Testimony - ***Reauthorizing the Weather Act: Data and Innovation for Predictions***

Statement of

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before the

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Subcommittee on Environment

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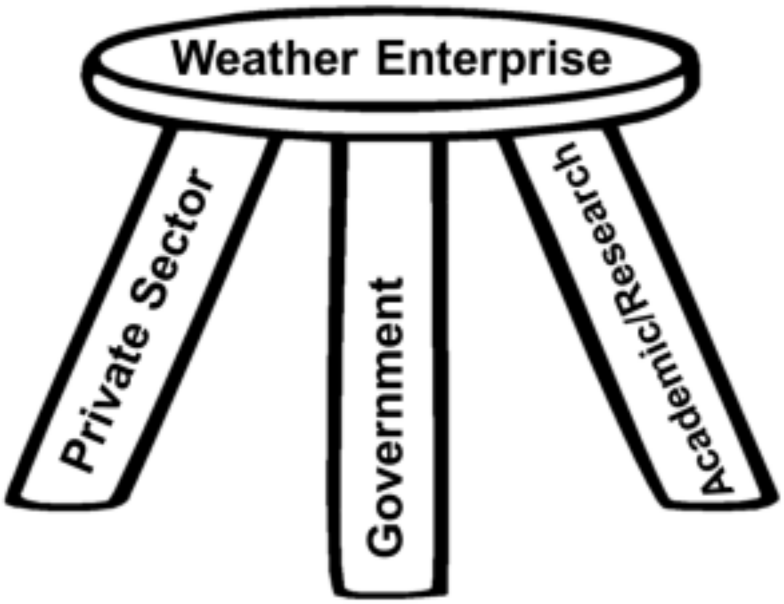
Chairman Miller, Ranking Member Ross, and members of the Environment Subcommittee. Thank you for inviting me to testify before you today on the importance of data innovation and prediction within upcoming Weather Act reauthorization. I am Dr. Tony Busalacchi, President of the University Corporation for Atmospheric Research, as well as an elected member of the National Academy of Engineering. Prior to serving as UCAR's President, I spent 16 years at the University of Maryland as the founding director of the Earth System Science Interdisciplinary Center (ESSIC) and before that spent another 18 years at the NASA Goddard Space Flight Center (GSFC), the last 10 years of which I was a chief of the Laboratory for Hydrospheric Processes and member of the Senior Executive Service.

UCAR is a nonprofit consortium of 122 member universities granting degrees in atmospheric and related fields in Earth system sciences. UCAR's primary function is management of the National Center for Atmospheric Research (NCAR) on behalf of the National Science Foundation. In addition to management of NCAR, UCAR hosts a suite of programs (UCAR Community Programs) that provide service and support to the academic community, including two that are relevant to the topic we are discussing here today.

NCAR is a Federally Funded Research and Development Center with over 600 scientists and engineers conducting weather, water, climate, air quality, and space weather research. Staff also manage supercomputers, research aircraft, and Earth observing systems that are available as a resource to the nation's research community. Our UCAR member universities and staff scientists conduct research for use by government agencies and the private sector. We aim to further the understanding of atmospheric and related Earth System phenomena and help create more accurate environmental forecasts that protect lives and property, spur economic growth, support the national defense, and enhance our quality of life.

I believe that the conversation we are having today on reauthorization of the Weather Act is an important one. This legislation is the perfect vehicle to bring together and strengthen relationships between private industry and academia within the weather enterprise, in partnership with the federal government. The U.S. Weather Enterprise consists of the three previously mentioned groups: the private sector, government, and academia, forming a triad whose cumulative efforts fulfill many different roles across society. The government's traditional role within this triad is the protection of life and property, and the enhancement of national security. This government role is grounded in the sustainability and dependability of observational data and models that have free and open access. The private sector's traditional role is to create customized and tailored weather products and services to a broad customer base of private individuals and businesses in a multitude of sectors. The academic community works to improve our common understanding of the Earth System, perform basic and applied research that leads to innovation, and trains the next generation workforce for both the government and private sector. It is important to the future success of the weather enterprise that each leg of the triad continues to grow, and that any contraction or reduction in size of any leg will negatively impact its diverse beneficiaries. As extreme weather events become more prevalent and costly, it is critical that innovation for prediction keep pace with our changing world.



The U.S. Weather Enterprise: consisting of the Government, Private Sector, and the Academic/Research Communities. Weakening any one leg of this triad weakens the whole. By working together, we provide a solid foundation that well serves the nation.

Today the capabilities of the private sector rival certain aspects of the National Weather Service. This is a success story for the United States that should be celebrated and is a result of three major factors:

1. Free and open data provided by the federal government
2. Free and open modeling software
3. The information technology revolution

For years, the model in the weather enterprise was that government supported research to improve forecasting was performed by the university community and federal labs. These innovations were then operationalized at federal agencies such as the National Weather Service at NOAA and several branches within the Department of Defense. These government entities would then take these forecasting innovations and deploy them to their respective mission areas. In the 1990's the National Weather Service underwent a period of rapid growth and modernization that coincided with the information technology revolution. For the first time, foundational observational data, computer codes for numerical weather prediction models, and software technologies such as data assimilation were accessible to the private sector at no cost. Private companies could now access government data, download it, and implement their own value-add enhancements to provide products and services that were more tailored to their customers' needs. According to the American Meteorological Society, leveraging government investment has allowed the weather enterprise private sector to flourish to the tune of more than $5 billion, including over 250 commercial weather companies. With continued robust government investment in data assimilation, high performance computing infrastructure, next generation modeling and observational systems, the weather enterprise can continue to grow along with it, providing critical public services that enhance our predictive capabilities to further protect lives, property, and our national security.

During my time at the NASA Goddard Space Flight Center, I was the source selection official for the Sea-Viewing Wide Field-of-View Sensor (SeaWiFS) instrument, which was one of the very first 'data buys' not only at NASA but also government wide. SeaWiFS was a satellite sensor that was launched by Orbital Sciences Corporation in 1997 to monitor the Earth's oceans from space. It provided important data on ocean color, temperature, marine chlorophyll, and biology that has been invaluable to the university research community. One of the primary benefits of SeaWiFS was its ability to measure ocean productivity by detecting chlorophyll and phytoplankton concentration in the water. This information is critical to understanding the health of marine ecosystems and the global carbon cycle. The data from SeaWiFS was made publicly available, and has led to numerous important studies and scientific discoveries in marine biology and ocean science, including the study of harmful algal blooms and the distribution of fisheries resources. SeaWiFS also led to several discoveries in atmospheric science. Researchers also used SeaWiFS data to study atmospheric aerosols and their impacts on climate as well as land surface vegetation cover.

SeaWiFS, while originally intended for ocean observations, created additional value as researchers found out how to utilize the data in other ways while studying the complete Earth system. SeaWiFS was retired in 2010 after exceeding its design lifetime. From my perspective SeaWiFS was a grand success as a data buy, and as a result I am very bullish on the role that the private sector can play with respect to data buys with attention to what are the best practices for such.

There is a tremendous amount of insight to be gained from the SeaWiFS mission as it applies to not only future oceans research and operations but weather forecasting and prediction as well. In 2011, the National Academies of Science, Engineering and Medicine released a consensus study report titled: “Assessing the Requirements for Sustained Ocean Color Research and Operations.”

The report outlined a number of successes from SeaWiFS that should be applied to future data buys from across the Earth system sciences, and came to one of the following conclusions:

> *“One of the unique strengths of the SeaWiFS mission was how well it engaged the U.S. and international science community of ocean color data users, as well as those with technical knowledge and insight on satellite data processing and bio-optical measurements. Although all NASA science missions have science teams, the Ocean Biology and Biogeochemistry program is unique in hosting annual Ocean Color Research Team meetings that are open to anyone. In this way, the SeaWiFS Project received input from a broad international group of scientists on algorithms, data quality, data products, validation, and other topics, from pre-launch throughout the mission. As a result, the project received important and unanticipated contributions that led to significant improvements.”* [1]

Furthermore:

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[1] National Research Council. 2011. *Assessing the Requirements for Sustained Ocean Color Research and Operations*. Washington, DC: The National Academies Press. https://doi.org/10.17226/13127.

"The strong engagement of the research community would not have been possible without SeaWiFS's exemplary open data policy and the ease with which data could be accessed. The implementation of an open access data policy with an efficient data distribution system built support for the mission. Such open data policies are the cornerstone for ensuring the robustness of the scientific method. In contrast, an open data policy with an inefficient data system can be problematic."

And finally, select recommendations related to data from the report:

"7. Support research on algorithm and product development;
8. Ocean color data products need to be reprocessed periodically to incorporate changes to calibration owing to sensor degradation and algorithm improvements. Level 0 data need to be permanently archived to allow reprocessing;
9. The construction of long-term ocean color data records requires that satellite data from multiple missions be reprocessed using the same vicarious calibration sources and similar algorithms;
10. The U.S. and international science community should be routinely included in evaluating sensor performance, product validation, and supporting research on ocean color applications;
11. A system is needed that makes freely available all raw, meta-, and processed ocean color data products, algorithms, and processing codes that can distribute the data rapidly and efficiently;
12. Detailed and comprehensive documentation of all aspects of the mission needs to be accessible (instrument, algorithms, in situ protocols, etc.); and
13. Institutional memory needs to be maintained to ensure transfer of knowledge and expertise from previous mission science and engineering teams to subsequent U.S. groups and international partners."

While these recommendations are specific to ocean color research, they can easily conform to operational private sector weather observation systems and provide an important basis for the development of best practices for data buys.

In reviewing the success of SeaWiFS and thinking about the future state of the weather enterprise and data buy best practices, there are several key questions about the private sector and the market for private weather data that must be answered.

1. How can best practices be approached?
2. What happens if one company monopolizes a data set?
3. What happens if a data provider stops offering a product or service, or in an extreme circumstance, goes out of business?
4. What can we do to better utilize existing data sets?

Answering these questions with smart policy choices will be key in ensuring that the private sector, the federal government, and academia can continue to thrive together.

In addition to my personal experience with SeaWiFS, the American Meteorological Society also has a strong policy statement on the need for Full, Open and Timely Access to Data, which I support. Between the NASEM report and the AMS policy statement, there are several common themes that should be emphasized in future legislation, and subsequently in a future framework outlining the best practices for commercial data buys.

Finally, the NOAA Science Advisory Board in 2021 issued “A Report on Priorities for Weather Research,” which emphasizes the importance of open data and consistent standards. It states that NOAA should “prioritize highly reliable, high-resolution (HR2) weather information dissemination, with inclusive and open science to maximize societal Benefits” and that NOAA should also “In collaboration with the broader weather community, establish consistent and open data standards to support open science; simple, general, cloud-optimized data formats and Application Programming Interfaces

(API) that support accessibility, usability, and preservability throughout the Weather Enterprise, and simplify R2O”[2]

It is imperative that we also continue to emphasize quality assurance of models and data. One of the important reasons for rapid progress in weather modeling and prediction is the community, open source model concept. This aspect of community engagement is another unique strength intrinsic to the United States. Allowing free and open access to models, like the various NCAR-developed Weather Research and Forecasting (WRF) Models or Model for Prediction Across Scales (MPAS), fosters the most rapid progress in future development of the prediction models by allowing for continuous development that draws on the depth and breadth of the U.S. research community. It is important to implement strong standards so that private companies are also held accountable and that their data and models are as effective as their proprietors claim. Verification, validation, and transparency are essential and should be especially so when considering private data buys being used for operational forecasting by government agencies. If the research community does not have access to model and observation algorithms, instrument characterization, and some level of IP, it becomes much more difficult to continue the interconnected development cycle when one side is open to collaboration and the other is not.

I am a staunch advocate of continued commercialization, and we should all support commercialization. There is ample evidence that suggests that more observation operations can be performed more easily, independently, and nimbly in this manner, which will continue to serve all three legs of the weather enterprise triad. However, it is important that, in facilitating continued commercialization in the weather enterprise, we do not lose sight or neglect the other two legs of the triad. One way to avoid this is for the government to develop robust data accessibility standards, so that academia can continue to conduct research and development which feeds back into the

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[2] NOAA Science Advisory Board, 2021: A Report on Priorities for Weather Research. NOAA Science Advisory Board Report, 119 pp. https://sab.noaa.gov/wp-content/uploads/2021/12/PWR-Report_Final_12-9-21.pdf

commercialization of new technologies. We must ensure that data is readily available in the public domain. Maintaining accuracy, quality, continuity, and reliability of data streams is critical to prediction and safeguarding life and property. All of weather forecasting is dependent on the long-term availability of quality data, and the last thing the enterprise needs is disagreement on standards.

One example that helps illustrate this need for data standards and the new paradigm within the weather enterprise is the development of the National Mesonet Program at the National Weather Service. Mesonets began as tools for the research community, beginning with the Oklahoma mesonet in 1982. Over the years, the research network monetized the data and now sells this observational data to the National Weather Service and other private parties. The Mesonet example illustrates how what first started as an observational network for research purposes then turned into a private enterprise developed product, leading to its eventual sustained use by the government in service back to the nation. I recognize that it takes time to generate and properly use observations in forecasting and prediction models. The mesonet data was, at first, not of sufficient quality for operational use. The mesonet had to be perfected over time, and once the data reached the quality necessary for operational use in numerical weather prediction, the weather enterprise was off to the races with a new business opportunity. In fact, the Oklahoma Mesonet model became so successful that in 2009, Congress followed the recommendation of another National Academies report: “Observing Weather and Climate from the Ground Up: A Nationwide Network of Networks” and created the National Mesonet Program at the National Weather Service. This program has now grown to more than three dozen networks covering all 50 states and is now the Weather Service’s largest data purchase program. It represents another grand success story. Data standards should not be controversial and should act as a two-way street between willing partners, with the federal government helping to determine the rules of the road in a collaborative manner. Strong data standards in academia allow for more efficient commercial development of new products like the mesonets, and conversely strong data standards allow for researchers to take commercialized data and put it back to use in the research and development pipeline.

A prime example of this positive feedback loop is the Constellation Observing System for Meteorology Ionosphere & Climate (COSMIC). COSMIC began in April 1995 when a prototype instrument designed by the Jet Propulsion Laboratory (JPL) went into orbit aboard the MicroLab-1 satellite on a mission conceptualized and planned by UCAR's GPS/MET team. The GPS/MET prototype obtained nearly 10,000 atmospheric soundings, fulfilling its role as a proof-of-concept experiment, and paved the way for the highly successful COSMIC-1 (2006-2020) and COSMIC-2 (2019-Present) missions. In 1997, UCAR began a new chapter in the development of the GPS Radio Occultation (GPS-RO) platform by entering into an agreement with the Taiwan National Space Organization (NSPO) to explore meteorological applications of Global Positioning System satellites. This collaboration resulted in the development of the FORMOSAT-3/COSMIC-1 constellation, and it solidified an important relationship with a key ally in the region. In addition to the collaboration with Taiwan's NSPO, COSMIC-1 also included NASA, NOAA, NSF, and what is now the United States Space Force.

From its launch in 2006 to its retirement in 2020, COSMIC-1 has made a huge impact. More than 4,000 researchers from 95 countries were registered users of COSMIC-1 data, which was freely available to users in all countries. Furthermore, COSMIC-1 was also able to provide 90% of its data soundings within three hours of collection. The GPS RO data from COSMIC-1 had direct marked improvement to global analyses of the neutral atmosphere and ionosphere, especially above the oceans, polar regions, and other hard-to-sample areas, leading to improved prediction of tropical cyclones, global weather, and space weather forecasting.

As a result of the COSMIC-1 program, private weather data companies like my colleagues from SPIRE were able to use the COSMIC-1 data and operational insights to develop their own observational systems for RO. This commercialization of RO observational systems should be celebrated and is another fine example of R2O technology development.

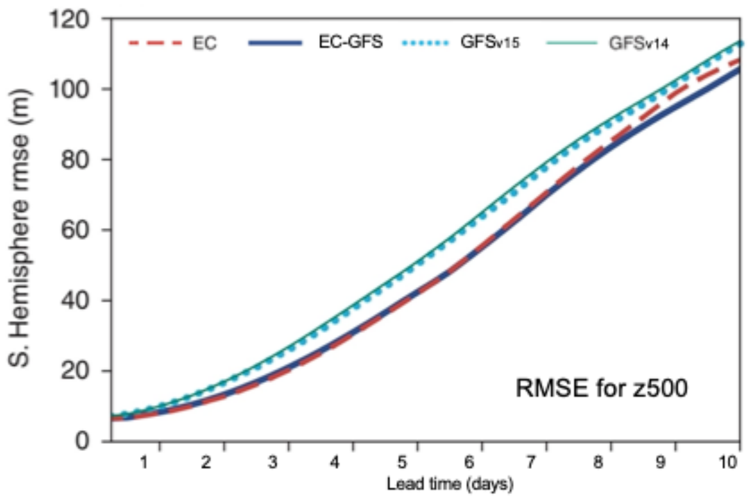
In 2019, after the success of COSMIC-1, U.S. agencies and Taiwan decided to move forward with a COSMIC-2 follow-on mission with new Global Navigation Satellite System Radio Occultation (GNSS-RO) technology. COSMIC-2 also includes secondary space weather payloads, including a Radio Frequency Beacon (RFB) transmitter and an Ion Velocity Meter (IVM). COSMIC-2 weather and space weather data products are typically available to operational centers within 30 minutes of observation, which is significantly faster than COSMIC-1. Together, this suite of instruments has provided the weather enterprise with a revolutionary increase in the number of atmospheric and ionospheric observations that are significantly benefiting both the research and operational communities.

Taken together, the development of COSMIC-1, the subsequent commercialization of GPS RO technology, and the new COSMIC-2 mission pioneering GNSS RO technology are a perfect example of how the research community, the government, and the private sector can work together to continue to drive innovation and create value together as technology development moves forward. The commercialization of GNSS RO technology would not have been possible without the government's involvement in establishing the requirements and standards, and the various phases of data purchases, including the commercial weather data pilot program. The success of COSMIC-1 and COSMIC-2 also demonstrates the need to ensure continuity of high quality, free-to-access RO observational data in support of weather, climate, and space weather operations and science. A government backbone for RO data should continue to provide a gold standard for the triad to adhere to. RO data from this backbone, provided by the U.S. and other countries, gives users reliable and freely available measurements to ensure that critical operational users have access to failsafe data sources in addition to those provided by the commercial sector.

One thing to consider about the discussion that we are having today about data innovation and prediction is that any progress on data standards, technology commercialization, research, and development will be constrained if we do not address shortfalls in our data assimilation capabilities and make better use of the data that the weather enterprise already has access to and paid for. Data assimilation is a field of data science that combines observations and models to produce the best analysis of the real world, which can be used as the starting point for prediction. In doing so, the goal is to estimate the most accurate current state of the system possible and then model and predict the system's behavior under changing conditions and inputs. This process is used extensively in Earth system science fields like meteorology, oceanography, climate, and numerical weather prediction (NWP). Observations can continually be fed into the model through data assimilation, increasing the model skill and accuracy.

Today's accurate weather forecasts provide enormous value to society. They enable officials to give early warning to communities in harm's way, saving lives and property, while also making the economy more resilient and strengthening national security. Despite their tremendous accuracy, the best forecasts can still only extend about 10 days into the future with enough skill to benefit the public. Even then, atmospheric conditions are constantly changing, altering the weather outlook significantly on very short time scales. The chaotic nature of the atmosphere can mean that the tiniest errors in the initial conditions for a model can translate into massive forecast uncertainty. Refining these initial conditions is incredibly important, and delivering more accurate predictions would provide even more far-reaching benefits to our country. They would, for instance, allow officials to be more precise with evacuation orders in the face of incoming hurricanes, help utilities take proactive steps to minimize power disruptions, give farmers more time to protect their crops from severe weather, and enable airlines to shift routes and adjust schedules as storms approach. While continued advances in both supercomputing and modeling are essential for improving forecasts, a particular area where increased resources will yield big returns is data assimilation.

America’s weather enterprise has a significant amount of data at its disposal, but U.S. weather forecasting capabilities continue to lag behind our European counterparts. This discrepancy is not due to a data deficit compared to the Europeans. Instead, it is because our European counterparts have made greater advances in data assimilation, and their forecast models are equipped with a better data assimilation system. Research has shown that the National Centers for Environmental Prediction (NCEP) operational model initialized with the European Centre for Medium-Range Weather Forecasts (ECMWF) analysis has compatible forecast skills with the European weather forecast models.

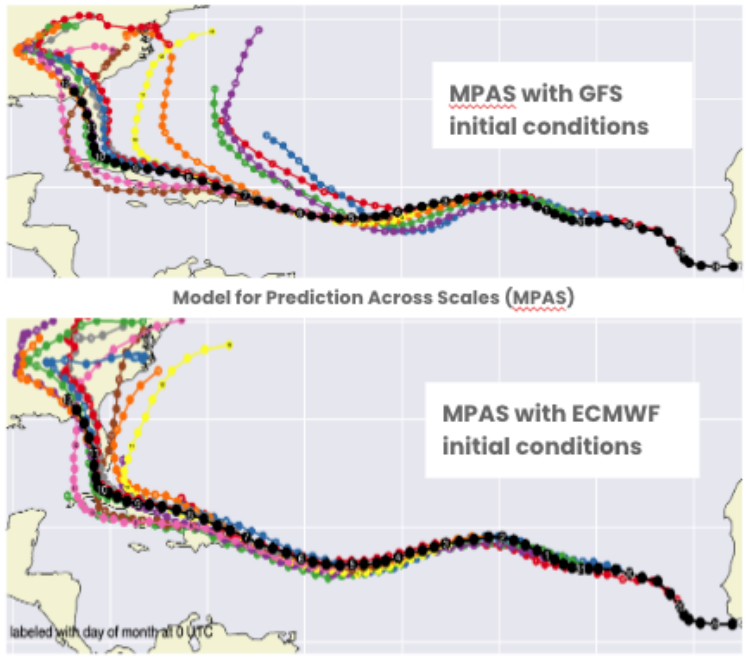


This figure shows the 500 hPa rmse (root mean square error) of ECMWF and various versions of NCEP GFS model over S. Hemisphere, from August 2015 to August 2016. Note that when the GFS model (dark blue line) was initialized with the ECMWF initial condition, it performed as good or better than the ECMWF model (the red dashed line). [From Magnusson et al. (2019).]

One example of the positive impacts of data assimilation on prediction is a recent analysis in which NCAR scientists used European initial conditions with the NCAR MPAS model to hindcast Hurricane Irma, which caused approximately $77 billion of damage in west central Florida in 2017. The results of that exercise are dramatically more accurate forecasts with European initial conditions vs. what the Global Forecast System (GFS) models produced with NCEP initial conditions.

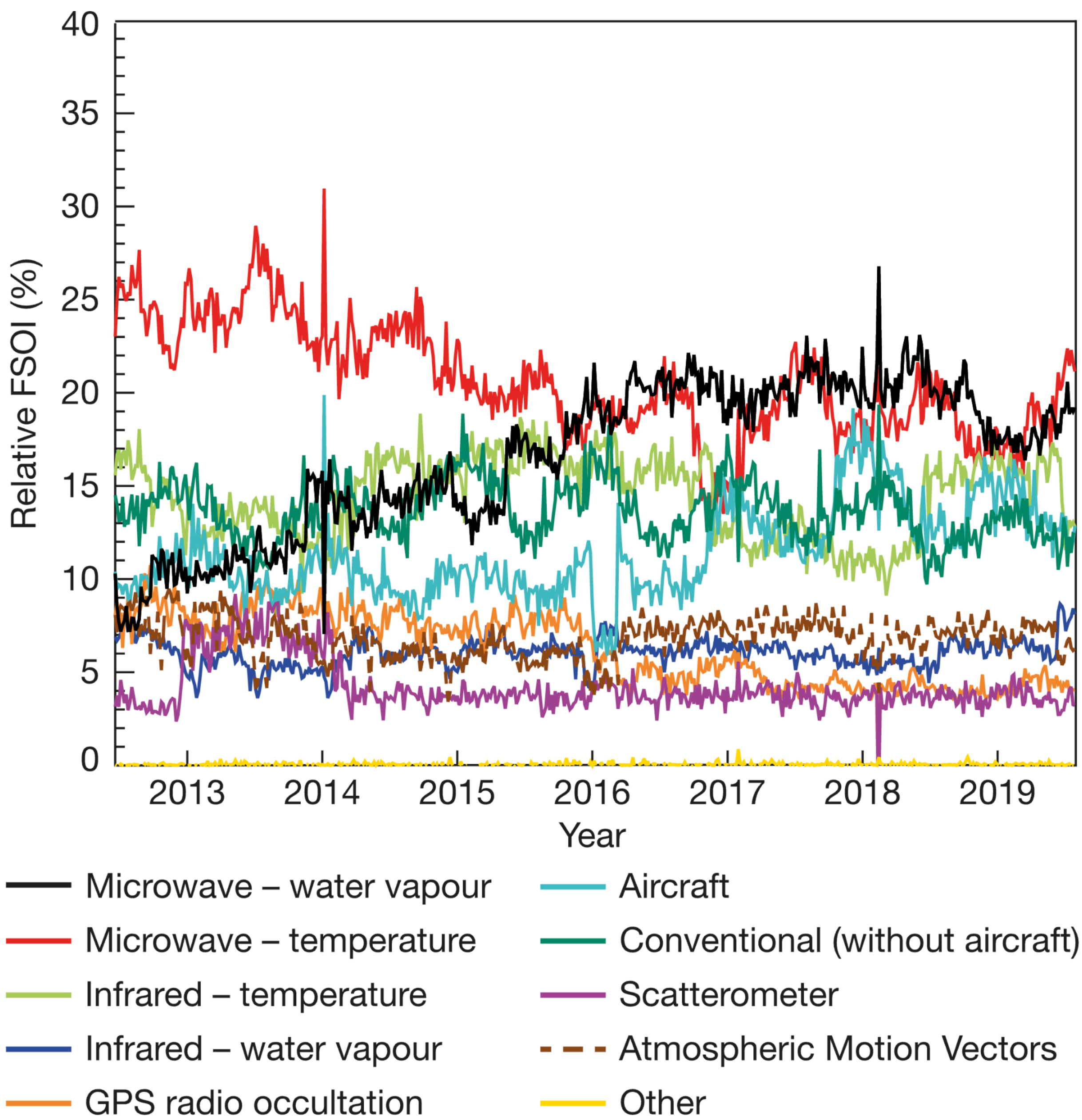
MPAS FORECASTS: HURRICANE IRMA

How you initialize the forecast through data assimilation has a crucial effect.



Here, MPAS forecasts initialized with ECMWF initial conditions produced more accurate tracks for Irma than forecasts initialized with NCEP initial conditions.

One of the reasons that European prediction capability remains ahead of U.S. capability is its ability to better utilize the data at its disposal. The U.S. GFS and the European ECMWF system have access to the same global observations, and yet American forecasts are less accurate. Why is that? The Europeans have been more organized and better coordinated their data assimilation and workforce training efforts to understand how to better utilize the data available to their forecasters. This focused collaboration has allowed sustained research on key development topics over more than a decade, producing beneficial results. An example is the gradually increased impact of water vapor sensitive microwave observations through the improvement of their use in cloudy and rainy conditions (below).



Relative sensitivity of the operational 24-hour forecast quality to various components of the observing system since 2013. ECMWF Newsletter Number 161 - Autumn 2019.

Such coordination on data assimilation is possible in the U.S. and has already started under the auspices of an interagency partnership called the Joint Center for Satellite Data Assimilation (JCSDA). NOAA, NASA, the U.S. Air Force, and the U.S. Navy are partnering on the Joint Effort for Data assimilation Integration (JEDI) project spearheaded by the JCSDA to build their next-generation data assimilation for Earth system science and prediction. The first recommendation in the 2021 report on Priorities for Weather Research by the NOAA Science Advisory Board is on the topic of maximizing the use and assimilation of underutilized satellite observations. Specifically, the recommendation states, “Prioritize resources to expand collaboration between NOAA, JCSDA, academia and other government agencies to perform research and development of satellite data assimilation and its operational transition, with JEDI as the open source to enable such collaboration.”

It is critical that policy makers make significant, targeted, and sustained investments in data assimilation and the operational modeling and forecasting workforce to create more accurate predictive forecasts in service to society with the existing observation systems we already have. Moving forward, any investment in future operational satellite systems should also include similarly robust investment in data assimilation to optimally exploit the information from those observations. This should be built into the total cost of the observational system at the outset, and not become an afterthought as it has in the past.

If we are to increase prediction skill and level the playing field with the Europeans, we must improve our return on investment for the existing observations we already have. For many satellite remote sensing observations, only a small fraction (on the order of 1%) is actually used in operations, due to limitations in computational efficiency and physical accuracy of the data assimilation software. With data assimilation investment advancements, we can increase that fraction by at least a factor of 10 in the next several years. Further gains could result from better observation error representation, better handling of physical interactions and radiative transfer modeling in cloudy conditions and over heterogeneous surfaces, and the use of artificial intelligence and machine learning for ultra-fast surrogate model development. These future advancements will need significant investment and continuous research over the next 10 years, but could potentially result in a significant increase in our ability to utilize observations data for predictive modeling.

As it stands now, the weather enterprise is not prepared for the data explosion that is coming its way. As instruments have improved and private sector platforms have been deployed, the magnitude and volume of observations is seeing exponential growth over the years. According to the JCSDA, many future observation instruments on next-generation weather satellites could produce several terabytes per day. If one were to ingest the same amount of data produced by the next generation of hyperspectral satellite sounders, you could fill up a Library of Congress worth of data in less than a year. This will undoubtedly stretch the capacity of our existing data pipelines and operators, requiring increases in efficiency. Furthermore, the explosion in the variety of data sources with the predicted increase of commercial data buys from constellations of small satellites will require significantly more flexibility in the data assimilation that only a collaborative development such as JEDI across multiple agencies, academia, and the private sector can achieve.

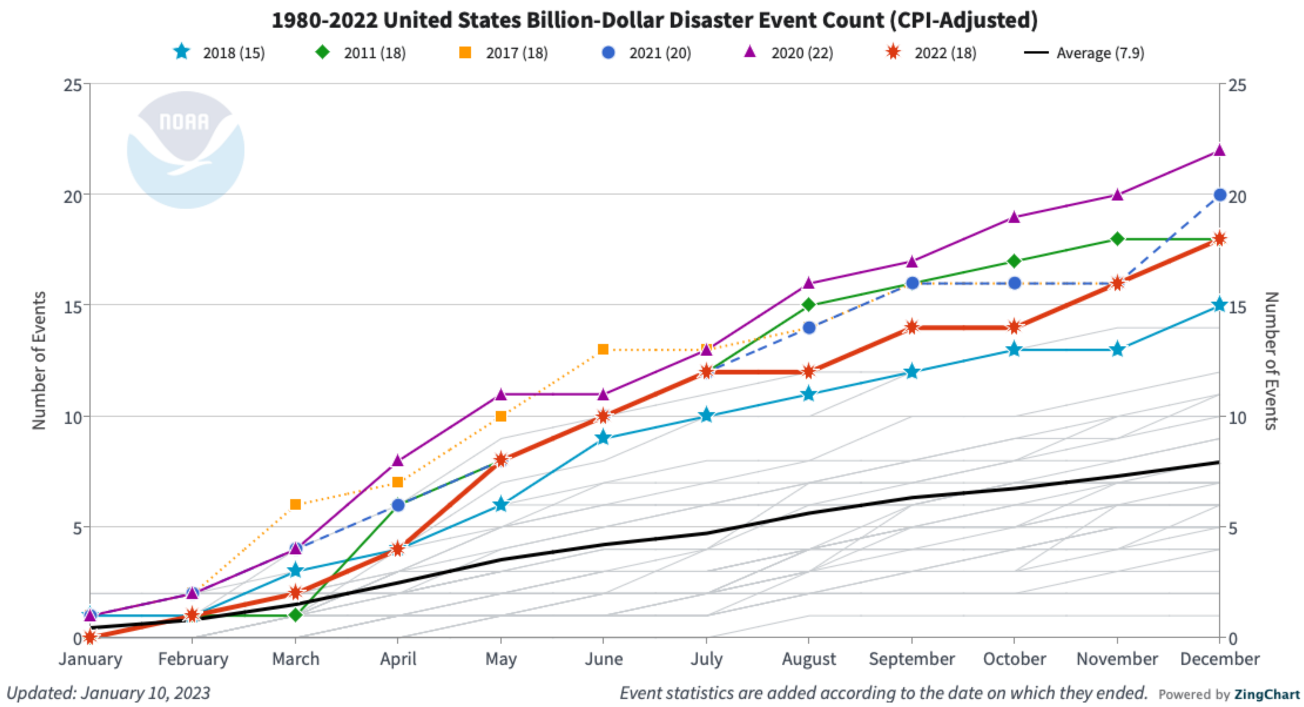
As part of the next Weather Act reauthorization, the committee should prioritize the rapid training and workforce development of the next generation of data scientists trained in assimilation. As it stands now, the majority of the world's expert data assimilation scientists hail from outside the United States. If the United States is serious about being competitive in this area, NOAA, NASA, NSF and other agencies with direct need for observational data for operational use or research must rapidly deploy resources into our universities and colleges to build out data science and software engineering programs or we risk falling behind even further. In addition to workforce development, the committee should also consider providing robust additional resources for academia and basic research in data assimilation, as well as guidance on the directions of data assimilation research to best meet the needs of the entirety of the weather enterprise for research and operations.

One thing to keep in mind is how consistent research and development continues to push the boundaries of understanding the Earth system as well the technology used to observe and predict it. Putting into place a robust, sustainable process to assess areas of potential growth and development in all areas of the weather enterprise, including data assimilation, will serve the triad well in planning for the future.

Finally, I ask the committee to consider the initiation of a decadal survey for the entire weather enterprise that would include a strong emphasis on data innovation for prediction, including but not limited to the themes I have discussed today including data standards and data assimilation. I am very supportive of the recommendations in the Priorities for Weather Research report that NOAA has published as it relates to data innovations. That being said, we still need to create and implement a process for the weather enterprise that allows for continued consideration of goals, recommendations, and accountability for putting those recommendations into practice. Prior to joining UCAR, I served as the co-chair of the National Academies' Decadal Survey for Earth Science and Applications from Space. This decadal provided a 10-year road map for NASA, NOAA, and USGS in how they could approach the future of space-based Earth observations.

The reason this is imperative is, as NOAA notes, the prevalence of billion-dollar weather disasters in our country that have continuously increased year-over-year, and show no signs of slowing down. Since 1980, the United States has sustained 341 billion-dollar weather and climate disasters, and the exceeded $1 billion.[3]

[3] NOAA National Centers for Environmental Information (NCEI) U.S. Billion-Dollar Weather and Climate Disasters (2023). https://https://www.ncei.noaa.gov/access/billions/, DOI: 10.25921/stkw-7w73



The total cost of these events has exceeded **$2.48 trillion**. As you can see, this problem is by no means slowing down. As I noted earlier in my testimony with the Hurricane Irma example, which cost $77 billion, more observational data and better data assimilation practices could have led to better initial conditions in prediction models. Such models, when utilized properly, can give first responders and emergency managers precious time to move people out of harm's way and protect property as best they are able to.

In addition to predicting extreme weather events, we also must strive to better predict seasonal and sub-seasonal weather conditions as well. While the economic disruptions may not be on the same scale as major weather events, going into a season unprepared as a result of less than accurate forecast can also cause cascading economic impacts, which over time could start to rival the economic costs from a single event. One recent example of this is the recent wet winter on the West Coast, where seasonal precipitation greatly exceeded forecasts. This unfortunately led to a lack of preparation, leaving water managers ill-equipped to capture excess precipitation during a period of extreme drought, and emergency managers to underestimate the threat of flash flooding on landscapes scarred by wildfire. In fact, as recently as last week, another atmospheric river delivered hurricane-force winds and rainfall to northern California, leaving over 120,000 PG&E customers without power.

Given the implications of weather on our society and the increased prevalence of major weather disasters across the nation, it is critical that we think strategically about the utilization of limited resources. A decadal process will allow us to prioritize what has to be done and do so in recognition of the current fiscal realities. The potential upside for the nation in implementing a more intentional decadal survey process for the weather enterprise, encompassing mid-way assessments and subsequent follow-on survey, is enormous. If we do it right, we can leverage every leg of the triad to spur successful growth of the entire weather enterprise. If we get it wrong, we risk falling behind with prediction capabilities that will sorely lack in comparison to the size of the problem that we as a society are facing.

The weather enterprise has come a long way since the *Fair Weather: Effective Partnership in Weather and Climate Services* report from the National Research Council was published 20 years ago in 2003. American ingenuity and competitiveness are second to none. For the weather enterprise to take the next big step, the next Weather Act should strive to facilitate an environment that allows for successful government-private-academic partnership with all three legs of the triad working together. This will require all legs to meet in the middle to address questions around not only data standards and accessibility, which we have discussed today, but other issues I know the committee will address in time as it starts to formulate legislative language around the reauthorization. If the next reauthorization can successfully break down silos within the weather enterprise and remove barriers between the various legs of the triad working together, the future of the weather enterprise is, in my opinion, very bright indeed.