REPORT TO CONGRESS

WEATHER RESEARCH AND FORECASTING INNOVATION: ANNUAL REPORT OF CURRENT AND PLANNED ACTIVITIES WITHIN THE OFFICE OF OCEANIC AND ATMOSPHERIC RESEARCH

Developed pursuant to: Title I, Section 102 of the Weather Research and Forecasting Innovation Act of 2017, 15 U.S.C. § 8501 note

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TITLE I, SECTION 102, CODIFIED AT 15 U.S.C. § 8512 OF THE WEATHER RESEARCH AND FORECASTING INNOVATION ACT OF 2017, CODIFIED AT 15 U.S.C. § 8501, INCLUDED THE FOLLOWING LANGUAGE:

(a) PROGRAM.—The Assistant Administrator for the Office of Oceanic and Atmospheric Research shall conduct a program to develop improved understanding of and forecast capabilities for atmospheric events and their impacts, placing priority on developing more accurate, timely, and effective warnings and forecasts of high impact weather events that endanger life and property.

(b) PROGRAM ELEMENTS.—The program described in subsection (a) shall focus on the following activities:

(1) Improving the fundamental understanding of weather consistent with section 101 [codified at 15 U.S.C. 8511], including the boundary layer and other processes affecting high impact weather events.

(2) Improving the understanding of how the public receives, interprets, and responds to warnings and forecasts of high impact weather events that endanger life and property.

(3) Research and development, and transfer of knowledge, technologies, and applications to the National Weather Service and other appropriate agencies and entities, including the United States weather industry and academic partners, related to —

(A) advanced radar, radar networking technologies, and other ground-based technologies, including those emphasizing rapid, fine-scale sensing of the boundary layer and lower troposphere, and the use of innovative, dual-polarization, phased-array technologies;

(B) aerial weather observing systems;

(C) high performance computing and information technology and wireless communication networks;

(D) advanced numerical weather prediction systems and forecasting tools and techniques that improve the forecasting of timing, track, intensity, and severity of high impact weather, including through —

(i) the development of more effective mesoscale models;

(ii) more effective use of existing, and the development of new, regional and national cloud-resolving models;

(iii) enhanced global weather models; and

(iv) integrated assessment models;

(E) quantitative assessment tools for measuring the impact and value of data and observing systems, including Observing System Simulation Experiments (as described in section 107, [codified at 15 U.S.C. 8517]), Observing System Experiments, and Analyses of Alternatives;

(F) atmospheric chemistry and interactions essential to accurately characterizing atmospheric composition and predicting meteorological processes, including cloud microphysical, precipitation, and atmospheric electrification processes, to more effectively understand their role in severe weather; and

(G) additional sources of weather data and information, including commercial observing systems.

(4) A technology transfer initiative, carried out jointly and in coordination with the Director of the National Weather Service, and in cooperation with the United States

weather industry and academic partners, to ensure continuous development and transition of the latest scientific and technological advances into operations of the National Weather Service and to establish a process to sunset outdated and expensive operational methods and tools to enable cost-effective transfer of new methods and tools into operations.

(c) EXTRAMURAL RESEARCH.—

(1) IN GENERAL.—In carrying out the program under this section, the Assistant Administrator for Oceanic and Atmospheric Research shall collaborate with and support the non-Federal weather research community, which includes governmental organizations, by making funds available through competitive grants, contracts, and cooperative agreements.

(2) SENSE OF CONGRESS.—It is the sense of Congress that not less than 30 percent of the funds for weather research and development at the Office of Oceanic and Atmospheric Research should be made available for the purpose described in paragraph (1).

(d) ANNUAL REPORT. – Each year, concurrent with the annual budget request submitted by the President to Congress under section 1105 of title 31, United States Code, for the National Oceanic and Atmospheric Administration, the Under Secretary shall submit to Congress a description of current and planned activities under this section.

THIS REPORT RESPONDS TO THE CONGRESSIONAL REQUIREMENT.

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I. Executive Summary

This annual report is in response to the Title I, Section 102, (codified at 15 U.S.C. § 8512) of the Weather Research and Forecasting Innovation Act of 2017, 15 U.S.C. § 8501 (hereafter referred to as the Weather Act), which was passed into law by Congress on April 18, 2017.

Section 102(a) of the Weather Act, requires the Assistant Administrator for the National Oceanic and Atmospheric Administration's (NOAA) Office of Oceanic and Atmospheric Research (OAR) to conduct a program to develop improved understanding of and forecast capabilities for atmospheric events and their impacts, placing priority on developing more accurate, timely, and effective warnings and forecasts of high-impact weather events that endanger life and property. The Weather Act specifies a number of program elements, outlined in Section 102(b), to be implemented with collaboration and support of the non-Federal weather research community, as prescribed in Section 102(c). Additionally, the National Integrated Drought Information System Reauthorization Act of 2018 (P.L. 115-423) amends Section 102(b) of the Weather Act, instructing NOAA to establish the Earth Prediction Innovation Center (EPIC) to accelerate community-developed scientific and technological enhancements into the operational applications for numerical weather prediction. Section 102(d) of the Weather Act directs the Under Secretary of Commerce to submit an annual report to Congress of current and planned activities related to the implementation of Section 102.

Please NOTE: This report covers OAR research and funds for the period from FY 2017 through FY 2019.

II. Background

OAR is NOAA's central research line office charged with studying and understanding changes in the Earth's environment. OAR delivers the mission-aligned research that the other NOAA line offices depend on to produce their operational products, which protect life and property and promote science-informed decision-making and a robust economy. Primary activities related to the Weather Act occur within OAR's weather portfolio through two programs and seven laboratories, as well as in close partnership with NOAA's 16 Cooperative Institutes. OAR's programs manage competitive and noncompetitive awards for intramural and extramural research that focuses on specific topics and emerging areas of research, such as using community-based modeling to improve forecasts models through EPIC. The programs also foster collaboration across NOAA, as well as with other Federal agencies and academic institutions. These efforts address the requirements in Section 102(c) of the Weather Act. Table 1 describes the past year's funding levels and the President's requested funding for OAR research Program, Project, or Activity (PPA) lines relevant to Section 102(c) of the Weather Act (Table 1).

III. Weather and Atmospheric Chemistry Research

Current and planned research in OAR's weather portfolio continually improves capabilities to provide more accurate and timely warnings and forecasts of various high-impact weather events. This is accomplished by prioritizing improvements in weather data observation, modeling, computing, forecasting, and warnings for the protection of life and property and for the enhancement of the national economy. OAR's weather research laboratories, programs, and partners are key contributors to advancing the prediction capabilities of NOAA's National Weather Service (NWS). Scientists working within OAR's weather portfolio focus many of their studies on atmospheric chemistry to accurately characterize atmospheric composition and predict meteorological processes to more effectively understand their role in severe weather. Such research provides the scientific basis for informed management decisions about weather. The work below is collaborative and crosscutting, so is funded from several PPAs, with the majority funded out of OAR's Weather & Air Quality Research through its operations, research, and facilities (ORF) funds, as well as resources provided by NWS. Research Supercomputing through procurement, acquisition, and construction (PAC) funds are primarily used to procure critical computing infrastructure that is used in the development and analysis of computational models that are intrinsic to many of the products highlighted below.

Table 1: NOAA Funding for Activities under Section 102(c) of the Weather Act
(Dollar Amounts in Thousands)

Subactivity Program, Project, or Activity (PPA)	**FY17 Enacted**	**FY18 Enacted**	**FY19 Enacted**	**FY20 President's Budget**
Weather & Air Chemistry Research (ORF)	**$113,758**	**$131,516**	**$135,380**	**$110,564**
Laboratories & Cooperative Institutes	$80,000	$85,758	$85,758	$66,690
U. S. Weather Research Program (USWRP)	$10,600	$13,136	$17,000	$28,237
Tornado Severe Storm Resch / Phased Array Radar	$13,158	$12,622	$12,622	$12,633
Joint Technology Transfer	$10,000	$20,000	$20,000	$3,004
OAR Procurement, Acquis.,& Constr. (PAC) Acct.				
Research Supercomputing	$36,379	$41,000	$41,000	$26,000

A. Recent Accomplishments

In 2017, OAR's weather research scientists began working on generating better predictions of dust storms, after linking an increase in such storms in the American Southwest to large scale changes in sea surface temperatures in the Pacific Ocean. In addition, scientists successfully tested a new observation tool to improve local precipitation forecasts for use in day-to-day operations at NWS. The operational code for a major upgrade to the Meteorological Assimilation Data Ingest System was also successfully transitioned to NWS, improving forecasts by allowing users to more easily access real-time measurements of valuable weather observations, such as floods, rivers, and snow amounts.

During the 2017 hurricane season, NOAA research scientists gathered data and improved weather forecasting skill by running and refining experimental models. Of the four models used for analysis, NOAA's Hurricane Weather Research and Forecasting (HWRF) model proved to be the best numerical hurricane forecasting model for strong winds, providing predictions of rapidly intensifying winds in Hurricanes Harvey, Irma, and Maria[1]. NOAA's experimental HWRF model improved track forecasts up to 7 percent when compared with the operational HWRF. Development of the experimental HWRF is funded out of the U.S. Weather Research Program PPA.

Figure 1: Track Improvement for All 2017 Forecasts

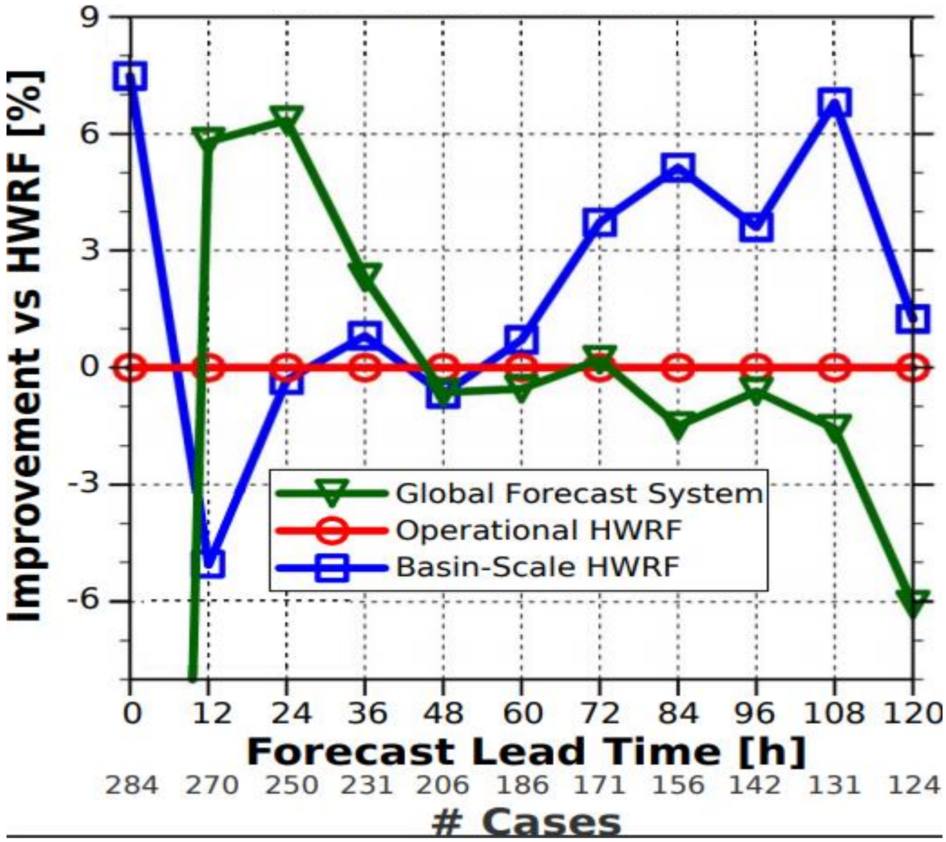


Figure 1 shows skill in percentage improvement (+ values) or degradation (values) of track forecast of the experimental basin scale HWRF (blue) relative to the operational HWRF model (red) run in 2017. The experimental HWRF improves the skill of the track forecasts over the operational HWRF beyond 2.5 days by up to 7 percent (the degradation at 12-hours is not significant as the difference in track errors at 12 hours is only a few nautical miles). The number of forecasts that go into this comparison is shown across the bottom of the figure. NOAA's experimental Global Forecast System (GFS) exceeded all other models in forecasting the track of Hurricane Maria.

[1] When compared to the Hurricanes in a Multi-scale Ocean-coupled Non-hydrostatic model (HMON), Basin Scale Hurricane Weather Research and Forecasting (HWRF) model, and 3-km Nested Finite-Volume Cubed-Sphere Dynamical Core (FV3) model

Figure 2: Model Predictions of Hurricane Maria

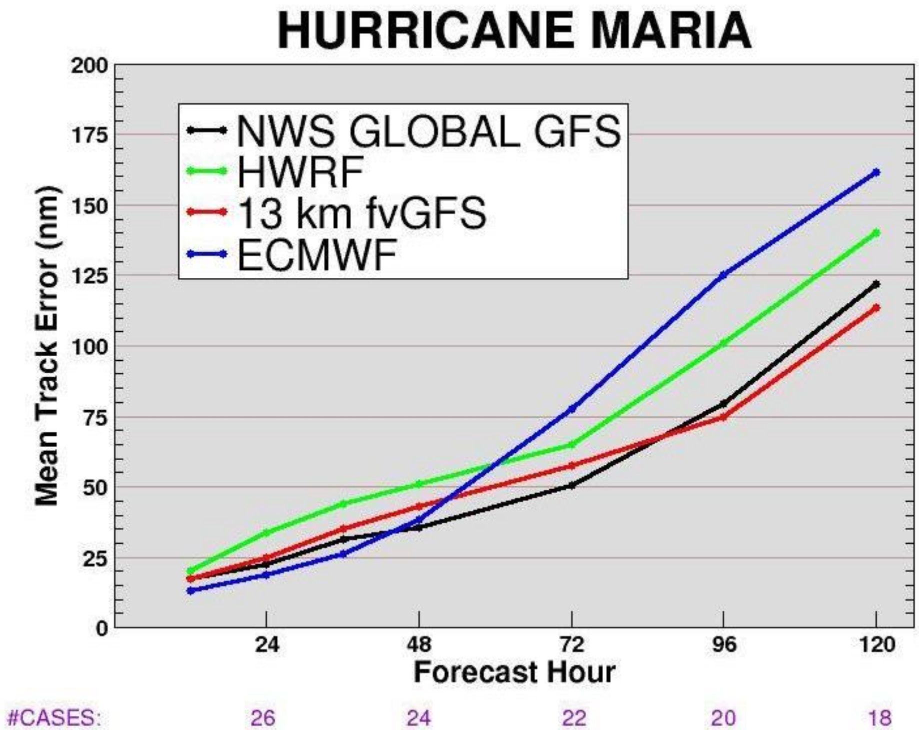
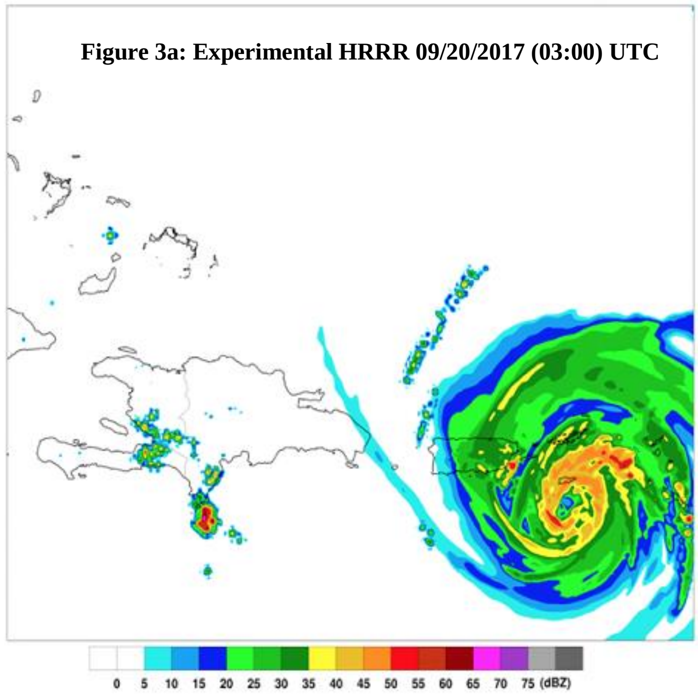


Figure 2 shows the mean track error (in nautical miles) for model predictions of Hurricane Maria, forecast from 12 hours to 120 hours. The number of cases is shown at the bottom of the image. When compared to the NWS Global GFS (shown in black), the experimental GFS (fvGFS, shown in red) was the top performer in the 4- to 5-day range. The operational HWRF is represented by the green line, while the blue line represents the European Centre for Medium-range Weather Forecasts model.

Figure 3: Comparison of Experimental HRRR Reflectivity Forecast (3a) vs. Observed Radar Reflectivity (3b) during Onset of Hurricane Maria



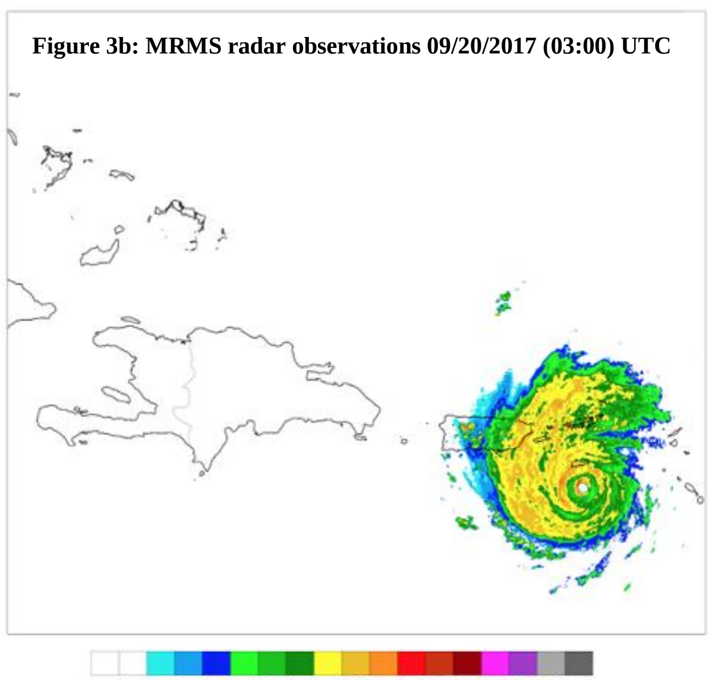


Figure 3 shows a comparison between NOAA's experimental High Resolution Rapid Refresh[2] (HRRRX) model (Figure 3a) versus radar observations from the Multi-

[2] https://rapidrefresh.noaa.gov/hrrr/

Radar/Multi-Sensor system (Figure 3b). Radar reflectivity (roughly representing rainfall rate, measured in dBZ) increases towards the right of the color bar. In this case, preliminary results of the HRRRX showed accurate 36-hour landfall, intensity, and rainfall forecasts for Hurricanes Irma and Maria, extending these forecasts 18 hours beyond the current HRRR operational model.[3]

Some additional OAR weather portfolio activities and their connections to the program elements listed in Section 102 of the Weather Act are referenced in the following sections.

B. Improved Communication of Environmental Information

Section 102(b)(2) of the Weather Act recognizes the need for improvements in communication of environmental information to the public. The NWS watch and warning process has not fundamentally changed in over 50 years. However, society, technology, and science have made great advances. The Forecasting a Continuum of Environmental Threats (FACET) paradigm modernizes the high-impact weather forecasting and communication process by adapting to evolving technology. At the core of this paradigm shift is a change in how weather forecasters communicate the public's vulnerability to extreme weather events. By using information based on probabilities, forecasters can provide the public more precise watches and warnings. This framework will enable decision-makers who require more advanced notice (such as hospitals, schools, and large venues) to set their own threat thresholds based on specific needs. It will also enable new science advances, such as Warn on Forecast (WoF) and Phased Array Radar (PAR), to be fully leveraged into better warnings and forecasts for society. Since hazardous weather forecasting is conducted by humans for humans, social and behavioral science is fully integrated into FACETs research and development. Collaborative research projects between OAR, NWS, and academic partners are beginning to move us toward the FACETs paradigm. In spring 2017, several experiments were conducted in the NOAA Hazardous Weather Testbed (HWT), bringing together NWS forecasters, researchers, and partners such as emergency managers and broadcasters, to evaluate early prototypes of forecast and warning technology based on the FACETs approach. This research is funded primarily through the Laboratories and Cooperative Institutes and the U.S. Weather Research Program PPA.

C. Forecaster and Researcher Collaboration

Section 102(b)(3) of the Weather Act requires feedback on NOAA's efforts to transfer knowledge, technologies, and applications to NWS. One avenue through which this is accomplished is the use of testbeds[4], where participants explore innovative radar and satellite technologies, decision support systems, and new weather and water prediction models. For example, researchers and forecasters work side-by-side throughout the year in HWT to develop, test, and evaluate new forecast and warning strategies. Each year, the HWT draws as many as 60 researchers and forecasters together for 6-to-8 weeks to review emerging ideas and answer the question, "What do forecasters need?" HWT scientists also

[3] https://research.noaa.gov/article/ArtMID/587/ArticleID/11/Research-plays-vital-role-during-relentless-hurricane- season

[4] http://www.testbeds.noaa.gov/

test new concepts and tools with forecasters in simulated settings using real-time forecasts. This cooperative approach promotes effective transfer of research into forecasting and warning operations. HWT are funded through the Laboratories and Cooperative Institutes and the U.S. Weather Research Program PPA.

D. Phased Array Radar

Currently, OAR is working with NWS and the Federal Aviation Administration (FAA) to demonstrate Phased Array Radar (PAR), one prospective application as described in Section 102(b)(3)(A) of the Weather Act. OAR is working to couple weather forecast model information with dual-polarized radar observations to better determine the type and intensity of precipitation, as well as add the ability to classify hail size and detect tornado debris. Other radar research includes developing PAR, which can reduce the time to scan a weather system from 4-to-5 minutes to less than 1 minute, providing earlier weather predictions.[5] The benefits of PAR technology has the potential to significantly advance NOAA's severe weather watches and warnings. PAR, can sample the atmosphere faster, and at higher resolution than current weather radar systems, resulting in more information over areas of severe weather as compared to traditional radars. Within the last year, NOAA has installed the Advanced Technology Demonstrator, which is the first dual polarization, phased array radar to be designed and built for weather radar studies. The installation began in July 2018, with the system undergoing integration testing and preliminary calibration activities. It is expected that the system will be ready for detailed weather radar studies in fiscal year 2020. This research is funded primarily through the Tornado Severe Storm Research / Phased Array Radar PPA.

E. Unmanned Aircraft Systems

Addressing the requirement in Section 102(b)(3)(B) of the Weather Act, NOAA's Unmanned Aircraft Systems (UAS) Program is working to advance the technological readiness of UAS and build capability for their application across the agency. In collaboration with a large and diverse range of partners, the UAS Program is demonstrating the utility of the technology for the agency through activities such as observing high-impact weather events like hurricanes with the use of the National Aeronautics and Space Administration's Global Hawk. Through the UAS Program's Sensing Hazards with Operational Unmanned Technology (SHOUT) project[6] and collaborative work at the NWS National Centers for Environmental Prediction / Environmental Modeling Center (EMC), Global Hawk dropsonde data were assimilated operationally in the HWRF and the European Centre for Medium-Range Weather Forecasts (ECMWF) models throughout 2015-2017 and in the GFS model starting in 2017. These data were incorporated directly into NOAA's operational HWRF model to assist in the forecast of Hurricanes Gaston, Hermine, and Matthew, as well as Tropical Storm Karl, and were also provided in real-time to NOAA's National Hurricane Center, where they were used for assessment of storm

[5] https://www.nssl.noaa.gov/tools/radar/mpar/

[6] "Impact Study of Global Hawk Unmanned Aircraft System (UAS) Observations for Hurricane Forecasting – Final Report", June 2017

strength and structure.[7] Evaluations with the 2017 operational version underway at EMC for the storms sampled in 2017 showed notable positive improvements in both track and intensity forecasts at longer lead times resulting from assimilation of Global Hawk dropsonde data, with skill improvements reaching up to about nine percent for track and 14 percent for intensity. The UAS Program is funded through the Laboratories and Cooperative Institutes PPA.

F. Engaging Citizen Scientists to Improve Weather Forecasts

In correlation with Section 102(b)(3)(C) of the Weather Act as an exemplary application of citizen science, the Meteorological Phenomena Identification Near the Ground (mPING) project is a crowd-sourcing, mobile phone app that allows anyone to submit precipitation observations to the NOAA National Severe Storms Laboratory (NSSL). These observations are used to validate and improve radar-based precipitation type (e.g., rain, sleet, snow, freezing rain, etc.) methodologies developed by NSSL in support of NWS forecasters. A database has been developed for efficient and secure collection and distribution of mPING observations via an open application program interface (API), which allows other application developers to access and distribute the data
Since October 2018, over 483,350 reports have been submitted to the database. During this time, the database has been queried 127.5 million times; of which 1.6 percent of these queries originated from NWS entities (126,000,000+ from a commonly-used commercial application called RadarScope that uses the open API, with the rest stemming from other entities). Finally, mPING improved the skill of winter precipitation-type forecasts for ice pellets and freezing rain (out to eighteen hours) by a factor of four to six over older techniques. The mPING project is funded out of the Laboratories and Cooperative Institutes PPA.

G. Advanced Numerical Weather Modeling

In reference to Section 102(b)(3)(D) of the Weather Act, NOAA's newest weather prediction tool, the Next Generation Global Prediction System (NGGPS), will dramatically improve U.S. operational weather and hurricane forecasting. Powered by the more efficient and more comprehensive Finite-Volume on a Cubed Sphere (FV3) dynamic core, NGGPS provides a new level of accuracy to weather forecasts. Using FV3, weather forecast models are capable of weather prediction on scales ranging from low-resolution global climate predictions to high-resolution severe weather modeling. In summer 2018, FV3 powered experimental hurricane forecast models at NOAA Research and the NOAA National Weather Service in parallel with operational forecast models. The experimental runs of the global FV3-powered system accurately predicted Hurricane Harvey's second landfall and performed as well as the industry standard European forecast model. The FV3-based runs also demonstrated improved track guidance compared to the U.S. operational Global Forecasting System, particularly in terms of the 3- to 5-day lead times. Development of

[7] Dunion, J.P., G.A. Wick, P.G. Black, J. Walker, 2018: Sensing Hazards with Operational Unmanned Technology: 2015-2016 Campaign Summary, Final Report. NOAA Tech Memo. OAR-UAS-001.

NGGPS and FV3 were funded out of the Laboratories and Cooperative Institutes PPA and additional funds from NWS.

Figure 4: Comparison of Experimental HRRR Reflectivity Forecast v. Observed Radar Reflectivity

Initialized 23 August, 7pm (CDT) | Initialized 24 August, 7pm (CDT)

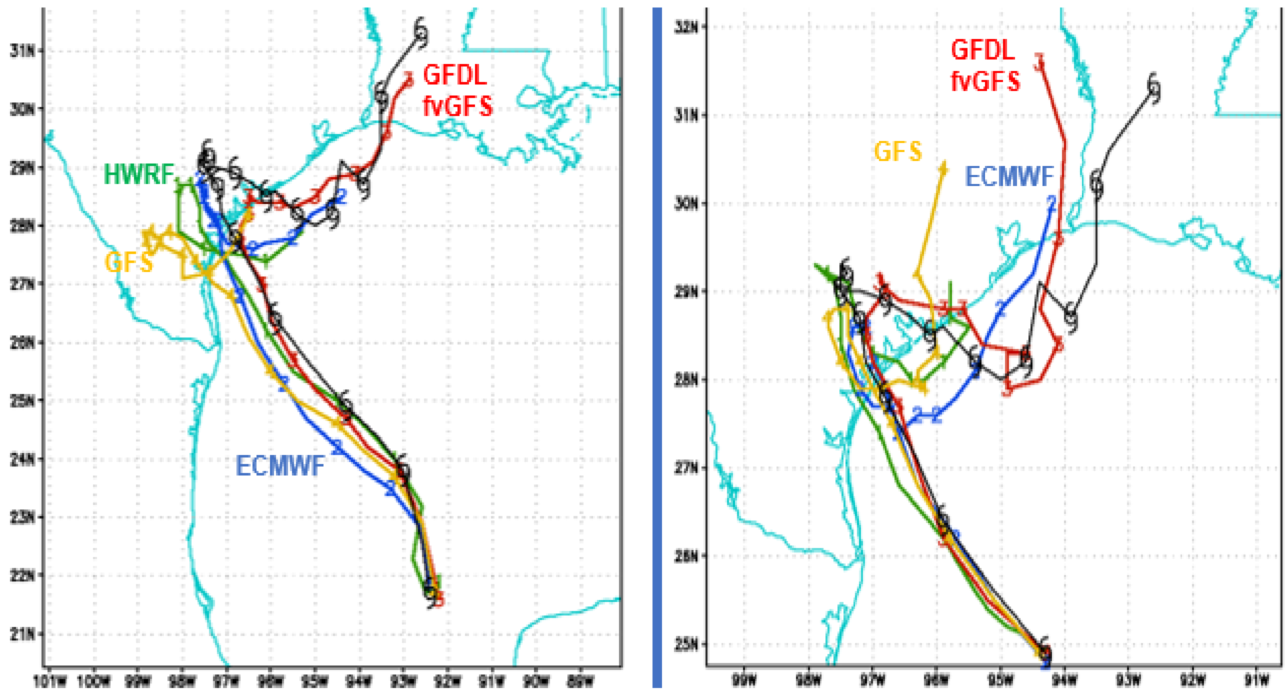


Figure 4 shows the various model predictions of Hurricane Harvey's second landfall event 5 days in advance. The models shown were initialized at 7 p.m. CDT on August 23 (left) and 24 (right), 2017. The experimental GFS (fvGFS) model (red line) correctly predicted landfall as well as the ECMWF forecast model (blue line), while predictions for the HW model (green line) and GFS model (yellow line) missed the mark. The black line represents the actual track of Hurricane Harvey.

H. Quantitative Assessment Tools

NOAA's Quantitative Observing System Assessment Program (QOSAP)[8] provides quantitative and objective assessment capabilities to analyze and evaluate current and future earth observation systems. These capabilities include observing system experiments (OSEs), which focus on identifying the impact of a current observing system on data assimilation and numerical weather prediction, while testing ways to improve the quality and usefulness of data products. QOSAP also includes observing system simulation experiments (OSSEs) which focus on assessing the potential impact of proposed and future observing systems on numerical weather, ocean, and climate prediction. By leveraging

[8] https://www.aoml.noaa.gov/qosap/

both OSEs and OSSEs, QOSAP aims to inform major decisions on the design and implementation of optimal observing systems, as well as increase NOAA's capacity to conduct quantitative observing system assessments. As required by Section 102(b)(3)(E), and described in Section 107 of the Weather Act, NOAA completed the Global Navigation Satellite System (GNSS) radio occultation (RO) OSSE experiment, through the use of a previously existing global OSSE system to determine the potential value of proposed GNSS-RO constellations for current operational numerical weather prediction systems. QOSAP is primarily funded out of the Laboratories and Cooperative Institutes PPA.

I. Atmospheric Composition and Meteorological Processes

Electrical processes play critical roles in determining thunderstorm severity and precipitation intensity. NOAA research, in line with Section 102(b)(3)(F) of the Weather Act, has made great strides in understanding these processes, and works to better measure and model these processes so as to improve the prediction of severe weather events. Field projects employing refined and new sensing technologies are a centerpiece of measuring cloud particles and storm electrification. Tools such as balloon-borne, high-speed particle imagers, for example, capture images of precipitation particles (e.g., rain, hail, graupel, snow, etc.) in their native environment of a cloud. These images, coupled with atmospheric measurements around the particles, allow NOAA scientists to better describe the relationships and interactions between microphysical, electrical, and large-scale dynamics of thunderstorms and precipitation. Other sensors for atmospheric electricity, chemistry, moisture, radiance, and precipitation are utilized to advance the understanding of thunderstorm processes. Armed with this understanding, NOAA scientists and partners improve severe weather prediction. This research is primarily funded out of the Laboratories and Cooperative Institutes PPA.

J. Earlier Warnings

An additional source of weather data and information, as referenced in Section 102(b)(3)(G) of the Weather Act, includes the need for earlier forecast warnings. Currently, NWS does not issue warnings for local severe weather until they see an early signal on radar, or the weather hazard is spotted. While this approach provides the public with an average tornado warning lead time of 13 minutes, some end-users such as hospitals, nursing homes, large venue operators, aviation officials, and others ideally require 30 minutes of lead time or more to effectively move citizens to safety. Through its WoF project[9], OAR is working to combine high-resolution surface satellite and radar data into an optimal set of analyses to initialize ultra-high resolution computer models that will predict specific weather hazards 30-60 minutes before they form. This will allow decision-makers to take more effective action to mitigate damage, reduce injuries, and avoid loss of life. The WoF Project is funded primarily by the Laboratories and Cooperative Institutes PPA, with additional funding provided by NWS.

[9] https://www.nssl.noaa.gov/projects/wof/

Figure 5: Increasingly Detailed Forecasts of Mesocyclone Intensity by Experimental WoF Prototype

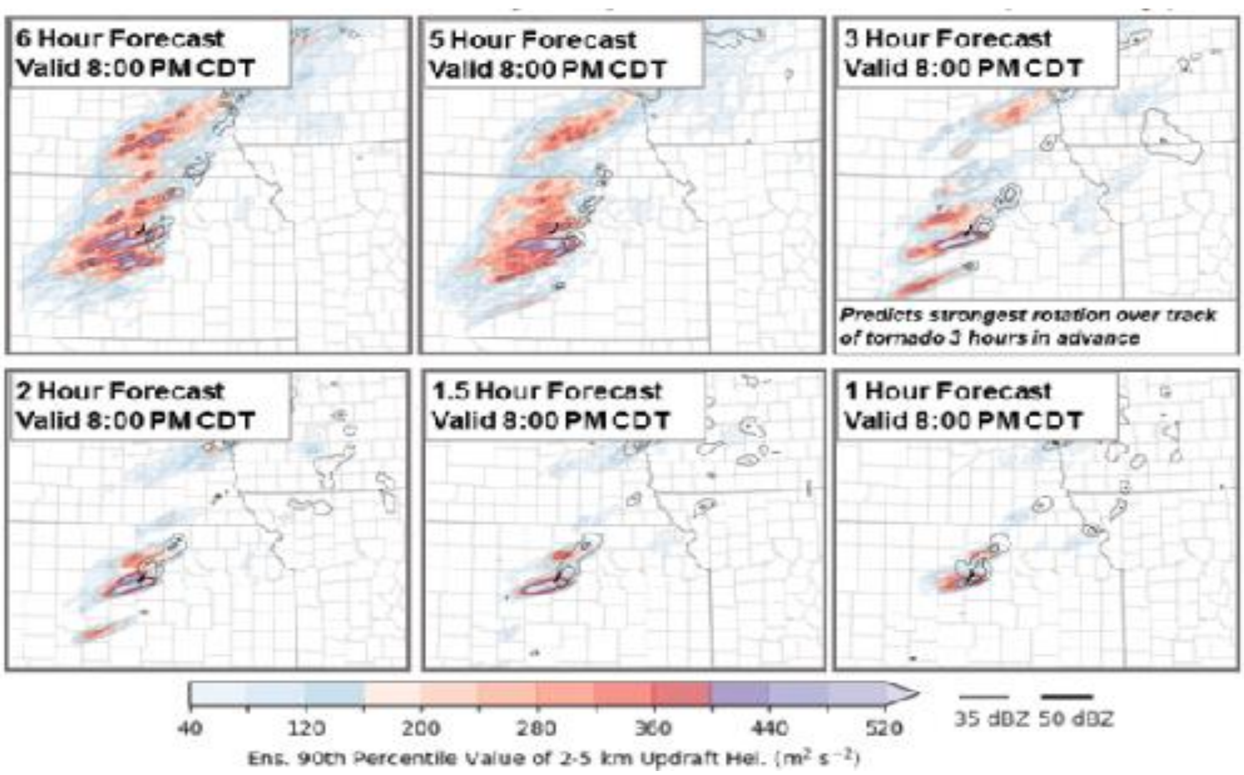


Figure 5 image shows forecasts from the experimental WoF prototype that demonstrate the potential to provide increasingly detailed information on the potential for significantly strong mesocyclones from watch and warning spatiotemporal scales. In this case, the WoF prototype predicted the strongest rotation over the track of an EF3 tornado 3 hours in advance. The color gradient from dark (purple/blue) to light (yellow/white) depict forecast rotation rates with increased rotation in the center of the tracks. The black lines represent the storm's location (reflectivity) at that current forecast time, along with accumulated rotation track paths of the mesocyclone from previous forecast times.

K. Technology Transfer

In reference to Section 102(b)(4) of the Weather Act, the U.S. Weather Research Program provides continuous improvements to understand, predict, and communicate information associated with hazardous weather and air quality events across the country. Results of this research are transferred to NWS after demonstration in several NOAA testbeds, which ensures continued development and transition of the latest scientific and technological advances into operations at NWS.

NOAA is also specifically addressing the requirements in Section 102(b)(4) through the Joint Technology Transfer Initiative (JTTI). JTTI was initiated in Fiscal Year (FY) 2016, funded in the Joint Technology Transfer PPA, and continues as of FY 2020, showcasing projects of interest to NWS operational entities. With the completion of competitions in FY 2019, JTTI has supported 83 projects, many of which are expected to transition into NWS operations over the next 3-to-8 years. Priority areas were identified in consultation between OAR and NWS, who also collaborated in reviewing proposals. Upon selection, each project was assigned an NWS employee to help develop a plan for transitioning the project into operations, which will ultimately be contingent upon the continued viability and merit of the project, as well as availability of transitional and operational funding support from NWS.

Resulting from a rigorous competitive process in FY 2016, JTTI-funded research began October 1, 2016 (FY 2017). Projects were funded for a period of 2 years, with the understanding that most would not begin to transition until the completion of the project period. Since the inception of JTTI, approximately 50 percent of the 70 funded projects from FY 2016 through FY 2018 (35 projects) have advanced at least one readiness level[10] over the last three years. Since the enactment of the Weather Act in April 2017, four projects have successfully transitioned into operations. The first project, "*Improving probabilistic forecasts of extreme rainfall through intelligent processing of high-resolution ensemble prediction"* (Colorado State University)[11], focused on improving probabilistic forecasts, will benefit forecasters of the NWS Weather Prediction Center (WPC). As a result of the JTTI grant, the project was successfully tested and evaluated at the Flash Flood and Intense Rainfall summer experiment of 2017 and implemented in the WPC operations office. The second project, *"Improving the use of dropsondes in NOAA operations"* (AOML and EMC)[12] was designed to improve the use of dropsondes in NOAA operations by implementing an algorithm to estimate dropsondes drift within the data assimilation system of HWRF. Through JTTI funding, the dropsonde drift algorithm was tested and successfully transitioned into NWS National Centers for Environmental Prediction operations. The remaining two JTTI-funded projects have resulted in advancements to the NOAA High-Resolution Rapid Refresh (HRRR) model (run operationally at EMC) and will become operational in the HRRR Version 4 release in 2020. The project, *"Development of NWS convective scale forecasting capability through improving GSI-based hybrid ensemble-variational data assimilation and evaluating multi-dynamic core approach"* (University of Oklahoma)[13], incorporates radar reflectivity data into the model to improve forecasting capabilities. The final project, *"Improving hail forecasts through operational implementation of HAILCAST Hail model"* (Atmospheric and Environmental Research, Inc.)[14], aims to improve the capability of hail forecasting in the model. In addition, five research projects have reached readiness level 8, and have been delivered to NWS for implementation into operations.

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[10] As described in NOAA Administrative Order 216-105B: Policy on Research and Development Transitions

[11] *"Improving probabilistic forecasts of extreme rainfall through intelligent processing of high-resolution ensemble prediction"*, Colorado State University, Fort Collins, Colorado

[12] *"Improving the use of dropsondes in NOAA operations"* AOML/HRD and EMC/NWS

[13] *"Development of NWS convective scale forecasting capability through improving GSI-based hybrid ensemble-variational data assimilation and evaluating multi-dynamic core approach"*, University of Oklahoma

[14] *"Improving hail forecasts through operational implementation of HAILCAST Hail model"*, Atmospheric and Environmental Research, Inc.

L. Improved Flood and Drought Predictions

Access to accurate rain and snowfall predictions are critical to both water and emergency managers, as they work to successfully balance water supply needs and assess impacts on local, regional, and national scales. As an example of the efforts required in Section 102(c)(1) of the Weather Act, OAR, through its partnerships with NWS and other Federal, state, and local water resource agencies, researches the extreme precipitation and weather conditions that can lead to flooding by evaluating new observations and modeling tools to improve forecasts. Results from OAR's Hydrometeorology Testbed enables forecasters to predict precipitation variables such as intensity, amount, and impacts more accurately and at higher resolutions, and allows the user to customize information to support local and regional decision-making. The Flooded Locations And Simulated Hydrographs (FLASH) project also introduces a new paradigm in flash flood prediction. FLASH produces flash-flooding forecasts up to 6 hours in advance with a 5-min update cycle. The primary goal of the FLASH project is to improve the accuracy, timing, and specificity of flash flood warnings in the United States, thus saving lives and protecting infrastructure. The FLASH project is funded through the Laboratories and Cooperative Institutes PPA.

IV. Summary

OAR's weather portfolio involves research spanning a host of program elements outlined in Section 102(b) of the Weather Act, and plans to continue to doing so. OAR, in conjunction with NWS and the non-Federal weather research community, will continue to support activities addressing the Nation's needs to prepare for future atmospheric and severe weather events. Additional information regarding planned research is thoroughly addressed within other reports in direct response to the Weather Act.

List of Acronyms

API	Application Program Interface
ECMWF	European Centre for Medium-Range Weather Forecasts Model
EMC	Environmental Modeling Center
EPIC	Earth Prediction Innovation Center
FAA	Federal Aviation Administration
FACETs	Forecasting a Continuum of Environmental Threats
FLASH	Flooded Locations And Simulated Hydrographs project
FV3	Finite-Volume Cube-Sphere Dynamical Core Model
GFS	Global Forecast System
GNSS	Global Navigation Satellite System
HRRR	High-Resolution Rapid Refresh Model
HRRRX	High-Resolution Rapid Refresh Experimental Model
HPC	High-Performance Computing
HWRF	Hurricane Weather Research and Forecasting Model
HWT	Hazardous Weather Testbed
JTTI	Joint Technology Transfer Initiative
MPAR	Multi-function Phased Array Radar
mPING	Meteorological Phenomena Identification Near the Ground
NCEP	National Centers for Environmental Prediction
NGGPS	Next Generation Global Prediction System
NOAA	National Oceanic and Atmospheric Administration
NSSL	National Severe Storms Laboratory
NWS	National Weather Service
OAR	Oceanic and Atmospheric Research
ORF	Operations, Research, and Facilities
OSEs	Observing System Experiments
OSSEs	Observing System Simulation Experiments

PAC	Procurement, Acquisition, and Construction
PAR	Phased Array Radar
PPA	Program, Project, or Activity
QOSAP	Quantitative Observing System Assessment Program
R&D	Research and Development
RO	Radio Occultation
UAS	Unmanned Aircraft System
U.S.	United States
WoF	Warn on Forecast