. global weather prediction is in third place in the world. The plot below shows a comparison of the skill of the 5-day model forecast for the U.S. (red line) and the European Center (black line) at a mid-tropospheric level (500 hPa). **We are not only behind, but we are not catching up.**



And more importantly than that, our weather prediction is substantially behind the state-of-the science. That means not providing warnings of severe weather as far ahead as we could. It means an economy that is not benefiting from the best weather guidance (such as agriculture and aircraft routing). There are real national costs to this.

I have explained the origin of the problems in previous blogs. They include:

1. Too many Federal agencies or government-supported labs trying to do the same thing (NOAA/NWS, Air Force, NASA, Navy, NCAR)
2. The academic community working on different models than used by NOAA/NWS.
3. Poor organization within NOAA, with multiple groups having responsibility for weather prediction.
4. Lack of strategic planning.
5. Lack of sufficient computer resources.
6. No priority for excellence.

It has been kind of depressing. The nation with a huge weather research capability and ability to zoom ahead of the pack, stuck in third rate status.

But there is a rare chance right now, the best in decades. The stars are aligned. And there is a critical meeting next week that might well decide which path the nation takes. **And it is all about EPIC.**

Why are the stars aligned?

1. The leadership of NOAA want to fix the problem.
2. The U.S. public and the U.S. Congress know there is a problem, with Congress even passing legislature (with funding) calling for major change.
3. The head of NOAA is a weather modeler (Neil Jacobs), as is the President's Science Advisor (Kelvin Drogemaier)
4. The private sector is demanding improvement.
5. THERE IS BIPARTISAN AGREEMENT ABOUT THIS.

Perhaps best of all, recent weather legislation calls for the development of national EPIC center, that would centralize U.S. efforts to build the best global forecast models in the world. (EPIC stands for Environmental Prediction Innovation Center).

Next week there is going to be a meeting on the nature of the EPIC that will take place in Boulder, Colorado. **An absolutely crucial gathering**--I will be giving a talk there and are part of the organizing committee.

Will self-interest, disciplinary fiefdoms, and legacy administrative structures give way to rational, more effective approach for developing U.S. weather modeling systems? We may know the answer in one week.

And this may be the last chance for NOAA. Private sector companies are in the wing that will take on global weather prediction if NOAA fails to advance to first tier. Not Space-X but Weather-X. And the U.S. Air Force already abandoned the U.S. modeling system for a non-American model (UKMET Office Unified Model). When the U.S. military gives up the American model, you know you have a problem. I will let all of you know what happens.

Wednesday, April 17, 2019

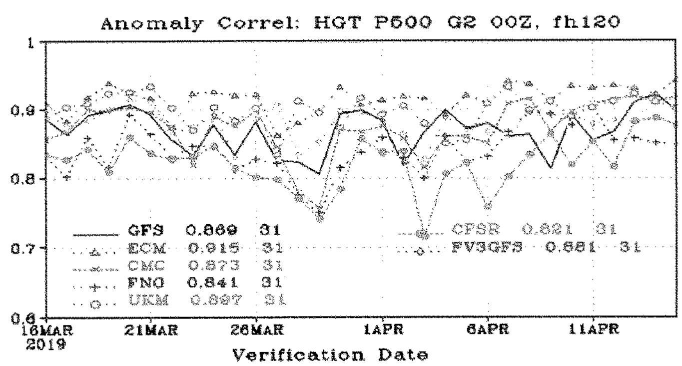
U.S. Numerical Weather Prediction: Darkest Before the Dawn?

U.S. operational weather prediction is undergoing a rough patch right now, with a new global modeling system that is proving not quite ready for prime time.

But there is reason for hope. A combination of new leadership and reorganization may turn things around during the next few years. The old saying, *it is darkest before the dawn*, may well prove true for operational numerical weather prediction in NOAA and the National Weather Service.

As I have described in many previous blogs, the U.S. is lagging behind in operational global weather prediction. Today and for many years, the U.S. global modeling system, the NOAA/ NWS GFS (Global Forecast System) model has trailed behind the world leader, the European Center Model, and is consistently less skillful than the UKMET office model run by the British. We are usually tied for third with the Canadian Model (CMC). And we lag behind the others even though the U.S. has the largest meteorological research community in the world.

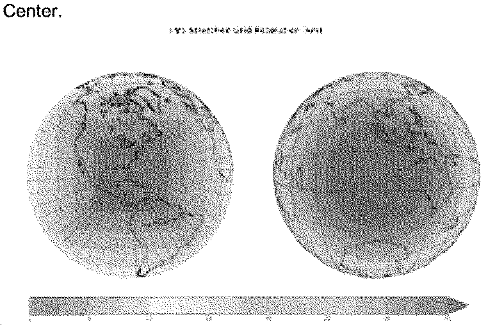
To illustrate the problems, here are the latest comparative statistics (anomaly correlations!) for the global skill of the 5-day forecast at 500 hPa (about 18,000 ft up) for a variety of models. 1 represents a perfect forecast. **The best forecast is the European Center (average of .915)**, next is the UKMET office (the British folks with a .897), third is the Canadians (CMC, .773), and **FOURTH is the U.S. GFS (.869).**



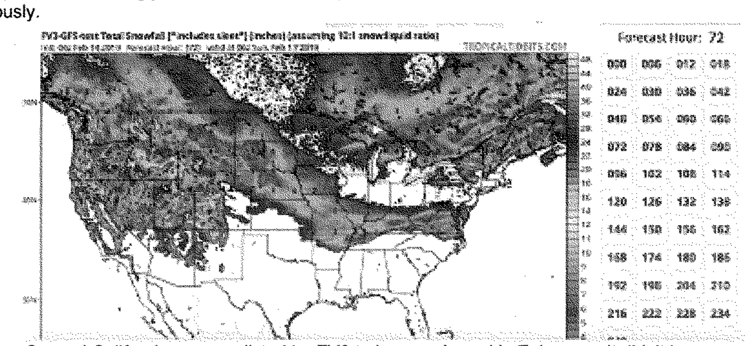
It is no secret why the GFS is behind: an old model, inferior data assimilation and use of observational assets, and relatively primitive model physics (e.g., how cloud processes, thunderstorms, turbulence, etc. are described). Inadequate computer resources contributed as well. *Data assimilation* is the step in which a wide variety of observational data is quality controlled and used to create a physically realistic three-dimensional description of the state of the atmosphere. The European Center does a very good job at this.

The inferiority of the U.S. global model has gotten a lot of press the last 6 years, particularly after the GFS showed itself to be clearly less skillful than the European Model for Hurricane Sandy. The hue and cry in the media resulted in a computer upgrade for the National Weather Service and the acquisition of a new global model, the NOAA Geophysical Fluid Dynamics Lab (GFDL) FV3. This new model has been running in parallel for nearly a year now.

But there are problems with the new FV3. The FV3's verification scores are only slightly better than GFS, something shown in the statistics above (FV3 was at .881, **in third place**). Part of the problem is that the FV3 is using the same data assimilation system as GFS, which is not as advanced as the one used by the European Center.



But there is something else: during the cold period of the past winter, the FV3 was predicting crazy, excessive snow amounts. And more detailed verification indicated that the FV3 was too cold in the lower atmosphere. Disturbingly, the NWS evaluation protocols were not able to delineate the problems previously.



Coastal California was predicted by FV3 to be snowbound in February, It didn't happen.

The FV3 was supposed to go operational in January, but was delayed until February because of the government shut-down. Then the snow/cold problem was revealed. According to my contacts in NOAA, they have found some, but not all, of the problems. **At this point, the operational implementation has been delayed indefinitely into the future.**

In some ways, this is NOAA's version of the Boeing Max disaster --in the hope of beating the competition, a software system was rushed into operations without sufficient testing and evaluation.

Another major problem? It appears that there aren't enough people inside the National Weather Service (NWS) who actually understand the new FV3 model.

FV3 was developed outside the NWS by a team under a very capable weather modeler, S. J. Linn, of the NOAA Geophysical Fluid Dynamics Lab. In essence, the model was "thrown over the fence" to the Environmental Modeling Center (EMC) of the NWS and few people there actually understand FV3 in any depth. About 3, according to my sources. S. J. Linn has recently moved back to Taiwan and is no longer available.

In addition to lacking depth of knowledge about the core FV3 modeling system, the NWS does not have much of an effort to improve the physics of the FV3, such as the microphysics that describes how clouds and precipitation processes work in the atmosphere. Physics is one of the key deficiencies of the U.S. models. And the data assimilation system was simply moved over from the inferior GFS.

But the situation is even worse than that. FV3 was supposed to be a *community modeling system*, one that could easily be run outside of the National Weather Service, including the universities and private sector. Having others use the model is essential: instead of only a handful of folks inside the NWS working on and testing the model, you get hundreds or thousands doing so. You end up with a much better prediction system that way.

MPAS
Model for Prediction Across Scales

FV3: Finite-Volume Cubed-Sphere Dynamical Core

But the NWS has put virtually no effort and resources into making FV3 a community modeling system, TWO YEARS after making the decision to use it. I have tried myself to use the latest release. There is no support, no tutorials, no help desk. Nothing. The code release is incomplete and poorly documented. The model code is hardwired for NOAA computers and some of my department's most accomplished IT people can't get it to run. Not good.

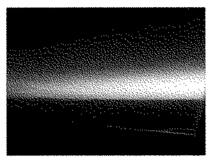
THE GOVERNMENT'S NEW WEATHER MODEL FACES A STORM OF PROTEST

In contrast, the major U.S. competition to FV3, the NCAR MPAS (NCAR is a consortium of many of the atmospheric sciences departments in the U.S.), is easy to run and has lots of support. One of my students got going on it in days.

The bottom line in all this is that the U.S. move to improved global prediction using FV3 is not going well.

The NWS has made the right move to hold off on implementation until FV3 is at least as good as the old GFS, considering the critical role the U.S. global model plays in American weather prediction.

But the dawn still beckons...



Things are pretty dark for U.S. global prediction right now. But there are some reasons for optimism.

First, the FV-3 is a better designed and more modern weather modeling system than the old GFS, including being more amendable to running on large numbers of processors. It can be the basis for improvement.

Second, NOAA/NWS leadership accepts there are problems and wants to fix it.

Of particular importance is that the key person responsible for U.S. operational prediction and observation, the Assistant Secretary of Commerce for Environmental Observation and Prediction and acting NOAA administrator, is Dr. Neal Jacobs, an extremely capable and experienced weather modeler, who led the successful effort at Panasonic before moving to NOAA. Dr. Jacobs knows the issues and wants to deal with them. Furthermore, there is a relatively new and highly capable head of the NOAA/NWS Environmental Modeling Center (where U.S. operational weather prediction takes place), Dr. Brian Gross.

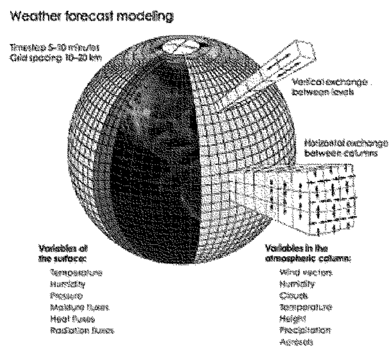
Dr. Neil Jacobs is now acting Administrator of NOAA

Add to that the new Presidential Science Adviser is Dr. Kelvin Droegemeier, an expert in high-resolution numerical weather prediction from the University of Oklahoma.

And consider that the U.S. Congress knows about the problem and has passed two pieces of legislation, the Weather Research and Forecasting Innovation Act of 2017 and National Integrated Drought Information System Reauthorization Act of 2018, that highlights problems with U.S. weather prediction and provides some needed resources. Another positive is that leaders of the NOAA Earth Systems Research Lab (ESRL), a group responsible for development of new U.S. models, are now committed to working closely with the NWS operational folks. Five years ago this was not the case.

So we have extremely capable leadership in NOAA who want to fix the problem and a Congress who wants to help. That is good--but it is not enough.

Now we come to the real problem, and why I am for the first time in years really optimistic.



The key problem with U.S. operational numerical weather prediction has never been resources, it has always been about organization. About too many groups, with too much resource, working on similar projects in an uncoordinated way. Furthermore, the universities and the Federal government have rarely worked together effectively.

But this may all be changing. NOAA leadership, with support from Congress, is about to set up an entity that will be the central development center of U.S. numerical weather prediction.

This center is called EPIC (Environmental Prediction Innovation Center) and would combine the efforts of both NOAA and the universities (NCAR). Done correctly, EPIC could lead to a much more effective and coordinated approach to developing a new U.S. global modeling capability. A modular, unified national modeling system shared between government, academia, and the private sector.

Will the U.S. FINALLY organize itself properly to regain leadership in global numerical weather prediction? Time will tell. But I am more optimistic today than I have been in years.

Tuesday, April 21, 2015

The U.S. Air Force Turns to a Foreign Weather Forecasting System

The United States Air Force has decided to drop its American weather prediction system (the Weather Research and Forecasting model, WRF) for the forecasting system developed by the United Kingdom (UKMET Office Unified Model).

As described below, this decision is a terrible mistake and will ensure substantial damage to U.S. weather prediction capability, waste precious financial resources, and undermine the U.S. Air Force's capacity to provide the best possible forecasts for U.S. pilots and Air Force operations.

This blog will tell you about this unfortunate situation, document a flawed decision-making process, describe the downside of this decision, and call for better-informed public officials and legislators to intervene.

The current situation

Today, the US Air Force makes regional forecasts around the world using the WRF model. WRF is an extraordinary success story; developed at the National Center For Atmospheric Research (NCAR) in Boulder, Colorado, WRF is used by thousands of users in the U.S., and is the predominant model used in the research community and the private sector. WRF is also heavily used by the National Weather Service and by many thousands of individuals, groups, and weather forecast entities around the world. WRF is probably the best example of a community model: highly flexible, state of the art, adaptive, with advances from the research community flowing into the effort, resulting in constant improvement.

During the mid-2000s, the AF took on WRF as their main regional modeling tool, using the U.S. global GFS (Global Forecasting System) model for their global predictions. The global model is used to provide boundary conditions for the regional model (WRF).

The AF adoption of WRF was a win-win for the nation. AF funding contributed to maintaining and improving WRF; in fact, the AF was the largest financial supporter of WRF. The AF in turn had the best possible regional model, one that was easy to use and highly capable, and a model that took advantage of the efforts of the vast U.S. weather research community. An improved WRF helped drive U.S. weather modeling research and was taken on by many private sector firms. The U.S. was clearly the world leader in this domain.

The Air Force fumbles

Late last year it became known the Air Force Weather Agency, which runs AF numerical forecast models, had decided to drop WRF and NOAA's GFS model, and turn to a foreign modeling system: the UKMET office model. A recent story in the Washington Post discussed this decision. This decision was made **without talking to U.S. national weather modeling partners (the National Weather Service and the U.S. Navy)** and appears to be the decision of one individual, Ralph Stoffler, acting head of the Air Force Weather Agency. Mr. Stoffler was an AF weather officer and has a BS in meteorology.

Ralph Stoffler

Checking with my contacts in the Air Force, I have learned that there were no long-term verification/comparison runs to demonstrate that the the UKMET office model would be superior to WRF. It is stunning that such a major decision would be taken without strong evidence of improvement.

Mr. Stoffler's plan greatly expands AF modeling into the global arena, moving to DUPLICATE the U.S. global prediction efforts completed by the National Weather Service and the U.S. Navy's Fleet Numerical Meteorology and Oceanography Center. There has always been an unfortunate relationship between Navy and Air Force weather operations, with substantial duplication of efforts. But the new AF plan goes beyond this and is **highly wasteful of U.S. weather prediction resources**.

The Met.Office

To run a state-of-the-art global model requires large resources, including the acquisition and quality control of vast amounts of data from many different satellites. A high-resolution global model also demands huge computer resources. Clearly, Mr. Stoffler has not considered these issues in depth before proposing his new approach.

Let me underline the fact that there is no evidence that the UKMET office model is a superior regional model. WRF has far more physics options and is much more widely tested at high resolution around the world. UKMET Office global forecasts have slightly better verification scores in the Northern Hemisphere that the NOAA GFS, but these differences are small. Furthermore, the NOAA GFS model is now undergoing rapid improvements (made possible by the new supercomputers NOAA is getting this year) and I suspect that by the end of 2016, the GFS will be as good, if not better, than UKMET. Thus, the AF could well end up with an inferior global forecast.

But it is worse than that. The UKMET office model is known to be difficult and unwieldy to use, and there will be a hugely expensive spin up at the AF to run this model and connect it to their production suite of products. Resource demands in running a state of the science global model are huge. And as I have described in previous blogs, the U.S. has TOO MANY models running, resulting in division of effort and waste. The AF is taking the wrong road.

But let's be honest here. This situation is a warning to the National Weather Service and the U.S. weather modeling efforts---if the U.S. Air Force is making plans to use overseas modeling systems, this is not a good sign.

Major Impacts on WRF

Air Force funding has been critical for the viability of the national regional weather forecast system (WRF), the one used here at the University of Washington, by the way. The AF has been the main Federal financial supporter of WRF. The loss of AF funding will greatly undermine WRF and its future development (including the revolutionary global MPAS model that would be its successor). WRF is the model used in many key forecasting systems in the U.S., such as the National Weather Service High Resolution Rapid Refresh system. The economic and scientific impacts of the AF action would be large and damaging to the U.S. weather prediction enterprise.

What needs to be done

The U.S. meteorological community and others need to speak loudly to Air Force management, the current administration, Congress, and others to stop this ill-advised AF action. The damage to the U.S. weather prediction capacity and AF weather prediction will be substantial if the proposed plan is followed. There is time to turn this around and restore a rational approach to weather prediction modeling the in the Air Force. Here in Washington State, I hope our Senators, Patty Murray and Maria Cantwell, will intervene.

Sunday, March 18, 2012

The U.S. Has Fallen Behind in Numerical Weather Prediction: Part I

Part II found here.

It's a national embarrassment. It has resulted in large unnecessary costs for the U.S. economy and needless endangerment of our citizens. *And it shouldn't be occurring.*

What am I talking about? **The third rate status of numerical weather prediction in the U.S.** It is a huge story, an important story, but one the media has not touched, probably from lack of familiarity with a highly technical subject. And the truth has been buried or unavailable to those not intimately involved in the U.S. weather prediction enterprise. This is an issue I have mentioned briefly in previous blogs, and one many of you have asked to learn more about. It's time to discuss it.

Weather forecasting today is dependent on numerical weather prediction, the numerical solution of the equations that describe the atmosphere. The technology of weather prediction has improved dramatically during the past decades as faster computers, better models, and much more data (mainly satellites) have become available.

U.S. numerical weather prediction has fallen to third or fourth place worldwide, with the clear leader in global numerical weather prediction (NWP) being the European Center for Medium Range Weather Forecasting (ECMWF). And we have also fallen behind in ensembles (using many models to give probabilistic prediction) and high-resolution operational forecasting. We used to be the world leader decades ago in numerical weather prediction: NWP began and was perfected here in the U.S. Ironically, we have the largest weather research community in the world and the largest collection of universities doing cutting-edge NWP research (like the University of Washington!). Something is very, very wrong and I will talk about some of the issues here. And our nation needs to fix it.

But to understand the problem, you have to understand the competition and the players. And let me apologize upfront for the acronyms.

In the U.S., numerical weather prediction mainly takes place at the National Weather Service's Environmental Modeling Center (**EMC**), a part of **NCEP** (National Centers for Environmental Prediction). They run a global model (**GFS**) and regional models (e.g., **NAM**).

The Europeans banded together decades ago to form the European Center for Medium-Range Forecasting

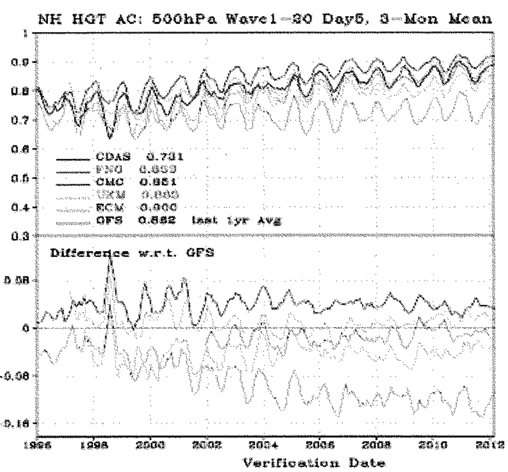
(ECMWF), which runs a very good global model. Several European countries run regional models as well.

The United Kingdom Met Office (**UKMET**) runs an excellent global model and regional models. So does the Canadian Meteorological Center (**CMC**).

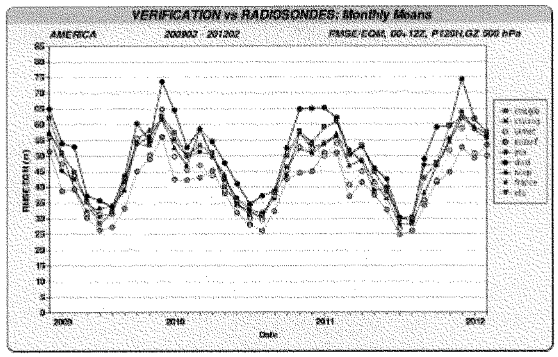
There are other major global NWP centers such as the Japanese Meteorological Agency (**JMA**), the U.S. Navy (**FNMOC**), the Australian center, one in Beijing, among others. All of these centers collect worldwide data and do global NWP.

The problem is that both objective and subjective comparisons indicate that the U.S. global model is number 3 or number 4 in quality, resulting in our forecasts being noticeably inferior to the competition. Let me show you a rather technical graph (produced by the NWS) that illustrates this. This figure shows the quality of the 500hPa forecast (about halfway up in the troposphere--approximately 18,000 ft) for the day 5 forecast. The top graph is a measure of forecast skill (closer to 1 is better) from 1996 to 2012 for several models (U.S.--black, GFS; ECMWF-red, Canadian: CMC-blue, UKMET: green, Navy: FNG, orange). The bottom graph shows the difference between the U.S. and other nation's model skill.

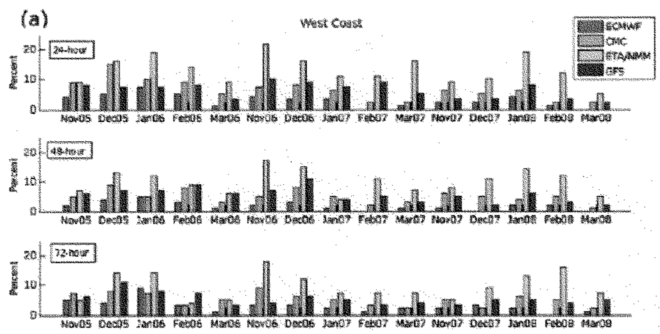
You first notice that forecasts are all getting better. That's good. But you will notice that the most skillful forecast (closest to one) is clearly the red one...the European Center. The second best is the UKMET office. The U.S. (GFS model) is third...roughly tied with the Canadians.



Here is a global model comparison done by the Canadian Meteorological Center, for various global models from 2009-2012 for the 120 h forecast. This is a plot of error (RMSE, root mean square error) again for 500 hPa, and only for North America. Guess who is best again (lowest error)?--the European Center (green circle). UKMET is next best, and the U.S. (NCEP, blue triangle) is back in the pack.



Lets looks at short-term errors. Here is a plot from a paper by Garrett Wedam, Lynn McMurdie and myself comparing various models at 24, 48, and 72 hr for sea level pressure along the West Coast. Bigger bar means more error. Guess who has the lowest errors by far? You guessed it, ECMWF.



I could show you a hundred of these plots, but the answers are very consistent. ECMWF is the worldwide gold standard in global prediction, with the British (UKMET) second. We are third or fourth (with the Canadians). One way to describe this, is that the ECWMF model is not only better at the short range, but has about one day of additional predictability: their 8 day forecast is about as skillful as our 7 day forecast. Another way to look at it is that with the current upward trend in skill they are 5-7 years ahead of the U.S.

Most forecasters understand the frequent superiority of the ECMWF model. If you read the NWS forecast discussion, which is available online, you will frequently read how they often depend not on the U.S. model, but the ECMWF. And during the January western WA snowstorm, it was the ECMWF model that first indicated the correct solution. Recently, I talked to the CEO of a weather/climate related firm that was moving up to Seattle. I asked them what model they were using: the U.S. GFS? He laughed, of course not...they were using the ECMWF.

A lot of U.S. firms are using the ECMWF and this is very costly, because the Europeans charge a lot to gain access to their gridded forecasts (hundreds of thousands of dollars per year). Can you imagine how many millions of dollars are being spent by U.S. companies to secure ECMWF predictions? But the cost of the inferior NWS forecasts are far greater than that, because many users cannot afford the ECMWF grids and the NWS uses their global predictions to drive the higher-resolution regional models--which are NOT duplicated by the Europeans. All of U.S. NWP is dragged down by these second-rate forecasts and the costs for the nation has to be huge, since so much of our economy is weather sensitive. Inferior NWP must be costing billions of dollars, perhaps many billions.

The question all of you must be wondering is why this bad situation exists. How did the most technologically advanced country in the world, with the largest atmospheric sciences community, end up with third-rate global weather forecasts? I believe I can tell you...in fact, I have been working on this issue for several decades (with little to show for it). Some reasons:

1. The U.S. has inadequate computer power available for numerical weather prediction. The ECMWF is running models with substantially higher resolution than ours because they have more resources available for NWP. This is simply ridiculous--the U.S. can afford the processors and disk space it would take. We are talking about millions or tens of millions of dollars at most to have the hardware we need. A part of the problem has been NWS procurement, that is not forward-leaning, using heavy metal IBM machines at very high costs.

2. The U.S. has used inferior data assimilation. A key aspect of NWP is to assimilate the observations to create a good description of the atmosphere. The European Center, the UKMET Office, and the Canadians using 4DVAR, an advanced approach that requires lots of computer power. We used an older, inferior approach (3DVAR). The Europeans have been using 4DVAR for 20 years! Right now, the U.S. is working on another advanced approach (ensemble-based data assimilation), but it is not operational yet.

3. **The NWS numerical weather prediction effort has been isolated and has not taken advantage of the research community.** NCEP's Environmental Modeling Center (EMC) is well known for its isolation and "not invented here" attitude. While the European Center has lots of visitors and workshops, such things are a rarity at EMC. Interactions with the university community have been limited and EMC has been reluctant to use the models and approaches developed by the U.S. research community. (True story: some of the advances in probabilistic weather prediction at the UW has been adopted by the Canadians, while the NWS had little interest). The National Weather Service has invested very little in extramural research and when their budget is under pressure, university research is the first thing they reduce. And the U.S. NWP center has been housed in a decaying building outside of D.C.,one too small for their needs as well. (Good news... a new building should be available soon).

4. **The NWS approach to weather related research has been ineffective and divided.** The governmnent weather research is NOT in the NWS, but rather in NOAA. Thus, the head of the NWS and his leadership team do not have authority over folks doing research in support of his mission. This has been an extraordinarily ineffective and wasteful system, with the NOAA research teams doing work that often has a marginal benefit for the NWS.

5. Lack of leadership. This is the key issue. The folks in NCEP, NWS, and NOAA leadership have been willing to accept third-class status, providing lots of excuses, but not making the fundamental changes in organization and priority that could deal with the problem. Lack of resources for NWP is another issue...but that is a decision made by NOAA/NWS/Dept of Commerce leadership.

This note is getting long, so I will wait to talk about the other problems in the NWS weather modeling efforts, such as our very poor ensemble (probabilistic) prediction systems. One could write a paper on this...and I may.

I should stress that I am not alone in saying these things. A blue-ribbon panel did a review of NCEP in 2009 and came to similar conclusions (found here). And these issues are frequently noted at conferences, workshops, and meetings.

Let me note that the above is about the modeling aspects of the NWS, NOT the many people in the local forecast offices. This part of the NWS is first-rate. They suffer from inferior U.S. guidance and fortunately have access to the ECMWF global forecasts. And there are some very good people at NCEP that have lacked the resources required and suitable organization necessary to push forward effectively.

This problem at the National Weather Service is not a weather prediction problem alone, but an example of a deeper national malaise. It is related to other U.S. issues, like our inferior K-12 education system. Our nation, gaining world leadership in almost all areas, became smug, self-satisfied, and a bit lazy. We lost the impetus to be the best. We were satisfied to coast. And this attitude must end...in weather prediction, education, and everything else... or we will see our nation sink into mediocrity.

The U.S. can reclaim leadership in weather prediction, but I am not hopeful that things will change quickly without pressure from outside of the NWS. The various weather user communities and our congressional representatives must deliver a strong message to the NWS that enough is enough, that the time for accepting mediocrity is over. And the Weather Service requires the resources to be first rate, something it does not have at this point.

Part II will discuss the problems with ensemble and high-resolution numerical weather prediction in the U.S.

U.S. Numerical Weather Prediction is Falling Further Behind: What is Wrong and How Can It Be Fixed Quickly?

Updated (see addition at the end)

It is a disappointing. The U.S. has the largest meteorological community in the world and led the development of numerical weather prediction for decades. The National Weather Service, stung by its relatively poor performance on Hurricane Sandy and publicity about inferior computers, was given tens of millions of dollars to purchase a world-class weather prediction system and to support forecast model development.

But the latest forecast statistics reveal an unfortunate truth: **U.S. operational weather prediction, located in NOAA's National Weather Service (NWS), is progressively falling behind the leaders in the field.** Even worse, a private sector firm, *using the National Weather Service's own global model*, is producing superior forecasts.

Something is very wrong and this blog will analyze why NWS global models are losing the race and **what can be done to turn this around**. As I will show, this situation could be greatly improved within a year, but to do so will require leadership, innovation, and a willingness to partner with others in new ways. I will also highlight a critical NOAA/NWS decision that will be made in the next several weeks, one that will decide the future of US weather forecasting for decades.

The Problem

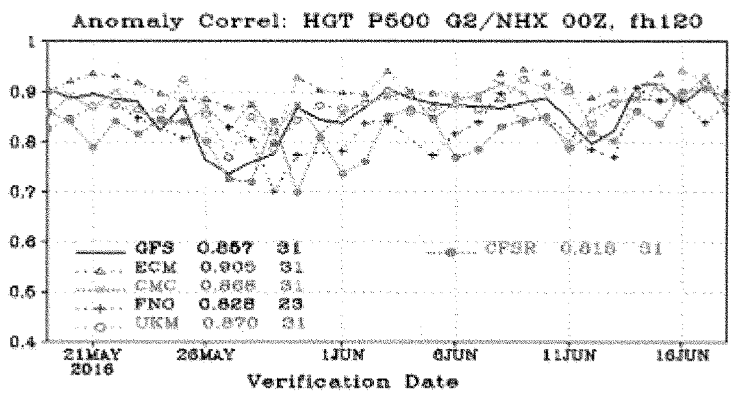
A number of media reports and several of my blogs have described the fact that U.S. numerical weather prediction (NWP) has fallen behind other nations and is a shadow of what this nation is capable of. **Global NWP is the foundation of all weather forecasts**, so it is critical to get this right. As we will see, it is not that U.S. global NWP is getting less skillful, but that other nations are innovating and pushing ahead faster.

For most of the last few years, U.S. operational global weather prediction, completed at the National Weather Service's Environmental Modeling Center (EMC) of NCEP (National Centers for Environmental Prediction), has been in third place: behind the world leader **ECMWF** (European Center For Medium Range Weather Forecasting) and the **UKMET** Office (the Brits). During the past several months, we have fallen further behind ECMWF and, to add insult to injury, the Canadians (the Canadian

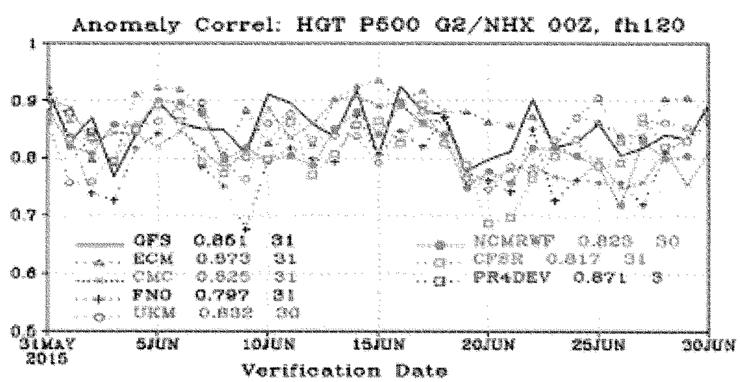
Meteorological Center, **CMC**) have moved ahead of us as well. US global weather prediction **is now in fourth place**, with substantial negative implications for our country. Let me demonstrate this to you.

One measure of forecast skill is *anomaly correlation (AC)*, a measure of how well a forecast matches observations (it ranges up to 1, the best). Below is the AC for the Northern Hemisphere for the day 5 forecast, evaluated at the mid-troposphere (500 hPa, around 18,000 ft).

The ECMWF is the best (red triangles), with the UKM (yellow) second best. Black is the US global model (**GFS**). Note that the US GFS not only has generally lower skill, but sometimes has serious **dropouts**, periods of MUCH worse skill. The legend has summary numbers for the period, showing that the GFS is in fourth place, and the Canadians in third place (light green). These statistics are from a NOAA/NWS website.



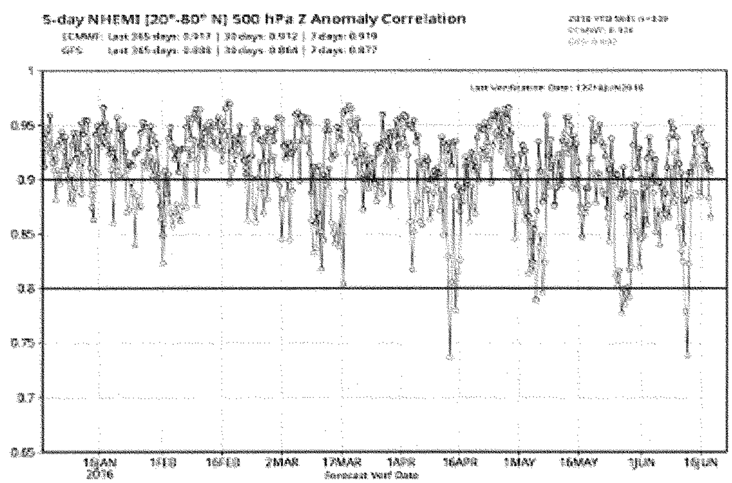
Let's compare this to the situation a year ago. Last June's statistics for the 5-day, Northern Hemisphere forecasts are shown below. We were ahead of the Canadians then. Look closely and you will see that difference between the US and ECWMF was less. I could show you many more plots like this that demonstrates that the US has fallen behind the leaders in global weather modeling.



During the past few months both the US and ECMWF upgraded their global models, but clearly the ECMWF upgrade was more effective, with ECMWF pulling further ahead.

A more detailed comparison (from WeatherBell analytics) of the US and ECWMF performance for 2016 is shown below (still 5 day forecast at 500 hPa) using the same verification measure (anomaly correlation).

ECMWF (blue color) is better nearly every day. Importantly, the ECWMF forecast is much more consistent, without the frequent (and substantial) drop outs of the US GFS. The U.S. (red colors) frequently declines to .8 or below, indicating of periods of large declines in skill. These are serious failure periods.



The bottom line is that Europeans and Canadians are pulling ahead of the U.S. National Weather Service in global weather prediction. I have a LOT more statistics to back this up if anyone has any doubts.

But it is worse than that. A private sector firm, Panasonic, has gone into the global weather prediction business **using the US global model (GFS) as a starting point**. Panasonic scientists have worked on fixing some of the obvious weaknesses in the U.S. modeling system and report they *have dramatically improved the forecasts over National Weather Service performance* (GFS model). They claim that their forecasts are not only better than the official US GFS model, but nearly equal to that of the vaunted ECMWF.

TV maker Panasonic says it has developed the world's best weather model

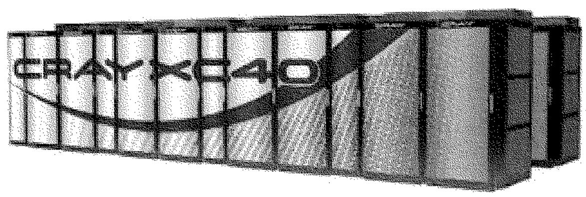
The company says it has beaten the GFS for a while and now equals the ECMWF.

I have talked to the chief scientist at Panasonic, Neil Jacobs, and he has shared some of the verification statistics, which look good. I told him the only way to prove that they have the world's best global model would be to share the forecasts and let a neutral third party verify them. He agreed to do so, including sharing the forecasts with the University of Washington. I doubt he would do that if their forecasts weren't as skillful as they claim.

Even worse? The US Air Force has abandoned the US GFS model, saying that it was inferior to the UKMET office model, which the AF will switch to.

So the National Weather Service's global model is falling behind international leaders AND a private sector firm starting with the same NWS model. Even the US military is abandoning it. Can it get any worse?

It can. The U.S. Congress gave the National Weather Service tens of millions of dollars for superb new computers, two CRAY XC-40s: one used for operations, and the other for development and backup. Unfortunately, the operational computer is only being lightly used, with its vast capacity not being applied effectively to make critically needed improvements in U.S. NWP.

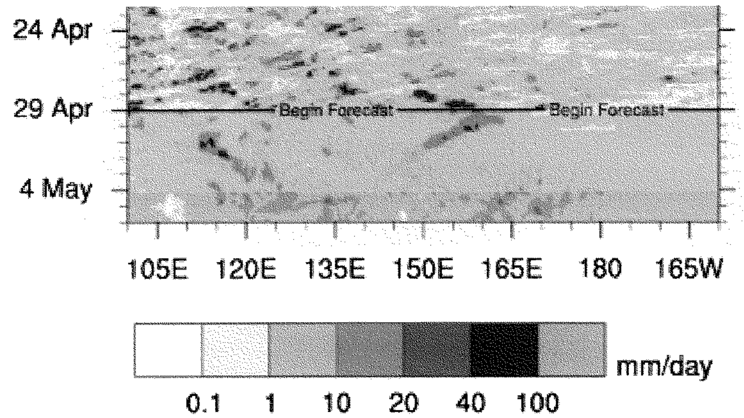


Key Deficiencies in U.S. Global Modeling

So why is US operational global weather prediction falling behind the leaders? Some of the problems with U.S. global weather predictions are well known and the essential "fixes" effected by Panasonic are no secret (and Panasonic should be commended for letting the community know what they are doing). To list only a few:

1. **The National Weather Service GFS has starkly inferior physics**, which means the descriptions of essential physical processes in the atmosphere. For example, the GFS model is using a primitive, two-decades old *microphysics scheme* (the software describing how clouds and precipitation work). As a result, there are serious errors in precipitation amounts and clouds, which in turn influences the evolution of the forecasts.

They are also using a very old and primitive *cumulus parameterization*, which describes the impacts of cumulus clouds and thunderstorms (called *convection*).
This results in poor prediction of convection, including critical features in the tropics (like the **Madden Julian Oscillation, MJO**), which in turn undermines extended range forecasts.



A plot of precipitation rate versus time and longitude for a portion of the western tropical Pacific (5N to 5S) for a two week period in April to early May 2016. Above the line are observations, and below the line is the US GFS model. Note how the character of the precipitation radically changes after the switch to the model. The model is doing a very poor job forecasting the character, amplitude, and movement of convection in the tropics. The ECMWF model is far better because they use a better cumulus parameterization (image courtesy of Michael Ventrice, the Weather Company, and University of Albany).

Importantly, the National Weather Service has few people working on model physics **and no strategic plan how to improve it.** Other centers (like ECMWF) have put great emphasis on physics and substantial scientific resources. Furthermore, the NWS has not entrained the expertise of the large US research community to help.

2. **The National Weather Service has less model resolution that its competitors.** The high-resolution ECMWF model has a grid spacing of 9 km compared to the 13 km used by the US GFS. More importantly, the ECMWF global ensemble system has TWICE the resolution of the American system (18 km grid spacing for ECMWF, 35 km for the US GFS). Ensemble systems play a critical role in data assimilation and probabilistic prediction. Considering the new computers acquired by the National Weather Service, this *resolution gap* is inexcusable.

ECMWF
EUROPEAN CENTRE FOR MEDIUM RANGE WEATHER FORECASTS

3. The ECMWF, UKMET Office, and Panasonic have far superior **quality control** of observations. Quality control reduces the amount of bad data used in the forecast processes.

4. ECMWF, UKMET, and the Canadians use a superior *data assimilation* system called 4DVAR. Data assimilation uses observations and the model to produce the best possible initial state (the *initialization*) for the forecast. Better initial states produce better forecasts. ECWMF has been using 4DVAR since 1997.

5. The other leading weather modeling centers use a greater range and volume of observations in their data assimilation systems. ECWMF, for example, has applied a far greater range of satellite observations

than the US, and Panasonic has great volumes of aircraft data (called *TAMDAR*), that the National Weather Service has been unwilling to purchase.

6. The other major weather forecasting centers have detailed strategic plans and visions of their future directions. The National Weather Service has no real strategic plan for global weather prediction. Or any weather prediction. Recently, they began a process to acquire their next generation global model (called NGGPS, Next Generation Global Prediction System), something I will talk more about below.

TAMDAR data on short-haul aircraft, collected by Panasonic, can enhance the quality of forecasts.

7. Other major centers have entrained the help of the research community in an effective way. The National Weather Service, until very recently, was isolated and had a go-it-alone attitude towards global weather prediction. Even today, they have no rational, organized way to encourage and reap the benefits of academic community research. Trust me, this is something I know about.

8. Until last year, the National Weather Service had starkly inferior computing resources compared to ECMWF, UKMET, and other major centers. It provided an excuse for NWS prediction being second rate. Today, the National Weather Service has first class computing and Congress wants to keep it that way. So that excuse is gone. The National Weather Service has the computing power to push forward rapidly and innovate, if it has the will to do so.

The Big Decision: The New NWS Global Model--MPAS or FV3?

The National Weather Service is about to make a critical decision regarding the replacement of its out-of-date GFS global weather prediction model. And this decision is a huge one, deciding the fate of US global weather prediction for the next several decades.

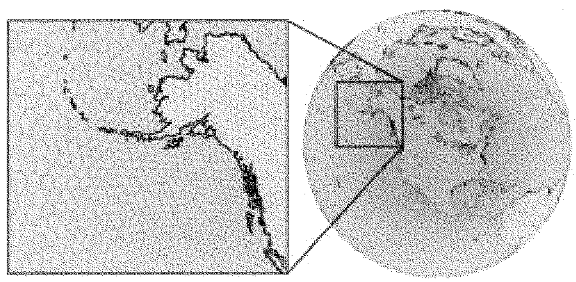
As noted above, this decision is part of a process called **NGGPS** and has been an attempt to rationally decide on the guts of the next US global model, something called its *dynamical core*. After testing a number of candidates, the choice is down to two.

The first is the MPAS model, developed by the National Center for Atmospheric Research, a consortium of US universities involved in atmospheric research. The second is the FV-3 model developed by the NOAA/NWS GFDL laboratory. As I have described in a previous blog, the clear choice is MPAS for many reasons.

MPAS
Model for Prediction Across Scales

MPAS uses an innovative geometry (hexagonal grid) that solves age-old model problems at the poles, while FV-3 uses a more traditional grid geometry. MPAS uses a superior grid structure (the "C" grid) that will produce far better high-resolution predictions than the problematic "D" grid of FV-3. And moving to high resolution is where global prediction is going.

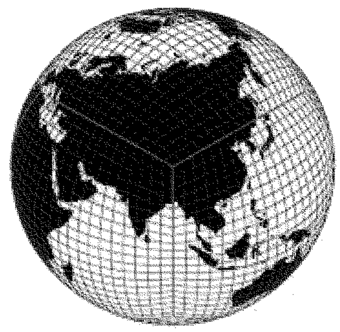
MPAS allows local refinement of resolution without adding additional "nested grids", as shown by the figure below. And MPAS' superior numerics offer better inherent resolution for a particular grid spacing, so one can run with coarser grids than FV-3 and secure equally good results (which reduces computer demands).



But there is something that goes beyond grids and model numerics. **Something even more important.** By picking MPAS, the National Weather Service will combine efforts with the huge US atmospheric sciences research community, with that community's model innovations (including physics and data assimilation) flowing into the National Weather Service. The isolation of NWS global prediction efforts would end.

But it is better than that. NWS research dollars could then help support global model research efforts that benefit both the operational and research communities. Other entities, such as the National Science Foundation, would able to help support research and development as well that would, in turn, improve operational skill, and hopefully a resurgent US global model, will bring the Air Force back into the fold.

But it is even better than that. A regional version of MPAS can be created and eventually replace the current regional model favored by the academic community, WRF, which was also developed at NCAR. So there is the potential for a national UNIFIED modeling system that could concentrate US weather modeling efforts, producing even more rapid advancement.



FV-3 grid

In contrast, the less innovative FV-3 model was developed by a small group in NOAA/GFDL with little experience in outreach and interaction with the university/research community.

You would think the global decision is obvious in favor of MPAS, but there are powerful voices inside NOAA that are pushing for an in-house solution.

The final decision on the future NWS global model will be made by Dr. Louis Uccellini, head of the National Weather Service. It will be one of the most important decisions he makes during his tenure. One choice, MPAS, will lead to a creative engagement with the US weather research community and the potential for the US to move rapidly into a leadership position in global weather forecasting. The other, FV-3, will continue and deepen National Weather Service isolation from the US academic community and continued mediocrity in global weather prediction.

In the mean time....

Even if MPAS is selected as the new U.S. global prediction model, it will take several years before the complete system is ready to go operational. As demonstrated by Panasonic, there are steps that the National Weather Service can take during the next six months to rapidly improve US global weather prediction. If I was the US weather prediction "czar", this is what I would do:

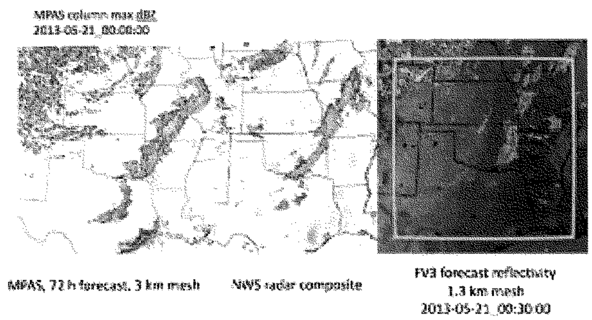
1. Start using the extraordinary capabilities of the new NOAA/NWS operational computers.

Increase the resolution of the US global ensemble system to 18 km (like ECMWF), increase the number of members to 50-75, and add physics diversity using stochastic physics. This will greatly improve US data assimilation and probabilistic prediction.

By increasing the resolution and quality of the global ensemble, the NWS can drop the redundant North America/only SREF (Short-Range Ensemble Forecast System), releasing more computer power for useful work.

2. Fix the obvious physics problems.

Update the model microphysics (moist physics) parameterization to something modern, like the well-regarded Thompson scheme used in WRF. Replace the old SAS convective scheme as well.



3. *Improve quality control.*

Follow the lead of Panasonic and upgrade the NCEP QC system.

4. *Work with the rest of the atmospheric science community (academia, private sector) to develop a detailed strategic plan for US numerical weather prediction and follow it.*

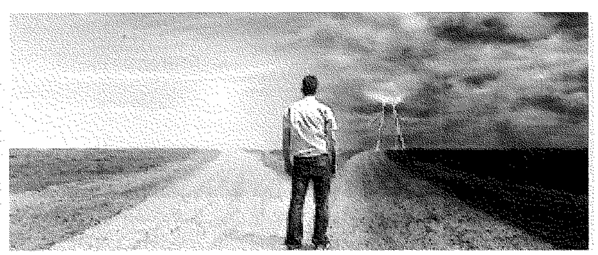
5. *Rework the structure and personnel of EMC, NCEP and NOAA labs to build coherent teams to work on key model issues (such as physics).*

Final Comments

Numerical weather prediction is one of the most complex activities done by our species, requiring billions of dollars of hardware, understanding and modeling of physical processes from the microscale to the planetary scale, complex computer science issues, and much more. World leaders in numerical weather prediction understand this challenge and know that it requires organization, planning, coherence, a long-term view, and innovation.

For too long, the National Weather Service has developed it models in a disorganized ad-hoc way, in isolation from the US research community. They have learned the hard way that one can not do state-of-the-art weather prediction development and operations that way.

NOAA and the NWS must change the way they do global modeling if they are to provide that nation and the world with the best global weather prediction. The opportunity and resources are now in place. The question is whether NOAA/NWS leadership will take the right path.



Important Addendum: June 22

I disappointed by a NOAA presentation this morning regarding testing between the two global model finalists: the NOAA/GFDL FV3 and the NCAR MPAS. I will blog further about this, but a few major points:

1. NCAR has pulled out because they feel the testing is inappropriate, and I have to agree.
2. All test models had to use the old GFS (current model) physics which are completely inappropriate at high resolution. In fact, GFS physics doesn't work well at any resolution. Like testing new racing cars on a muddy road--you can't do it.
3. The future of global prediction is at convection-allowing resolution (4 km or less grid spacing). But these resolutions were hardly tested (48 out of the 50 tests were at 13 km grid spacing or more).
4. Some of the results were clearly bogus, like the radically poor results of a 13-km forecast run and a hurricane simulation that had rain in the eye of the MPAS hurricane). Something was clearly wrong with the tests.
5. The testing had no vision of testing a configuration that might be used operationally in ten years (e.g., convection allowing over the globe). It was all about testing a configuration nearly identical to the current GFS.

Wednesday, October 29, 2014

The U.S. is Falling Further Behind in Numerical Weather Prediction: Does the Obama Administration Care?

The computational resources available to the U.S. National Weather Service (NWS) for numerical weather prediction **is rapidly falling behind leading weather prediction centers around the world**.

Unfortunately, the Obama administration does not seem to care and the U.S. is retreating into second tier status. Such a degradation is not only completely unnecessary, but needlessly weakens the economic competitiveness of the U.S. and puts our citizens at risk. Amazingly, Congress appropriated the money to address this problem **a year and a half ago**, but the administration has not made use of the funds. There are words to describe such inaction, but this is a family oriented blog.

Numerical weather prediction (NWP) is the central technology of weather forecasting. State-of-the-art weather prediction demands huge computer resources and thus the ability to forecast well **depends on access to the top supercomputers in the world**. Some numerical weather prediction models are run globally at moderate resolution, while others are run at ultra high resolution over smaller domains to predict small-scale features such as severe thunderstorms. Thus, a large nation, like the U.S., requires far more computer power than, say, South Korea or the United Kingdom.

During the past several years, I have blogged repeatedly about lack of computer power available to U.S. operational weather prediction, and particularly the forecasts made at the NOAA/NWS Environmental Modeling Center (EMC). Many others in the meteorological community have done the same. One and a half years ago, the U.S. Congress, recognizing the problem, provided NOAA with 25 million dollars to buy a more powerful supercomputer. **Amazingly, the U.S. administration has still not ordered the machine.**

The reason is that NOAA had signed a long-term contract with IBM (a bad move, by the way) and IBM sold their supercomputer hardware business to Lenovo, a Chinese firm. The administration did not want to purchase such a computer from a Chinese firm. And so nothing has happened.

CRAY

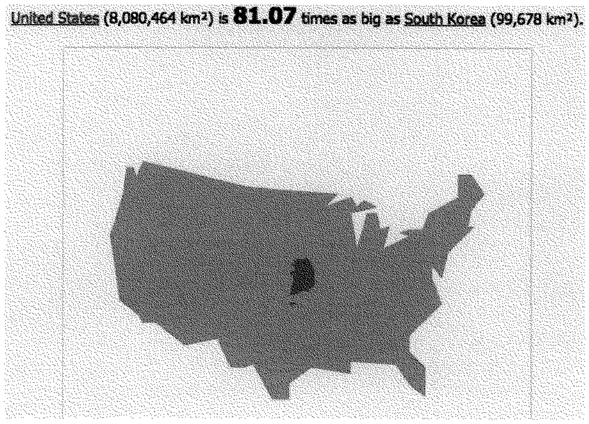
THE SUPERCOMPUTER COMPANY

There were many options that could have fixed the problem. IBM could have purchased a supercomputer from CRAY, a U.S. firm. NOAA could have broken the contract with IBM. Or the administration could have gone ahead with the Lenovo machine (which was the same computer they would have bought anyway). But the Obama administration clearly is not very interested in weather prediction, and the problem has festered.

But it is worse than that. Other nations and groups are pushing ahead rapidly in weather computer acquisition, leaving the National Weather Service in the dust.

Yesterday, CRAY Computer announced the UK Met Office has ordered an extraordinary 125 million dollar system (CRAY's newest XC-40 hardware) that will delivery a throughput of roughly 15 petaflops (a petaflop is one quadrillion operations per second). The current NWS computer is capable of .21 petaflops and they are upgrading this fall to a machine of .8 petaflops. So the UKMET office will have TWENTY TIMES the computer power of the U.S. The area of the US lower 48 states is 33 times larger than that of the UK.

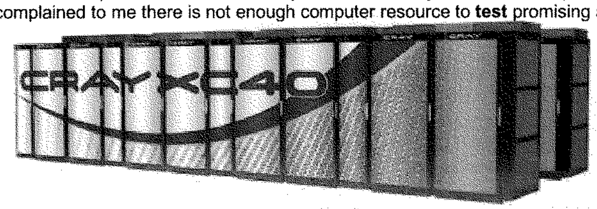
In June, the Korean Meteorological Administration (KMA) purchased TWO CRAY XC-30 computers, each capable of 3.1 petaflops. Yes, their new machines will be nearly FOUR TIMES faster than the UPGRADED U.S. weather computers. Let's see, Korea is 1/81 the size of the lower 48 states.



The European Center For Medium Range Weather Forecasting (ECMWF) just completed their first of several upgrades, buying two XC-30 computers from CRAY, each with 1.8 petaflops capacity--more than twice as fast as the U.S. upgrades. And importantly, ECMWF only does global prediction and thus does not have the responsibilities for high-resolution local forecasting like the National Weather Service. They need far less computer power, yet possess far more than the U.S. operational center.

Heard enough? I have more examples, but the message is clear: **the U.S. is rapidly falling behind in thecomputational resources necessary for high quality numerical weather prediction.** Sadly, this administration has the funds for a major upgrade, one that would at least secure a petaflop machine capable of revolutionizing U.S. weather prediction, but they can't seem to figure out how to buy it.

I know a lot of people inside NOAA and National Weather Service, including scientists working on the next generation of weather prediction models. Many are frustrated by the lack of computer power--one of them recently complained to me there is not enough computer resource to **test** promising advances.



My back-of-the envelope-calculation is that the National Weather Service needs a minimum of 20-30 petaflops of computer power to provide the American people with state-of-the science weather prediction that would improve the life of everyone in important ways.

For example, there are several reports by the U.S. National Academy of Sciences and other advisory groups suggesting that the U.S. needs ensembles (many forecasts run simultaneously) run at high resolution (2-3 km grid spacing) to provide better forecasts of thunderstorms, and particularly severe ones. Such ensembles would greatly improve the detailed weather forecasts for smaller-scale features in the rest of the country (Northwest folks, think Puget Sound convergence zone or mountain precipitation). But the NWS simply does not have the computer power to do it. New multi-petaflop machines would make it possible.

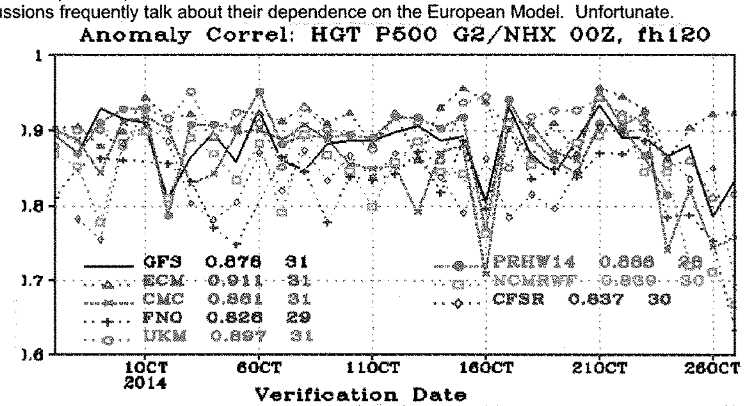
Defying drizzle: UK to build world's fastest weather forecasting supercomputer

By Sebastian Anthony on October 28, 2014 at 2:02 pm | 17 Comments

U.S. companies fork over millions of dollars a year to the European Center for the best forecasts...that would end with the new computers. And there are so many other critical forecast problems that would be lessened with more computer power, like better hurricane predictions days to a week out.

The U.S. atmospheric sciences community is the intellectual leader in meteorology and weather prediction and many of our research advances are applied overseas, such as at ECMWF and the UKMET office. The American people deserve to take advantage of the research they are paying for, but that can't happen with inferior computers and inferior forecasts. And yes, our forecasts are still inferior, with the NWS unable to match the resolution and data assimilation approaches of its rivals overseas.

Want proof? Here are the latest statistics for global 5-day forecasts at 500 hPa (about 18,000 ft above sea level) for several major international forecasting centers during the past month. Higher (closer to 1) is better. The top group is the European Center (ECM,the red triangle), with an average score of .911. The U.S model (GFS) is nearly always below them and had frequent and disturbing "drop outs" where forecast skill plummeted for a day or so (U.S. average is .876). Second place is the UKMET office (orange circles, .897) and expect them to soar with their new hardware. U.S. forecasters in their weather discussions frequently talk about their dependence on the European Model. Unfortunate.



And we can't simply use the European Center for our weather predictions, since they will **never** do the high-resolution prediction over the U.S. than we need, among other things. That is the job of the National Weather Service.

So folks, how do we fix this?

First, the Obama administration needs to start taking weather prediction seriously, which they obviously don't. The President's Science Adviser John Holdren seems to be fixated on climate issues and does not appear to appreciate that good weather prediction is a primary means of protecting the American people from current and future extreme weather events. The administration needs to figure out a way to order a large multi-petaflop machine for the National Weather Service, getting past the objections of some bureaucrats about Lenovo computers. Or simply order a CRAY (I had lunch with a CRAY representative and they are enthusiastic about helping).

The President and Science Advisor John Holdren need to give more priority to weather prediction

Second, the American people and the weather community need to complain loudly about the current situation. The media can help us get the message out, something they did to great effect to secure the funding in the Sandy supplement in the first place.

Third, our congressional representatives need to make this a major issue and push the administration to act.

As I have noted in my earlier blog, securing adequate computer resources is only the first step in producing a renaissance in U.S. weather prediction capabilities. But it is a critical and important first step, and it is time to finally deal with this self-inflicted problem. Weather prediction is essential national infrastructure, like highways and education. With second rate infrastructure, a nation declines.

If nothing is done by September 2015, the money for the new weather supercomputer will be lost. It would be a tragedy for U.S. weather prediction and the American people. Let's make sure this does not happen.

World leader in global medium-range numerical weather prediction

Time to teach ECMWF some humility

Clifford F Mass
Short Narrative Biography

Cliff Mass is a professor of atmospheric sciences at the University of Washington. His specialty is numerical weather and climate prediction and the meteorology of the western U.S.

Cliff Mass majored in physics at Cornell University, where he worked with Astronomer Carl Sagan on a model of the Martian atmosphere and with Stephen Schneider of NCAR on climate modeling.

After Cornell he entered the Ph.D. program at the University of Washington, with his doctoral work on African wave disturbances, the forerunners of tropical storms and hurricanes in the Atlantic.

Leaving the UW, Cliff joined the faculty of the Meteorology Department at the University of Maryland, where he taught synoptic meteorology and weather prediction, and worked on a variety of research topics, from Northwest weather circulations and high-resolution modeling, to the climatic implications of the Mount St. Helens eruption.

After three years at Maryland, Cliff moved to the University of Washington as an assistant professor in the Department of Atmospheric Sciences. During the next few decades, Cliff and his students have systematically studied the weather and climate of the western U.S., completing over seventy papers on West Coast phenomena as varied as orographic precipitation, coastal surges, the Catalina Eddy, and the Puget Sound convergence zone, to onshore pushes, downslope windstorms, and various local gap winds. Numerical simulation has been a key tool for his group, which now runs the most extensive local high-resolution prediction system in the United States. He is also heavily involved in regional climate modeling for the western U.S.

Cliff has been involved in a number of other initiatives, including the acquisition of coastal radar on the Washington coast, improving the infrastructure of the National Weather Service, the use of smartphone pressure observations for weather prediction, and the improvement of K-12 math education. He is the author of the 2008 book "The Weather of the Pacific Northwest" and broadcasts a weekly weather information segment on KNKX, a local public radio station. Cliff also writes a weather blog (cliffmass.blogspot.com)

Cliff Mass, a full professor at the UW, is a fellow of the American Meteorological Society, has been an editor of a number of meteorological journals, is a member of the Washington State Academy of Sciences, has published over 120 papers, and has served as a member of a number of National Academy committees. He is currently a member of the WRF Research Applications Board, a member of the NOAA/UCAR UMAC committee, and a member of several American Meteorological Society committees. He is now working on a new book "The Secrets of Weather Prediction."

Mr. CASTEN. Dr. Neilley, you are recognized for 5 minutes.

TESTIMONY OF DR. PETER P. NEILLEY, IBM DISTINGUISHED ENGINEER AND DIRECTOR OF WEATHER FORECASTING SCIENCES AND TECHNOLOGIES, THE WEATHER COMPANY, AN IBM BUSINESS

Dr. NEILLEY. Thank you, Chairman Casten, and Ranking Member Marshall, and Ranking Member Lucas, and all Members of the Subcommittee, thank you for the opportunity to address the Subcommittee today. My name's Peter Neilley, and I am the Director of Weather Forecasting Sciences and Technologies at the Weather Company, part of IBM. I oversee a team of scientists and engineers that develop a broad suite of technologies that are used to create and distribute weather forecast products and services for both the U.S. and the rest of the world. The U.S. is fortunate to have the most vibrant weather enterprise anywhere in the world, with deep partnerships between Federal, academic, and private sectors creating the delivery services for the Nation. The Weather Company and IBM are proud to be active contributing members to that weather enterprise.

Numerical weather prediction, or NWP, is the foundational technology used to create nearly all weather forecasts today. At The Weather Company we employ many of our own numerical weather prediction models, but are also heavily dependent on the forecasts from numerical weather prediction models by NOAA and others. Because of that dependency, The Weather Company has deep interest in the quality of numerical weather prediction forecasts produced by NOAA. Accordingly, I actively participate in numerous advisory boards, committees that discuss and make recommendations on means of improving numerical weather prediction capabilities for the Nation, including the Earth Prediction Innovation Center. The community workshop for the Earth Prediction Innovation Center held this past summer gathered nearly 300 stakeholders from inside and outside of the Federal Government to inform NOAA and the community on early ideas for implementing EPIC, and a summary report of those findings, I believe, was released just yesterday by NOAA.

The U.S. has a rich history in developing and operating numerical weather prediction systems that date back to the 1950s. Today numerical weather prediction capabilities are developed and deployed in numerous places, including NOAA, the Department of Defense, the Department of Energy, NASA, at National Science Foundation-funded institutions, academic organizations, and the private sector. Each corner of this numerical weather prediction community has created modeling capabilities tailored to the mission of each one of those individual institutions. Unfortunately, there is no overarching national strategy guiding the organization interaction of these activities, which has led to less than optimum efficacy in any one of them.

Further, there is no obvious existing place within the enterprise where such a strategy might be formulated and executed. As a result, there is a very broad set of NWP capabilities across the Nation. Some of them good, but few of them as good as they could be. In fact, when compared to models developed by international counterparts in Europe and the U.K., our global numerical weather prediction systems from NOAA and other members of our national enterprise are materially less accurate, and have been for decades. As a result, our Nation is significantly less prepared, and less resilient to the adverse impacts of weather and climate than we could be.

Today I wish to convey four key points to the Subcommittee. First, under the leadership of Acting Administrator Jacobs, and his vision for EPIC, we have before us a generational opportunity to address the shortcomings of our Nation's NWP capabilities, and elevate them to the world's best.

Second, EPIC, as proposed by Dr. Jacobs, envisions the creation of a state-of-the-science institution for the community, and by the community, where the numerical weather enterprise collaboratively works together using a common framework of tools and technologies. This would enable the most effective, and efficient, development of advanced numerical weather prediction capabilities in support of both NOAA, and all the other numerical weather prediction stakeholders across the Nation.

Third, to execute this vision, NOAA must construct EPIC as a semi-autonomous and externally managed national institution that will establish, catalyze, organize, and manage a large and diverse scientific and technical community collaboratively working toward the betterment of NWP. NOAA would be a major constituent in the EPIC community, participating in both its government and scientific endeavors, but would only be one of the many stakeholders drawing value from its accomplishments.

Finally, in order to achieve this vision, numerical weather prediction stakeholders across the Federal Government must embrace and actively participate in EPIC. As outlined in my written testimony, I think Congress plays an important role in fostering and incentivizing such participation, as well as helping to ensure the long-term success of EPIC. Thank you for the opportunity to address the Subcommittee today, and I also look forward to your questions.

[The prepared statement of Dr. Neilley follows:]

Testimony of

DR. PETER P. NEILLEY, THE WEATHER COMPANY, AN IBM BUSINESS

to

THE SUBCOMMITTEE ON ENVIRONMENT

of

THE COMMITTEE ON SCIENCE, SPACE, AND TECHNOLOGY

of

THE UNITED STATES HOUSE OF REPRESENTATIVES

Hearing on

"A TASK OF EPIC PROPORTIONS: RECLAIMING U.S. LEADERSHIP IN WEATHER MODELING AND PREDICTION"

NOVEMBER 20, 2019

Introduction

Chairman Fletcher, Ranking Member Marshall, and Members of the Subcommittee - good afternoon and thank you for the opportunity to address the subcommittee today. My name is Dr. Peter P. Neilley and I am the Director of Weather Forecasting Sciences and Technologies at The Weather Company (TWC), an IBM Business. I oversee a team of scientists and engineers that develop a broad suite of technologies, including numerical weather prediction (NWP), that are used to create and distribute weather products and services for our business. We serve a global footprint of individuals and businesses through our branded products, including The Weather Channel, weather.com, and Weather Underground, through a variety of global business specialized products serving the aviation, energy, retail, insurance, transportation and agriculture markets, as well as through our distribution partners including Apple, Google and Facebook. We routinely distribute over 30 billion forecast products each day to an estimated 1-2 billion individual daily users worldwide. Our core weather products are created from a proprietary forecast production engine that is heavily dependent on our own internal NWP capabilities and on the output of NWP models operated by the National Oceanic and Atmospheric Administration (NOAA) and other international weather services.

In addition to my role at TWC/IBM, I have served or actively serve on a number of committees, working groups, and advisory boards involved in the development and creation of weather forecasting sciences and services. This includes past chairman of the American Meteorological Society (AMS) Committee on Weather Analysis and Forecasting, as well as service on numerous NOAA-related committees and working groups including EISWG[1], UMAC[2] and as co-chair of UCACN.[3] More recently I am serving on the Environmental Predication Innovation Center's (EPIC's) Community Workshop organizing committee. I understand EPIC is the subject of today's hearing and the focus of my comments herein.

My interests in advancing NWP capabilities for the nation are rooted in a deep, personal, and visceral interest in the betterment of weather forecasting to serve society, as well as a professional interest in creating superior weather products for TWC/IBM. It is from both perspectives that I address the subcommittee today. I also believe my testimony is largely consistent with the summary findings of the EPIC Community Workshop Organizing Committee presented at the end of the workshop held this past August.

State of NWP in the United States

The U.S. has the largest, broadest, and most diverse NWP community in the world, with activities occurring in several federal agencies (including NOAA, NASA, DOE, and DoD), numerous national laboratories, a large number of academic institutions as well as a growing number of commercial enterprises. As a result, we have a broad set of national NWP capabilities, often tailored to the needs of the specific institution hosting the activities.

Unfortunately, there is no unified national strategy that guides the investments in, development of, or operation of NWP across the nation. While diversity in scientific advancement is a good thing, the extreme diversity and breadth of NWP activities across the nation has actually led to underperformance in most of our NWP capabilities. Our nation's uncoordinated approach to NWP has resulted in broad capabilities that are good, but often not great. As a result, our nation is significantly underprepared for, and less resilient to, the impacts of weather and climate on our lives, economy and national security.

The issues identified above are also reflected at NOAA and the National Weather Service (NWS). NOAA has a history of insular NWP development, creating and deploying a broad portfolio of NWP models that has led to operational capabilities that are often less accurate than some international counterparts, a result that has been widely analyzed and reported for decades. Fortunately, there have been considerable efforts by NOAA over the past several years to simplify its NWP portfolio and to seek new NWP capabilities from the broader community. The NWS's implementation of the High-Resolution Rapid-Refresh model based on a model developed by the National Center for Atmospheric Research (NCAR) now represents the world standard in short-term (under one day) operational NWP. More recently, the NWS has transformed the heart of its global medium-range (1-15 day) Global Forecast System (GFS) from an aged, home-grown model to one first developed at Princeton University (the Finite Volume Cubed Sphere, or FV3). This transformation is part of the Next Generation Global Prediction System (NGGPS) program and the cornerstone of NOAA's Unified Forecast System (UFS). It holds promise in reducing the accuracy gap between NOAA's global modeling capabilities and the current standard established by the European Range

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[1] EISWG is the Environmental Information Services Working Group, a standing working group of NOAA's Science Advisory Panel.
[2] UMAC is the UCACN Model Advisory Committee.
[3] UCACN is the UCAR Community Advisory Committee for NCEP. UCAR is the University Corporation for Atmospheric Research and NCEP is the National Centers for Environmental Prediction, one of the major divisions of the National Weather Service.

for Medium Range Weather Forecasting (ECMWF). However, alone it is likely insufficient to achieve or sustain NWP superiority for the nation.

A Collaborative Approach to NWP Superiority

While the recent NWP modernization efforts at NOAA are encouraging, they represent only a small fraction of what NOAA and this nation could achieve with a more coordinated and holistic approach to NWP development and deployment. Stakeholders and participants across the NWP community have agreed on this for more than a decade, and it has been reflected in numerous studies and reviews. This approach would create new paradigms, institutions and cooperative cultures that foster collaborative, efficient and effective NWP development across the nation. It would also create processes by which the broader NWP community can rapidly inject scientific and technical advancements into operational weather forecasting at NOAA and elsewhere.

There is substantial evidence that a broad collaborative approach to NWP development can result in superior NWP operational capabilities. For example, NCAR's WRF-ARW, MPAS, and CESM models are widely regarded as one of the world's best models for regional, global, and climate NWP, respectively. Each model has a large, vibrant community of active users and developers that contribute to the overall efficacy of the models. These communities represent all facets of the weather enterprise, including those that wish to use models for operational NWP purposes and as instruments to advance the atmospheric sciences. The communities have flourished not because of specific-funded initiatives to help develop the models, but rather because the modeling systems represent state-of-science capabilities that are highly attractive to researchers and users. The communities exist because of the modeling capabilities, and not necessarily to develop the model. However, the communities end up contributing to the advancement of the models, which in turn attracts even more members to the community.

Despite the long-held vision that a more community-oriented approach to advancing NOAA's NWP capabilities is needed, and despite some of the advancements NOAA has made recently, it remains difficult for external scientists to participate in advancing NOAA NWP. Three of the more significant barriers are:

- Inaccessibility to the model codes and the required infrastructure to assist in understanding and using those codes.
- Limited processes by which advancements from the community can easily be incorporated into the NOAA models. The new UFS governance approach to NOAA's global modeling is a step toward improvement but is still far from optimally effective.
- Insufficient access to suitable computational resources to develop, test, and run the codes.

As a result, participation in the advancement of NOAA's modeling capabilities is limited to a relatively small set of developers that have inside, privileged, or unique access. Outside participation in NOAA NWP development is relatively minor compared to the participation levels of the NCAR WRF, MPAS and CESM communities mentioned earlier. As compared to entities such NCAR, NOAA is less experienced and has fewer tools available to it to establish and manage a community of participants for NWP development.

EPIC: A Generational Opportunity

Under the leadership of Acting NOAA Administrator Dr. Neil Jacobs, NOAA has realized the need to create new paradigms for more effective infusion of external science and capabilities into its modeling portfolio. The Environmental Prediction Innovation Center (EPIC) concept proposed by Dr. Jacobs represents a unique, generational opportunity to dramatically improve NOAA's and the nation's overall NWP capabilities by creating an institution that enables, catalyzes and entices broad participation in a common NWP R&D process. The EPIC vision is strongly aligned with the decades of recommendations about improving the NWP capabilities for the nation. Given the strong alignment of the community around EPIC, and the support for it from the leadership at NOAA, there is a unique opportunity to make the most substantial improvements in the NWP capabilities for NOAA and the nation in a generation.

If successful, EPIC will not only provide the nation with the world's most accurate weather and climate forecasts, it will also significantly advance the NWP capabilities of all the other institutions involved in NWP including NASA, DoE, DoD, national laboratories, NCAR, academic institutions, and private enterprise. This broader improvement beyond just NOAA is perhaps the larger payoff for EPIC to the nation, and it is imperative that our nation seizes this opportunity.

There are at least two approaches to how NOAA could design EPIC to advance its engagement with the broader community. In the first approach, NOAA could identify the specific scientific advancements needed, and methods to development them, and then frame EPIC around those requirements. Alternatively, NOAA could establish EPIC with a much broader and holistic approach to NWP improvements that would catalyze the broadest possible creativity and advancements in NWP, with a subset of the best and most relevant of those advancements imported into NOAA NWP capabilities. The first approach would represent an extension of the status quo methods of NOAA engagement with the community, a model that has clearly not resulted the NOAA having the best modeling capabilities. The second approach results in a pipeline of scientific and technical advances that can far exceed the predetermined, more narrow new capabilities NOAA would otherwise have identified. Evidence from experiences to date suggest that broader catalytic approach to engaging with the community will result in a substantially more effective end result for NOAA than the narrow, focused and tightly managed approach.

Essential to the success of EPIC is the breadth and diversity of participants in the EPIC community. In order to achieve this, the following characteristics of EPIC are critical:

- The fundamental mission of EPIC must be for the betterment of NWP, and not narrowly focused on the immediate and future needs of the NOAA. The science advancements within EPIC should support a broad set of NWP activities, a subset of which will have direct, material impact on NOAA's operational NWP capabilities.
- A broad set of NWP components, and not just the set of components currently or planned to be in operations at NOAA must be available and supported by EPIC. This includes dynamic cores, physics, data assimilation methods, and associated coupled models. This is critical to engaging the broadest community possible by creating a cauldron of scientific capabilities that entice users to participate.
- Strong partnership with related and adjacent institutions such as the Joint Center for Satellite Data Assimilation, the National Center for Atmospheric Research, and many of NOAA's cooperative institutes.

- EPIC must be a community-owned institution, operated outside of NOAA, and governed by and for the community. NOAA would be an important constituent in that community, but not the majority member.
- Details about the operation of EPIC, including governance, technologies, support structures (e.g. documentation, user help, etc.), technical processes (code management, testing procedures, computing allocation, etc.), funded research, and other subcontracts that facilitate its success, must all be determined by the managing structure of EPIC, and not mandated or micromanaged by NOAA. NOAA must cede authority for operating EPIC to the managing entity. Once established, NOAA's focus should be on deriving value from EPIC's accomplishments by reducing them to practice.
- The EPIC managing entity must be beholden and accountable for the success of EPIC. Bold measures of success should be established for EPIC and should include the breadth of community participation in EPIC, and the degree of improvement it delivers to the nation's NWP capabilities. Goals should include near term (1-2 years) and long-term (3+ years), with at least one near-term goal demonstrating the potential value of the long-term EPIC vision.

EPIC's success will mean bringing together a breadth of the nation's NWP activities under one umbrella. This umbrella must still allow for diversity of scientific creativity, but in an R&D framework that can reduce the most relevant and important achievements to operational capabilities for NOAA. To catalyze that participation, EPIC must create a capability that entices such participation, rather than one that directs it.

Although this new paradigm calls for NOAA to relinquish tight control on the organization, management, and operation of EPIC, it should not be taken that NOAA becomes a passive bystander. Rather, NOAA perhaps plays the most significant role of any one participant by:

- Participating as an active member in the science and technical development work within EPIC;
- Identifying the most promising and useful new science and technologies developed in EPIC and reducing them to practice inside its operational models;
- Ensuring the framework of the institution is designed in such a way to facilitate rapid reduction to practice of the new science and technologies developed in EPIC;
- Providing a flow of "operations to research" feedback to EPIC to help guide priorities for EPIC directed R&D;
- Serving as the primary federal agency supporting EPIC, providing sufficient funding to sustain it and assisting in the coordination with other federal stakeholders such as NSF and DoD.

Barriers to Success

There are several barriers to EPIC's success that will need to be addressed. These include:

- Compared to other entities like NCAR, NOAA has less experience and fewer tools needed to establish and manage a broad community of participants. EPIC represents a sea change in how NOAA advances its NWP capabilities and there will be institutional barriers as a result. A particularly important change is the need to delegate authority to an external entity to construct, manage and operate EPIC for NOAA and the community in order to optimize its efficacy and ability to deliver world-leading NWP capabilities back to NOAA. Both strong leadership within

NOAA embracing the EPIC vision as well as several near-term successes are critical in overcoming this barrier.

- As mentioned earlier, NCAR has already established the world's leading NWP scientific and technical communities around its regional, global and climate modeling systems. The size and reach of these communities are impressive, vastly larger than any other community modeling efforts in the world. It is essential that EPIC and these established communities unify otherwise there will be competing NWP development communities. For example, if in several years from now a graduate student seeking a modeling platform to assist in their thesis studies must choose been EPIC and the NCAR communities, rather than going to EPIC as the singular source of the superset of NWP technologies, then EPIC is likely to fall significantly short of accomplishing the potential of the vision outlined here. Since the NCAR communities are established and entrenched, it might be difficult for an upstart EPIC community to gain traction and critical mass unless it strategically integrates with the NCAR communities. Central to accomplishing that will be including the MPAS dynamical core in the EPIC modeling framework.
- NWP development and operations has always been significantly limited by the amount of high-performance computing (HPC) available to develop, test and run the models on. Some studies have estimated that the weather and climate NWP community has a need for up to 100 times the computing power currently available to it. Within the EPIC framework not all of the computing needed to conduct the breadth of science envisioned will be done using EPIC-provided compute resources. In fact, a majority of the computer resources may be provided by facilities otherwise available to participates in EPIC. These could range from a graduate student's laptop, to HPC facilities at major national laboratories. However, we should expect that EPIC will need substantial computing resources to support its permanent staff, and to allocate to a subset of its participating scientists. The EPIC managing entity should be given an initial modest budget (perhaps $5M) to establish foundational computing resources, and then quickly develop within its first year a long-term computing strategy and budget.

Congressional Support

EPIC represents a significant opportunity for the nation and major change that will substantially improve our nation's NWP capabilities. It is important that all stakeholders that have influence on, participation in, or dependence on EPIC outcomes embrace the vision, collaborate on its implementation, and participate in its activities. This includes Congress which should use the legislative power to foster EPIC's initial establishment and sustain its long-term durability as a national resource. The initial authorization of EPIC in the *National Integrated Drought Information System Reauthorization Act of 2018* was sufficient to get the establishment of EPIC started, but additional congressional support to ensure its success is needed. This includes:

- Encouraging federal agencies that participate in NWP development and operations, including DoD, DoE, NASA, and NSF to embrace EPIC as a national infrastructure that will aid the development of NWP capabilities in all sectors, not just NOAA, and to work to identify means by which those agencies can substantially contribute to, participate in, and benefit from EPIC.
- Direct NOAA to establish EPIC in the manner discussed herein, and in particular, to delegate authority to create, manage, and operate EPIC by an independent entity in a manner that entices community ownership and participation in the institution.

- Plan for long-term sustaining budgetary support for EPIC including base funding to support its permanent staff and facilities, ongoing research funding grants, and significant increases in computing resources. It is premature to gauge the exact level of the support needed. Determining long-term budgetary needs should be an early initial focus of EPIC's managing entity, but depending heavily on the computing, staffing, and facilities strategy that the EPIC managing entity pursues, annual EPIC costs would certainly exceed the initial appropriation and be recurring. This is ultimately a question for NOAA and EPIC to determine.

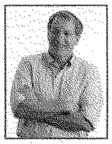
Summary

EPIC represents a singular, generational opportunity to elevate U.S. NWP capabilities to the best in the world by establishing a center of excellence that brings together the uncoordinated scientific and technical NWP developments found in all corners of the enterprise under one, unified umbrella. EPIC's success would not only ensure that NOAA will create the world's best weather and climate forecasting services for the nation, but it will extend those benefits to all other corners of the U.S. NWP community including other federal agencies, national laboratories, academic institutions and private enterprise. Doing so will optimize the resiliency of the nation to the impacts of weather and climate on our lives, livelihood, economy and national security.

Success of the EPIC opportunity critically depends on at least these factors:

- EPIC is founded as a national institution, set up and managed by an independent entity outside of NOAA, constructed and operated in manner that entices broad scientific and technical participation, and is beholden to delivering the world's best NWP capabilities back to NOAA and EPIC's other participants.
- Leadership in embracing EPIC by all sectors of the NWP community, including by leaders in NOAA and all other federal stakeholders involved in NWP.
- Sustained funding for EPIC, particularly for infrastructural staffing, facilities, research grants and computing.

Many of the country's primary operational NWP capabilities have underperformed relative to international counterparts for decades, partly as a result of a distributed, uncoordinated approach to its development and operation without an overall guiding national strategy or vision. EPIC represents the best opportunity in a generation to correct this and deliver to the nation superior weather and climate services that optimize the return on the investments the country is making in the science.



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Dr. Peter P. Neilley

Overview

Dr. Neilley has about 30 years of experience in meteorology, mostly developing state-of-the-science technologies in weather forecasting for public use and weather-dependent markets. Dr. Neilley was a scientist at the National Center for Atmospheric Research between 1991 and 2001 conducting research on various aviation weather problems and the application of artificial intelligence methods for weather forecasting applications. He served as a principal scientist for a project to understand and predict terrain-induced and convective weather hazards in Hong Kong Airport and similar programs in Juneau and Colorado Springs. He was also the lead scientist developing an operational and automated weather forecasting system, derivatives of which are used today to drive forecasts consumed by billions of people daily. In 2001, Dr. Neilley became chief scientist at Weather Services International (WSI) Corp., leading a team of scientists developing methods for improved forecast technologies for a wide sector of markets. In 2007, Dr. Neilley became Vice President of Forecasting for WSI, responsible for both the research and operational forecasting including WSI's extensive aviation weather forecasting branch. In 2009, Dr. Neilley was promoted to Senior Vice President of Forecasting for The Weather Company, WSI's parent organization that includes The Weather Channel, weather.com, EEC Weather Radars (until 2012), Weather Underground and other holdings. In 2016, after The Weather Company's acquisition by IBM, Dr. Neilley was named an IBM Distinguished Engineer.

Dr. Neilley is active in the community and currently is co-chair of the UCAR Community Advisory Committee for NCEP that reviews and advises the National Weather Service on its core operational centers. He also served on the UCACN Model Advisory Committee for NOAA and more recently on the EPIC Summer Community Workshop planning committee. He recently completed a six-year tenure on NOAA's Science Advisory Board's Environmental Information Services Working Group where he was the principal author of the NOAA-adopted Open Environmental Information Services paradigm that contributed to the creation of the recent NOAA Big Data Initiative. He was a longtime member and chair of the American Meteorological Society's Committee on Weather and Forecasting and championed the first international weather forecasting conference and first joint conference between the AMS and the National Weather Association. He also served as an executive member of the AMS Forecast Improvement Group. He has also served as a member of the National Research Council's Surface Transportation Weather task force the FAA's Turbulence Product Development Team. In 2017, Dr. Neilley was named a Fellow of the American Meteorological Society.

Education

Ph.D. Meteorology, Massachusetts Institute of Technology 1990.Jules Charney Scholarship in Meteorology. Thesis titled "Interactions between synoptic-scale eddies and the large-scale flow during the life cycles of persistent anomalies." Randall M. Dole, advisor.

M.S. Meteorology, Massachusetts Institute of Technology, 1984. *Thesis titled "The vertical structure of the New England coastal front."* Richard E. Passarelli, advisor.

B.S. Meteorology, McGill University, 1982 University Scholar of Great Distinction, American Meteorological Society Undergraduate Scholarship Prize (2nd place).

Mr. CASTEN. Dr. Aulignė, you are recognized for 5 minutes.

TESTIMONY OF DR. THOMAS AULIGNÉ, DIRECTOR OF THE JOINT CENTER FOR SATELLITE DATA ASSIMILATION, UNIVERSITY CORPORATION FOR ATMOSPHERIC RESEARCH (UCAR)

Dr. AULIGNÉ. Good afternoon, Chairman Casten, Ranking Member Marshall, Ranking Member Lucas, and Members of the Subcommittee. Thank you for the opportunity to testify today. I am Dr. Thomas Aulignė, Director of the Joint Center for Satellite Data Assimilation at the University Corporation for Atmospheric Research. As a trained meteorologist, I care deeply about improving the quality of our weather models, which help build a weather-ready nation, and save lives and property. My experience in academia and operational centers gives me a unique perspective on the so-called valley of death separating research and operations.

For more than 30 years, weather prediction in the United States has been trailing behind other international centers, most notably the European Center. Previous actions and additional funding have failed in regaining U.S. leadership. This leads me to propose a disruptive vision for EPIC, reconsidering organizational roles, governance, and funding models. My view is that only with radical change is it realistic to expect radical improvement.

Drawing from my previous experience at the European Center, I have concluded that the secret sauce fueling their success story has the following ingredients: Focus, innovation, excellence, and accountability. While the U.S. weather enterprise is often described as the uncoordinated giant, plagued by fragmentation of resources, the Europeans rally behind the strength of a common goal. The success of EPIC lies in a clear, non-overlapping mission, with clear responsibility and accountability.

EPIC should launch a focused effort with one goal, develop the best weather prediction system for the Nation. Success should be directly measured, and EPIC's director should be held accountable. We need a center of excellence, attracting the best talents that can drive the Center's goals, guide the community, and work toward operational requirements. This dream team will be supported by lean decisionmaking, efficiency-driven operations, and strategic allocations of resources. On this aspect, we need massive investment in high-performance computing, leveraging the elasticity of the cloud.

EPIC should provide a collaborative environment, where scientists from the government, academia, and the private sector can gather to conduct innovative code development, and explore high-risk, high-reward research. This requires building a research model accessible by the entire community, and paired with an effective process to transfer research to operations.

As EPIC focuses on encouraging and incorporating innovative science, it should also utilize an innovative business model. I am convinced that EPIC can draw from the success of the Joint Center for Satellite Data Assimilation. Its distributed structure, following a hub and spokes approach, increases the government's ability to engage world class scientists and engineers. Its agile team, at the intersection of multiple Federal agencies, is reinventing collaboration, and exploring innovative pathways. In fact, the Joint Center is already applying the European secret sauce to better assimilate observations to initialize model forecasts. This major science problem is the highest priority for EPIC.

I dream of EPIC as an agile center, where scientists can focus on science, red tape is reduced to a minimum, decisionmaking is streamlined, and community collaboration is entirely result-driven. The implementation of EPIC should be delegated to a single trusted partner that has strong connections to the community and the government, building a bridge across the valley of death.

In conclusion, EPIC represents a unique opportunity. We have one shot to get it right, and business as usual is not an option. We need to reinvent the way we transition weather research to operations. The breadth and depth of the U.S. research community is second to none. EPIC can use is ingenuity to reach, and even surpass, forecast improvement goals, and collectively reclaim American leadership in weather modeling and prediction.

Thank you for your attention. I look forward to answering any question you have.

[The prepared statement of Dr. Aulign√© follows:]

Written Testimony of

Dr. Thomas Auligné

Director of the Joint Center for Satellite Data Assimilation (JCSDA),
University Corporation Atmospheric Research (UCAR) Research to Operations Center

before the

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

A Task of EPIC Proportions: Reclaiming U.S. Leadership in Weather Modeling and Prediction

November 20, 2019

Chairwoman Fletcher, Ranking Member Marshall, and Members of the Subcommittee, thank you for the opportunity to testify on this important topic. I am Dr. Thomas Auligné, Director of the Joint Center for Satellite Data Assimilation (JCSDA) at the University Corporation for Atmospheric Research (UCAR).

As a trained meteorologist, I deeply care about improving the quality of our observations and numerical models, which form the foundation for operational forecasts that save numerous lives and property, and help us build a Weather Ready Nation. My experience in academia and weather centers in the United States and Europe provides me with a unique perspective on what is often described as the *valley of death* between research and operations.

For more than 30 years, the United States weather prediction has been trailing behind other international centers, most notably the European Centre. Previous actions and additional funding have not resulted in re-gaining US leadership.

What are the underlying reasons for NOAA's lack of rapid improvement?

The persistent numerical weather prediction (NWP) performance gap in the U.S. cannot be explained by lack of talent, nor is it due to insufficient financial resources. Rather, the key factors that prevent NOAA from closing the gap are due to the organizational complexity of NWP development in the US. We have been unable to define clear organizational "swim lanes" (centers of excellence) internally within NOAA, nor are these well defined across other relevant U.S. government agencies, research institutions and universities. As a result, there is a great deal of overlap and gaps in the work, and much of it leads to dead ends.

NOAA needs to focus on the development of a single community system that can outperform other leading NWP systems. Instead, resources tend to be dispersed across many different organizations and systems, each with sub-critical and often unpredictable support. This inevitably leads to reduced quality. The situation is exacerbated by the multiplicity of roles that the relevant organizations are required to assume. NOAA's Environmental Modeling Center in particular is under-resourced and unable to reliably support some key customer needs, such as the regular production of supporting data sets and real-time assessments of forecast quality.

Setting directions and making the right decisions on NWP development is extremely difficult in such a complex multi-organizational enterprise. Responsibilities, accountability and authority are spread across line offices and laboratories whose missions are not solely focused on weather prediction system improvement. This leads to ponderous and unclear decision-making processes. Difficult decisions are often farmed out to slow-acting committees. Outcomes are often not sufficiently informed by scientific and technical evidence or pre-established criteria.

Similarly, allocation of resources in this situation is inevitably sub-optimal. Funding managers are often far removed from leaders of the science development. Funding for NWP research and development originates in many different offices within NOAA, so that a cohesive program for effective transfer of research to operations (R2O) is very difficult to achieve. Moreover, funding on specific topics is usually short term (less than 3 years) and unpredictable, and commonly dispersed to many competing labs, institutes, and universities, rather than concentrated in centers of excellence.

NWP performance gains are directly related to availability of high-performance computing and data handling systems. Sufficient reserved capacity for research and development work, and reliable access to it, is crucial. The use of many different computing systems, each with different operational constraints, and usually subject to strict access restrictions, does not promote effective collaboration.

Finally, NOAA has difficulties recruiting and retaining world-class talent. In part this is because of the daunting number of roles a scientist must assume (scientist, software engineer, data manager, customer hand-holder, meeting goer), and in part because of the low-bid support contract model.

This leads me to propose instead a *disruptive* vision for the Earth Prediction Innovation Center (EPIC), reconsidering organizational roles, governance, and funding models. I posit that only with radical change is it realistic to expect radical improvement. Drawing from my own experience, I concluded that the main ingredients of the *secret sauce* fueling the European Centre supremacy are focus, innovation, excellence, and accountability.

Lessons from the European Centre for Medium Range Weather Forecasting (ECMWF)

Focus: While the U.S. Weather Enterprise is often described as the *Uncoordinated Giant,* Europeans rally behind the *strength of a common goal*. EPIC's only goal should be to develop the next world-leading weather prediction system for the Nation.

Innovation: The approach is to significantly accelerate the rate of forecast improvement through an effective research to operations process. EPIC should also provide a collaborative environment capability, where scientists from NOAA, academia and private industry can gather to conduct innovative co-development and associated testing. The collaboration capability will be designed to stimulate innovation, allow scientists to conduct higher-risk work, and boost productivity.

Excellence: I believe that EPIC needs to be a Center of Excellence with world-class permanent and visiting staff who can drive EPIC goals, guide the community, and build connections with operational prediction personnel to yield significant results and spur the kind of innovation NOAA seeks. EPIC needs to incorporate best practices regarding lean decision process, strategic allocation of resources, and optimized efficiency.

Accountability: Success should be evaluated by measuring how EPIC is improving forecast skill, and EPIC's Director should be held directly accountable. Any result-driven enterprise needs to start with a gap analysis. ECMWF's supremacy in weather forecasting is often attributed to its state-of-the-art data assimilation system, and this should constitute the highest priority for the success of EPIC.

The Importance of Data Assimilation

Data assimilation is a complex process to *recalibrate* the model initial conditions with the latest observations, and it requires vast amounts of staffing and computational resources. Due to the chaotic nature of the Earth system, small errors in describing the model initial conditions can result in large forecasting errors. Studies have shown that the quality of the data assimilation and the model are equally important in order to produce skillful forecast. Figure 1 illustrates how improved data assimilation has the potential to be a game changer for EPIC.

In the United States, the focal point for data assimilation, born of an inter-agency collaboration tackling this big science issue is the Joint Center for Satellite Data Assimilation (JCSDA).

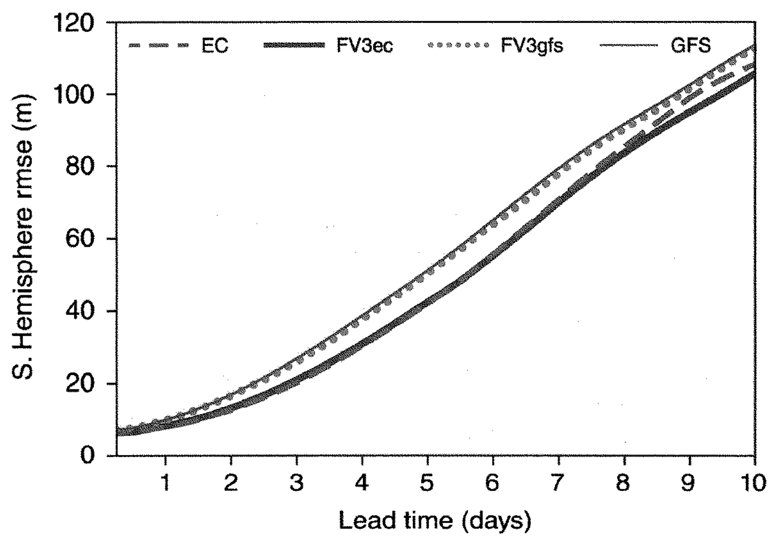

Figure 1: from Magnusson et al., 2019 (https://doi.org/10.1002/qj.3545) representing a measure of forecast error as a function of forecast lead time. The green solid (resp. dotted cyan) curve shows the performance of the previous (resp. current) NOAA operational system. The dashed red curve shows better performance of the leading European Center (ECMWF). The dark blue curve corresponds to the current NOAA operational model initialized from ECMWF analysis. With some minor caveats, this figure demonstrates the importance of data assimilation on improving forecast quality.

Experience at the Joint Center for Satellite Data Assimilation (JCSDA)

The JCSDA is an interagency research center involving NOAA, NASA, the U.S. Navy and Air Force, working to become a **world leader** in applying satellite data and research to operational goals in environmental analysis and prediction. Its mission is to accelerate and improve the quantitative use of research and operational satellite data in weather, ocean, climate and environmental analysis and prediction systems.

Under its current director, and with full support of its partner agencies, the JCSDA has recently taken a new approach aimed at disrupting the current state-of-the-art in weather prediction. The culture of the renewed "Joint Center" is similar to that of a start-up in a traditional market sector. Four interdependent elements are central to this culture: *Focus, innovation, excellence* and *accountability*.

The clear *focus* of the renewed Joint Center is on leveraging existing US capabilities and talent to reach world-leading performance in the next-generation NWP system. The *innovation* required to achieve this goal is enabled by providing shared infrastructure and tools for agile development of new data assimilation systems, with the ability to run experiments in the Cloud in collaboration with the wider research community. The Joint Center is attaining critical mass as a center of *excellence* by its ability to attract world-leading data assimilation scientists, both as staff and collaborators. Management style and practices emphasize *accountability*, e.g. by transparency in reporting to clearly defined targets set by the partner agencies.

In a nutshell, the Joint Center is already applying the European *secret sauce* within the American ecosystem to tackle a *big science* issue. It is also expanding to new technologies such as Cloud computing and artificial intelligence. As EPIC focuses on encouraging and incorporating innovative science, it should also utilize an innovative business model. Bold and aggressive steps are required in establishing a center that is impactful, effective, and concrete. As such, we can draw from the success of the JCSDA, a reinvented multi-agency partnership with the connective tissue to the research community.

Necessary ingredients for success: what will make EPIC different and successful?

A focused effort—without distractions or fragmentation of resources—on a single end-to-end NWP system needs to provide the *strength of a common goal* that has led to the success of the European Centre.

In order to allow for efficient research to operations (R2O), EPIC will need to support operations to research (O2R) by making the operational Earth system prediction available to the research community. R2O and O2R can be integrated into a R2O2R process. The objective is to provide an operational-grade system that can be used and further developed outside the NOAA operations. In order for this system to be used in basic research, it must be flexible enough to be configured for simpler, perhaps more idealized setups. This requires to develop and maintain an end-to-end research system tested under operational constraints, such as real-time conditions.

EPIC will need to be the architect and code integrator in charge of the development of the system. This includes the duty to carefully integrate selected developments from NOAA labs, universities and research centers. By acting as the focal point for model development, EPIC will accelerate the R2O process. The process will need to take an agile, focused and measurable approach that will demonstrate the value of community involvement. EPIC's responsibility will cover continuous delivery of improved analysis and prediction software that can be used by operations and research partners.

Critical to EPIC's success is the establishment of milestones and goals that can provide evidence of success. These goals should be established along scientific needs, computing needs, and organizational needs, and be part of a well-considered, comprehensive and agreed-upon R2O2R strategic plan. EPIC should be evaluated via metrics and scores that quantitatively measure forecast skill improvement. That is where EPIC's success lies: a narrow, non-overlapping mission with clear responsibility and accountability.

EPIC Management, Planning, and Governance structure

Accountability needs to be paired with adequate delegation of authority. The Director of EPIC will need proper alignment between responsibility and authority to lead the organization to meet its mission. EPIC will be managed by expert scientists familiar with operational constraints and relying on a streamlined executive structure, lean decision making, and agile governance. The new center will be staffed with the best scientists and software engineers who will a) actively collaborate with subject-matter experts in other labs and universities, carefully selecting and integrating contributions from the community to improve the system, b) work undistracted by proposal writing and unnecessary meetings, c) rely on state-of-the-art infrastructure to boost productivity internally and across the enterprise, and d) implement new technology best practices, such as small, nimble, agile, fast, efficient developments.

EPIC oversight by the community should be done in a manner that ensures proper oversight, but that also eliminates oversight redundancies and streamlines some of the many NOAA community engagement, advisory, and oversight entities. As such EPIC governance can be inspired by the existing multi-agency governance for the Joint Center for Satellite Data Assimilation (JCSDA). A center with a *hub-and-spoke* structure, as depicted in Figure 2, would increase NOAA's ability to engage world-class scientists and engineers, while ensuring result-driven collaboration and accountability of core personnel employed in the external community partner hosting EPIC, as well as visitors and joint appointments.

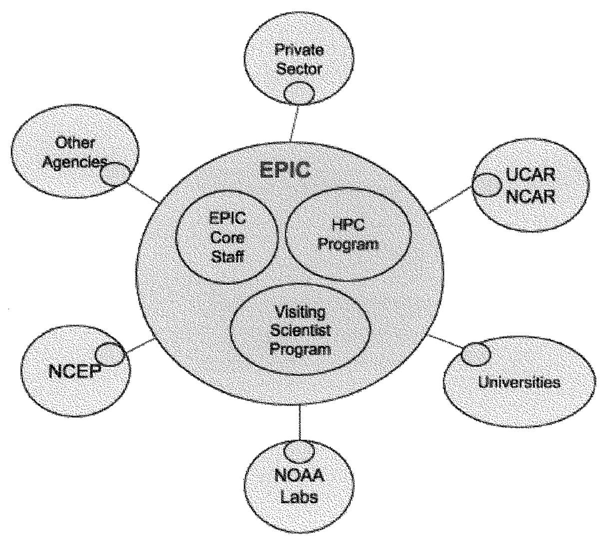

Figure 2: Schematic of the proposed distributed structure for EPIC, following a Hub-and-Spoke approach.

Critical to EPIC's success is the existence of a transparent governance and a coordinated core team dedicated to the R2O2R process. A critical mass of resources and scientific and software engineering expertise is needed to provide the continuous engagement with the government and the community that is needed in a distributed environment. A central location for the community to engage with a community-based model system and obtain information about the system is essential to establishing a useful user support framework. Scientific, technical and administrative expertise will be comprised of a combination of core staff, visitors, and in-kind contributions.

A vibrant EPIC visiting scientist program, ranging from students and early-career scientists to established researchers, that will attract operationally- relevant talent from across the university and private sector community. Such a program would facilitate the collaborative work needed to test and share ideas. This could include Federal employees participating for a limited number of years, then returning to their home institution with new and improved skills.

EPIC will require adequate staffing and computing resources. Funding will need to be on par with the mission of the organization, and stable year-over-year so top-class staff can be recruited and retained. Furthermore, the best brain power will have no effect without a massive investment in high-performance computing, which is a key element of numerical forecasting.

Cloud-Based High Performance Computing

Central to the success of EPIC will be the ability of community researchers and developers to interact with and manipulate models in a non-NOAA environment. The implication is that experiment results and software developed in the context of EPIC must be accessible and portable across systems. Cloud computing, with its recent and rapid technological advancements, provides a unique opportunity for improved capabilities, leveraging resources that are elastic and broadly accessible. Recent studies show that large numerical applications can run efficiently on Cloud platforms, rendering them the technology of choice for an organization like EPIC.

For efficiency reasons, the usage and processes to access Cloud computing resources should be managed by EPIC. In particular, there should be no external restrictions with regard to innovative solutions that deliver accurate forecasts on time. Quantitative estimation of resources should be driven by the sole objective to regain leadership in global weather forecasting. Starting with the current cost of NOAA operational forecasting, and extrapolating foreseeable evolutions in science, EPIC should allocate at least five times more computing power and storage capacity for research. We anticipate the need for *significantly increased* computing capacity to bring EPIC to a comparable level with other weather forecasting organizations around the world. This is a critical requirement for success.

External Engagement and Community Modeling

EPIC should leverage existing and successful community capabilities contributions of scientists on specific tasks that are well scoped and scheduled. More specifically, EPIC could engage the research community through task orders (contracts with delivery-specific scopes) that will focus on specific development needs. These task orders could be synthesized through conversations that will delineate statements of need, statements of work, definition of deliverables, schedules, milestones, and mechanisms for accountability of deliverables. EPIC can assume the role of system architect and integrator, and break developments down into *work packages* that may be outsourced to the community where appropriate. Strong collaboration and accountability should be expected for the development of work packages.

EPIC should ensure that a successful partnership exists between NOAA Labs and EPIC in order to ensure that parallel efforts specific to operational model development are shared. To this end, EPIC should engage NOAA to scope high-level research priorities, involve staff in co-development of the community system, and ensure smooth technology transfer. EPIC should continuously test and deploy its developments against operations. Technology transfer could be driven by operational scheduling constraints, and can consistently take advantage of the latest available code release. Continuous integration and continuous delivery following the widely adopted DevOps approach (Figure 3) will help avoid inefficiencies and will provide a powerful risk mitigation strategy for R2O2R.

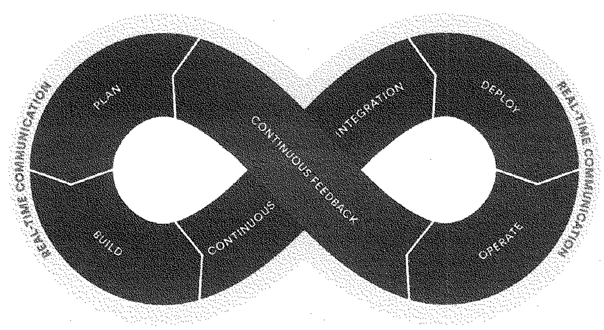

Figure 3: DevOps approach to build, test and release weather prediction capabilities faster and more reliably. Continuous feedback and integration, once properly formalized, will allow to efficiently interface research developments with operational cycles.

EPIC should also work to share successes and look for opportunities to leverage other agencies working with programs focused on weather prediction developments (e.g., NASA, DoD, DoE, NSF). In addition, international partners have a vast amount to offer to improve the R2O2R process.

Figure 4: Illustration of the vision of EPIC as an agile and focused entity that will efficiently steer the U.S. weather prediction enterprise (aka the 'Uncoordinated Giant') to its destination.

Concluding Remarks

EPIC should be a center hosted by a trusted community partner with reach into academia, government, and the private sector. A single acquisition implementing the Hub-and-Spoke organizational model inspired by the JCSDA will make the trusted partner accountable for the success of EPIC, while ensuring the necessary connection with operations. If NOAA were instead to host EPIC internally and contract out separate pieces of requirements, the program would lack the success assuredness and contractors would lack agility and would have few tools and incentives to encourage community participation.

I dream of EPIC as an agile center (Figure 4), where scientists focus on their science, red tape is reduced to a minimum, a streamlined executive structure is directly accountable, and community collaboration is entirely result-oriented. Let the government - in connection with academia, industry - articulate operational forecasting needs and establish milestones, and EPIC can use the community's ingenuity and vast resources to reach and even surpass forecast improvement goals.

Finally, Chairwoman Fletcher, Ranking Member Marshall, and Members of the Subcommittee, I invite you to reflect on this pivotal question: should EPIC be a mere facilitator within NOAA's research to operations process, or do we need a paradigm shift in order to collectively reclaim the United States' world leadership in weather prediction?

Dr. Thomas Auligné
Director, Joint Center for Satellite Data Assimilation (JCSDA),
Interim Director, UCAR Research to Operations Center
University Corporation Atmospheric Research (UCAR)

Dr. Thomas Auligné is the Director of the Joint Center for Satellite Data Assimilation (JCSDA), a research center based on a multi-agency partnership between NOAA, NASA, the U.S. Navy and Air Force. He is responsible for the mission to accelerate and improve the quantitative use of satellite data in weather, ocean, climate and environmental analysis and prediction systems. Before joining the JCSDA in 2015, Dr. Auligné has held research scientist positions at National Center for Atmospheric Research (NCAR), the European Centre for Medium-Range Weather Forecasting (ECMWF), and Météo-France. Dr. Auligné earned a M.S. in Meteorology and a Ph.D. in Atmospheric Physics in Toulouse, France. His main topics of interest are data assimilation, remote sensing, artificial intelligence, Earth system prediction, and improving transition from research to operations.

Mr. CASTEN. Thank you. At this point we will begin our first round of questions. The Chair will recognize himself for 5 minutes.

I want to start by thanking you, Dr. Jacobs, for a really productive meeting we had in my office last week on NOAA, and the future of weather forecasting, the role of science, the Enlightenment. We had a wide-ranging conversation, I appreciate it. And I really just want to emphasize again how much I appreciate you taking the time, as we discuss in greater depth today the EPIC program, and the future of U.S. weather modeling. And I also want to make sure that we keep in mind the great work of the National Weather Service forecasters, and their efforts to ensure that communities receive timely and accurate forecasts of major weather events 24/7/365.

To that end, Dr. Jacobs, I will again echo my concerns about NOAA's FY20 budget request to eliminate 110 full-time equivalents, and I just want to reiterate the ask I made in our meeting, and my subsequent letter, which I will use my power as Chair, with unanimous consent, to enter into the record. I just would ask that you follow up with the Committee on the issues raised in that letter. Thank you.

Dr. Jacobs, in your testimony you discussed how, once integrated into the infrastructure of NOAA, that EPIC will be used within the Unified Forecast System to improve the forecast skill of NOAA's other modeling initiatives, including climate and ocean models, which, as a scientist myself, I geek out on how that would all work, and the idea of actually having a model that can both research and model many types of events, hydrological changes, sea level rise, fisheries, and harmful red tide. Can you help us understand, what is your timeline under which EPIC can improve these other economically and ecologically important forecasts, and especially with tying in near-term weather to crucial longer-term climate models?

Dr. JACOBS. Sure. Thank you very much for the question. Very much appreciate the time we spent together, and appreciate your interest in NOAA and numerical weather prediction. The Unified Forecasting System is a way to sort of streamline our production suite. Inside of the National Center for Environmental Prediction, we run a lot of different models, from high-resolution short-range convection, to dynamic climate models, medium-range models, and then we have wave models, ocean models, hydrological, biological, ecological models. We're trying to get all of these in a unified system, and this sort of hinges on the NCAR/NOAA MOA (memorandum of agreement), where we were looking at a common code base, and a common infrastructure. The Finite Volume Cubed Sphere, FV3, dynamic core was actually written as a dynamic climate model, but we realized we could actually use it at high resolutions as a weather model. What's appealing to me here is when we can unify a lot of the code architecture, then we eliminate a lot of these redundant kind of parallel development programs, and have the same amount of people all focused on a unified forecasting system.

The timeline is essentially—we really wanted to focus on the global model first because the global model provides the boundary conditions for all of the other models. In other words, if you're interested in looking at a forecast for harmful algal bloom, we have biological models for that, but those models depend on a hydrological model, which models how there's runoff, and, of course, that depends on the weather model, which forecasts precipitation. So the first sort of foundation of this is implementing the global model, and then all of the other models that use that for initialization will then be implemented.

Mr. CASTEN. And, I'm sorry, just because I'm tight on time, and I want to get one more question in, any ballpark on schedule, or is it too soon to say?

Dr. JACOBS. Well, we're already pretty far down the road in developing the Unified Forecast System. We're expecting—we've been—we've actually just had a public release of the seasonal—the sub-seasonal version of the code. It's on GitHub now, but it's supported yet for the community, so we're really trying to work on the model support for that. These upgrades will be coming out on GitHub as I speak. We're hoping to get the RFP (request for proposals) for EPIC out early next year.

Mr. CASTEN. OK. Dr. Mass, with the little time I have left, I want to raise with you a conversation I had with Dr. Jacobs, given your numerical modeling background. I sit on the AI (artificial intelligence) Task Force on Financial Services, and we have this continuing conversation around—in a world of machine learning and AI, there's this tradeoff between precision and accuracy and transparency of algorithms. As we build out more and more sophisticated weather models, given your background in modeling, do you see tradeoffs coming in the weather forecast model as we get more precision with machine learning, but potentially start to separate from the fundamentals in the models that we've relief on that have some level of physical understanding? And is there anything that we should be concerned about as a Committee if that break happens?

Dr. MASS. I don't know if concern is the right word, but I think the marriage of AI with modeling is very powerful. AI is—and machine learning's very powerful for quality control, but just as importantly for post-processing and model output, so you need both. You need the dynamical models, but you need machine learning on both sides, so—together they're much more powerful.

Mr. CASTEN. OK. And I see I am out of time, so I now recognize Ranking Member Marshall for 5 minutes, who we have missed—Mr. Lucas, you are recognized for 5 minutes.

Mr. LUCAS. Thank you, Mr. Chairman. I appreciate the opportunity, and, Dr. Jacobs, you've been before the panels enough times to know that occasionally we ask about the same thing, we just come at it from slightly different angles. And, with that in mind and in spirit, I'd like to note that I am concerned that NOAA may be approaching EPIC implementation as something of a software issue, or the agency views the biggest challenge to improving weather forecasting is simply improving existing software. What assurance can you give the Committee that NOAA's engaging the academic community and the private sector to ensure that this is truly a community-based weather prediction model?

Dr. JACOBS. Well, the primary assurance I can give you is that it'll have to exist outside of NOAA, and having the involvement of industry and academia is essential. This will all be built into the request for proposals. We had a big meeting in August. We just released the report of that meeting yesterday, and we had a lot of stakeholders from all the sectors involved and contributing, so the whole point and design of this is to—is a stakeholder-run program, with an operational outcome that NOAA should benefit from.

Mr. LUCAS. And along that line, Doc, I'm a Member of a body where there seems to be an ever-increasing turnover, so when I ask this, I ask this in the politest of terms. What assurance can you give the Committee that EPIC will continue past your tenure at NOAA?

Dr. JACOBS. Well, once the RFP—once——

Mr. LUCAS. And I'm not predicting the length of anyone's tenure. I'm just asking about continuality.

Dr. JACOBS. No, this was a top priority for me, and making sure this lives past my tenure is extremely important, and that's another reason why having it, you know, externally managed would ensure that if it's inside of NOAA, then NOAA, you know, has complete and total direction. If it's external, even if—I mean, I expect that NOAA will have a seat at the table in guiding what it does, but largely driven by external stakeholders will ensure that, even if I'm not at NOAA anymore, it will still be successful.

Mr. LUCAS. And along that line, if you could expand a little bit on your current acquisition strategy, and the timeline that we're very concerned about here about implementing EPIC?

Dr. JACOBS. So there's the RFP, which we expect to go out early next year, first month or two, and then an additional—so there's two sort of acquisition strategies we're concerned about. One of them is where does EPIC live? We'll learn that when the award goes out. Then there's the acquisition of cloud-based compute resources. This is a little bit trickier. So we have a need to procure cloud-based resources, but right now, with the Federal acquisition regulations, it's very complicated for us to try to figure out how to buy cloud compute on a demand that fluctuates. It's not just like buying a rack of servers.

Mr. LUCAS. And as an elected official, I would be remiss if I didn't ask how universities, such as The University of Oklahoma, would have a chance to participate in EPIC?

Dr. JACOBS. Well, my hope——

Mr. LUCAS. They're are homegrown questions, you know, wherever we come from.

Dr. JACOBS. I, you know, so obviously their expertise is largely in convective weather forecasting, and there's a component of this that will deal with that weather forecasting. I would hope that they would be both contributing model improvements, as well as benefiting from some model improvements, as well as the Mesonet Program, and all of the different observing systems. We'll be able to test those in this open cloud-based architecture, which I think will benefit not just the forecasting, but the observation systems going into the models.

Mr. LUCAS. And one more time, touch on what you would define as the milestones that will reflect our progress toward closing the gap with the Europeans?

Dr. JACOBS. So the first initial milestones of success would just be how many external stakeholders are using the code, so we would want to monitor how many downloads, what's the user interest? And after that we would, you know, we would hope that we would start to see contributions and improvements coming back, but the initial steps are just getting the external stakeholders engaged in the program.

Mr. LUCAS. And, Dr. Mass, you're not exempt from these kind of questions either. I ask this, and I think I know the answer, but I'm going to ask, does the broader weather research community support EPIC?

Dr. MASS. I think the answer's clearly yes, but we want EPIC to be something that does serve the entire community. That's crucial.

Mr. LUCAS. Thank you, Doctor, and with that I yield back, Mr. Chairman.

Mr. CRIST [presiding]. Great. Thank you very much. Thank you to the witnesses for being here today. We all appreciate your attendance.

The ability to forecast hurricane tracks has greatly improved since the 1960s. Forecasting hurricane intensity has also improved, but less so than the track forecasts. In fact, in 2017 Congressional Research Service reported on forecasting hurricanes and found that the biggest challenge facing the National Hurricane Center is how to improve the ability to predict hurricane intensity. Being able to better predict how strong a hurricane will become, as well as when and where it will peak in intensity, is key for the district I represent along the west coast of Florida, which, as you know, is incredibly vulnerable to hurricanes year in and year out.

So, Dr. Jacobs, given how costly hurricanes are to the United States, and in particular to Florida, how will EPIC improve hurricane intensity prediction, if it will?

Dr. JACOBS. My expectation is that it will. The focus primarily for hurricane intensity is largely centered around two things: Two-way coupled modeling, with an emphasis on sea surface temperature, because that's essentially the fuel; and the physics in the model. So there's a deficiency in the model physics that needs a lot of research and improvement. EPIC will essentially be the external sandbox where stakeholders can test their improvements to both the physics, as well as the two-way coupling of the models, and then, additionally, new observations, new observing systems.

So there's a lot of new observing systems coming online, not necessarily NOAA assets, but industry assets, and even academic devices, that we don't have the internal bandwidth to test the impact of those obs in our system, but we can test the impact of those observing systems in the proposed EPIC sandbox.

Mr. CRIST. Great. Would any of the other witnesses care to comment on how EPIC will improve hurricane prediction? Dr. Neilley?

Dr. NEILLEY. Thank you, Mr. Crist. I think one of the critical ways in which EPIC can improve hurricane forecasting is by marriage of the Unified Forecast System with next-generation data assimilation techniques, particularly the types of technologies that are being developed in Dr. Auligné's group. There has been numerous scientific evidence that data assimilation, taking the observations that Acting Administrator Jacobs mentioned, and using them to initialize the model, can be one of the most important aspects of getting the hurricane forecast right. EPIC, if crafted correctly, is the cauldron in which entices all of these scientific capabilities to come together and be married to improve our weather forecasting capabilities.

Mr. CRIST. Great. Thank you very much. Any others? Yes.

Dr. AULIGNÉ. Let me tag along to this response. So there's multiple evidence showing that, if we're looking at the quality of the forecasting, the skill of the initial conditions and the actual model are equally important, and data assimilation is handling the initial conditions for the model, so we're actually blending together observation and previous model forecasts to actually optimize these initial conditions, which due to the chaotic nature of the atmosphere, are propagating and amplifying in the forecasts, so it's actually a critical component of forecast accuracy.

Mr. CRIST. Great, thank you. I wanted to ask—I'm running out of time. I wanted to ask one additional question, if I might. In addition to weather forecasting, NOAA's also responsible for researching and modeling other types of environmental concerns, such as red tide and algae bloom, which, as you know, is of great interest in the Sunshine State. Dr. Jacobs, can you discuss how EPIC will help improve forecasting for red tide and other harmful algae blooms?

Dr. JACOBS. So, as I was explaining earlier, a lot of these harmful algal bloom models depend on the atmospheric model forecast of precipitation and runoff to determine when there'll be triggers. Ultimately we are going to put in all of these secondary downstream models, so to speak, into the EPIC program. In conjunction with this, if we have an external repository for the modeling system, as well as the code that we're running on the cloud, we need to have an archive and repository for observations, and so building our observation system in the cloud is going to be essential both for initializing and verifying the models. And that's largely what NOAA's Big Data Project is focused on.

Mr. CRIST. Thank you very much, Dr. Jacobs. I would now like to recognize the Chair, Madam Fletcher.

Chairwoman FLETCHER. Thank you, Mr. Crist, for sitting in the Chair. I believe my first order of business will be to recognize Mr. Murphy for 5 minutes.

Mr. MURPHY. Thank you, Madam Chair. Thank you, gentlemen, for coming this afternoon. My area of expertise for the weather is looking up and seeing whether I need an umbrella or not, so thank you for giving me a heads up on that. Just one actually really kind of rudimentary question. Can someone just explain to me, in terms that I might understand, the difference between the European models and the American models? In other words, when I look at hurricanes, I live in eastern North Carolina, so we love to do the hurricane watch, and we see the American model is doing one thing, and then the European model is doing another thing. What's the fundamental difference between those two models?

Dr. JACOBS. So I'm going to try to answer this real fast, and then hand it over to the rest of the panel, but the primary fundamental difference is how the European center does data assimilation, and that's basically how they generate the initial conditions in the model. They use a true what we call four dimensional variational data assimilation, and right now the NOAA modeling system uses a four dimensional ensemble variational assimilation, but it's not a—they don't truly vary time as the fourth dimension.

Mr. MURPHY. Is he being truthful?

Dr. AULIGNÉ. Yes. So the principles—the fundamental equations are the same. The way that these models are implemented are quite different, like two car models can be quite different, although the principle of the car is the same. So, in terms of data assimilation, there's definitely a lot of emphasis in Europe on the algorithms, and the use of additional instruments, and more data, so that translates into actually additional forecast skills.

Mr. MURPHY. All right. Thank you. One other question. In medicine, we look forward to every new advancement, and what things are going to happen. But I will ask this question, and this is, you know, an honest, hard question. What is going to be our ROI (return on investment) on this? In other words, where are we now, stagnant now, and then if EPIC is fully instituted, how much more advanced do we truly, honestly, expect to be? In other words, what can we gain from this in implementing this system? Yes, sir, Dr. Mass?

Dr. MASS. Well, there's no reason to think the European Center is as good as we can be. American research capabilities far exceed that of Europe as an aggregate, so our skill can be better than that. I think we could catch up within years if we just got the data assimilation right, and then, over a longer period of time, improve physics. I think we could be ahead of them in 3 to 4 years if we really put the energies into it.

Mr. MURPHY. All right. Just a follow-up question, because I'm a function over form kind of guy, when we have hurricanes coming toward the east coast, everybody acts the same. They buy their water, they get their bread. How is this going to make it any different? Again, I'm just looking, you know, I believe in research, I believe in the advancement of knowledge by all means, but how is it going to change the lives of the average American, say on the east coast, with hurricanes?

Dr. NEILLEY. All people make decisions in all types of weather events, whether or not it's a hurricane, or a more mundane thunderstorm in the afternoon. Anytime you can make better decisions because you have better information, you're better off. There are estimates that the national economy is on the order of a trillion dollars dependent on weather, and by incrementally improving our weather forecast, if we can make that dependency down by, say, just 1 percent, that alone is a $10-billion payoff for our economy. I think that's the ROI that you asked for.

Mr. MURPHY. All right. Thank you. Chairwoman, I yield back my time.

Chairwoman FLETCHER. Thank you very much. I will now yield myself 5 minutes for questions, and I apologize for just arriving, as I believe my colleague Mr. Babin did. We were voting in another Committee. But I'm really glad to be here to see all of you, and I appreciated your written testimony. I'm sorry I missed your initial comments, but I do have a couple of questions that I think haven't been covered yet.

It's clear, from the written testimony, the recommendations from the Environmental Information Services Working Group, that a strong, accountable, and vision-oriented leadership and management is needed to ensure EPIC's success. To my understanding, there isn't a clear plan for that leadership, or management, or governance at this point, and so I want to ask all of you, what are your thoughts about who should lead EPIC and how it should be structured? And, Dr. Jacobs, I'd like to start with you.

Dr. JACOBS. So I'm going to answer this question at a very high level, because, really, the point of EPIC is to have it governed by the weather enterprising community, so I'd be interested to hear what the weather enterprising community had to say. The request for proposals is going to have some guardrails, but part of what we're going to be asking in the RFP is also proposal of a governance structure. You know, NOAA obviously has to be involved, but we want involvement from private sector and academia.

And ultimately EPIC may end up, you know, it could be, you know, end up at a university, it could end up at UCAR (University Corporation for Atmospheric Research), it could end up in industry, it could end up in some kind of combination of all of the above. The only things that I really would like are that its' got to be external to NOAA, NOAA's got to have a seat at the table, it's got to have an operational outcome for NOAA forecasting products in mind, and, other than that, a lot of the governance is going to be part of the proposal of wherever it ends up.

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

Dr. MASS. Well, this is going to be a community modeling system, so the community needs to be there. There needs to be at least an advisory committee that's in place. There needs to be some kind of group that encompasses all the people that are putting money into it, so that'll be there. But there needs to be leadership. One person has to be responsible. There has to be a leader, a director of EPIC, somebody who's responsible, and if it doesn't work out, heads will roll, that person. So you need responsibility, one point of responsibility.

Chairwoman FLETCHER. Thank you. Dr. Neilley?

Dr. NEILLEY. Thank you. I think the most critical characteristic of a successful EPIC is the breadth of the science and diversity of science that takes place in it. In order to achieve that, EPIC has to be crafted in a way that the scientific community is enticed to participate, and is not sort of mandated or directed to participate. It is the place to go to conduct numerical weather prediction science in the world, and, as such, it will create, therefore, the best numerical weather prediction science, and come back to benefit NOAA and others.

Who should lead EPIC is the institution that is best able to create that enticing institution that scientists want to go to, and that's who should lead them.

Chairwoman FLETCHER. Thank you, Dr. Neilley. Dr. Auligné?

Dr. AULIGNÉ. So I think that one of the main risks for EPIC is fragmentation. We want, first, to make sure we have a clear focus, and clear—as Dr. Mass was saying, clear accountability. We need to make sure we can define and measure success, and can have somebody accountable for it. Then we need to have these clear connections with the community, and clear connection with the government as well. So it can't be completely inside the government, because we're not trying to replace NOAA. We're not trying to replace the research and the R&D (research and development) in NOAA. We're trying to supplement, and really help the government with more agility, and more connection to the community. So that's basically what I think is required for the institution that would lead it.

Chairwoman FLETCHER. OK, thank you. And I want to follow up, Dr. Mass, on your comment about leadership, there needs to be clear leadership. Do you have ideas, or a vision, or a thought, of what that leadership should look like, not a specific person, obviously, but when we talk about what is the structure, and I'm going to circle back to Dr. Jacobs in a second, but what does that look like to you, or what should it look like, in terms of that leadership?

Dr. MASS. Well, we can see that. We can see our competition, the European Center. They do have a leader, a scientific leader, that oversees the whole program. That's the responsible person. But they do have an advisory board that's there as well that represents all the various countries that are involved, and they have scientific advisory committees. So they give us somewhat of a pattern of what we could follow that's been highly successful.

Chairwoman FLETCHER. OK. Thank you. And, Dr. Jacobs, you mentioned in your testimony about the RFP, so I just wanted to get a follow up on that as well to know your thoughts about sort of a dedicated staff and leadership team, and if that is something planned, and if so, when it will be announced?

Dr. JACOBS. So that's largely going to come out of the responses from the RFP, wherever the award goes, but, to Dr. Mass' point, I think we'll probably end up finding a—where we have some type of board, and then a single-point person who has autonomy, accountability, and control over the budget. Some of the things that I've seen have failed in the past were run by individuals who had complete autonomy, and no budget authority, so they couldn't actually execute great decisions.

Chairwoman FLETCHER. Thank you, that's helpful. I have managed to go over my time already, so I'm going to yield back, and I'm going to recognize Dr. Babin for 5 minutes. Thank you very much.

Mr. BABIN. Thank you, Madam Chair, appreciate it, and appreciate all of you expert witnesses for being here. Dr. Jacobs, as you know, the 36th District of Texas, over in the southeast portion, was hit especially hard by Hurricane Harvey in 2017. Additionally, Tropical Storm Imelda dumped a record amount of rainfall in my district just a few months ago, in September. This storm came out of nowhere, with a severity that surprised everyone, and left most of my constituents without time to prepare for it.

Let's jump ahead, hypothetically, just a few years into the future, where EPIC has been successfully implemented, and is operating. Can you walk us through the processes of a fully functioning EPIC as the storm approaches, and how the days leading up to, and immediately following a storm like Harvey or Imelda, and how that would be different?

Dr. JACOBS. Sure. Thank you very much for the question.

Mr. BABIN. Yes, sir.

Dr. JACOBS. So the fully successful EPIC will happen, pardon the pun here, but way upstream from these precipitation events. So what would happen is—when you look at the National Water Center, which is a fantastic center, they've got the National Water Model, it's, you know, it's a very successful program, but if there is one weak link in the National Water Model, it's that we have to forecast properly where the rain's going to fall, otherwise we don't know where the runoff is going to go.

And so having EPIC be the center where we actually feed in inputs to improve the forecast of prediction of rain will then subsequently improve the prediction in the hydrological models. So a lot of this will happen months to years in advance, but you will see the improvements of those actual forecasts find their way down into, you know, things like, you know, not just hydrological models, but also biological and ecological models as well.

Mr. BABIN. Sure. OK. And I also serve as the Ranking Member of the Space Subcommittee here, with the privilege of representing Johnson Space Center. I know the impacts that one government facility can have on an entire region. As it stands, EPIC will be a virtual center that will have tremendous benefits by operating in the cloud, both in terms of cost and innovation. Again, looking ahead to years down the road, when EPIC will be running smoothly, and surely will be the gold standard at that time, is there a scenario where a physical center, rather than a virtual center, could be beneficial to EPIC's mission?

Dr. JACOBS. Absolutely. Thank you for allowing me to clarify this. I have often referred to EPIC as a virtual center because EPIC, when it's listed in the budget proposal, was—as $15 million, and I didn't want anyone in the budgeting process to think I was planning to actually build a brick and mortar center for only $15 million. So, when we put out the RFP, EPIC will have to live somewhere. There will have to be people in seats, at computers, in some type of facility, whether it's a university or other, you know, other facility, there will have to be a physical center. In addition to that, if we have the opportunity to expand this program, it's entirely probable that we, you know, we would need an additional physical center for this somewhere.

Mr. BABIN. Right. Yes, sir. Dr. Mass?

Dr. MASS. Well, even if we're very successful creating the best weather prediction system in the world, we're still going to need the computers. So if we don't have vastly increased computer resources, we're not going to be able to deliver the forecasts that we really want to. That's really important.

Mr. BABIN. I understand. Thank you. Well said. You know, I'll yield back, Madam Chair. Thank you very much.

Chairwoman FLETCHER. Thank you, Mr. Babin, and thank you to all of our witnesses. I know we just rushed in, and unfortunately, we have to go back and vote in our other Committee. I'm sorry to say, but since we have all come and gone from the hearing, I really appreciate all of you coming in, testifying, sharing your thoughts. I think this is really exciting to see what's happening, and I'm grateful for all of you participating today.

Before we bring the hearing to a close, I also want to mention that the record will remain open for 2 weeks for additional statements from Members, and any additional questions that the Committee Members may have for the witnesses. But, for now, the witnesses are excused, and the hearing is now adjourned.

[Whereupon, at 2:57 p.m., the Subcommittee was adjourned.]

Appendix I

Answers to Post-Hearing Questions

ANSWERS TO POST-HEARING QUESTIONS

Responses by Dr. Neil Jacobs

HOUSE COMMITTEE ON SCIENCE, SPACE, AND TECHNOLOGY
"A Task of EPIC Proportions: Reclaiming U.S. Leadership in Weather Modeling and Prediction"

Questions for the Record to:
Dr. Neil Jacobs
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)

-----Submitted by Chair Lizzie Fletcher-----

1. **NOAA's Fiscal Year 2020 budget request includes $15 million total to establish EPIC.**
   a. What is NOAA's plan for spending the requested $15 million?
   b. What are the short- and long-term funding needs for EPIC?

Answer:

A) NOAA's Earth Prediction Innovation Center (EPIC) will advance weather modeling skill and international leadership in the area of numerical weather prediction. The President's fiscal year (FY) 2020 budget request included $15M for EPIC to provide community-driven advances to the Unified Forecast System (UFS), a comprehensive modeling and prediction system. The UFS will enable NOAA to simplify and modernize its numerous forecast models, each of which has to be improved and maintained, to a seamless suite of models that produce forecast products from sub-hourly to seasonal predictions and from local to global scales. NOAA has released a draft 5-year strategic plan for EPIC, which includes an investment strategy for the program, and a Request for Proposals (RFP) for the initial elements of EPIC to be funded initially with FY 2020 appropriations. The draft EPIC strategic plan was released on January 10, 2020, and the RFP was released on March 23, 2020. The results of the RFP should provide NOAA with software engineering, user support services, and software infrastructure for the UFS using cloud high performance computing (HPC). These are three critical areas for EPIC's infrastructure necessary for both engaging the modeling community and research and development. Other aspects of EPIC include engaging the community by hosting workshops and tutorials to train the next generation of model developers who will enhance our numerical modeling systems. The draft 5-year strategic plan for EPIC is available on our website at https://owaq.noaa.gov/EPIC-Strategic-Plan-2020. The RFP can be found at https://beta.sam.gov/opp/6b54b55cc282464597320df962b2740f/view.

B) NOAA's draft 5-year strategic plan for EPIC includes the investment strategy for the program, goals for improving weather forecasting, and details on the foundational needs of NOAA. These needs include creating the infrastructure for EPIC via the ongoing RFP and simultaneously beginning community research efforts towards improving numerical weather modeling. The President's Budget for FY 2021 requested $15 million for EPIC, a $7M increase over the $8M enacted in FY 2020 for EPIC.

2. **The U.S. Air Force discontinued using NOAA's global weather model in 2015, opting instead to use the United Kingdom's Unified Model. Other U.S. agencies have been working on their own numerical weather models, separate from the NOAA model.**
    a. How should EPIC persuade the Air Force and other U.S. agencies to use and contribute to EPIC's Unified Forecast System?
    b. How should EPIC foster interagency coordination, and what should the roles of various agencies be within EPIC's framework? Which agencies should be involved in EPIC?

Answer:

A) EPIC is intended to make the UFS the optimal model platform for use by NOAA to support its operational forecast mission to protect life and property and improve economic growth. It will also be used by other agencies to support their environmental modeling mission needs. It will do so by providing a framework to accelerate community-developed enhancements into the UFS and its operational applications. The UFS will be scientifically credible, computationally flexible, and available to the entire scientific community for use in development of system improvements and operational applications. As elements of this system are implemented, all stakeholders in weather forecasting, including the Department of Defense, other federal departments and agencies, academia, and private industry, will be encouraged and empowered to use and contribute to the further development of the UFS. As the UFS applications continue to grow in scope, it's imperative that organizations run their own UFS applications and contribute source code back to the UFS repository that will be hosted by EPIC. Ongoing coordination across agencies is part of the community engagement strategy to ensure the success of EPIC.

B) EPIC will initially focus on improving the UFS weather application and achieving the goals and objectives laid out in the EPIC Strategic Plan while also working closely with NOAA to successfully support the modernization of the modeling production suite described in the UFS Strategic Implementation Plan (SIP). Other federal agencies and academia will benefit from EPIC's tools and services, which will in turn serve the entire weather modeling community. Interagency coordination and involvement are highly important to the success of EPIC; however, agencies must see benefit and value in joining this effort to support their respective missions and outcomes. In order to enhance the value proposition to the weather enterprise, EPIC must produce advanced modeling tools that are documented and easy to use by the community of users. NOAA is initiating this effort and is already engaging multiple agencies on finding common goals to advance the various missions, consistent with the authorizations of those agencies.

-----Submitted by Chairwoman Eddie Bernice Johnson-----

1. How should EPIC encourage researchers in academia and the private sector to contribute to EPIC's Unified Forecast System, rather than continue to work on their own separate numerical weather prediction models?

Answer: NOAA is making every effort to engage federal partners, the academic community, and the private sector during the 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, held the EPIC Community Workshop in August 2019, held an Industry Day with vendor meetings in September 2019, and released a Request for Proposals in March 2020. All previous engagements were successful and have helped to refine our vision and strategy in development of the program.

To enable a broad and vibrant community of UFS users and developers to contribute to the UFS, EPIC will provide user support services (USS), which will nurture a collaborative, community-based framework to support, advise, and educate a cadre of system and software users, as well as developers, to work on improvements and advancements to the operational forecast system. The UFS code will be well-documented and extremely user-friendly, such that, in a matter of hours, a researcher in academia or the private sector can install and test the code, then quickly begin running the code for development purposes. Once the state-of-the-art UFS code is available and accessible for use, academics and others will have these tools to use as a baseline for beginning their research and work.

2. To determine whether EPIC is on its way to meeting its mission, there must be benchmarks through which Congress, the weather community, and the public can measure its success. Tangible metrics will help to inform Congress and our Committee as to what EPIC's current and future funding needs are, and whether additional resources will need to be allocated in order to make it a successful program.

a. What are the best ways to measure EPIC's success? What metrics of accountability would be the most useful and appropriate to determine the efficacy of the program going forward?

Answer: Quantifiable metrics for EPIC's success are essential. Initial metrics will be based on stakeholder engagement, including parameters such as quantifying the counts of software, downloads, user requests for support, and the sector diversity of users of the UFS. EPIC's success will be determined by quantifiable improvements to NOAA weather prediction models in the near term and earth system models in the longer term. The rate of adoption of the UFS by the community is critical to the success of EPIC, as we expect our ability to leverage their work will lead to improvements in our forecast systems. We expand on these metrics in the draft EPIC strategic plan released on January 10, 2020, available on our website at https://owaq.noaa.gov/EPIC-Strategic-Plan-2020.

-----Submitted by Ms. Suzanne Bonamici-----

1. The National Science Foundation (NSF) awards grants to fund basic research, while NOAA largely funds applied science research.
   a. How has this funding paradigm affected the weather forecasting community? Given one of the goals of EPIC is to improve research to operations and operations to research, how should EPIC award grants to solve this? What types of awards would be the most appropriate to accomplish its mission, and what levels of funding would be needed?

Answer: Applied and basic research are synergistic efforts. Both are essential to advancing the state of science generally and weather forecasting specifically. NOAA looks forward to continuing to partner with NSF, within the bounds of our authorities, to support researchers in order to improve earth system models and make advancements within the UFS by leveraging the contributions of the basic research community.

For research-to-operations (R2O) funding, EPIC will leverage components of existing NOAA testbeds and multi-Agency Centers, particularly the Joint Center for Satellite Data Assimilation (JCSDA) and the Developmental Testbed Center (DTC). In addition, EPIC will use existing funding opportunities, such as the Joint Technology Transfer Initiative (JTTI), to support grants and cooperative agreements that focus on advancements in the UFS. EPIC will build on best of processes associated with research to operations to research (R2O2R) for software engineering as well as for numerical weather prediction (NWP) to infuse best practices into software development that engages and enables integration of the weather research and development community.

NOAA, through EPIC, will integrate its processes and capabilities for model science and code development, including data assimilation and related codes, system architecture, and providing support to enable community modeling and computational efficiencies. We will accomplish this through the RFP announced on March 20, 2020 (released on March 23, 2020) that will lead to a contract to provide NOAA with software engineering, user support services, and software infrastructure for the UFS using cloud HPC. In the coming year, EPIC will continue to engage the academic community through tutorials, workshops, and cooperative agreements and grants based on the availability of funding. Potential startup grants would go to support graduate students and researchers needed to build a community of UFS users.

2. NOAA has partnered with universities to enhance weather research capabilities through the Cooperative Institute system. In June of this year, NOAA awarded University of Maryland in College Park with a 5-year, $175 million funding agreement for the Cooperative Institute for Satellite Earth System Studies, a national consortium of more than 2 dozen academic and nonprofit institutes. This CI builds on the success of previous CIs between UMD and NOAA.
   a. How should EPIC involve the Cooperative Institutes and leverage the brainpower and partnerships there?

Answer: Cooperative Institutes (CIs) will be critical partners in establishing and expanding upon EPIC as it works to improve the UFS. CIs provide scientific expertise in meteorology, oceanography, hydrology, air quality, and climate. As EPIC is able to build and support a unified set of applications that make up the UFS, EPIC will strategically engage all of the CIs in scientific innovation. One of the keys to EPIC's success is successful adoption of the UFS as a research and development platform for the community. As EPIC is able to provide model development tools and software, the first community of users is within the CIs. Having the CIs transition their research to the UFS model development framework will accelerate improvements to our weather prediction systems. Fostering the CI and broader research community is part of our vision to maintain and grow the community in partnership with NOAA, ultimately contributing to the success of EPIC.

-----Submitted by Mr. Paul Tonko-----

1. The mission of the National Weather Service is to "provide weather, water, and climate data, forecasts and warnings for the protection of life and property and enhancement of the national economy." Its vision is to create a Weather-Ready Nation that is "prepared for and responds to weather, water, and climate-dependent events." As such, the National Weather Service provides critical data that informs both daily weather and extreme event forecasts. These forecasts are extremely important to all Americans.
    a. How will EPIC benefit the mission of the National Weather Service and improve upon the important daily and extreme weather forecasts that Americans so heavily rely on?

Answer: Daily weather and extreme event forecasts that are produced operationally by the National Weather Service (NWS) are founded on the guidance provided by numerical models. Improving the UFS and Numerical Weather Prediction models – a key feature of EPIC – will directly result in improvements to these forecasts, thus contributing to timely warnings for the protection of life and property.

2. Considering that the "I" in EPIC stands for innovation, EPIC must spur new research and operational developments in order to be successful. I'm particularly interested in how EPIC will stimulate innovation in the climate research space. EPIC has the potential to combine the expertise and skills from across the weather enterprise to make significant advances in climate research and modeling.
    a. Given that the world is already feeling the devastating impacts of climate change, should EPIC be focusing on climate modeling as well?

Answer: It is expected that the scope of EPIC will expand to include other operational model applications and mission priorities outlined in the Weather Research and Forecasting Innovation Act of 2017 (WRFIA), such as convective allowing models (*i.e.*, High Resolution Rapid Refresh) and fully coupled subseasonal-to-seasonal (S2S) forecast systems (*i.e.*, the Climate Forecast System, National Water Model, Ocean Forecast Systems).

Responses by Dr. Cliff Mass

Responses by Professor Cliff Mass, University of Washington, to questions provided by the House Committee on Science, Space and Technology

HOUSE COMMITTEE ON SCIENCE, SPACE, AND TECHNOLOGY

"A Task of EPIC Proportions: Reclaiming U.S. Leadership in Weather Modeling and Prediction"

Questions for the Record to:
Dr. Cliff Mass
Professor of Atmospheric Sciences
University of Washington

Submitted by Chair Lizzie Fletcher

1. **NOAA's Fiscal Year 2020 budget request includes $15 million total to establish EPIC.**
   a. **What are the short- and long-term funding needs for EPIC?**

2. **The U.S. Air Force discontinued using NOAA's global weather model in 2015, opting instead to use the United Kingdom's Unified Model. Other U.S. agencies have been working on their own numerical weather models, separate from the NOAA model.**
   a. **How should EPIC persuade the Air Force and other U.S. agencies to use and contribute to EPIC's Unified Forecast System?**
   b. **How should EPIC foster interagency coordination, and what should the roles of various agencies be within EPIC's framework? Which agencies should be involved in EPIC?**

1. EPIC, if it is to serve its crucial national role, requires substantially more funding to be successful. Funding must be sufficient to support approximately 100-150 scientists and computer staff. $15 million is reasonable for the first year, but Congress should budget substantially more (~50-100 million per year) over the long term. There will rarely be a better investment for the American people. I should note that some funding could/should be found by reducing support of many of the inefficient, redundant efforts now in place, and transferring the funding to EPIC. Substantial funding is also needed for the computer resources required by EPIC (5-10 million per year).

2. EPIC should be supported to rapidly build a superior prediction system and once this excellence is demonstrated, Congress should strongly encourage or require that U.S. agencies implement it. Congress has the power to do so. It will difficult for agencies not to use a superior American system. Agencies that should be involved in EPIC include: NOAA, NASA, DOD, USDA, and NSF. Congress can encourage such agencies by increasing funding to EPIC, while reducing model development resources in these agencies.

HOUSE COMMITTEE ON SCIENCE, SPACE, AND TECHNOLOGY

"A Task of EPIC Proportions: Reclaiming U.S. Leadership in Weather Modeling and Prediction"

Questions for the Record to:
Dr. Cliff Mass
Professor of Atmospheric Sciences
University of Washington

Submitted by Chairwoman Eddie Bernice Johnson

1. **How should EPIC encourage researchers in academia and the private sector to contribute to EPIC's Unified Forecast System, rather than continue to work on their own separate numerical weather prediction models?**

2. **To determine whether EPIC is on its way to meeting its mission, there must be benchmarks through which Congress, the weather community, and the public can measure its success. Tangible metrics will help to inform Congress and our Committee as to what EPIC's current and future funding needs are, and whether additional resources will need to be allocated in order to make it a successful program.**
   a. **What are the best ways to measure EPIC's success? What metrics of accountability would be the most useful and appropriate to determine the efficacy of the program going forward?**

1. Academic researchers and the private sector can be encouraged to use and contribute to EPIC's Unified Forecasting System by ensuring that it is a community modeling system, one that is well documented and supported. This is not true now. The community should have a voice in the development and management of the national UFS system and should be major players in EPIC. If the EPIC-created UFS is the best, the academic community and private sector will want to use it. Finally, the academic community and private sector are highly motivated by research funding, and the availability of such funding will greatly encourage participation in the national system.

2. Benchmarks and metrics are crucial. They range from measures of global, large-scale skill (e.g., anomaly correlations of 500 hPa flow) to fidelity of local precipitation statistics. EPIC should be required to demonstrate rapid improvement in these measures, equaling the European Center within 3 years, and demonstrating superior performance within five. With sufficient resources, this is achievable. One should note that NOAA has not made progress against the European Center, UKMET Office, or the Canadian Meteorological Center during the seven years since Hurricane Sandy, which was accompanied by substantial funding by Congress.

HOUSE COMMITTEE ON SCIENCE, SPACE, AND TECHNOLOGY

"A Task of EPIC Proportions: Reclaiming U.S. Leadership in Weather Modeling and Prediction"

Questions for the Record to:
Dr. Cliff Mass
Professor of Atmospheric Sciences
University of Washington

Submitted by Ms. Suzanne Bonamici

1. The National Science Foundation (NSF) awards grants to fund basic research, while NOAA largely funds applied science research.
    a. How has this funding paradigm affected the weather forecasting community? Given one of the goals of EPIC is to improve research to operations and operations to research, how should EPIC award grants to solve this? What types of awards would be the most appropriate to accomplish its mission, and what levels of funding would be needed?

2. NOAA has partnered with universities to enhance weather research capabilities through the Cooperative Institute system. In June of this year, NOAA awarded University of Maryland in College Park with a 5-year, $175 million funding agreement for the Cooperative Institute for Satellite Earth System Studies, a national consortium of more than 2 dozen academic and nonprofit institutes. This CI builds on the success of previous CIs between UMD and NOAA.
    a. How should EPIC involve the Cooperative Institutes and leverage the brainpower and partnerships there?

1. NSF needs to be a major player in EPIC. Unfortunately, NSF has developed an attitude in which it does not see itself playing a role in helping support U.S. operational weather prediction. This must change. NSF and EPIC need to work closely together, with NSF supporting related basic research that will solve key problems facing EPIC. For example, understanding and improving modeling of essential atmospheric processes. NOAA/NASA/DOD can support grants that are further down the chain towards operations.

2. The Cooperative Institutes should assist in working on the science and technologies underlying environmental prediction. Ensuring CI involvement requires both prioritization and moving funding to the right institutes and investigators.

Questions for the Record to:
Dr. Cliff Mass
Professor of Atmospheric Sciences
University of Washington

Submitted by Mr. Paul Tonko

1. The mission of the National Weather Service is to "provide weather, water, and climate data, forecasts and warnings for the protection of life and property and enhancement of the national economy." Its vision is to create a Weather-Ready Nation that is "prepared for and responds to weather, water, and climate-dependent events." As such, the National Weather Service provides critical data that informs both daily weather and extreme event forecasts. These forecasts are extremely important to all Americans.
   a. How will EPIC benefit the mission of the National Weather Service and improve upon the important daily and extreme weather forecasts that Americans so heavily rely on?

2. In your testimony, you describe the problems with NOAA's FV3 system, which is the National Weather Service's newest global model, created in response to the U.S. modeling failure with Hurricane Sandy. You describe the FV3 as "NOAA's version of the Boeing Max disaster," in that it was rushed into operations without sufficient testing and operations in an effort to catch up to the European Centre. In fact, the National Weather Service has delayed its implementation.
   a. Why hasn't the FV3 met its goals of improving the U.S. model, and what lessons can be learned from its development and delayed timeline?
   b. Should EPIC focus on improving the FV3, or should it focus on creating a new model, or build on a different, existing model?

3. Considering that the "I" in EPIC stands for innovation, EPIC must spur new research and operational developments in order to be successful. I'm particularly interested in how EPIC will stimulate innovation in the climate research space. EPIC has the potential to combine the expertise and skills from across the weather enterprise to make significant advances in climate research and modeling.
   a. Given that the world is already feeling the devastating impacts of climate change, should EPIC be focusing on climate modeling as well?

1. The improved modeling/forecasting system created by EPIC will be critical for the success of the NWS. Model forecasts are the key ingredient for everything the NWS does, from daily forecasts to predicting extreme weather. The mediocre models used by the current NWS undermines its ability to serve and protect the American people.

2. The National Weather Service had to delay implementation because they failed to sufficiently test the FV-3 system (thus like the Boeing MAX).

a. They made some fixes and implemented FV-3 last summer. The results have been disappointing, with no significant improvement in forecasting skill. FV-3 has not improved skill because the deficient NOAA/NWS data assimilation system was not replaced and because the physics in FV-3 is not appreciably improved over the old GFS.

b. EPIC should work on improving FV-3 and give priority to building a state-of-the-art data assimilation system. FV-3 is simply a dynamical core, and only one part of the total forecasting system. Down the road this dynamical core could be replaced if necessary. EPIC must take a holistic view of all components of the weather prediction system, guided by the best science and involving the entire U.S. prediction enterprise.

3. Climate and weather prediction are not distinct activities, since they use essentially the same models. Climate modeling is rapidly moving down in scale to that of weather prediction. Creating the best weather/ocean/ice prediction system for the shorter time periods will automatically create the best climate model as well. Congress must keep this in mind. First, Congress needs to collapse down all the redundancies in the weather prediction space. Then it must reduce the redundancies in the climate space. Finally, it must bring the weather and climate activities together. This country is wasting huge amounts of resources with all the redundancies. Case in point: heavily funding DOE to build a new climate model from scratch (ACME).

Responses by Dr. Peter P. Neilley

House Committee on Science, Space, and Technology

"A Task of EPIC Proportions: Reclaiming U.S. Leadership in Weather modeling and Prediction"

Dr. Peter P. Neilley's Response to

Questions for the Record to Dr. Peter P. Neilley

A. Questions submitted by Chair Lizzie Fletcher

1. NOAA's Fiscal Year 2020 budget request includes $15 million total to establish EPIC.
   a. What are the short- and long-term funding needs for EPIC?

   The short-term funding needs are to establish EPIC in the framework as described in my written testimony. At a minimum, this should include:
   - Identifying and contracting with an external entity to establish, manage, and run EPIC.
   - Recruiting, hiring, salaries, and supporting expenses for critical base staff including a director, about six scientific and technical staff, and two support and administrative staff members.
   - Basic facilities including offices, equipment, and related costs.
   - Contracted services, including initial computing resources.
   - Support for initial scientific collaborations with the community including initial research and development (R&D) grants, community meetings, software support and training, documentation creation, etc.
   - Establishment and support for community advisory board(s).
   - Overhead to the parent institution that establishes and manages EPIC.

   It is possible, if not likely, that the initial $15 million appropriation will largely be consumed by these initiation costs.

   Long-term needs for EPIC likely may include:
   - Salary and supporting costs for permanent EPIC staff.
   - High-performance computing supporting some of EPIC's scientific endeavors.
   - Funding to support scientific collaborations, including funded R&D grants, conferences, workshops, travel and technical publications.
   - Ongoing community support costs (e.g. "help desk", documentation, tutorials, workshops and ongoing software infrastructure maintenance).
   - Ongoing support for external review and management boards.
   - General management overhead.

   The managing institution that establishes EPIC should be charged with conducting a thorough estimate of EPIC's long-term funding requirements within nine months of

EPIC's establishment. Even if only some EPIC participants receive HPC support, it is likely that high-performance computing costs will be the primary driver of the long-term costs, and it is reasonable to estimate that these costs could be many tens of millions of dollars annually.

2. The U.S. Air Force discontinued using NOAA's global weather model in 2015, opting instead to use the United Kingdom's Unified Model. Other U.S. agencies have been working on their own numerical weather models, separate from the NOAA model.
   a. How should EPIC persuade the Air Force and other U.S. agencies to use and contribute to EPIC's Unified Forecast System.

      Absolutely critical to EPIC's success is involvement from all corners of the U.S. modelling community. Such wide involvement can only be achieved and sustained by creating a scientific institution that entices scientists and organizations (such as the Air Force) to participate. Two key characteristics of EPIC that would catalyze such participation include:
      - An accessible breadth of scientific and technical capabilities that enables a comprehensive set of research in, and application of, numerical weather prediction models for multiple scientific research and operational forecasting purposes.
      - A community approach that encourages and facilitates participation in EPIC regardless of participant's interests, rather than narrowly focused solely on NOAA's direct interests.

      If EPIC is created as a scientific institution that encourages wide-ranging involvement from stakeholders in the modelling community, then not only will it help achieve NOAA's goals of world-leading NWP capabilities, but will also help other entities participating in EPIC achieve world class results in their use and application of NWP.

   b. How should EPIC foster interagency coordination, and what should the roles of various agencies be within EPIC's framework? Which agencies should be involved in EPIC.

      EPIC will foster interagency coordination if it is created as a community institution serving the community, rather than an institution focused on serving NOAA only. The roles of the federal agency participants should be to develop and execute strategies that enable them to contribute to, participate in, and derive value from EPIC's modelling capabilities. All federal agencies, and the institutions they support (such as the National Center for Atmospheric Research (NCAR) and the NOAA Cooperative Institutes) that develop and operate weather and climate models should be involved in EPIC.

B. Questions submitted by Chairwoman Eddie Bernice Johnson

1. How should EPIC encourage researchers in academia and the private sector to contribute to EPIC's Unified Forecast System, rather than continue to work on their own separate numerical weather prediction models.

   EPIC should be constructed as the world's leading source for science and technology to aid in research, development and application of numerical weather prediction models. If EPIC is constructed with this goal, then researchers will be enticed to participate and contribute to EPIC as it will be the best source of science and technology to advance their mission and interests. In addition, EPIC should provide targeted research grants and access to high-performance computing to a subset of its participants to encourage R&D in specific areas that EPIC deems important to building a world-class modelling capability. However, it should not be necessary for EPIC to directly fund or provide computing resources to most participants. For example, NCAR's Weather Research and Forecasting (WRF, Model for Prediction Across Scales (MPAS) model, and Community Earth System Model (CESM) communities are currently the world's leading modelling communities and generally do not provide financial or HPC support. These NCAR communities should be considered prototypes for EPIC's formulation and eventually folded into EPIC so there is a single NWP community rather than competing communities.

2. To determine whether EPIC is on its way to meeting its mission, there must be benchmarks through which Congress, the weather community, and the public can measure its success. Tangible metrics will help to inform Congress and our Committee as to what EPIC's current and future funding needs are, and whether additional resources will need to be allocated in order to make it a successful program.

   a. What are the best ways to measure EPIC's success? What metrics of accountability would be the most useful and appropriate to determine the efficacy of the program going forward?

   First, EPIC should establish an audacious mission statement towards creating the world's leading community modelling capabilities as the critical enabler towards establishing the U.S. as the definitive world's leader in numerical weather prediction. Second, EPIC and its managing institution should be accountable to aggressive measures of success towards that mission. These should include short-term goals that measure the success of the establishment of the EPIC institution, and then longer-term goals that measure the degree of success of the nation becoming the world's preeminent NWP entity. The short-term goals should include measures of the breadth of community participation, the breadth of NWP science and technology enabled and supported by EPIC, and tangible demonstrations of the potential gains in NWP efficacy that will be realized in the long-term. The long-term goals should be laser focused on returning the U.S. to NWP superiority in all applications including those at NOAA and elsewhere across the U.S. NWP enterprise.

C. Questions submitted by Ms. Suzanne Bonamici.

1. The National Science Foundation (NSF) awards grants to fund basic research, while NOAA largely funds applied science research.
    a. How has this funding paradigm affected the weather forecasting community? Given on of the goals of EPIC is to improve research to operations and operations to research, how should EPIC award grants to solve this? What types of awards would be the most appropriate to accomplish its mission, and what levels of funding would be needed?

There is no doubt that the NSF has played a critical role in developing NWP capabilities for the nation. This includes support for the major modelling communities created by the NCAR, as well as funding more specific R&D endeavors to develop and test next generation NWP science and technologies. In fact, several of the operational NWP capabilities at NOAA today including the High-Resolution Rapid Refresh (HRRR) model, Hurricane Weather Research and Forecast System (HWRF) model and NOAA Water Model have roots in NSF-supported science. However, at the same time, the disassociation of NSF grants from direct support of operational NWP capabilities has been one catalyst in the fractured and uncoordinated U.S. NWP efforts.

Moving forward, there is no need to continue separating basic research and operational NWP R&D anymore. Rather, our nation should strive to develop a holistic, most centralized approach to developing NWP technologies that enables a broad set of world-class applications of the resulting models both for operational use at NOAA and other agencies and for assisting more basic scientific research. EPIC represents a unique chance to establish and execute against such a holistic national NWP strategy. EPIC, the NSF and other federal agencies that award grants to advance NWP or associated science should be directed to do so in a coordinated fashion in a manner that involves and advances EPIC. More specifically, NSF should strongly encourage its awardees to use, draw upon, and contribute to EPIC's capabilities. This includes NCAR which should be directed to seek ways to merge its existing and highly successful NWP communities (WRF, MPAS and CESM) with EPIC by inclusion of its modelling technologies in the Unified Forecast System (UFS). Failure to do so will result in competing NWP science communities in the nation, which will perpetuate the uncoordinated national approach to NWP we currently have.

2. NOAA has partnered with universities to enhance weather research capabilities through the Cooperative Institute system. In June of this year, NOAA awarded University of Maryland in College Park with a 5-year, $175 million funding agreement for the Cooperative Institute for Satellite Earth System Studies, a national consortium of more than 2 dozen academic and non-profit institutes. This CI builds on the success of previous Cis between UMD and NOAA.
    a. How should EPIC involve the Cooperative Institutes and leverage the brainpower and partnerships there?

The most critical attribute of EPIC is becoming the world's leading source of NWP related science and technology for the community. Doing so will attract and entice participation in EPIC and therefore scientists and scientific institutions such as the NCAR and the NOAA Cooperative Institutes will naturally gravitate to EPIC to further their specific missions. Building EPIC in a manner that attracts participation in it, rather than one depends on mandated or funded participation in it, is the only pathway towards long-term success of EPIC and ensuring national NWP superiority at NOAA and elsewhere across the nation. Hence, EPIC must be constructed "for the community" and be managed "by the community" in order to build an institution and supporting science and capabilities that support a much more diverse set of applications than just those narrowly focused on NOAA's direct and immediate needs. It is through this attracting characteristic of EPIC that the CI's will seek to participate in EPIC in a sustainable way.

D. Submitted by Mr. Paul Tonko.

1. The mission of the National Weather Service is to "provide weather, water, and climate data, forecasts and warnings for the protection of life and property and enhancement of the national economy." Its vision is to create a Weather-Ready Nation that is "prepared for and responds to weather, water, and climate-dependent events." As such, the National Weather Service provides critical data that informs both daily weather and extreme event forecasts. These forecasts are extremely important to all Americans.
    a. How will EPIC benefit the mission of the National Weather Service and improve upon the important daily and extreme weather forecasts that Americans so heavily rely on?

The primary goal of EPIC must be to develop the world's best NWP capabilities that can be applied for a broad set of uses including supporting the world's most accurate global and regional NWP operations at NOAA. Doing so will enable the NWS to provide the world's most accurate and relevant weather and climate forecast products to the nation and hence optimally serve its mission. This is the most important end-result that should embodied into EPIC's mission.

2. Considering that the "I" in EPIC stands for innovation, EPIC must spur new research and operational developments in order to be successful. I'm particularly interested in how

EPIC will stimulate innovation in the climate research space. EPIC has the potential to combine the expertise and skills from across the weather enterprise to make significant advances in climate research and modeling.

a. Given that the world is already feeling the devasting impacts of climate change, should EPIC be focusing on climate modeling as well?

   In the past, separate NWP models have been developed and tailored for regional, global, and climate modelling. Historically, there have been sound scientific reasons for this more individualized approach. However, as our science has matured, a more holistic approach to NWP has emerged in which a common set of modelling capabilities can be applied to a broad set of NWP applications ranging for high-resolution, short-term weather forecasting through multi-decadal climate simulations. The UFS at the heart of EPIC represents such a holistic modelling capability and therefore, will naturally become a tool for supporting climate modeling as well.

   A critical catalyst to EPIC's success in supporting climate modeling will be the degree of participation in EPIC by the established climate modeling community such as NCAR's CESM community. Therefore, NSF, NCAR, and EPIC should be encouraged to work together to merge the capabilities supported by the CESM with the UFS so that there becomes and most holistic and efficient institution to support climate science.

Responses by Dr. Thomas Aulignė

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

"A Task of EPIC Proportions:
Reclaiming U.S. Leadership in Weather Modeling and Prediction"

<u>Questions for the Record to:</u>
Dr. Thomas Aulignė
Submitted by Chair Lizzie Fletcher

1. What are the short- and long-term funding needs for EPIC?
It is essential to align funding resources with scope of work. NOAA's FY20 budget for EPIC requests $12.3M of new funds together with $2.7M of redirected JCSDA funds. This is modest compared to the multi-billion dollar U.S. weather prediction enterprise. Short-term, EPIC's budget should be entirely dedicated to hiring world-class scientists and engineers to build a center of excellence, operating like a skunkwork project, and focusing on delivering operational-grade improvements for global numerical weather prediction. This requires supplementing EPIC's budget with significant high-performance computing resources. Long-term, once EPIC has demonstrated value, funding may be expanded to address a broader suite of applications such as subseasonal-to-seasonal prediction, regional high-resolution prediction, climate reanalyses, atmospheric constituents, etc.

2a. How should EPIC persuade the Air Force and other U.S. agencies to use and contribute to EPIC's Unified Forecast System?
The proof is in the pudding. The U.S. Air Force and other national and international agencies are naturally drawn to excellence. They also need to map a path to address their specific mission needs (e.g. cloud analysis and prediction) and ensure their operational requirements will be met. Building a center of excellence with scope and governance that extend beyond NOAA's mission is key to success. The best approach may leverage ongoing fruitful collaboration with USAF on next-generation data assimilation, a critical component of numerical weather prediction.

2b. How should EPIC foster interagency coordination, and what should the roles of various agencies be within EPIC's framework? Which agencies should be involved in EPIC?
Regarding interagency coordination, EPIC can leverage the experience of the Joint Center for Satellite Data Assimilation (JCSDA). It is essential to focus coordination toward tangible deliverables that demonstrate value. An effective way to achieve this goal is to map a collaborative work plan to develop generic reusable software. This ensures that "jointness" can reach beyond the abilities of individual agencies, while accommodating for diverse missions. EPIC should at minimum involve the partners of the JCSDA, namely NOAA, NASA, USAF and Navy. It should also prepare for gradual extension to NSF, EPA, DoE, and other branches of DoD. Governance should be inclusive of all partners and result-driven. Resources should be allocated to facilitate collaboration among partner agencies. A welcoming center of excellence that clearly boosts agencies abilities to fulfill their mission will always outperform a top-down imposed collaboration box to tick.

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

Questions for the Record to:
Dr. Thomas Auligné
Submitted by Chairwoman Eddie Bernice Johnson

1. How should EPIC encourage researchers in academia and the private sector to contribute to EPIC's Unified Forecast System, rather than continue to work on their own separate numerical weather prediction models?
The most obvious response is to subject government funding to pre-defined requirements increasing return on investment. There are also other incentives that can be used. Community scientists want to stand on the shoulders of operational centers to perform state-of-the-art research, however the bar is usually very high to use operational codes and it is often incompatible with publication requirements. We need to bring operational codes to 'research grade', which goes beyond availability, documentation and support. A key goal of EPIC should be to simplify and modularize complex systems in order to lower the bar of entry for contributors and allow for future innovative improvements. These community contributions should then be quickly tested and integrated without significant burden to the contributors.

2. What are the best ways to measure EPIC's success? What metrics of accountability would be the most useful and appropriate to determine the efficacy of the program going forward?
If EPIC is limited to be a facilitator in NOAA's research-to-operations and operations-to-research process, it will fail. Instead, EPIC needs to be responsible for providing forecast skill improvements, and it should have significant autonomy with its own processes and innovative solutions. Therefore, a key measure of success for EPIC should quantify operational-grade improvements to the data assimilation and modeling systems. Starting with operational requirements, forecast score metrics can be defined a priori, and they will determine EPIC's target and accountability. Additional metrics should assess how EPIC is addressing its long-term goal of a flexible system, which will easily integrate new data and algorithms, project on future computing architecture, and involve an expanded base of researchers.

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

Questions for the Record to:
Dr. Thomas Auligné
Submitted by Ms. Suzanne Bonamici

1. The National Science Foundation (NSF) awards grants to fund basic research, while NOAA largely funds applied science research. How has this funding paradigm affected the weather forecasting community? Given one of the goals of EPIC is to improve research to operations and operations to research, how should EPIC award grants to solve this? What types of awards would be the most appropriate to accomplish its mission, and what levels of funding would be needed?
It may be argued that this funding paradigm has deepened the gap between research and operations often described as the 'valley of death'. Given its limited budget, EPIC should avoid a shotgun approach to awarding grants. Instead, EPIC should start with defining work packages needed for the overall system as well as processes for their integration. It should then compete contracts and hold award winners accountable for promised deliverables. In this business model, EPIC would operate as trusted agent and system integrator, similarly to the successful approach followed by the European Commission to execute its Copernicus services.

2. How should EPIC involve the Cooperative Institutes and leverage the brainpower and partnerships there?
It is undeniable that CIs involve brainpower and partnerships that are essential to leverage. EPIC's role should be to provide tools facilitating the adoption of operational codes for research purposes, and reciprocally to accelerate the transition of good ideas into operations. This will involve training of the community, co-development, and the implementation of hierarchical testing procedures.

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

Questions for the Record to:
Dr. Thomas Aulígné
Submitted by Mr. Paul Tonko

1. How will EPIC benefit the mission of the National Weather Service and improve upon the important daily and extreme weather forecasts that Americans so heavily rely on?
The best way for EPIC to provide value for the NWS is by providing operational-grade improvements, i.e. innovative solutions to the deficiencies of the forecasting system that have been tested and have demonstrated value in an operational-like environment. These improvements will be easily transitioned to NOAA's operational numerical weather prediction, which is the cornerstone of the Weather Ready Nation approach.

2. Given that the world is already feeling the devastating impacts of climate change, should EPIC be focusing on climate modeling as well?
EPIC needs to start with a clear scope aligned with its modest budget, and with measurable outcomes. Once success of this innovation center is established, scope may be expanded to various components of the Earth system and additional applications. We should stress that short-term improvements to weather forecasting should also result in advancements in climate science through better coupled modeling and analysis capabilities, which are key elements for seasonal and long-term forecasting.

Appendix II

Additional Material for the Record

LETTER SUBMITTED BY REPRESENTATIVE SEAN CASTEN

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INVESTIGATIONS

SELECT COMMITTEE ON
THE CLIMATE CRISIS

November 12, 2019

Dr. Neil Jacobs
Assistant Secretary of Commerce for Environmental Observation and Prediction
Acting Under Secretary of Commerce for Oceans and Atmosphere
National Oceanic and Atmospheric Administration
1401 Constitution Avenue NW, Room 5128
Washington, DC 20230

Dear Dr. Jacobs,

I am writing you to express my growing concern about political interference, the erosion of protections for scientific integrity, and the independence of the critical work done by forecasters at the National Weather Service (NWS) and the National Oceanic and Atmospheric Administration (NOAA). As you are aware, the American public relies on the NWS for accurate, factual information in times of natural disasters, like Hurricane Dorian. This information is critical so Americans can make life-saving decisions about what precautions they need to take to ensure they are safe in natural disaster including if they must evacuate. Public trust in this information is vital. The only factor in issuing weather predictions should be science, not the political whims of a President or of his Administration. This must be the understanding of all those involved in federal weather forecasting.

However, recent events have left me increasingly concerned that under this Administration NOAA and NWS are failing to live up to their core mission in that they are putting political interests ahead of the interests of communities threatened by extreme weather that will only continue to intensify as the impacts of the climate crisis grows.

While there have been a number of individual incidents that have caused consternation over the agency's direction under this Administration, none have been as truly alarming as the events surrounding the forecasting of Hurricane Dorian earlier this year. As noted by the New York Times, following the President's repeated claims that Hurricane Dorian could impact the city of Birmingham, Alabama and the surrounding communities, despite no evidence to support the claim from official forecasts issued by the NWS, the NWS forecasters located in Birmingham rightly took steps to reassure their community that they were not expected to be impacted by the storm.

I want to be clear. These forecasters did their job. They took the best available science and communicated factual information to a public that was relying on them. They did what Congress, the law, and the American people expected of them.

Yet, instead of supporting the work of these forecasters, NOAA actively undermined the integrity of these forecasters and the NWS by issuing a statement contradicting local forecasters stating that "Birmingham National Weather Service's Sunday morning tweet spoke in absolute terms that were inconsistent with probabilities from the best forecast products available at the time." In addition, it was later revealed in reporting by the New York Times that Secretary Ross had intervened on behalf of the President prior to the issuing of the statement, threatening the firing of political staff if the agency's perceived contradiction of the President was not "fixed."

People gather their loved ones and flee their homes in fear when they hear about these storms, and it is extremely concerning that Secretary Ross would threaten to fire scientists for simply stating the facts. Knowingly issuing false weather forecasts is a crime punishable by law and it is outrageous that Secretary Ross would pressure his own staff to break that law. But perhaps more concerning is how these actions threaten the continued integrity and independence of the NWS and NOAA. Americans must be able to rely on these agencies for accurate information that they know is not tarnished by the political whims of the current Administration. If storms and natural disasters become partisan facts, the impacts could be devastating.

Would local evacuation orders be followed if the NOAA and the President insist a storm is not threatening a community when it clearly is? How can the public be assured that the forecasts of the NWS, if NOAA and the Administration refuse to stand by them? These are important questions and they must be addressed.

To that end, I applaud the decision of the Commerce Department's Office of Inspector General to investigate these events including the statement released by NOAA on September 6, 2019. Yet more must be done to restore faith and public trust in the integrity of the work done by the NWS and NOAA moving forward.

I would be remiss if I did not mention the continued uncertainty surrounding NOAA's FY20 Budget Request which calls for cutting 110 full time equivalents (248 positions) in forecasting at the NWS. These cuts would effectively eliminate about 20% of forecasters from the nation's 122 Weather Forecast Offices which the agency's Budget Justification concedes would result in the reduction of "operation times at various offices" and would present a "potential risk to the public and partners."

I am alarmed at how these cuts would impact the capabilities of the NWS not just to provide accurate localized weather forecasting services, but in building critical relationships necessary to maintain the trust of communities in times of extreme weather events. While it is possible that these cuts could be justified by improvements in weather modeling, I am alarmed that the House Science Committee has not been presented with these findings despite repeated requests for information regarding the facts that informed the decision-making process that led to these cuts. I was also concerned that when pressed on these issues at the Science Committee hearing on May 16, 2019, you made statements that seemingly contradicted the Agency's Budget Justification, including that "we're not making any cuts to our operating capability," and indicating that "we are not planning to cut any staff or personnel there" in reference to a question about NWS personnel.

These seeming contradictions and general unwillingness to provide detailed accounting of the decision-making process which informed the requested cuts to the NWS, further undermine the integrity of the agency in a way that damages public trust. I'd like to urge you and your staff to further clarify your position on these cuts while providing committee a clearer account of how this decision was initially made.

As we see more and more severe weather as a result of the climate crisis, we cannot afford to have an NWS that the public cannot trust. The American public must have confidence in NWS forecasts and the integrity of the agency and leaders that oversee this process. Thus far, I am afraid this Administration has fallen short of that standard.

Despite all of this, I hope that we can work together, and I hope that we can rebuild that trust. The mission of the NWS and NOAA are important to keeping the public safe and the science they provide us about our weather, oceans, atmosphere, and climate are invaluable public goods that must be protected. Weather forecasting should not be partisan, and science cannot be up for debate. I know that the NWS and NOAA are staffed with lifetime public servants committed to the mission of these great agencies. I admire this mission immensely and I will stand ready to work with you to uphold it.

Sincerely,

Sean Casten
Member of Congress