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ON
TO OBSERVE AND PREDICT: HOW NOAA PROCURES DATA FOR WEATHER FORECASTING

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Chairman Harris, Ranking Member Miller, and members of the Committee, thank you for your leadership and the continued support you have shown the Department of Commerce's National Oceanic and Atmospheric Administration (NOAA). I am honored to be here as the Assistant Administrator of NOAA's National Environmental Satellite, Data, and Information Service and Vice Chair of the NOAA Observing Systems Council (NOSC) to discuss how NOAA procures data for weather forecasting and its environmental mission.

In order for NOAA to accomplish its mission, it is essential that all parts of the agency work together. That is particularly true in the area of predictive capability to protect life and property. In this arena, NOAA's National Weather Service (NWS) develops requirements for needed observations. To acquire the necessary observations, NWS works in conjunction with other parts of NOAA and non-NOAA partners that provide critical data and observations. For example, the National Environmental Satellite, Data, and Information System (NESDIS) works with the NWS to meet their requirements for satellite observations, and NOAA's Office of Oceanic and Atmospheric Research (OAR) uses current and next-generation research and technology to identify the optimal mix of observing platforms and systems that we should be exploring. My testimony will outline how the elements within NOAA work together to accomplish this goal.

NOAA's mission to provide science, service and stewardship to the nation is fundamentally dependent on observations of our environment from the surface of the sun to the bottom of the sea. These observations are the backbone of NOAA's predictive capabilities. NOAA must ensure operational weather, ocean, climate, and space weather data are available seven days a week, 24 hours a day, to address critical needs for our nation such as timely and accurate forecasts and warnings of severe weather, solar storms, and ocean events such as tsunamis and storm surges.

NOAA's Need for Observations

Observing the environment requires integration of all available sources to include both *in-situ* and remotely-sensed data from satellites. No single observation source can stand on its own. Data from *in-situ* observation platforms are an important component, but their measurements are relatively scarce, particularly over the oceans, polar regions, or where there are increasing national security concerns. Satellite observations of the atmosphere, ocean and land provide global coverage of these critical information sources, as well as *in-situ* space weather measurements. These data facilitate the development of environmental predictions and weather forecasts and warnings that are vital to protecting life, property and promoting economic productivity of United States interests at home and abroad.

Over land, weather observations, including temperature, wind, and moisture are needed to understand current weather conditions, which may evolve and result in dangerous severe weather. Land observations of soil moisture and observed rain and snow are essential to determine the potential for flooding or drought. Radar observations detect conditions favorable for tornadoes and detect the location and amounts of precipitation that may cause flash flooding. Additionally, recognizing that our advanced technology-based economy and national security is increasingly vulnerable to space weather, solar wind and near-Earth geomagnetic and ionospheric observations are vital for the protection of our critical technology infrastructure. This infrastructure includes, but is not limited to public and private sector satellites, communication systems, aircraft navigation systems, and our electrical power grid.

Our Nation's environmental predictive capabilities are supported by four foundational pillars:

- observations;
- high performance computing,
- forecast model systems and supporting research; and
- our people, who provide forecasts and warnings to key decision makers.

By sustaining and strengthening these pillars through improved observations, computational capacity, modeling, and research, we can maintain the current forecast capabilities that our society has come to expect. Additionally, these pillars foster forecast improvements that will revolutionize the way society views and exploits environmental information across the entire spectrum, from near-term weather forecasts to long range weather and climate predictions. For example, coupled models provide improved simulations of the interaction between the ocean and atmosphere, which result in more timely and accurate predictions of tropical cyclone tracking and intensity. Timely and accurate predictions are critical to minimizing unnecessary evacuation and increasing public confidence so that affected populations will react appropriately to warnings. This, in turn, will result in reduced loss of life, assuming that potentially affected populations heed the advanced warnings of ocean surges, inland flooding, and damaging winds and tornadoes when they are issued.

Additionally, developing and acquiring higher resolution observations and models will teach us how the atmosphere behaves leading up to the formation of a tornado, and will allow us to "warn-on-forecast" and more precisely predict where flash flooding, or particularly heavy snow bands, or dust storms will occur, or even when a tornado will strike, with increased warning lead-times double or triple today's average of 12 minutes.

Environmental observations had once been the sole purview of the Federal government, owing primarily to the cost, size and complexity of the systems involved. However, weather and related observations and information services now cut a broad swath through various public, private, and academic sectors, having diverse missions and applications. NOAA attempts to collect and make use of available data from federal, state, local government funded networks, university funded, or private sector data sources, leverages data from international sources, and purchases data from commercial sources. NOAA does not unnecessarily duplicate the observing systems of others, but rather accesses and leverages the reliable and available data it needs to implement its science, service, and stewardship mission.

While acquisition of these data is funded from all of NOAA's line and program offices, coordination for determining the best means of acquiring these data is overseen by the NOAA Observing Systems Council (NOSC). The NOSC is chaired by the Assistant Secretary of Commerce for Environmental Observation & Prediction, and its vice-chairs are the Assistant Administrator for Weather Services, the Assistant Administrator for Satellites and Information Services, and the Director of the NOAA Office of Marine and Aviation Operations (OMAO). NOSC membership is comprised of a representative from each NOAA Line Office and OMAO as well as the Chief Financial Officer and the Chief Information Officer. The NOSC has established an Observing System Committee (OSC) to provide a holistic, on-going assessment and analysis of NOAA's observing system portfolio and to make recommendations to the NOSC regarding the optimal mix of capabilities to meet NOAA's mission. The NOSC and OSC are supported by the Technology, Planning, and Integration for Observations (TPIO) program. The NOSC Terms of Reference is located at https://www.nosc.noaa.gov/purpose.php.

NOAA's data activities are governed by its full and open data policy consistent with the Office of Management and Budget's (OMB's) Circular No. A-130 and the 2010 National Space Policy of the United States[1]. These policies provide the framework that allows NOAA to widely distribute its products and services to support its public safety and global environmental monitoring mission. Today's testimony provides an overview of the processes and challenges that NOAA faces in meeting its needs for observations to fulfill our mission.

Determining Requirements

NOAA is responsible for collecting environmental information to meet its current mission requirements and determining our requirements for future data and information. Atmospheric weather and climate models of today will be transforming to an "earth system" model in the future which will involve coupling atmospheric data with ocean, land, ice and space-based data. Historically, weather and climate models incorporated only atmospheric inputs and outputs, and only recently have been integrated with ocean models to provide a more robust picture of our earth system. To the extent possible, NOAA incorporates data collected and processed from

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[1] http://www.whitehouse.gov/omb/circulars_a130_a130trans4
http://www.whitehouse.gov/sites/default/files/national_space_policy_6-28-10.pdf

other sources, but it is not NOAA's responsibility to collect and process data that do not fulfill our mission needs. NOAA ensures that its data are available for open and unrestricted use, and honors specific agreements to the contrary when private data sources are used.

NOAA's observation requirements are derived from the data needs of NOAA's operational and research programs. Weather forecast models require detailed information about the earth's environment including atmospheric temperature, moisture content, pressure, wind direction and wind speed, as well as ocean observations, including ocean temperature, wave height, and ocean surface winds. For river and flood forecasts, river flow data as well as soil moisture, soil temperature, rainfall, and snow depth are required. Finally, space weather prediction requires constant monitoring of the sun and the space environment, for solar flares and coronal mass ejections, and for geomagnetic and ionospheric disturbances.

Evaluating and Validating Requirements

NOAA established the NOSC to provide a systematic assessment of NOAA's observation requirements and the range of systems available or needed to meet these requirements. This effort has included a disciplined process of documenting, validating, and assessing the relative priorities of NOAA's observing requirements. This process entails:

1. Working across NOAA units (e.g., Programs, Strategic Objectives, etc.) to identify and document, in a standardized, prioritized structure, all their observational needs to meet their mission.
2. Applying a verification and validation process to each set of Priority-1 (mission critical) observation requirements for review and endorsement by the NOSC.
3. Tracking updates to observational requirements as directed by the Programs on both an as-needed and periodic review basis.
4. Assessing the means by which observing requirements are met, including the level of requirements satisfaction, as well as gaps in observing capabilities.

The process to document NOAA's observation requirements involves close coordination with NOAA program leaders and Subject Matter Experts (SMEs) to capture information in an extensive database called the Consolidated Observation Requirement List (CORL). The following attributes are captured for each requirement: geographic coverage, vertical resolution, accuracy, sampling interval, data latency and long-term stability.

Once documented, each Program's requirements are verified and mapped to their associated Government Performance and Results Act (GPRA), NOAA performance measures and Regional Collaboration (RC) performance measures. Verification is the process by which the SMEs in a given program review, concur, and sign off on all the Priority-1 requirements that they are submitting. Verification is documented by the signing of a Program Observation Requirement Document (PORD). The PORD summarizes the programs' observation requirements and performance level required for each observation. The signatures of the program leaders on the PORD constitute verification of their observing requirements.

Once requirements are verified, each NOAA program provides documentation to support validation of each requirement and its specified attributes. Validation is important as it provides independent confirmation of the needs of the program either through the results of scientific studies, operational use, or independent review by SMEs. Both the program leadership and the NOSC support team, which includes technical staff in the TPIO, assess the applicability of the documents, prepare a summary of the validation of Priority-1 requirements, and present a summary to the NOSC for their endorsement of the validation process.

The affected line office representative to the NOSC reviews and signs the PORD, concurring that the requirements are accurately captured and meet Line Office needs. Lastly, the signatures of the NOSC co-chairs on the PORD constitute endorsement of the validation process conducted on the programs' set of observing requirements.

The validated requirements then serve as the basis for justification for acquiring NOAA observing systems to satisfy those requirements or fill gaps in observing data.

NOAA operational forecast models are one of the main drivers of its observational requirements. From a NWS perspective, these models require detailed information about the structure of the atmosphere (e.g. wind direction and speed; temperature; pressure and moisture) in order to produce a forecast. These data are acquired through three basic means:

- surface-based upper air observing systems (radiosondes);
- aircraft;
- NEXRAD radar, including dual-polarization modifications; and
- polar-orbiting and geostationary satellites.

Satellite data are particularly critical for gathering global atmospheric data, as well as collecting measurements over the oceans and other data sparse areas. On a global scale, integrated, (otherwise known as coupled) atmosphere-ocean forecast systems provide improved weather forecasts by adding the interaction between ocean and atmosphere. This also results in more accurate predictions of tropical cyclone behavior and the development of major storm systems, such as those that can produce devastating tornado outbreaks and disruptive winter weather. On smaller and shorter timescales, very high resolution observations and forecast systems, together with high performance computing, can provide the type of short-term severe weather predictions that will allow for more precise forecasts -- to the neighborhood or wind farm scale, for example. Data from radars are used along with satellites to support NOAA's warning programs in advance of severe weather systems.

Observational requirements are also derived from NOAA's mission responsibilities for oceans and climate. NOAA is an international leader in the use of moored buoys, floats, drifters, and other systems that are used to understand and predict the physical ocean. These include observations of the biochemistry of the ocean, including changing acidity and other ocean chemistry, as well as observations of the chemical and aerosol constituents of the atmosphere. NOAA maintains a global chemistry monitoring network for atmospheric constituents including greenhouse gases, aerosols, ozone, and other important substances.

Finally, detailed information necessary to produce a space weather forecast comes from the space environment. These measurements: solar wind, solar radiation, and magnetic field are observed by operational polar-orbiting and geostationary satellites, and a research satellite at the Lagrange-1 point. From these platforms, NOAA is able to derive data to support space weather monitoring, and forecasts and warnings.

Requirements Assignment to Observing Systems

The validation of all of NOAA's observational requirements is an on-going process. Once validated, observing requirements can be assessed against existing or planned observing systems. If gaps are identified where no observing systems collect or measure the required observation data, NOAA pursues meeting these un-met requirements – either through the development of its own observing system(s) or acquiring it by other means, including partnering for or leveraging data from other federal agencies, foreign governments, state and local governments, academic and private assets; as well as purchasing data from commercial sources.

When NOAA plans and develops an observing system it documents the requirements the system must achieve in a Level One Requirements Document (L1RD). Level I requirements are the highest priority mission requirements derived from the CORL. These requirements form the basis for generating the lower level, system/component requirements documents (e.g., Level II requirements documents). The L1RD includes information on which CORL observation requirements the planned system will be capable of measuring to the performance level required. L1RDs are approved by the NOSC.

NOAA regularly evaluates new observing capabilities for their potential to improve its mission capabilities or decrease its costs. For example, it is currently evaluating Phased Array Radar, Unmanned Aircraft Systems, and Autonomous Underwater Vehicles to determine the extent to which technologies can meet NOAA's observation requirements.

Requirements Validation for Satellite Data

The requirements for NOAA's next generation geostationary and polar orbiting environmental satellites are primarily associated with providing continuity of the capability currently being provided from by NOAA's existing, on-orbit satellite systems, the Geostationary Operational Environmental Satellites (GOES) and Polar-orbiting Operational Environmental Satellites (POES). The next generation satellites will include technology upgrades, since the technology currently being flown on legacy GOES and POES satellites is largely from the 1980s. Lastly, the next generation geostationary (GOES-R) and polar-orbiting (Joint Polar Satellite System or JPSS) satellites will include technological enhancements which have been demonstrated on a number of research platforms. For example, instruments on JPSS are being developed based on demonstrated successes on the NASA Earth Observing System (EOS) satellites, as well as the Suomi National Polar-orbiting Partnership (Suomi NPP) satellite.

GOES-R requirement process - Initial GOES-R observation requirements were set forth in the 1999 NWS Operational Requirements Document for future geostationary satellites. The requirements within this document were gathered and prioritized through collaboration with

NWS Headquarters, NWS Regions, National Centers for Environmental Prediction, and the nation-wide network of NWS Forecast Offices. The GOES-R Level 1 Requirements Document (L1RD) was signed by NOAA leadership in June 2007. The L1RD has been updated periodically as changes were made to the GOES-R Program.

NPOESS/JPSS requirements process - U.S. operational polar-orbiting observation requirements originated with the NPOESS program (the predecessor to JPSS), where the observing requirements were documented in the Integrated Operational Requirements Document (IORD). This document was approved by each member of the NPOESS Tri-agency partnership (NOAA, DOD, and NASA). After NPOESS was restructured, NOAA initiated the JPSS Program to meet NOAA's polar-orbiting observation requirements in the afternoon orbit. The observation requirements for JPSS are documented in the JPSS Preliminary L1RD that was signed in September 2011. These requirements were vetted through a cross-NOAA team to ensure any unnecessary carry over from NPOESS was removed. The JPSS Final L1RD will be signed once the Program is baselined[2].

L1 (Lagrange point) requirements – NASA's Advanced Composition Explorer (ACE) satellite, which was launched on August 25, 1997, is the sole provider of real-time, in-situ solar wind data timely enough to provide early warning of pending and potentially damaging solar activity. Based on a multi-agency study by the Administration, directed by the Office of Science and Technology Policy, the Deep Space Climate Observatory (DSCOVR) was selected as a follow-on mission to ACE. DSCOVR is a partnership among NASA, NOAA, and DoD which will ensure the continuity of critical real time solar wind measurements. The DSCOVR L1RD has been drafted and is currently in the signature cycle. The spacecraft is being refurbished and is expected to launch in 2014.

Space-based ocean altimetry -- NOAA is procuring Jason-3, a satellite radar altimeter jointly with EUMETSAT, France's Centre National d'Etudes Spatiales (CNES), and NASA. Jason-3 will be an operational follow-on satellite to Topex/Poseidon, launched in 1992; Jason-1, launched in December 2001; and Jason-2, launched in June 2008. NOAA has been using Jason data to support its operational oceanography mission, surface wave forecasting and evaluation, and hurricane intensity forecasting. These Jason data are also being used in large scale oceanic models to track the onset, duration, and intensity of seasonal climate events such as El Nino and La Nina. These data are also being used in models that are currently tracking the marine debris from the Tohoku earthquake and tsunami (March, 2011).

Optimizing NOAA's Observing System Portfolio

NOAA has also developed an inventory of its observing systems capabilities, which are summarized in Observing System Summary reports[3]. This inventory includes system capabilities, system points of contact, system owners, system descriptions, numbers of sensors/systems deployed, and a detailed lists of system/sensor performance for the various environmental parameters that the systems measure.

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[2] P.L 112-55 requires a JPSS baseline by the 4Q FY2013.
[3] https://www.nosc.noaa.gov/OSC/oss.php

NOAA is evaluating individual systems against validated observing requirements; NOAA also evaluates the relative effectiveness of the suite of NOAA observing systems in meeting its observation requirements. To address this portfolio perspective, NOAA applies a number of software tools that provide both a graphical and analytical framework to help decision makers select the best portfolio (combination) of observing systems based on considerations such as cost and operational benefit. The process of capturing information about NOAA's observing requirements and systems is called the NOAA Observation Systems Integrated Analysis (NOSIA) capability. The NOSIA process uses a portfolio optimization tool, the MITRE Portfolio Analysis Machine (PALMA ™)[4] as a cornerstone to this framework. Before beginning the acquisition and development of new satellite observing systems, NOAA often conducts an analysis of alternatives (AoA) to investigate potentially lower cost approaches to the government developed systems.

In addition to these prioritization tools, NOAA uses numerical forecast systems, similar to NWS' current operational weather prediction system, to estimate the impact of observing system options. These approaches include withholding existing observations from assimilation into weather prediction models and observing the magnitude of the degradation in predictions. Atmospheric, oceanic, and/or earth system models can also be used to simulate observations that would be produced by new or modified observing systems and to estimate the impact of those observations on our predictive capability.

One technique, called "adjoint sensitivity experiments" shows the amount of forecast error reduction contributed by each observation in a predictive model. A second technique, called an Observing System Experiments (OSE), or "data denial experiment," involves systematically adding or denying an existing observation to a control forecast to determine the differences that induces in the forecast accuracy. NOAA conducted a series of OSEs to demonstrate the possible impact of the loss of polar-orbiting satellite observations to the "Snowmageddon" event in February 2010.

NOAA is also exploring expansion of quantitative observation assessments for future observing systems. These assessment tools, including Observing System Simulation Experiments (OSSEs) may provide a way to evaluate observing systems that yields optimization of both systems and savings in the future. OSSEs use multiple models to estimate the benefits of a hypothetical (either new or modified) observing system. They use simulated observations (instead of real observations) and are designed to measure the impact of adding future instruments to current observing systems. If a future instrument requires new data assimilation, i.e. algorithms or techniques that do not currently exist, NOAA may not be able to fully assess the impacts of the instrument using the OSSE, the OSSE may underestimate or overestimate the impact.

Adjoint sensitivity experiments and Observing System Experiments are two critical tools providing decision makers with an understanding of the impact of existing observing systems and data streams on NOAA's mission service areas. OSSEs can provide decision makers with an understanding of proposed observing systems by simulating the impact of what might be built. In

[4] PALMA is a trademark of the MITRE Corporation.

this way, the benefits of an observing system or type of observation can be estimated before it is designed, built, and launched into orbit.

NOAA employs these types of simulations to determine the viability of new data and information from proposed new instruments. This information can assist decision makers with trade-offs in instrument or orbital configurations and methods of assimilating a new type of observing system can be determined. These data impact experiments can identify an optimal configuration for a future observing network and help recognize weaknesses in the processing or assimilation of the observations.

Because of the challenges posed with observing the environment, it is often necessary to test, evaluate, and compare different types of instruments or observations to determine which one alone or in combination with others is best suited to meet a particular set of observational requirements. A specific case involves examining the Gulf Stream IV (GIV), which provides data about the atmosphere in large circulations, such as hurricanes and winter storms. In a "data denial experiment," comparing computer models with and without these data that would have been obtained from a GIV, determined there is a 20 percent improvement in hurricane track forecasts when the data are available. These types of studies are important to quantify improvements from new or existing data sources..

Testing the efficacy of observing systems through data denial experiments and simulating measurements that proposed new observing systems will provide allows NOAA to make the decisions necessary to optimize its observing system portfolio. The resulting benefits include:

- Gaining a well-defined quantitative foundation for the design and acquisition of observing systems;
- Developing a quantitative understanding of the impacts of existing observing systems; and
- Delineating between the impacts of new observing systems and an alternative mix of current systems.

Maximizing Cost Effectiveness for Observations

NOAA develops an observation acquisition plan through its annual programming and budgeting process known as the Strategic Execution and Evaluation (SEE). The SEE is the process NOAA uses to ensure linkage between NOAA's strategic vision and its programs, budget development, and annual operating plans. The SEE process ties strategy, planning, programming, and budgeting together to determine the best allocation of resources, given performance of existing and planned programs against mission requirements. As part of choosing the appropriate solution, the SEE process involves the NOSC evaluation of possible approaches to meeting NOAA's observing requirements. The NOSC, in offering input to the SEE process, uses the suite of analysis tools mentioned above.

NOAA is continually evaluating new observing capabilities for their potential to improve its mission capabilities or decrease costs while still providing equivalent capabilities. For example, it is currently evaluating Phased Array Radar, Unmanned Aircraft Systems, and Autonomous

Underwater Vehicles to determine how these technologies could fit into the total set of observing capacity.

Leveraging Data from non-NOAA Observations Systems

Even with these robust quantitative assessments and prioritization mechanisms feeding NOAA's planning and programming process, maintaining NOAA's observational capability is an on-going challenge. NOAA continues to pursue agreements with owners and operators of local/regional observing networks, whenever possible and cost effective, to create and leverage a national "network of networks." NOAA's assets are foundational and provide the backbone for a network of local/regional observing capabilities.

NOAA is moving from the era when it was the only entity able to sustain observations and maintain the national networks, to one where NOAA will benefit from leveraging and being integrated into other's capabilities. NOAA's expertise will focus on enhancing value of the data and information, maximizing the exploitation of this data in making operational forecasts and warnings and ensuring data are valid, rather than being the only source of data. For example, NOAA is working with the renewable energy community to obtain mesoscale data that will be used in NWS computer forecast systems to provide more accurate and timely weather forecasts that can be used by both NWS forecasters and private sector forecasters.

NOAA has made extensive use of its partnerships with other space agencies, both nationally and internationally. These partnerships allow for mutual full and open access to data from spacecraft, and include a range of partnership options, including reciprocal hosting of instruments on each others' satellite platforms, as well as partnerships where each agency is responsible for specific elements of the satellite system. These arrangements have proven extremely beneficial for all parties since costs and development burdens are shared.

The commercial sector is already significantly involved with NOAA's satellite acquisition activities. Through contracts, NOAA leverages the expertise of the commercial sector to develop concepts and to build spacecraft, instruments, and ground systems for the government. NOAA has a continuing process to assess the availability and viability of data from commercial sources, and routinely purchases space-based scientific data from the commercial sector. NOAA will pursue potential agreements with the commercial sector when it can provide data that addresses NOAA's requirements at a reasonable cost to the taxpayer. Some of the key considerations the commercial sector must demonstrate include:

- Ability to provide sustained and uninterrupted observations to meet operational requirements,
- Compliance with NOAA's data policy for full and open exchange and distribution of data,
- Demonstrated technical feasibility to acquire and deliver the observations and data in a reliable and timely manner, and
- Affordability of operations and cost-effectiveness to the Government.

Conclusion

NOAA will continue to use all available data to ensure the best possible forecasts and warnings for the protection of the public. NOAA will further expand the public-private partnerships to collect weather related data whenever possible, however, recognizing that a foundational set of observations are a critical national asset required to protect life and property. NOAA will explore and leverage all opportunities, while operating in a cost-effective manner.