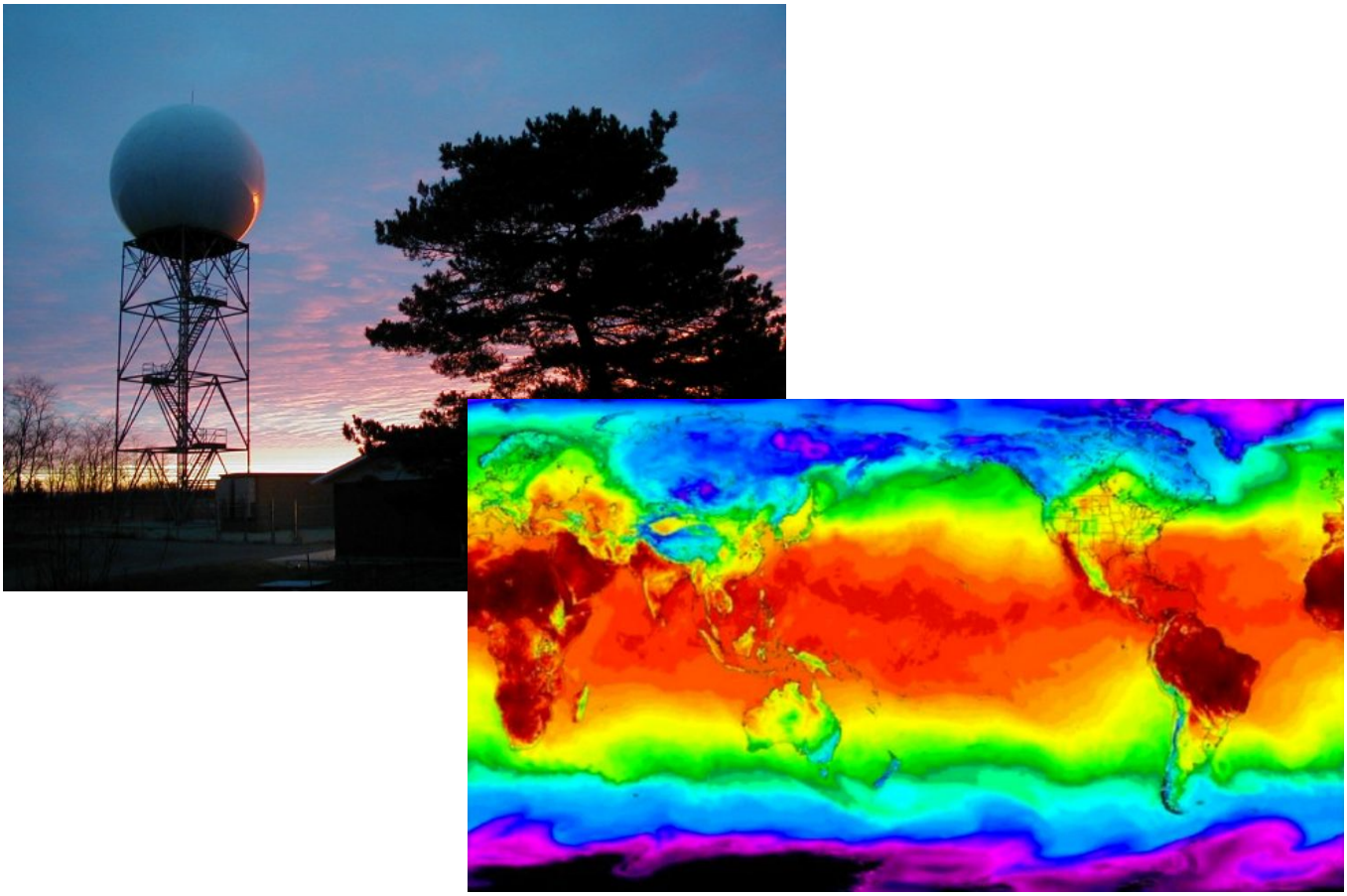
National Weather Service Enterprise Analysis Report

Findings on changes in the private weather industry

June 8, 2017



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[Cover Photos: Radome at La Crosse, WI Weather Forecast Office, A sample of Panasonic's global model (Image via Panasonic Weather Solutions)]

EXECUTIVE SUMMARY

In 2016, the National Weather Service (NWS) conducted a study to better understand the current and future landscape of the broader weather enterprise[1] in the United States. This document details the findings generated from this study.

The study focused on understanding the private weather industry component (i.e., America's weather industry) of the weather enterprise. This was accomplished by conducting a market diagnostic of the private weather industry, including customer demand, key innovations, competitive landscape, and growth trends, drawing upon publicly available information and interviews with users of weather services, private industry companies and experts in academia and National Oceanic and Atmospheric Administration (NOAA) and NWS. The study did not focus in detail on the international weather enterprise, the academic sector in the United States, or the water and climate enterprise, although these topics are lightly covered in this report.

NWS mission and role

The NWS has a dual mission – to provide observations, forecasts, and warnings of weather, water and climate for the protection of life and property *and* enhancement of the national economy:

- To better protect life and property, the NWS is undergoing an organization-wide transformational change effort to allow us to evolve to build a Weather-Ready Nation through providing impact-based decision support services to core partners in the public safety community.
- It is estimated that between three-to-six percent of variability in US GDP can be attributed to weather (up to $1,344B annually using 2011-2014 GDP estimates), illustrating the importance of the NWS's role in enhancing the national economy. The NWS provides the foundation to enable businesses to derive economic value from weather knowledge (estimated at roughly $13B across sectors if fully monetized) and a thriving private weather industry (estimated current market value of $7B) that provides businesses and other customers with the tailored products needed to unlock that value [2].

Trends and changes in the weather enterprise

The weather enterprise is undergoing significant change, driven by two factors:

1. There is increasing global demand for weather services as weather events become more volatile and costly (the average number of $1B weather events per year between 2008-2015 doubled compared with the prior 35 years)[3]. This is forcing businesses to improve their analytics capabilities and find new opportunities for weather data to drive business improvement.
2. Disruptive technologies such as miniaturization, Internet-of-Things (IoT), artificial intelligence, big data, and analytics are transforming all sectors of the economy. These new technologies are also fueling advances in weather

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[1] Weather enterprise defined here as public sector, private industry, and academic institutions with a weather focus

[2] Sources provided in Appendix 2

[3] NOAA National Center for Environmental Information, US Billion-dollar weather events and climate disasters

prediction and decision support and offer the potential to unlock more value from weather data.

Weather companies are investing in these technologies and developing new capabilities across the value chain[4]:

- Private industry capabilities are increasing rapidly in decision support, as companies develop new offerings that combine business and weather data, incorporate advanced visualization techniques, and take advantage of smart devices. Companies may begin to use these capabilities to serve public safety as well as business.
- The private industry is also developing capabilities upstream in the value chain, particularly in emerging space- and ground-based observation technologies and machine learning[5], with potential to significantly improve weather forecasting.

Outlook for the future of the NWS and private industry in the enterprise

Conversations with the private industry (both customers and providers of weather products), academia, and across NWS provide valuable perspectives on the role of the NWS going forward. We heard:

- The NWS has an important role as the impartial and authoritative voice on public safety and is a trusted partner to emergency managers, but could seek to collaborate more with the private industry in this role by looking for opportunities to harness commercial capabilities, engaging with companies to address risks, and identifying areas where private industry services can complement core NWS services.
- The NWS plays a key role in enabling the weather enterprise by providing weather, water, and climate data at the forefront of science, and by partnering with the private industry and academia to drive innovation – especially to operationalize emerging technologies and foster community model development.
- While many in the private industry have built upon the NWS's infrastructure, products and services thus far, there is potential for this paradigm to shift as private industry capabilities increase and businesses become more dependent on weather, water, and climate information.

[4] Value chain conceptualized as starting with observations and monitoring, following with modeling and forecasting and ending with service delivery.

[5] Type of artificial intelligence (AI) that provides computers with the ability to learn without being explicitly programmed. Machine learning focuses on the development of computer programs that can change when exposed to new data.

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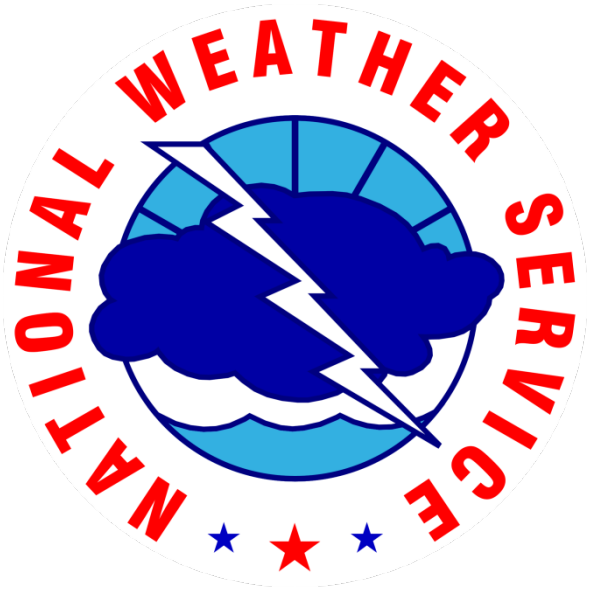

THE NATIONAL WEATHER SERVICE'S MISSION AND ROLE

The National Weather Service's mission is to "*Provide weather, water, and climate data, forecasts and warnings for the protection of life and property and enhancement of the national economy*."

Generating weather information involves a vast infrastructure of space and terrestrial-based weather observations, numerical weather models, and scientific development that require significant investment and coordination, and are not necessarily profitable for private industry players to provide. Further, there is a clear public safety rationale for providing universal access to weather forecasts and severe weather warnings, regardless of a particular community's ability to afford such information. Thus, the weather enterprise has a compelling need for a robust public sector agency that can both maintain the infrastructure needed to support a public good and provide universal access to weather information as a public service. This view is widely recognized by private industry companies, who have shared their need for an enduring and public weather service in multiple forums, and by the general public, which values the weather information that the NWS provides at approximately $280 per household per year, or more than $30B in total across the country annually[6].

[6] Lazo et al. (2008) "300 Billion Served – Sources, Perceptions, Uses, and Values of Weather Forecasts" – estimates of the value of weather information come from surveys asking participants their willingness to pay for weather information

As a result, the NWS is the foundation and central agent in a vibrant and dynamic group of government, academic, and private industry players that make up the weather enterprise. Through its central offices, the NWS maintains and improves the observations and weather models needed to issue forecasts. Through its nationwide network of regional and local offices, the NWS translates weather forecasts into useful information for public safety.

Through a longstanding policy of making data available for free to the public, as well as its role as a global leader in structuring and ensuring environmental data exchange, the NWS has enabled a thriving private industry to develop. Until recently, the role of the private industry consisted largely of selling observational equipment to the NWS and NOAA, communicating the NWS's data to the public through a variety of consumer media and distribution channels, and customizing NWS data and forecasts for business users[7]. The role of academia has historically been to conduct the basic and applied research needed to continually improve observations and models.

This report examines in more detail the way in which the NWS currently fulfills its mission to protect lives and property *and* enhance the national economy and outlines trends and advances in the broader weather enterprise –particularly the private weather industry. Although this report focuses primarily on weather, it recognizes the growing importance of water and climate data as areas for the NWS to further develop. Finally, while the focus of this report is domestic, it is worth mentioning that the NWS and NOAA also play a valuable global role, not only in advancing weather science that benefits the global community, but also in understanding global requirements and assisting developing countries with their capacity development.

[7] AMS (2012) "State of the Weather and Climate Enterprise"

Protecting lives and property

For the NWS, protecting lives and property means generating and sharing the best, most actionable environmental intelligence and decision-making support to partners in public safety. In support of this goal, and in response to emergency managers, water managers, and government officials at the local, state, and federal levels and independent reports by the National Academy of Sciences and the National Academy of Public Administration in 2012 and 2013[8], the NWS undertook an office-wide analysis over the past two years (the NWS Operations and Workforce Analysis, or OWA). This analysis focused on:

- enhancing the quality and consistency of impact-based decision support services (IDSS) for core public safety partners noted above;
- leveraging technology to ensure the most efficient, consistent, and effective creation of forecasts;
- aligning NWS strategically and flexibly to match the workforce to new workload demands; and,
- building a workforce that is highly trained in the entire spectrum of observations, forecasts, and warning delivery through IDSS to core partners.

These focus areas and the approach for implementing them will continue to be refined as the NWS moves into testing and evaluation, but the safety mission endures.

Enhancing the national economy

The NWS fulfills its mission to enhance the national economy by providing both weather information that benefits the nation's industry and the foundation for a thriving private weather industry.

How NWS benefits the national economy

Both routine weather, like rain and temperature fluctuations, and extreme weather, like hurricanes, tornadoes, and tsunamis, affect the ability of businesses across all sectors to produce and sell products and services. Recent perspectives of the impact of weather on the economy estimate that 30 percent of the economy is impacted by weather[9], with between three and six percent of the annual variability in US GDP attributable to weather (up to $1,344B using 2011-2014 GDP estimates)[10]. Reducing that uncertainty unlocks significant value for all sectors, as businesses can plan for

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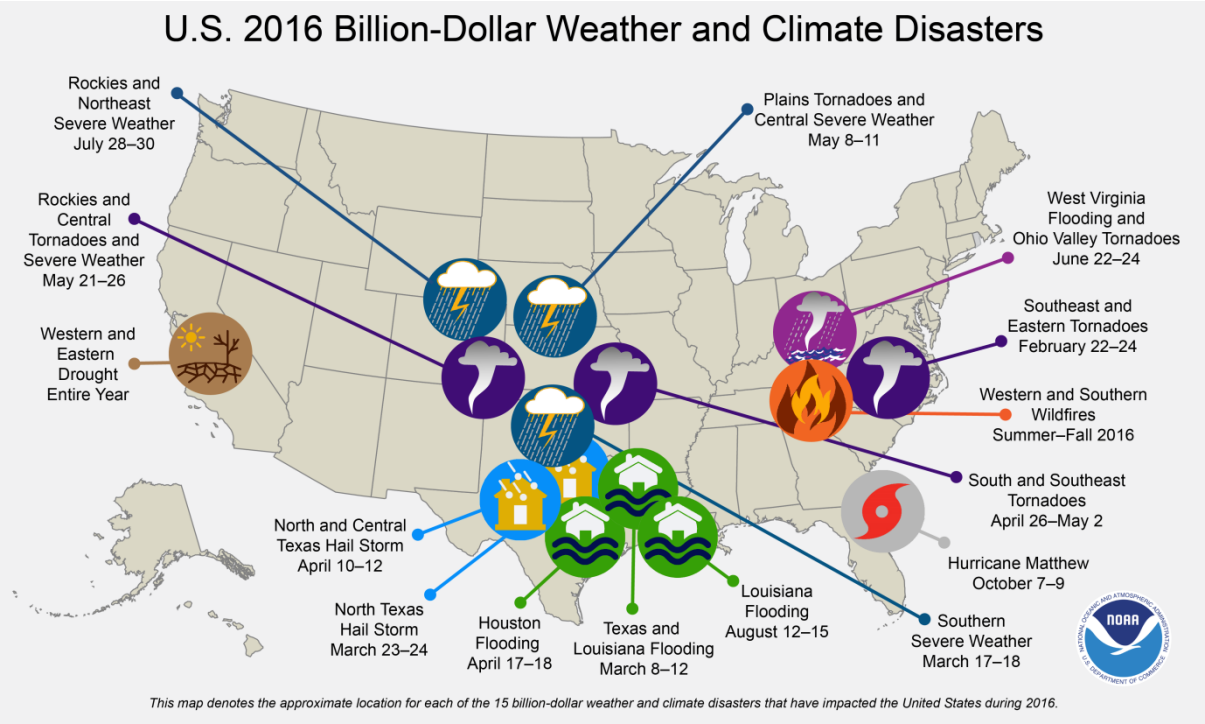
8 National Academy of Sciences (2012) "Weather Services for the Nation: Becoming Second to None"; National Academy of Public Administration (2013) "Forecast for the Future: Assuring the Capacity of the National Weather Service"

9 Dutton (2002) "Opportunities and priorities in a new era for weather and climate services" in the *Bulletin of the American Meteorological Society*

10 Lazo et al. (2013) "US economic sensitivity to weather variability"; updated for years 2011-2014, see Appendix for details

weather to reduce risk, prepare for emergencies, and increasingly, improve business performance by capitalizing on weather-dependent behavior.



Rough estimates suggest the total value of weather data that could be captured across all industries in the US could be in the range of $13B,[11] indicating a significant enhancement to the national economy.

How NWS enables a growing private weather industry

The private weather industry is a key component of unlocking the value of weather data across a wide range of businesses and economic sectors and represents a significant component of the national economy in and of itself. While most companies remain privately held, making it difficult to confirm the size of the private weather industry, its market capitalization is estimated at $7B and predicted to grow 10-15 percent annually[12] as it continues to serve consumers, businesses, and governments both in the U.S. and abroad. AccuWeather, for example, has begun to serve consumers and businesses in China, and other companies have worked with governments in developing countries to build out their weather infrastructure[13]. Through acquisitions, large companies like Panasonic, IBM, and Monsanto (which was recently purchased by Bayer) have entered the weather space in the past five years, signaling increased interest and likely even greater growth in the private weather enterprise to address the growing needs of a wide range of businesses, including those in the energy, agriculture, and transportation sectors.

Businesses rely heavily on private industry providers for weather information to meet specific needs not currently the focus of the NWS. For example, weather

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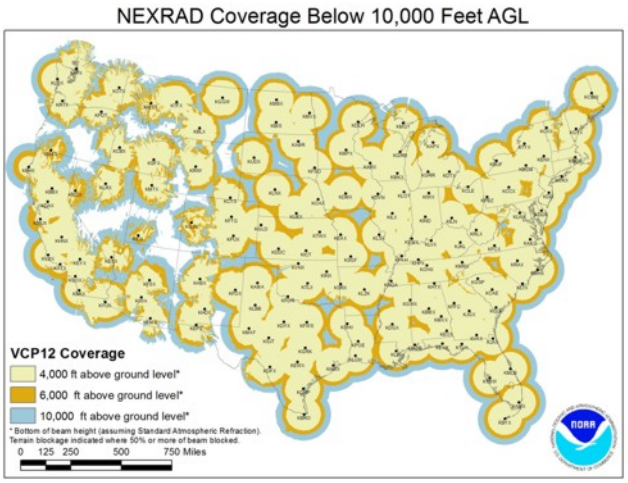
11 Based on the relationship between sector-level weather GDP variability and the value of weather data in certain industries, calculated in the NOAA (2012) "Value of a weather-ready nation"

12 UCAR and Wharton School of Business (2013) "Today's forecast for the weather business: increased revenues and a focus on innovation"

13 Company websites

companies provide businesses with tailored forecasts that map directly to key decision points within an increasingly competitive environment; weather information at very high resolutions for specific areas of interest (e.g., wind forecasts at the resolution of individual wind farms); and rapidly-updated weather information in emergencies.



The products and services offered by private weather companies are largely grounded in free access to timely, robust, and widely available NWS data. Without this common foundation, the private weather, water, and climate enterprise would likely be constrained. NWS core products and services include: a national set of radars, satellites, and ground stations; the staff who maintain them and provide initial analysis; global agreements through which the NWS aggregates data from around the world; the assimilation of this data into a suite of numerical models; and NWS forecasts that many in the private industry use to varying degrees.

Providing the foundation for the private weather, water and climate industry, and for a thriving business-to-business market, is thus a key way in which the NWS fulfills its mission to enhance the national economy – a role that the private industry values.

> "*The NWS is an enabler of economic development.*" – Weather services company

> "*The NWS's key role has been to serve as the foundation for the tremendous growth that the enterprise has experienced and will continue to experience.*" – Weather services company

TRENDS AND CHANGES IN THE WEATHER ENTERPRISE

The weather enterprise is undergoing significant change as the private weather industry expands relative to the public sector. This expansion is driven by two factors:

1. Growth in the value of weather information to the U.S. economy resulting in an increasing demand for weather services.
2. Disruptive technologies[14] offering the potential to unlock more of this value through improved weather prediction and service delivery.

[14]Technology that displaces an established technology and shakes up the industry or a ground-breaking product that creates a completely new industry. "The Innovator's Dilemma," by Clayton M. Christensen (1997).

Growth in the value of weather data

There are three main reasons for the increasing value of weather information to the economy:

1. **The cost of disaster damage is increasing**, with the average number of $1B weather events per year between 2008-2015 doubling compared with the prior 35 years[15]. As companies become more vulnerable to extreme weather events their use of weather information to inform risk management decisions will increase. Federal and state government agencies will also increasingly benefit from weather information as they work to manage and mitigate the losses from these extreme weather events in a cost-effective way.

2. **Businesses are becoming more sophisticated in their ability to take advantage of weather data and respond to impending extreme high-impact events,** as they invest in big data and analytics skills, with 76 percent of global organizations planning to increase or maintain their investments in big data over the next two to three years[16].
3. **Industries that have not traditionally used weather data for decision making** are finding opportunities to increase revenue and reduce costs. For example, by combining weather data with purchasing trends and consumer demand data, a grocery chain learned that even a small change in temperature can result in a significant shift in what people buy, and as a result improved its revenues by modeling this impact and managing inventory accordingly[17].

Technological trends driving advances in prediction and decision support

Several technological trends that are transforming all sectors of the economy are also fueling advances in weather prediction and decision support. In particular, the Internet of Things[18], robotics, and miniaturization are driving advances in observations; decreased supercomputing costs and machine learning are enabling advances in modeling and forecasting; and, big data and analytics, cloud, mobile computing, and smart devices are fueling innovations in service delivery. These advances offer the potential to unlock more economic value

15 NOAA National Center for Environmental Information, US Billion-dollar weather events and climate disasters

16 ViewPoint survey on Big Data, DN-VGL (2016)

17 Press search on grocery chain Tesco partnering with retail analytics firm Dunhumby in the UK

18 The interconnection via the Internet of computing devices embedded in everyday objects, enabling them to send and receive data.

from weather information. As a result, private industry companies see significant growth opportunities and are investing in these technologies to develop new products and services[19].

Private industry innovations in service delivery and decision support

Innovations in service delivery are focused on improving ease-of-use, personalization and decision making[20]:

- A key value proposition of companies has been to provide users with weather information in a format that is easy to interpret and relevant to their specific needs. Companies are building on this with visualization tools and dashboards that are integrated with users' daily operating systems.
- Companies are also developing "personalized weather-on-demand" services that deliver information to users wherever they are on their mobile devices. For example, AccuWeather has patented technology to tailor weather forecasts based on user location. (AccuWeather has issued a free license to two of these patents to the NWS [21].)
- Companies are also seeing significant opportunities to automate routine weather-related actions through smart devices. Schneider, for example, is incorporating weather data into its home thermostats to automatically regulate household and business energy use.
- The potential offered by analytics and big data appears to offer the most significant growth prospects for companies, and formed the rationale for two of the largest recent acquisitions in the weather enterprise – IBM and Monsanto. IBM's purchase of The Weather Company (TWC) in January 2016 was motivated by the goal of combining IBM's artificial intelligence capabilities (Watson) and its global cloud with TWC's high volume weather data platform to provide an unprecedented potential for the integration of weather and business enterprise data. Similarly, Monsanto's acquisition of Climate Corporation in 2013 was motivated by the potential value of combining weather, water, and climate data with other agriculture data. This was a key step in Monsanto's strategic evolution from its seed and chemicals business into data science services.

These new private industry offerings in service delivery, combined with the growing value of weather data to businesses, will likely help the industry grow by offering compelling products to business customers eager to buy them. Comparing the estimated potential value of weather data across industries ($13B) with the most recent revenue estimates from private weather industry service providers ($0.5B to 2.5B as of 2015[22]) shows the potential for at least five times growth in the size of the private weather industry[23], as attractive new product offerings enable businesses to capture more cost savings and revenue growth from the weather information.

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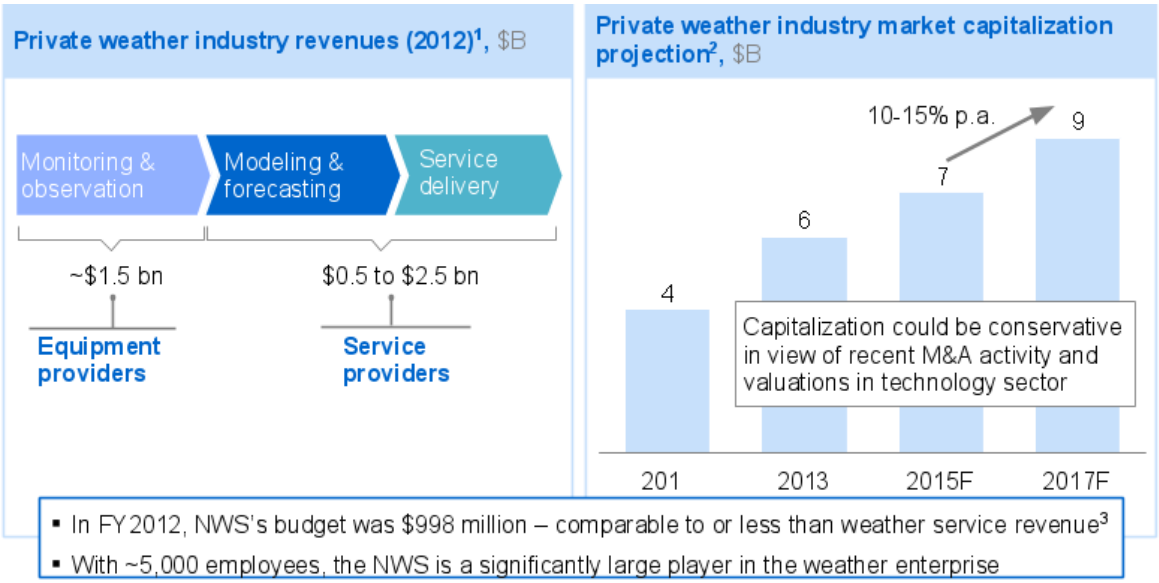
19 Company interviews; recent M&A activities; media

20 Company interviews; recent M&A activities; media

21 AccuWeather press release (Sept, 2015)

22 AMS (2012) "State of the Weather and Climate Enterprise" estimates US weather services revenues at $2.5bn; MarketsandMarkets report (2016) estimates US forecasting services at $500-600m and global at $2.1bn

23 See Appendix 2 for additional details



Increased private industry decision support capabilities may also translate into increased service to the public safety community. Currently, most emergency managers regard the NWS as their core partner for decision support, but also use commercial products for ancillary needs such as data visualization. Some companies have focused on specific public safety needs that the NWS does not address: Earth Networks, for example, provides lightning alert services for schools and parks in Broward County, FL, which is especially vulnerable to lightning strikes. IBM has incorporated weather data with other operational data in its emergency management solution, primarily targeted at cities. More companies may develop offerings that similarly take advantage of proprietary observations, operational data, connected smart devices, machine learning, and analytics to provide custom forecasts and decision support for public safety agencies.

Private industry innovations and growing capabilities upstream in the value chain

In addition to advances in service delivery and decision support, private industry capabilities have grown in the core weather infrastructure needed to produce weather information, such as environmental observations and monitoring and numerical weather prediction and forecasting. Several innovations have particular potential to impact the weather enterprise[24].

Environmental observations and monitoring

- Companies are beginning to develop infrastructure to monetize space-based data. The NOAA COSMIC missions have demonstrated the potential of global positioning system (GPS)-radio occultation (RO) sensors to improve the quality of atmospheric observations, particularly over the oceans. Several companies are attempting to develop commercial GPS-RO data products and are interested in selling data to NOAA or the NWS, instead of selling expensive satellite equipment for NOAA to own and operate.

[24] Unless stated otherwise, all direct quotes are derived from interviews with private industry companies conducted October-November, 2016, and have been edited lightly for clarity

"*The trends of miniaturization and robotics will enable the private sector to replace some of NOAA's satellite infrastructure.*" – GPS-RO player

- Rapid growth in smart, connected devices and personal weather stations has increased the data available for weather monitoring and may have the potential to increase the accuracy of hyperlocal weather forecasts. Companies report that they see huge potential from the growth in weather data from smart devices.

  "*We expect there to be an explosion of data from phones, drones and personal weather stations, and we intend to be there to aggregate the data.*" – Data aggregation start up

- The private industry has also taken an active role researching other innovative observational technologies such as LIDAR, drones and unmanned vehicles, which are still in early stages of development and commercialization but have the potential to fill important current gaps.

  "*We see a lack of observations of the boundary layer as a key gap in the industry today. We're focusing resources on LIDAR technology to profile water vapor and detect the top of the boundary layer.*" – Equipment provider

Weather modeling and forecasting

- The rapidly decreasing cost of high performance computing has made numerical weather prediction more accessible to private industry. This has allowed several private industry companies to adapt regional models from the research community (e.g., the Weather Research and Forecast model) for specific use cases and to make better use of proprietary observational data by using it to improve model output[25]. Select companies with additional resources have also begun to run global models. As computing costs continue to fall and companies experiment with new computing techniques, such as the use of graphical processing units (GPUs) rather than central processing units (CPUs) to run models, more private industry companies will likely become involved in regional and global modeling.

  "*I foresee that we will soon have as rich a private sector involvement in global modeling as we see in regional modeling. What is enabling this is the falling cost of supercomputing and increased access to new observation data.*" – Integrated weather company

- Additionally, academia has continued to advance the science of numerical weather prediction. The High Resolution Rapid Refresh (HRRR) model, which is now part of the NWS's operational mesoscale modeling suite and widely recognized as the state of the art in mesoscale modeling, was developed in academic and NOAA research labs in partnership with the NWS, rather than entirely in-house[26].

25 Company interview, November 2016

26 NOAA press release, 2014

- In forecasting, many companies are adopting machine learning and advanced statistical techniques to post-process model output from the NWS, other Met agencies, and sometimes from proprietary models to improve forecasts at a range of time and space scales.

"*We do a lot to make forecasts better, including using machine learning for multi-model ensembles and bias correction*." – Weather service provider

A more complex private weather industry landscape

As companies have expanded their capabilities, the competitive landscape has grown increasingly complex and dynamic in recent years. Players in the current landscape are pursuing a more diverse range of strategies to complement and in some cases compete with the freely provided data and services offered by the NWS.

On the observations side, while traditional equipment providers still retain contracts with NWS and NOAA for large pieces of the observational infrastructure (for example, the GOES-16 satellite, launched recently and built on contract with Lockheed Martin), a new type of company is emerging with business models that seek to monetize data, instead of selling equipment, to a broader range of buyers. The GPS-RO company Spire, for example, claims to be profitable by selling imaging data to shipping companies[27].

Additionally, many service companies now also rely on proprietary observational networks to provide highly localized weather information to specific industries. The Climate Corporation, for example, uses weather stations to provide farm-level precipitation forecasts; Earth Networks has built a range of forecasts and data based on its lightning alert systems. These companies monetize their data collection infrastructure through more tailored forecasts. Some of these companies also manufacture and sell equipment (for example, Vaisala), or sell data (companies involved in the Mesonet program) that the NWS uses.

In this respect, there has been a nearly complete shift of the private industry from being "secondary" providers of weather information – essentially repackaging and distributing NWS data provided for free – into "primary providers" that augment and supplement the NWS's data with their own forecasts[28].

Indeed, Panasonic may have gone the farthest in this shift. Its weather division (Panasonic Weather Services) touts its global model (adapted from the NWS's GFS model), initialized with a blend of public and proprietary observations and a proprietary data assimilation methodology. Panasonic Weather Services positions itself as competing with NWS and internationally. It does appear that other companies entering into global or regional modeling continue to rely on the NWS's infrastructure for model initialization.

27 Spire VP DeChassy quoted in *Via Satellite* (2015)

28 AMS (2012) "State of the Weather and Climate Enterprise"

An increasing number of analytics companies are incorporating weather data into industry-specific analytic offerings that are sold through software (software as a service or one-off) and consulting services. For example, CoreLogic provides address-level claims verification reports, and Planalytics identifies weather-related improvements for consumer businesses.

The larger integrated players that collect proprietary data, run their own models (but still rely on the global models of the NWS and academia), create forecasts, deliver services to businesses, and distribute information to consumers are AccuWeather and IBM-TWC. With an estimated 500 to 1,000 employees each, these two companies remain the industry's dominant players (TWC announced in November 2016 that it is adding 400 new hires)[29]. The next set of players range in size from 50-150 employees, with the vast majority of companies still consisting of small consultancies[30].

OUTLOOK FOR THE FUTURE OF THE PRIVATE WEATHER INDUSTRY AND THE NWS

While many in the private industry have built upon the NWS's infrastructure, products and services thus far, there is potential for this paradigm to shift as private industry capabilities increase and businesses become more dependent on weather, water, and climate information. This raises three questions:

1) To what extent will the private industry's capabilities change relative to the NWS?
2) How likely are they to be able to perform the activities needed for one or more parts of the weather value chain independently of the NWS?
3) How do private industry companies see the role of the NWS in a changing enterprise?

Future private weather industry capabilities relative to the NWS

The extent of the shift in sector capabilities will likely vary across the weather value chain[31]. In monitoring and observations, the expense required to maintain the vast network of space-based and ground-based observations and aggregate the data needed to initialize a global weather model and monitor weather throughout the US suggests that private industry companies will likely not seek to replicate the NWS role here.

However, the growth of observational systems operated and maintained by the private industry is likely to result in an expansion of commercially available data that

[29] AccuWeather website Fact Sheet; The Weather Company press release (Nov 16, 2016); LinkedIn page

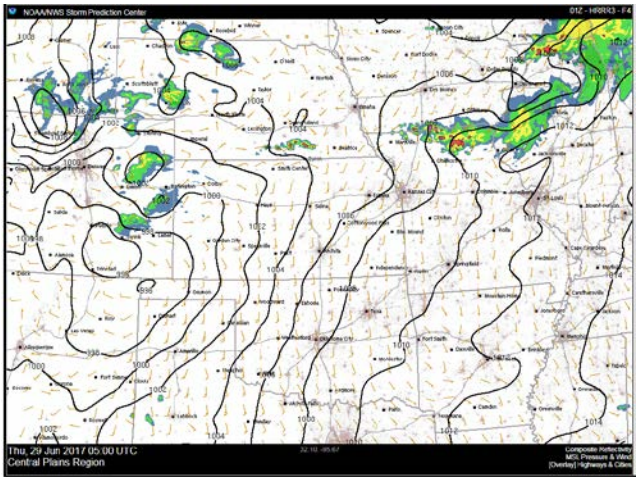
[30] Private industry interviews (Nov 2016)

[31] NWS leadership workshop (Oct 2016); interviews with academia and companies (Oct - Nov 2016)

could improve both highly localized weather monitoring and the initialization of global weather models.

In weather modeling, one or more private industry companies could develop capabilities in modeling at the regional or global scale that are superior to the NWS modeling center. However, no private industry company will likely replicate the complete and dependable infrastructure to run the full suite of NWS models needed for prediction at all scales with 99 percent reliability.

Forecasting and service delivery carry the strongest possibilities for a wholesale shift in private industry capabilities relative to the NWS. Multiple private industry companies will potentially be able to significantly substitute for the NWS's capabilities in issuing forecasts and weather warnings. Companies such as AccuWeather and Schneider Electric cite independent evaluations by ForecastWatch to validate that they have superior forecasts for specific needs (such as short-term temperature or precipitation), while IBM claims to have a 1-½ day lead over public sources for hurricane forecasts[32].



Similarly, some companies currently deliver more tailored, localized information to the emergency management community, and those investing in advanced decision support could offer tools that potentially surpass the NWS's IDSS capabilities. However, it is unlikely that the private industry will replicate the NWS's vast field network of co-located meteorologists who have intimate knowledge of the unique needs of core public safety partners. For the most part, private industry companies expect the NWS to remain the primary service provider for emergency managers, and as a result, are limiting their investments to areas that clearly augment and complement NWS capabilities, not replace them.

Perspectives from the private weather industry and academia

Recent conversations with private companies and academic researchers have provided additional perspective on the NWS role in a changing enterprise[33].

Enabling and shaping the enterprise

Overall, private industry companies highly value the NWS's unique role as the enabler of the enterprise. The majority encourage the NWS to continue to provide the best possible observations and forecasts to enable the enterprise to grow, and stress that maintaining a core observational infrastructure will become even more important as observations from new sources (e.g., smartphone pressure sensors)

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32 AccuWeather, Schneider Electric and The Weather Company websites and press releases; ForecastWatch.com

33 Unless stated otherwise, all direct quotes are derived from interviews with private sector companies conducted October-November, 2016 and have been edited lightly for clarity.

will need more rigorous calibration and quality control using tested, reliable observations.

> "*We would like to see you continue to provide good observational data and model output and continue to provide data at higher resolution and more frequently.*" – Weather service provider

> "*The broad IoT market is going to have to be underpinned by a high-quality sensor array - the federal government is going to have to be that underpinning.*" – Major integrated player

Within this viewpoint, companies that use NWS data to provide a product or service to businesses want the NWS to focus on advancing the science of weather in valuable areas that the private industry cannot fill, such as seasonal forecasting, and to find ways to make data more available for the private industry to use and monetize. One company, for example, cited NWS's success in moving its radar data to the cloud as part of the NOAA Big Data Initiative, and hoped the NWS would continue to pursue similar opportunities.

> "*The NWS should continue to invest in data observations. Figure out what is valuable but not covered by the market – climate data, for example.*" – Weather service provider

> "*There is much interest in sub-seasonal and seasonal forecasts, the so-called 'holy grail' of weather forecasts. It requires extensive resources to [run] and produce these forecasts, resources only a public-sector leader like NOAA could provide.*" – Environmental analytics provider

Companies also highlight the role that the NWS could play to help drive innovation. Companies developing emerging observational technologies believe the NWS could do more to help them bring these technologies to market faster. For example, by communicating its requirements to the industry, and testing the impact of new commercial observations on model output. GPS-RO players, in particular, expressed a desire to see the NWS and NOAA advance a technology that could significantly improve weather forecasting.

> "*I would like NOAA [NWS] to be more curious – like the U.S. Air Force and the National Science Foundation. It's essential that you figure out the impact on your forecast based on the data quality. Communicate to the industry what data you're looking for and want to test.*" – GPS-RO start-up

While the enterprise largely benefits from the NWS' free data policies and global data exchange agreements, a few companies noted how this model could provide challenges in the future. WMO policies surrounding commercial data essential for global models will need to be clarified in order to maintain a market for emerging observation companies, such as GPS-RO providers. Similarly, one company interviewed noted that the NWS free data policies prevent them from sharing with the NWS improvements they have made to the global weather model, as their competitors would then have access to these same model improvements. However, currently this appears to be a minority viewpoint, as other companies that have made modifications or improvements to global or regional models express interest in sharing most of these back to the research community. These companies also urge the NWS to more quickly incorporate research advancements into its modeling suite. This view is in consensus with perspectives from leaders in academia, who

push the NWS to collaborate more with the research community on developing the next advances in numerical modeling and forecasting.

> *"The NWS needs to leverage the research community for its model development much more, rather than relying on development in-house."* – Leading academic

Ensuring public safety

Companies respect the public safety mission of the NWS and its authoritative voice in issuing forecasts, weather watches, warnings, and advisories. Only one company interviewed expressed the belief that competing warnings would not pose a public safety problem – but even it emphasized the need for the NWS to remain second-to-none and share the basis for its warnings with the industry.

> *"Public safety is a primary role for the NWS."* – Weather services provider

> *"We believe the government must be the authoritative voice; we don't mess with NWS warnings- it would create too much confusion."* – Weather services provider

> *"We support the public safety mission of the NWS but we are increasingly seeing emergency managers come to the private sector because their problems are bigger than weather."* – Weather services provider

All companies seek more clarity on the products and services the NWS views core to its public safety mission, versus what the NWS will leave as a potential market for the private industry. Further, companies that offer decision support services urge the NWS to consider where the private industry could add value by providing innovative public safety services.

> ***"****If the NWS owns the EM segment, the private sector won't invest in public safety. The government will never be able to take advantage of innovations and move as fast as the private sector."* – Weather services provider

Finally, companies are eager for continued dialogue with the NWS, point to the benefits of a more collaborative relationship, and encourage the NWS to develop a systematic process to identify and follow up on specific areas of public-private collaboration.

"The transparency on IDSS has been great. We are looking to understand in what areas we can complement the NWS. The partner meetings are fundamental for us." – Weather equipment and services provider

"We want to know where you're going. We try not to duplicate NWS services. Instead, we seek those customers not already served by the NWS or in need of tailored, value-add services." – Weather services provider

CONCLUSION

As the NWS evolves in the face of change, we will need broader strategic thinking based on a deeper understanding of changes underway in the weather, water, and climate enterprise. Further, our stakeholders will benefit from the NWS having a comprehensive strategic view of the future that new leadership can reference and build upon. Therefore, the timing is opportune for the NWS to use the findings in this report on trends in the private weather industry to communicate and act on a path forward to strategically engage with the broader enterprise.

APPENDIX 1 – ACRONYMS

AOP: Annual Operating Plan

COSMIC: Constellation Observing System for Meteorology, Ionosphere, and Climate

GDP: Gross Domestic Product

GPS-RO: Global Positioning System Radio Occultation

HRRR: High Resolution Rapid Refresh

IDSS: Impact-based Decision Support Services

IoT: Internet of Things

LIDAR: Light Detection and Ranging

NOAA: National Oceanic and Atmosphere Administration

NWS: National Weather Service

OOE: Office of Organizational Excellence

OWA: Operations and Workforce Analysis

WRF: Weather Research and Forecasting (model)

WRN: Weather-Ready Nation

APPENDIX 2 – WEATHER ENTERPRISE FIGURES

Weather information use in business

- Sensitivity of businesses to weather (from Lazo et al, 2011[34], hereafter "Lazo et al"):
  - Weather sensitivity is defined as the variability in economic output of a sector (e.g., agriculture, communications, and manufacturing) that can be attributed to variability in weather. The definition for economic output used by Lazo et al. is gross state product (GSP), the state-level equivalent of GDP (total revenues minus costs for all firms in a sector)
  - Lazo et al. used a two-step process to quantify weather sensitivity. First, the authors used nonlinear regression to model the relationship between sectoral GSP, three indicators of non-weather variability in economic activity (available capital, total labor hours, and energy consumed), and four indicators of variability in weather (heating degree days, cooling degree days, total precipitation, precipitation standard deviation). The regression was conducted using state-level data from the National Climate Data Center and the Bureau of Economic Analysis spanning 1976-2000 for the 48 contiguous states, and summed over the 11 economic sectors. Second, the authors created 70 estimates of sectoral GSP using 70 years of weather variables and holding the economic variables constant at their 1996-2000 averages. The authors quantified weather sensitivity by sector as the percent range in sector GSP over the 70 estimates (the difference between the minimum and maximum of the 70 GSP estimates, divided by the average GSP estimate). The authors then calculated percent ranges for total GSP summed within each state, to measure state economic sensitivity to weather, and aggregated GSP across all states and all sectors to quantify national economic sensitivity to weather at 3.4 percent of GDP.
  - This report then used sector-level GDP from the Bureau of Economic Analysis averaged over 2011-2014 (to reduce impact of any unusual years for a given sector) and multiplied by the sector-level percent ranges from the Lazo et al analysis to find the total amount of weather-sensitive GDP by sector. Taking these estimates and dividing by total 2011-2014 average private industry GDP would suggest that 6 percent of total private industry GDP is sensitive to weather. This differs from the 3.4 percent number in Lazo et al for two reasons: 1) This report looks at the sensitivity of private industry GDP, rather than total GDP, and 2) This report's methodology differs, in that the Lazo et al analysis used the original 70 simulations of GSP rolled up into GDP, whereas here the percent ranges derived from those simulations are used.
- Value of weather data
  - In order to estimate the potential value of weather data across sectors, this report made the assumption that the value of weather data across sectors (i.e., the increased revenues, reduced revenue loss, or costs avoided due to access to a weather forecast) is proportional to the weather sensitivity of a sector – the more sensitive a sector is to weather, the higher potential value of weather data. This report further assumed that this proportion would be

[34] Lazo et al. (2013) "US economic sensitivity to weather variability"

largely consistent across sectors. The proportion was calculated using available estimates of the value of weather data for specific sectors. The NOAA-NWS "Value of a weather-ready nation" report[35] contains several estimates of the value of weather forecasts across a range of sectors and specific use cases. Two estimates of value – for agriculture and utilities – are assumed to be fairly representative of the total value of weather data to those sectors.

- We collected and displayed estimates of weather sensitivity for other industries, but did not include these in our calculation of the proportion of weather sensitivity to weather value, as we did not have confidence that these other estimates represented entire industries.
- Using the value of weather data to the agriculture and utilities industry and comparing with the weather sensitivity of those sectors, this report calculates the proportion of weather sensitivity to weather value to be 1 percent. Applying that proportion to the total weather-sensitive GDP across the entire private industry ($1334B) yields an estimate of the total value of weather data of $13B
- Given the assumptions made in calculating the total value of weather data (principally, that the proportion of weather sensitivity to weather value remains constant across industries and that the estimates of weather value we used in the calculation represents the value across entire industries), it is important to note that the $13B estimate is an order of magnitude estimate only, and should be treated as such.

Size of the weather enterprise

- Industry revenues
  - The AMS "State of the weather enterprise, 2012" report contains an estimate of weather industry revenues from the NRC Fair Weather report (2012), which bases its estimate on procurement budgets of relevant government agencies and previous economic analysis. That report estimates total private industry revenues at $4-5B, with service provider revenue estimated at $2.5B
  - A more recent market report by IBIS Watch (2014) estimated US forecasting services revenues at $500 million
  - MarketsandMarkets estimated global forecasting systems revenues at $1.5B in 2015 and global forecasting services revenues at $1.1B in 2016, with US forecasting services at roughly $550m
- Industry capitalization
  - Separately from the analysis of industry revenues, a report from the UCAR COMET program estimated the capitalization of the private weather industry at $6B in 2013 and growing 10-15 percent annually. The technical definition of industry capitalization is the total number of publicly traded stock shares in an industry multiplied by their share price. Industry capitalization is often used as a proxy for the total market value of an industry, which is how we are

35 NOAA (2012) "Value of a weather-ready nation"

using the term here and how the UCAR report uses the term, as most players in the private weather industry are not publicly traded companies.

- The UCAR report did not contain details on how it arrived at the industry capitalization estimate. However, the following check using data around the IBM's acquisition of The Weather Company provides some confidence that this report is consistent with the other sources we used:
  - News reports estimated that IBM valued The Weather Company (excluding the Weather Channel) at $2B when it bought TWC.
  - The IBIS market report estimates that TWC and AccuWeather have 50 percent market share of the service provider market – which is 60 percent of the total weather industry.
  - If we assume TWC (less the Weather Channel) was about twice as large as AccuWeather prior to the IBM acquisition, then TWC has 66 percent x 50 percent x 60 percent = 20 percent of the total market.
  - 20 percent of $7B (current estimate of the value of the weather industry) = $1.4B, which is close to the estimated market value of TWC when it was acquired by IBM.