Written Testimony of

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

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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).

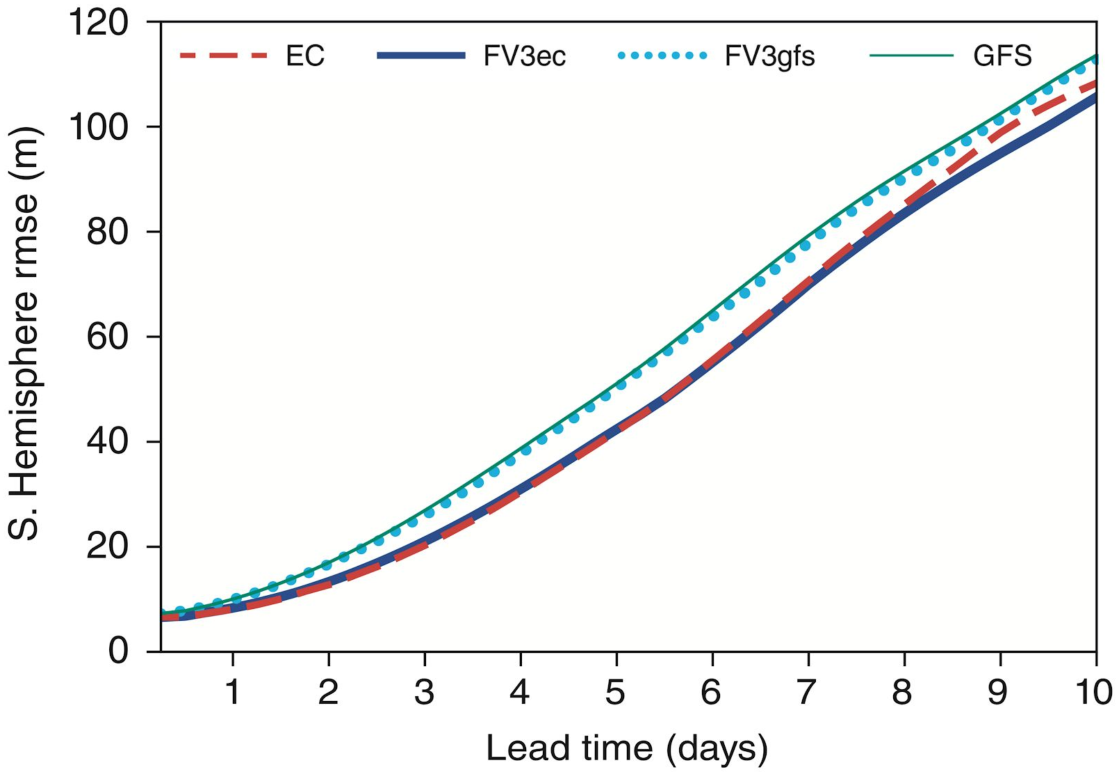

Figure 1: from Magnusson et al., 2019 (https://doi.org/10.1002/qj.3545) representing a measure of forecast error as a function of forecast lead time. The green solid (resp. dotted cyan) curve shows the performance of the previous (resp. current) NOAA operational system. The dashed red curve shows better 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.

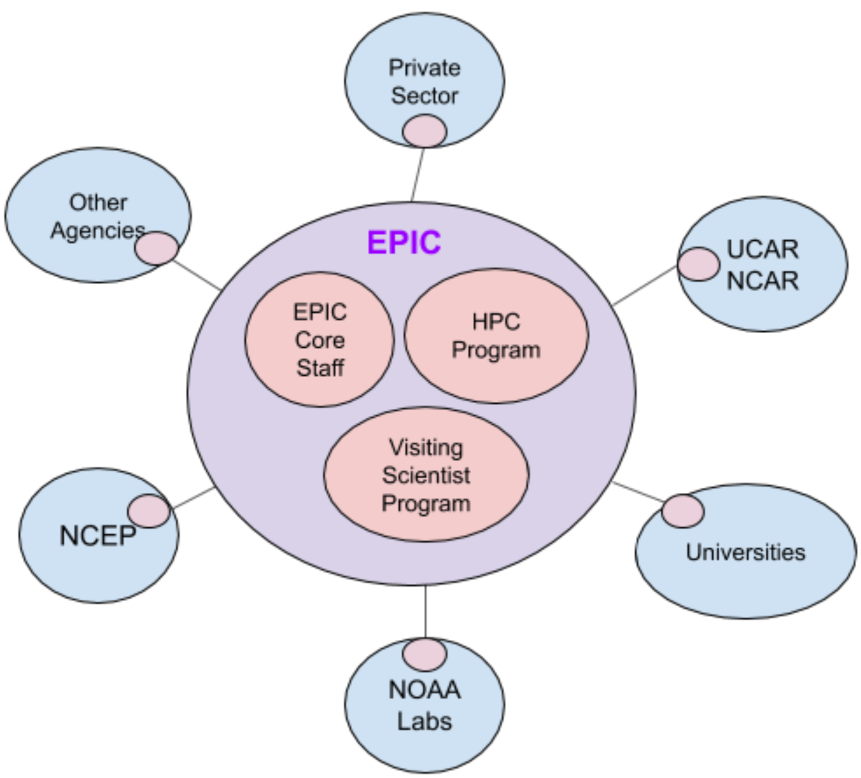

Figure 2: Schematic of the proposed distributed structure for EPIC, following a Hub-and-Spoke approach.

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.

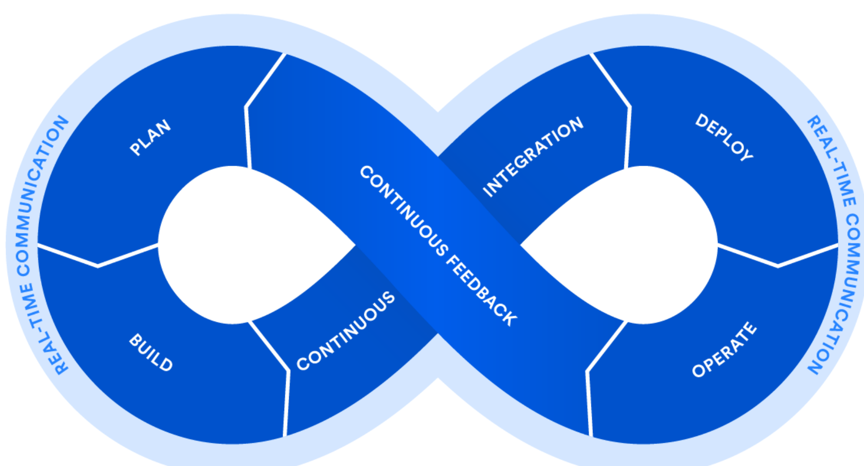

Figure 3: DevOps approach to build, test and release weather prediction capabilities faster and more reliably. Continuous feedback and integration, once properly formalized, will allow to efficiently interface research developments with operational cycles.

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?

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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.

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Appointments

2015-present	Director, Joint Center for Satellite Data Assimilation.
2019-present	Program Director, UCAR Community Programs, Boulder, CO
2015-2016	Faculty, University of Maryland in College Park, MD.
2014-2015	Project Scientist III, NCAR/MMM, Boulder, CO.
2009-2014	Project Scientist II, NCAR/MMM, Boulder, CO.
2007-2009	Project Scientist I, NCAR/MMM, Boulder, CO.
2004-2007	Research Scientist, European Centre for Medium-Range Weather Forecast, Reading (ECMWF), UK.
2001-2004	Research Scientist, Météo-France CNRM/GMAP, Toulouse, France.
2000-2001	Marketing Manager, Météo-France, Paris, France.
1999-2000	Consultant, French Olympic Sailing Team, Quiberon, France.

Professional Preparation

2007	PhD in Atmospheric Physics, Paul Sabatier University, Toulouse, France.
1999	M.S. in Meteorology, Ecole Nationale de Météorologie, Toulouse, France.

Research Interests

Advanced data assimilation techniques in numerical Earth system modeling. Assimilation of new satellite instruments. Use of high-resolution remote-sensing observations in the presence of clouds. Bias correction and impact of observations on forecast error. Applications to reanalyzes, coupled systems, situational awareness, renewable energy.

Recent Refereed Publications

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