Summary Statement of Antonio J. Busalacchi, Jr.

Today's weather enterprise is a triad that consists of the academic/research community, the public sector, and the private sector. The government's traditional role within this triad is the protection of life and property, and the enhancement of national security. This public sector 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 work force for both the government and private sector. The three work together in a public-private partnership that, on the world stage, is often more the exception than the rule. This is a particular strength of our nation's approach to the weather enterprise. These three pillars of success have yielded the world's most comprehensive and successful array of weather services in support of the public AND private good. While the roles of each of these legs of the weather enterprise must continue to evolve, weakening any single leg will compromise the entire enterprise, and will negatively impact its diverse beneficiaries. We must also recognize that the private sector has been built upon and has benefitted from the foundation of the free and open approach to data and models. As a result of the tremendous public investment there has been an enormous return to the public in terms of jobs and innovation. From a policy perspective the companies we see here today are direct beneficiaries of our policy decisions 20 years ago. The real issue that confronts us is what do we want this enterprise to look like 20 years from now? I think we should act with caution so as not to do any harm, and ensure that the marketplace maintains its competitiveness and no barriers to entry are erected. In short, we need to find a workable method to strategically plan the entire enterprise.

The last major study from the National Academies that addressed the public-private interface in depth was the "Fair Weather" report of 2003. As a result of that report NOAA worked to produce a new policy to support the dissemination of environmental information to the public, which was more than just weather data. In 2012 the National Academies released a report on "Weather Services for the Nation: Becoming Second to None" that was an assessment of the NWS's Modernization program. The report had three main recommendations for the NWS: I. Prioritize Core Capabilities, II. Evaluate Function and Structure, and III. Leverage the Entire Enterprise. It is this last recommendation that I have dealt with most in my testimony. I believe it is time to revisit these two reports and re-assess, given the fluid situation in the weather enterprise, what the respective roles and responsibilities should be among the three pillars. We are lacking a national strategy for the entire weather enterprise and we run the risk of losing sight of the big picture. At one moment we may be occupied by the challenges of commercialization of satellite observations, the next moment by the potential of private sector models, and the next by procuring models from another country; all at the expense of what is best for the nation as a whole. I am concerned by the potential for fragmentation of our enterprise. I can easily see a scenario where Company X takes publicly supported and freely available models and data, and adds unique value to them, Company Y sells some data to the government but withholds some data for its business purposes, and Company Z has its own proprietary models and data that are not available for the common good. Is this what is best for our nation to protect lives, property, and support our military in the field? Continued improvement in our forecasting ability requires that observations be reliable and accessible, and forecasts for the public good be verified, validated, and transparent. Prior to taking on my new position with UCAR, I was co-chairing the next Decadal Survey for Earth Science and Applications from Space. As requested by Congress, all of the space sciences have a long history of these decadal surveys that the agencies are beholden to, in addition to the insight they provide to Congress, OMB, and OSTP. We have no such activity for the weather enterprise. Given the ever evolving nature of the weather enterprise I would submit we need an active and ongoing strategic planning process as could be achieved by Congress requesting a decadal survey for the weather enterprise inclusive of mid-way assessments and subsequent follow-on surveys. There is considerable upside potential for the nation if we do it right. We have much to lose if we do it wrong.

Private Sector Weather Forecasting: Assessing Products and Technologies

Statement of

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before the

Subcommittee on Environment

Committee on Science, Space and Technology

U.S. House of Representatives

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Good Morning Chairman Bridenstine and Ranking Member Bonamici, and members of the subcommittee. I am Dr. Tony Busalacchi and I am Director of the Earth System Science Interdisciplinary Center and Professor of Atmospheric and Oceanic Science at the University of Maryland. Prior to coming to the University of Maryland 16 years ago, I was a civil servant for 18 years at the NASA Goddard Space Flight Center (GSFC), the last 10 years of which I was a laboratory chief and member of the Senior Executive Service. Effective August 1, 2016, I will be the next President of the University Corporation for Atmospheric Research or UCAR. UCAR is a nonprofit consortium of 109 member universities granting degrees in atmospheric and related earth sciences. UCAR's primary activity is to manage, on behalf of the National Science Foundation, the National Center for Atmospheric Research (NCAR) and UCAR's Community Programs. NCAR is a Federally Funded Research and Development Center with over 600 scientists and engineers performing cutting-edge weather and atmospheric research, and staff that manages supercomputers, research aircraft, and Earth observing systems. The UCAR member universities and staff scientists conduct research for use by government and the private sector to further our understanding of atmospheric phenomena, and help to create more accurate weather forecasts across the nation.

As part of my responsibilities at NASA/Goddard I served as the source selection official for contracts to the private sector for observations and technologies. At the University of Maryland my group has entered into a number of Memoranda of Understanding and Non-Disclosure Agreements with the private sector involved in Earth observations and prediction. We also host a cooperative institute that is joint with NOAA's National Environmental Satellite, Data, and Information Service (NESDIS) and the National Weather Service (NWS). From 2009 through 2014, I chaired the Board on Atmospheric Sciences and Climate (BASC) for the National Academies of Sciences, Engineering and Medicine. I believe that these experiences are directly relevant to this hearing and I will draw on them in my remarks below.

Following the suggestion in the committee's letter inviting me to testify, I will organize my testimony around the following questions that I believe are critical in examining the weather forecasting products and technologies of the private sector:

1. What constitutes the current weather enterprise and how did we get to our present state?

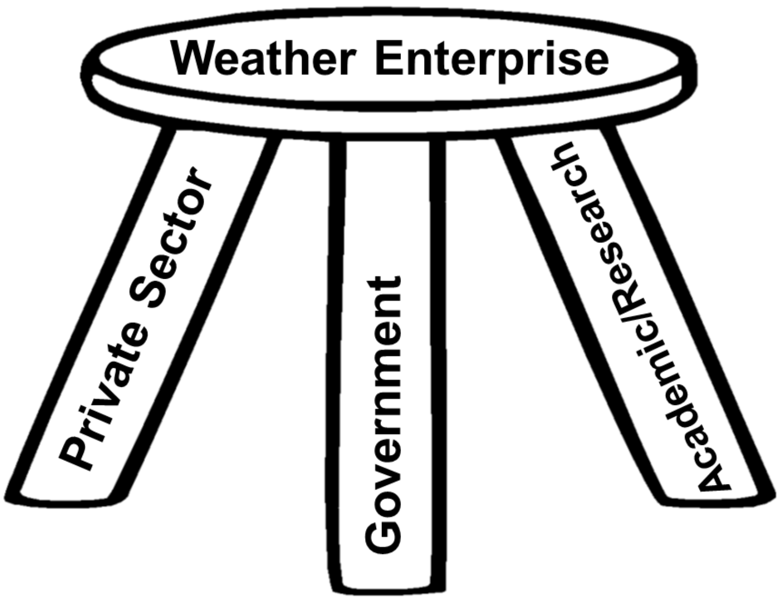
2. What key lessons can we glean from the development of the weather enterprise over time and what do they mean for the future of the enterprise?

3. What is the forecast for the future of the weather enterprise?

4. What processes and policies are needed to identify roles and responsibilities? What, if any, are the next steps for Congress?

1. **What constitutes the current weather enterprise and how did we get to our present state?**

Today's weather enterprise is a triad that consists of the academic/research community, the public sector, and the private sector. The government's traditional role within this triad is the protection of life and property, and the enhancement of national security. This public sector 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 work force for both the government and private sector. The three work together in a public-private partnership that, on the world stage, is often more the exception than the rule. This is a particular strength of our nation's approach to the weather enterprise. These three pillars of success have yielded the world's most comprehensive and successful array of weather services in support of the public AND private good. While the roles of each of these legs of the weather enterprise must continue to evolve, the diminution of any single leg will compromise the entire enterprise, and will negatively impact its diverse beneficiaries.



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.

This 3-way partnership has not always been the norm in our country's history. While Thomas Jefferson and Ben Franklin may vie for the title of America's "founding meteorologist", it was not until 1870 that the country decided to tackle weather in a more scientific manner. The Weather Bureau was established in 1870 in the Department of the Army Signal Corp and is in fact one of the few areas that has an actual organic act. The establishment of the Weather Bureau in the Department of the Army was for good reason; the military understood the implications and consequences of weather on military operations. History is filled with stories of campaigns shortened and empires ruined by bad weather. From Patton in the Bulge in 1944, to the sandstorms of 2003 in Iraq, and to the raid that killed Osama Bin Laden, weather has always been a factor in operations and it is as critical as ever to today's national security. Our combatant commanders in the field need and deserve the world's best actionable weather information.

There was, however, no private sector in 1870 making forecasts other than the Farmer's Almanac. The rise of the private sector in weather forecasting began after World War II as our veterans returned home. Today's capabilities of the private sector that rival certain aspects of the National Weather Service is a success story that has developed over the past several decades owing to three major factors;

a. Free and open data;

b. Modeling software that is free and open; and

c. The Information Technology revolution.

For years the model in the weather enterprise was government supported research to improve forecasting that was handed from the university community and federal labs to operational agents such as the National Weather Service at NOAA as well as within the Department of Defense. The government entities would then use those advances to improve forecast skill in their respective mission areas. This model changed rapidly in the 1990's with the modernization of the National Weather Service which occurred during a period of rapid growth in information technology capabilities. For the first time, foundational observational data, computer codes for numerical weather prediction models, and software technologies such as data assimilation (that merges the observations with the model information) were accessible to the private sector at no cost. Advances in information technology allowed private companies to access government data, download it, and add their own value to computer codes and observations to produce a suite of products that were tailored to meet specific customer needs. This heavy leverage of the government investment has enabled a private sector to flourish and develop a unique set of services and products.

The American Meteorological Society has compiled information that estimates the broad U.S. weather and climate industry at more than $5 billion, including some 250 commercial weather companies that generate roughly $2 billion. The recent acquisition of the Weather Company by IBM has been estimated to be a $2B purchase in and of itself. Why did IBM buy the Weather Company? IBM bought The Weather Company because there is now an opportunity to inject weather forecasting and weather data into many more products and services enabled by rapidly developing information technology capabilities. As technology rapidly improves and it becomes easier and more cost-effective to perform more and more sophisticated weather forecasting operations, the triad – the private sector, government, and academia – will need to continually reassess what are the appropriate roles and responsibilities of each sector.

I believe the march towards commercialization will continue and we should all support commercialization. There is ample evidence to suggest that more weather operations can be performed easily, independently, and nimbly in this manner. Additionally, it is evident that there are opportunities for companies to incorporate rapidly developing technologies more quickly. As a case in point, one of my colleagues at the University of Maryland is collaborating with Panasonic Weather Services that funds one to two of his graduate students in this area of data assimilation. While it took nearly nine months to resolve intellectual property issues on both sides, this has proven to be a mutually beneficial collaboration. In addition to just the funding, on the university end there is ultimate flexibility in the experiments being run for the sponsor, ample supercomputing time, rapid turnaround time for experiments, and the students are exposed to the real-world needs of a specific sector/application that can only help to enhance their employment opportunities after graduation. It is also my understanding that a number of the personnel developing the data assimilation methodologies at Panasonic were formerly employed at NCAR. This is just one example of the vibrant and healthy working relationship between the research community and the private sector.

With respect to the government and the private sector, the National Weather Service relies on the private sector to disseminate and amplify public safety messages for high impact weather events. From the use of apps, to social media, to broadcast meteorologists personalizing NWS warning information, the private sector is critical to helping the NWS protect lives and property as part of its Weather-Ready Nation initiative. We need only turn on our TV at night to see that the NWS relies on the private sector to broaden access for the display, delivery, and archive of NEXRAD radar data. Therefore, the private sector is a critical partner in making real-time radar data available to the broadcast media, emergency management community, and general public.

The NWS also operates several major programs that facilitate the purchase of data from the private sector, universities, and other non-federal operators of observing networks:

- The National Mesonet Program (NMP) was created by Congress following the 2009 release of the National Academies' report "Observing Weather and Climate from the Ground Up: A Nationwide Network of Networks." A key recommendation of that report was for NWS and other agencies to leverage data from existing sources, where possible, in lieu of deploying new federal infrastructure to fill gaps in the nation's federal weather observing systems. Begun as a program to purchase data from a relatively small number of surface networks located mostly in the south-central United States, the program has now grown to encompass more than three dozen networks covering all 50 states, and is NWS's largest data purchase program.
- The Aircraft Based Observations (ABO) program is NWS's primary program for purchase of data from sensors mounted on commercial aircraft that serve major airport hubs domestically and globally.
- For many years, NOAA's Global Systems Division in Boulder provided observations of "total precipitable water" at 400+ locations across the United States, by processing the signals from ground-based GPS receiving stations at those locations. As it turns out, the GPS microwave signal is highly sensitive to atmospheric water vapor content. These data are very valuable to forecasting significant weather events where total atmospheric water content is a driving ingredient; such has heavy rainfall and flash floods. As part of the effort to transition this capability into NWS routine operations, NWS partnered with the private sector to process the signals and provide the precipitable water data, at a significantly reduced cost relative to what would be been possible with an in-house processing capability.
- Lightning Data, including the precise locations of cloud-to-ground strikes and the locations of in-cloud flashes, have been provided to NWS for many years by the private

sector, which operate many networks for that purpose and provide a cost-effective solution. These data are critical to fire weather forecasting operations and applications related to airport and aviation safety.

The government also engages the private sector for operational forecast model development and improvement. For example, AER, a private company, competed for and won Federal funding to develop a technical package to handle how radiant energy drives the atmospheric circulation in forecast models. The manner in which this is handled in weather prediction models can be very compute intensive. The first Rapid Radiative Transfer Model (RRTM) was implemented in August 2003. AER provided code to the NWS to test in the NWS' global prediction environment. RRTM provided an improvement to the model accuracy. The NWS and the Joint Center for Satellite Data Assimilation (JCSDA – including NOAA, NASA, and DoD) have since then maintained a long-standing relationship with AER for the treatment of radiation physics in these models. This has been a good partnership for both parties. Over the years this technical package has been updated and implemented in a range of different U.S. models. AER's code is recognized as being state of the science and is used by other weather prediction centers around the world.

With respect to collaboration between the government and the research community, the Weather Research and Forecasting (WRF) Model is a mesoscale numerical weather prediction system designed for both atmospheric research and operational forecasting needs. The model has served a wide range of meteorological applications across scales from tens of meters to thousands of kilometers. The effort to develop WRF began in the latter part of the 1990's and was a collaborative partnership principally among NCAR, NWS, the Air Force Weather Agency (AFWA), the Naval Research Laboratory, the University of Oklahoma, and the Federal Aviation Administration (FAA). WRF has also served as an important platform for the private sector to build upon.

We must also acknowledge that the growth of the private sector weather enterprise products and services has been built on the public investment, with a free and open data policy, and with forecasting technologies and techniques developed – and still developing – within the government and academic sectors. The government forecasts serve as a baseline standard by which private sector entities can and should compare their products and services. This has enabled considerable economic benefit to the U.S. due to this leveraging of the public data and models. We should be reminded that many of my fellow panelists have benefitted from this collaboration-based model. It is critical that this collaboration be maintained to support the next generation of private sector companies that will be able to develop products and services that will benefit our society and economy even further than this class of private companies has. I believe this is a great return on investment of public tax dollars and goes largely unnoticed. As the entire weather enterprise continues to mature, we must ensure that the American public remains well served. The best way of doing this is via a set of best practices and in continued partnership among the three pillars.

2. **What key lessons can we glean from the development of the weather enterprise over time and what do they mean for the future of the enterprise?**

There are many lessons and insights that have been gained over time when it comes to understanding what improves weather models and their associated forecasting skill. I would like to focus on four areas that empower both public and private forecasts, and discuss why they are critical;

a. Consistency of Data
b. Quality Assurance of Models and Data
c. Sustainability
d. An Enterprise that must continually evolve to ensure greatest value to the nation.

Long-term continuous observations (aka, data) can be considered boring and mundane, but they are absolutely critical to making a forecast and accelerating improvement in forecasts locally, regionally and globally. The United States has benefitted tremendously from long-term satellite, airborne, and ground based data that has been derived from observations. It is essential that we maintain an optimal mix of this suite of observations as each has unique strengths related to the quality of high impact weather services. The U.S. has, in fact, been the global leader in this area and despite problems with some satellite programs; the overall record of federal support for long-term baseline operations has been rock solid. In fact the U.S. pioneered the use of weather satellites and assimilated those data into numerical weather prediction models in rapid fashion. The ensured provision and access to quality data over appropriate temporal and spatial resolution is essential and the U.S. has done this in partnership with international collaborators, and now more and more with the private sector. This trend will continue to play out, but a key question we need to answer is what data have the biggest impact on improving forecasting skill? We cannot purchase data just for the sake of purchasing it, but rather it must meet a validated forecasting requirement and ultimately improve forecast skill in a significant, cost effective manner. We must ensure that the data are readily available in the public domain and meet the standards for accuracy, quality, continuity, and reliability given that such data are needed to save lives and property, and support national security. Open assessment and verification of the data is critical. All of weather forecasting is singularly dependent on the long-tern availability of quality data.

It takes time to generate and properly use the observations in the forecast models and this is where the research enterprise and its academic leg have played a crucial role in helping to tease the signal from the noise. A great example in recent times that highlights a new paradigm is the aforementioned National Mesonet Program at the National Weather Service which is a “network of networks” ground based observing system. While mesonet observations today provide important data to support weather models, it is important to remember that there was a ramping up period to ensure that the observations were of sufficient quality to go into the Numerical Weather Prediction models. This is a very important illustration of the three partners in the weather enterprise. Mesonets started as research tools in universities (starting with the Oklahoma mesonet), then morphed into privately run networks that now sell data to the National Weather Service and other private parties. Again, the blending of academic interest with a public need for data provided by a private company suggests how the weather enterprise can function to best serve the nation. All three parts of the triad are important. However, even to this day this day this is not a simple turnkey operation as improvements in network design, scope, and instrumentation continue within both the research community and private sector. Future evolution of the mesonet must be guided by good policy and solid technical requirements involving all parts of the triad.

It is also imperative to discuss the importance of quality assurance of models and data. One important reason for rapid progress in weather modeling is the community model concept. Given the scope and complexity of today's weather prediction models, the community model allows open and free access to new development which has contributed to continuous improvement of weather models. This must be maintained. In the case of a private company, when intellectual property is not shared, continued advancement for the entire enterprise as a whole can be hindered. We have seen examples where in the past a model was developed and licensed at one university, only to be surpassed in performance, over a short period of time, by open-sourced community developed models that draw on the best of the best and subsequently evaluated by various members of the community. In this field there is strength in numbers.

Across the national marketplace, companies claim superior products and services. Good business watchdog groups and government agencies hold those claims accountable and determine them false or accurate. In the open market it is *caveat emptor*. It is important that best practices and accountability measures are maintained to ensure that private weather models perform as well as their proprietors claim. Verification, validation, and transparency are essential. This is particularly critical to establish if protection of life and property were to ever depend exclusively on private models. Given that improvements within the private sector are propriety and an important part of the business model, no one can verify that they got good results for the right reasons. Can their results be replicated? Are they testable? This is all part and parcel of the scientific method. Perhaps, there is the need for a third party, trusted agent, or honest broker to ensure accountability. Additionally, it is critical that government models persist to be held up as the gold standard for quality assurance. Because government modeling is so transparent with respect to the private sector (and academia even more so), works so closely with the research community for continuous improvement, and requires fidelity to protect life and property, government forecasts should be the benchmark for forecasting. This is a key public service role that the federal government will need to continue to play for many years.

Equally important is that the government currently and regularly distributes forecasts over multiple domains and time scales; across short, medium, and long range; from global to regional, and across atmospheric, ocean, coastal, hurricane, land surface and space weather domains. Given we are dealing with a coupled atmosphere-ocean-land system, to forecast for one domain, you ultimately need a system that functions well across space and time scales; i.e., a seamless approach to forecasting for which NCAR is helping to lead the way in this regard. Improvements will come from lessons learned in data assimilation, initialization, and other techniques honed in various modeling endeavors and communities. This is a huge challenge, and the unification of global and regional models is a major goal of the NWS' Next Generation Global Prediction System. Many of these domain and time specific forecasts are not currently attempted by the private sector. As private companies are profit driven, remote areas with low economic value may be neglected and underserved by the private sector if there is no government effort. The government must maintain, entrain, and obtain the capability and talent to perform well these modeling efforts.

Finally, many have addressed the issue of the sustainability of the observations. Over time the federal government has sustained the weather architecture on many fronts and this has resulted in basic services, products, and growth of the private sector. The government model is based on a public goods service model that has been acknowledged for quite some time. Due to indemnification, the federal government has the responsibility to make the forecast for the high-impact anomalous weather event. The government has been and will be there to make that forecast. One can reason this is exactly why government exists.

If the government relies on the private sector for critical data streams and those companies decide to exit the market we will see degradation in forecast quality. I believe we need to think about the sustainability of the data buy model as it pertains to weather. This is an issue I raised when I spoke to you this past November. Several years ago the DOD and the intelligence community stood up imagery companies with the thought that they could create a private market that was ancillary to their primary customer. Even though there has been 60 years of heritage for space-based imagery, when it came to leveraging off the national security investment, that market did not materialize and the two major companies in the field merged. That is a result I would not like to see anywhere in the weather enterprise.

Sustainability of efforts in the private sector is not just a figurative matter of life and death for those companies providing the data to the government. It is in fact a literal matter of life and death to those people who depend upon the forecasts that are generated through the use of that data—and it cannot be turned off. Much like the previous example this is a matter of national security. Similarly, sustainability in forecasting is critical as well. To achieve continuous advancement in weather modeling, existing and former models need to be readily accessible to judge improvement and reliability of new modeling efforts. NOAA's current Next Generation Global Prediction System process currently ensures that models of the future will be categorically and objectively better than models of the past. Nonetheless, the government needs to continually strive at accelerating and embracing innovation from the academic/research and private sector parts of the triad while maintaining reliability. We simply cannot afford to accept the status quo. More can and needs to be done in this regard.

3. What is the forecast for the future of the weather enterprise?

Given that we have touched on how we got to the current state of the weather enterprise, I feel compelled to comment about the future and make a "forecast". I believe we will see greater international alignment on weather than we currently see, and we will see a role for both academia and the private sector in that future that is robust and productive. Furthermore, I believe we will see weather analytics and hyper local weather forecasts rise at a pace unseen in history with tremendous benefits to society everywhere and this will require the triad of interests to work together in an even more cogent manner.

Let me start by pointing out that during the Cold War, Soviet and American forecasters worked together and communicated regardless of what the situation was between Moscow and Washington. I make this point because despite how bad things were at a political level, the "forecasters culture" is one of cooperation and collaboration. This example epitomizes how weather is by its very nature international. Weather fronts that moved across the former Soviet Union are known today as "Siberian blasts" and "polar vortexes." People in Washington DC know these terms, but they emanated from relationships built decades ago and the fact is Soviet forecasters helped us and we helped them because it was the right thing to do.

While this is a bilateral example, we all realize that the globalization of weather and the ability to make quality forecasts has greatly benefitted lives across the planet. The establishment of the World Meteorological Organization (WMO) was to address the very nature of the global scope of weather. The WMO has over time focused on global cooperation and it is this global cooperation that has led us down the path of our current hyper local forecasting capabilities that can now be done by both public and private sources across the planet.

The WMO has worked to establish data protocols and share information. That sharing led many in academia to get access to data to transform research results into better models and understanding of local and regional weather patterns. It also led many innovative companies to use that same data to create unique and specialized products to serve customers around the globe and expand weather products into new markets.

Moreover, I believe the future weather enterprise will be much more integrated today because individual countries cannot afford to build by themselves the complex tools such as satellites and models. They realize that by integrating their systems with other countries they will get a bigger return on their investments. Observations have led the way. In 2003 under the leadership of then Secretary of State Colin Powell, the United States led an effort called the Global Earth Observing System of Systems (GEOSS); a prime example of international coordination that leads to integration and alignment. The developed countries who are signatories to GEOSS bring large observing systems to the table. The developing nations that in the past treated their observations as national secrets bring those data or bring areas that have not had access to observations to the international community; associated products and services then result to the betterment of all. GEOSS did not start with technologies, but focused on nine societal benefit areas and then worked from those to develop areas that needed to be addressed by technologies. GEOSS is represented at the WMO as an ad hoc organization and is referred to as the Group on Earth Observations (GEO). Any country can access data if it is a signatory. What the WMO and GEO have done is create alignment in weather never seen before. As a result, the private sector in the United States has access to these data to reach markets everywhere. Perhaps in the future we will see global alignment in regards to weather modeling and data assimilation. We are not there yet, but it is clear that by working together, the meteorological services around the world, and their associated researchers in universities and the private sector, will all benefit from this collaborative model of alignment.

Finally, this alignment in our own country has already resulted in private sector weather analytics and hyper local forecasts that address a variety of events in a fashion unheard of even 10 years ago. Several of the people on this panel have hour-by-hour forecasts that provide users with real time data matched with GPS to a site-specific location. Some on this panel use open source models, then add their own proprietary data and/or technologies to deliver aviation forecasts that make air routing more efficient. Others target specific components of the energy sector to meet emerging wind and solar forecast requirements. The opportunities for new hyper local industry specific forecasts in the United States and abroad are nearly limitless. We now see this as normal in the digital age, but it is a relatively new phenomenon. This market is in its infancy.

The emergence of hyper local forecast products requires more computational power and models that scale from a global to regional to local level. It requires three-way cooperation among all members of the weather triad to ensure that the public knows the values and limitations of these capabilities. It also requires government and private sector research investment to keep the United States on the cutting edge in delivering these products and services.

4. What processes and policies are needed to identify roles and responsibilities? What, if any, are the next steps for Congress?

Clearly, the weather enterprise is dynamic and it relies on all three participants. What can Congress do to leverage the best forecast at the least cost? What is the role of the public sector given we have emerging capabilities in the private sector we could not have imagined 20 years ago? What is the best path forward? Are government and academia making best use of existing vehicles for collaboration with industry such as SBIR and STTRs? These are salient questions. At the same time we must recognize that the private sector has been built upon and has benefitted from the foundation of the free and open approach to data and models, and as a result of the tremendous public investment there has been an enormous return to the public in terms of jobs and innovation. From a policy perspective the companies we see here today are direct beneficiaries of our policy decisions 20 years ago. The real issue that confronts us is what do we want this enterprise to look like 20 years from now? I think we should act with caution so as not to do any harm, and ensure that the marketplace maintains competitiveness and no barriers to entry are erected. In short, we need to find a workable method to strategically plan the entire enterprise.

From my perspective we need to support, encourage and promote collaboration across the academic, government, and private sectors. My future organization UCAR/NCAR has a strong and proven track record in this regard. UCAR/NCAR has served admirably over the years as an effective and efficient conduit for interaction with both the government and the private sector. Programs like the Research Transition Acceleration Program (RTAP) at NOAA are trying to bridge the notorious valley of death between fundamental research and application. RTAP would prioritize projects based on opportunities to advance NOAA's mission. NOAA funded research projects identified for transition will be evaluated and prioritized for funding based on a common set of criteria, including mission criticality, societal benefit, early stakeholder engagement, and plans for reliable delivery of products and services. When appropriate, RTAP funds could be used to transition research performed by other government agencies and non-governmental entities. NOAA is not averse to the idea that the research or operations program managers could be non-NOAA managers – or not be funded by NOAA. The only requirements for receiving RTAP funding, be it the private sector or academic sectors, would be that a technology to be transitioned must meet the common criteria, advance NOAA's mission, and fulfill a NOAA-mission application or operational need.

Bridging the valley of death is not just a bridge from academia to public sector organizations, but it has to be a series of bridges with flow in both directions: academia to/from the private sector, academia to/from the government, private sector to/from the government. Obviously, these bridges will not be easy to construct and maintain when dealing with delicate matters such as intellectual property, but the barriers are not insurmountable. Programs such as RTAP and others can ensure that the government's continuous role in weather forecasting can be a source of opportunity for continued improvement of modeling in the academic and private sectors, and for all products and services that the country relies on.

Furthermore, the government acquisition cycle can no longer keep pace with the academic and private sector innovation cycles. Our ability to innovate in areas like weather analytics are tailor made for new and exciting commercial products. Weather is big business and growing, but how do we define the terms of engagement for the various participants so that competition can flourish and obstacles can be addressed before they emerge?

Are we are at the point where Congress directs the National Weather Service to focus only on the high impact anomalous event and remove itself from day-to-day forecasting? Some might say that the day-by-day forecasting can be handled by Artificial Intelligence, i.e., that off the shelf machine learning algorithms could take a model forecast and automatically generate maximum and minimum temperatures without much need for the private sector. Is it the proper role for the government to maintain the back bone in collecting the essential observations and making high resolution global forecasts that are freely available? Clearly to date, this has enabled the private sector to derive products to serve their customers. At a minimum, we need to make sure that essential data are collected to support forecasting and be easily accessible; regardless if it is done by the government or private sector. It is also essential that high quality, high accuracy forecasts be available for the protection of life and property, and support of national security. I think it would be a mistake if we were to ever find ourselves dependent on any one single company. Let us also not lose sight of the fact that most of my testimony pertains to tomorrow's weather. This is undoubtedly important, but society is increasingly recognizing the need for improved weather predictions on subseasonal to seasonal time scales. Earlier this year the National Academies issued a report on "Next Generation Earth System Prediction: Strategies for Subseasonal to Seasonal Forecasts" that I helped initiate when I chaired BASC. With this information, planning and design decisions can be made that reduce our vulnerability to tomorrow's weather before it arrives. A case can be made that this is the single best weather related investment in the future that Congress could make. I make these statements to make a point. There are serious policy considerations that deserve review and attention from Congress and the weather community.

The last major study from the National Academies that addressed the public private interface in depth was the 2003 Fair Weather report on “Effective Partnerships in Weather and Climate Services.” That was 13 years ago and much has happened since then. As a result of that report, NOAA worked to produce a new policy to support the dissemination of environmental information to the public, which was more than just weather data. In 2012 the National Academies released a report on “Weather Services for the Nation: Becoming Second to None” that was an assessment of the NWS’s Modernization program. This report addressed three main challenges:

- Keeping Pace with accelerating scientific and technological advancement.
- Meeting Expanding and Evolving User Needs in an increasingly information-centric society.
- Partnering with an Increasingly Capable Enterprise that has grown considerably since the time of the Modernization Program.

The report had three main recommendations for the NWS: I. Prioritize Core Capabilities, II. Evaluate Function and Structure, and III. Leverage the Entire Enterprise.

It is this last recommendation that I have dealt with most in this testimony. I believe it is time to revisit these two reports and re-assess, given the fluid situation in the weather enterprise, what the roles and responsibilities are now and should be in the future given our changing environment in the field. We are lacking a national strategy for the entire weather enterprise. Until and unless all three parts of the triad give their best effort toward a strategic planning process, we will run the risk of losing sight of the big picture. At one moment we may be occupied by the challenges of commercialization of satellite observations, the next moment by the potential of private sector models, and the next by procuring models from another country; all at the expense of what is best for the nation as a whole. I am concerned by the potential for fragmentation of our enterprise. I can easily see a scenario where Company X takes publicly supported and freely available models and data, and adds unique value to them, Company Y sells some data to the government, but withholds some data for its business purposes, and Company Z has its own proprietary models and data that are not available for the common good. Is this what is best for our nation to protect lives, property, and support our military in the field? Prior to taking on my new position with UCAR, I was co-chairing the next Decadal Survey for Earth Science and Applications from Space. As requested by Congress, all of the space sciences have a long history of these decadal surveys that the agencies are beholden to, in addition to the insight they provide to Congress, OMB, and OSTP. We have no such activity for the weather enterprise. Given the ever evolving nature of the weather enterprise I would submit we need an active and ongoing strategic planning process as could be achieved by Congress requesting a decadal survey for the weather enterprise inclusive of mid-way assessments and subsequent follow-on surveys. There is considerable upside potential for the nation if we do it right. We have much to lose if we do it wrong.

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He has served extensively on National Academy of Science/National Research Council (NAS/NRC) activities, including as Chair of the Board on Atmospheric Sciences and Climate, Chair of the Climate Research Committee, Chair of the Committee on Earth Science and Application: Ensuring the Climate Measurements from NPOESS and GOES-R, as Co-chair of the Committee on National Security Implications of Climate Change on U.S. Naval Forces, and as a member of the Committee on Earth Studies, Institute of Medicine Committee on the Effect of Climate Change on Indoor Air Quality and Public Health, Committee on Assessing the Impacts of Climate Change on Social and Political Stresses, and Committee on the Assessment of NASA’s Earth Science Program. Dr. Busalacchi currently serves as Co-Chair of the NRC’s Decadal Survey on Earth Science and Applications from Space, and he also serves on the Intelligence Science and Technology Experts Group (ISTEG).

In 2016, he was elected to the National Academy of Engineering (NAE). In 2014 he was elected as Chair of the American Association for the Advancement of Science (AAAS) "Section W" on Atmospheric and Hydrospheric Sciences as well as being elected as a Trustee to the University Corporation for Atmospheric Research (UCAR) Board of Trustees. Professor Busalacchi has received numerous other awards and honors. Among these, in 1991, he was the recipient of the prestigious Arthur S. Flemming

Award, as one of five outstanding young scientists in the entire Federal Government. In 1995 he was selected as Alumnus of the Year at Florida State University, in 1997 he was the H. Burr Steinbach Visiting Scholar at Woods Hole Oceanographic Institution, in 1999 he was awarded the NASA/Goddard Excellence in Outreach Award and the Presidential Rank Meritorious Executive Award. He is a Fellow of the American Meteorological Society (AMS), the American Geophysical Union (AGU), the American Association for the Advancement of Science (AAAS), and in 2006 was selected by the AMS to be the Walter Orr Roberts Interdisciplinary Science Lecturer. As part of his broader professional interests Busalacchi builds on his family background and also provides a broad range of consulting services including wine education, wine list and wine program consulting, and viticultural weather and climate forecasting services, nationally and abroad via www.VinoVeritasLLC.com.