Annual Accomplishments

OFFICE OF WEATHER AND AIR QUALITY
National Oceanic and Atmospheric Administration

A Weather-Ready Nation informed by world-class weather research

FY2019

OFFICE OF WEATHER AND AIR QUALITY

National Oceanic and Atmospheric Administration

Office of Weather and Air Quality Annual Accomplishments FY2019 | December 2019
Acting Director: Kandis Y. Boyd, Ph.D., PMP
Acting Deputy Director: Hernan E. Garcia, Ph.D.

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From front row, left: John Opatz*, Chantel Bivins*, Michele Olson*, Segayle Thompson*[P], Winnifred Mutuli*, Tamara Battle*, Bill Lapenta[P] (in memoriam), Krishna Kumar*[P], Jessie Carman[P], Sarah Perfater*, Mark Olsen*[P]

Not pictured: Chandra Kondragunta[P], Hernan Garcia[P], Andrea Ray[P]

Legend: Affiliates are denoted with (*) and doctorates are denoted with ([P]).

Photo credit: Emily Larkin, NOAA (September 2019)

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Notes: (1) Unless otherwise noted, all images are courtesy of NOAA or researchers funded by NOAA. (2) Every effort was made to compile accurate data and information; OWAQ regrets any errors or omissions. (3) Projects with signed transition plans per the FY2019 Annual Operating Plan Metric Tracker are denoted with . (4) Digital version last updated January 14, 2020.

ON THE FRONT AND BACK COVERS: A windmill standing alone against a supercell thunderstorm. Credit: Stephen Corfidi, NOAA's National Weather Service (2018).

IN MEMORIAM

William Michael Lapenta

September 21, 1961 - September 30, 2019
In memory of our dear colleague

We will forever remember Bill's brilliant contributions to the atmospheric sciences, his passion for supporting the next generation, and his dedication to us.

Annual Accomplishments

FY2019 >>

LETTER FROM THE ACTING DIRECTOR

Kandis Y. Boyd, Ph.D., PMP
Acting Director, Office of Weather and Air Quality
NOAA's Office of Oceanic and Atmospheric Research
December 2019

Transitioning the Research that Informs World-Class Forecasts

In Fiscal Year (FY) 2019, NOAA's Office of Weather and Air Quality (OWAQ) found, funded, fostered, and transitioned research that transformed forecasts for tropical cyclones, hazardous weather, flooding, and air quality. OWAQ did this by supporting our nation's leading scientists, engineers, and research organizations as they answered questions about what to expect from our weather, our water, and our climate.

In addition to managing 184 active projects, and while continuing to serve as NOAA's Office of Oceanic and Atmospheric Research lead for executing congressional directives such as the Weather Act of 2017[1] (reauthorized 2018[2]) and Disaster Supplementals[3], OWAQ served as the lead for the formulation and implementation of the Earth Prediction Innovation Center (EPIC). Authorized by Congress in 2019, EPIC is designed to support community modeling and other innovations to produce timely and accurate forecasts.[2]

Our team has mourned losses this year, but we have stayed together and we have remained resilient. As always, extraordinary teamwork and dedication made all of this possible. In particular, I acknowledge our team and partners for:

- ☑ Increasing the number of active projects from **84 to 184**, a **119% increase** over the prior fiscal year.
- ☑ Increasing the number of multi-institutional collaborative projects from **34 to 73**, a **114% increase** over the prior fiscal year.
- ☑ Shepherding a budget increase from **$37.1 million to $40.9 million**, a 10% increase over the prior fiscal year.

The pages that follow report on our progress towards our goals, our accomplishments, and the priority research that OWAQ was directed to fund. With our team and partners, our accomplishments in FY2019 are now our momentum for FY2020.

We are strong. We are resilient. We are OWAQ.

Sincerely,

ANNUAL ACCOMPLISHMENTS

Executive Summary

As of October 2019, ten weather and climate disaster events across the United States (U.S.) have caused losses in excess of $1 billion each. That mix of tropical cyclones, severe storms, and flooding events resulted in the deaths of 39 people and had significant economic effects. Moreover, this is the fifth consecutive year in which ten or more billion-dollar disaster events have impacted the U.S.[4] Given this reality, research funded by OWAQ is necessary to inform the timely and accurate forecasts and warnings that make it possible to save lives, reduce property damage, and enhance the national economy.

VISION: A Weather-Ready Nation informed by world-class weather research.

MISSION: Finding, funding, and fostering collaborative weather and air quality research to discover, develop, and transition products, tools, and services for timely and accurate weather and air quality forecasts.

In just one year, OWAQ more than doubled the number of active projects from 84 (Fiscal Year (FY) 2018) to 184 projects (FY2019). Each project was funded with a single intention: to transition research that will transform weather forecasts. In this, OWAQ was guided by the office's vision, mission, and goals and supported by the weather enterprise that includes NOAA, other Federal agencies and entities; state, tribal, and local governments; academia; other not-for-profits; and the private sector.

Goal 1. *Improve effective communication of weather information to strengthen decision-making and forecasting ability.* OWAQ funded research and hosted workshops to share research-based best practices. In particular, OWAQ:

- **Objective 1.1.** Enhanced the integration of social, behavioral, and economic science across OWAQ's research programs (19% of projects in FY2019).
- **Objective 1.2.** Integrated social, behavioral, and economic science research findings into weather enterprise applications and, through engagement, identified gaps to support future SBES research priorities.
- **Communications.** Clarified and expanded the information and resources at http://owaq.noaa.gov; updated the office's communication plan; and enhanced the office's social media presence.
- **Events.** Hosted twelve workshops on topics as diverse as social science, the Earth Science Prediction Capability, and the Earth Prediction Innovation Center; hosted sessions at national conferences such as the American Meteorological Society's annual meeting and the American Geophysical Union's fall meeting; and briefed the OWAQ research portfolio to multiple internal and external audiences.
- **Reports & Publications.** Co-authored and cleared three reports to Congress consistent with the mandate in the Weather Research and Forecasting Innovation Act of 2017;[5] and funded research that fostered more than 31 peer-reviewed publications.

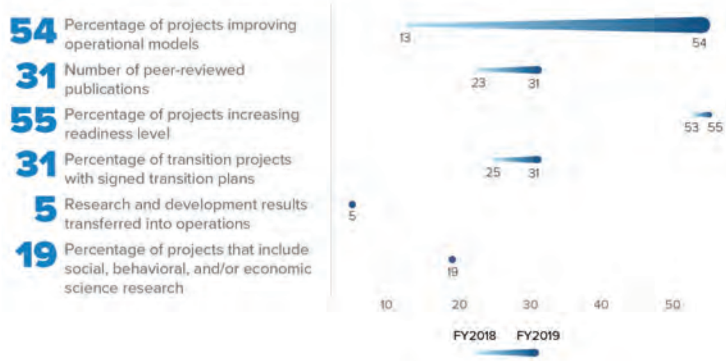

FIGURE 1. The Office of Weather and Air Quality by the Numbers for FY2019 with a Visualization of FY2019 Compared to FY2018. Image credit: Office of Weather and Air Quality Annual Operating Plan FY2019 (2019).

In design and execution, OWAQ's goals explicitly serve OAR's goals, especially:

Goal 2, Detect Change in the Ocean and Atmosphere
Goal 3, Make Forecasts Better
Goal 4, Drive Innovative Science

Goal 2. *Advance models and forecast tools to produce the best weather forecasts and warnings to build a Weather-Ready Nation.* OWAQ and partners advanced models and forecast tools through the overall research portfolio. In particular, OWAQ:

- **Objective 2.1.** Advanced the development and implementation of NOAA's Unified Forecast System.
- **Objective 2.2.** Advanced Subseasonal-to-Seasonal (S2S) forecasts.
- **Objective 2.3.** Improved severe weather prediction capability.
- **UFS and EPIC.** Formulated and began implementing the Earth Prediction Innovation Center to support the Unified Forecast System, community modeling, and other innovations toward timely and accurate forecasts.
- **S2S.** Co-hosted the Subseasonal Climate Forecast Rodeo Symposium in which forecasters competed in real-time to predict the temperature and precipitation for one year.

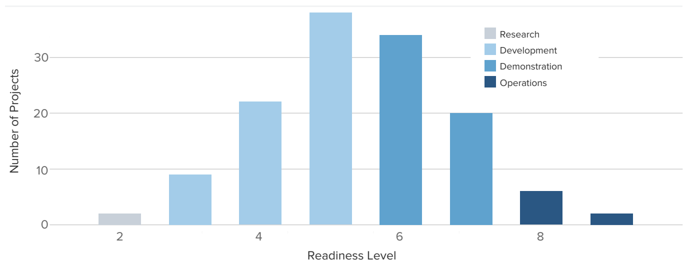

FIGURE 2. Distribution of Projects by Readiness Level in FY2019 (Active Projects; Levels Range from Basic Research (1) to Deployment (9)). Image credit: Office of Weather and Air Quality Metrics (2019).

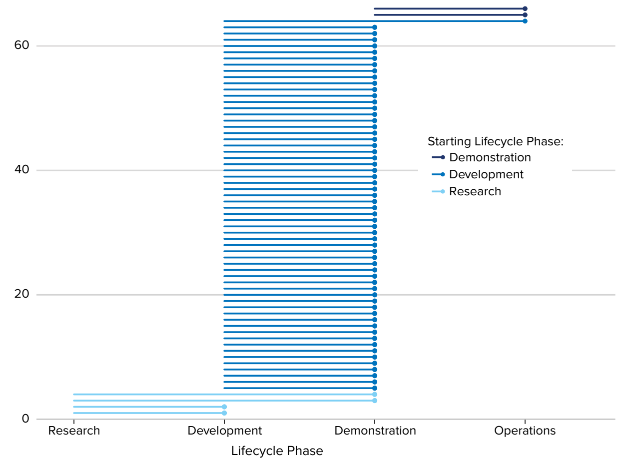

FIGURE 3. Shifts in Readiness Level Based on Starting Lifecycle Phase for FY2019 (Active Projects). Image credit: Office of Weather and Air Quality Metrics (2019).

- **FACETs.** Expanded the next-generation severe weather watch and warning framework as part of the Forecasting a Continuum of Environmental Threats (FACETs) program.
- **APAR.** Also enabled a major milestone on Airborne Phased Array Radar (APAR) (e.g., APAR Trade Studies, Line Replaceable Unit Development, joint National Science Foundation (NSF) and National Center for Atmospheric Research C-130 Vibration Testing, APAR Observing System) that qualified the work to advance to the second round review for the NSF's Mid-scale Research Infrastructure competition.
- **Funding.** Awarded research grants totaling $16.2 million while continuing to foster and transition previously-funded research.

Goal 3. *Effectively and efficiently manage the advancement and transition of weather research.* OWAQ and partners transitioned weather research into operations and responded in a timely and effective manner to NOAA's Congressional mandates. In particular, OWAQ:

- **Objective 3.1.** Advanced the development and transition of weather research to operations (R2O) with 58 signed transition plans.
- **Objective 3.2.** Ensured operations and management processes are well documented, maintained, and refined.
- **Objective 3.3.** Responded in a timely and effective manner to NOAA's Congressional mandates, including co-authoring and clearing three reports required by the Weather Act.
- **Notices of funding.** Redesigned the Notice of Funding Opportunity (NOFO) to include diversity and inclusion and with deadlines that serve the academic and research communities. For the NOFO release, redesigned the presentation and frequently asked questions for the website.
- **Partnerships.** Engaged partners, especially in NOAA's National Weather Service (NWS), to better inform research priorities, in general, and the NOFO, in particular.
- **Planning.** Improved the transition-planning partnerships and process to ease the burden on principal investigators and to speed the transition into societal applications. Jointly with NWS partners, developed a new R2O transition plan review and approval process to ensure robust planning, preparation, and resource allocation for transitioning selected project outputs into NWS operations following project completion. Using this new approach, 58 projects already have signed transition plans.

Goal 4. *Develop and support a diverse and inclusive work environment that promotes equal access to the opportunities OWAQ offers.* OWAQ developed and supported a diverse and inclusive work environment that promoted equal access to the opportunities OWAQ offers by recruiting and maintaining a diverse and highly qualified workforce; promoting and enhancing the inclusion of OWAQ's diverse workforce; and integrating and promoting diversity and inclusion as a core consideration throughout OWAQ's funding mechanisms. In particular, OWAQ:

- **Objective 4.1.** Recruited and maintained a diverse and highly qualified workforce including federal employees identifying as white (57%), black or African American (29%), and Asian (14%) and summer interns hired through the Pathways Programs for Students and Recent Graduates.
- **Objective 4.2.** Promoted and enhanced the inclusion of OWAQ's diverse workforce. Supported the Diversity and Inclusion Summit; continued to develop stronger relationships with minority-serving institutions; and participated in the Women of Color STEM [Science, Technology, Engineering, and Mathematics] Conference.
- **Objective 4.3.** Integrated and promoted diversity and inclusion as a core consideration through OWAQ's funding mechanisms; for example, added a requirement

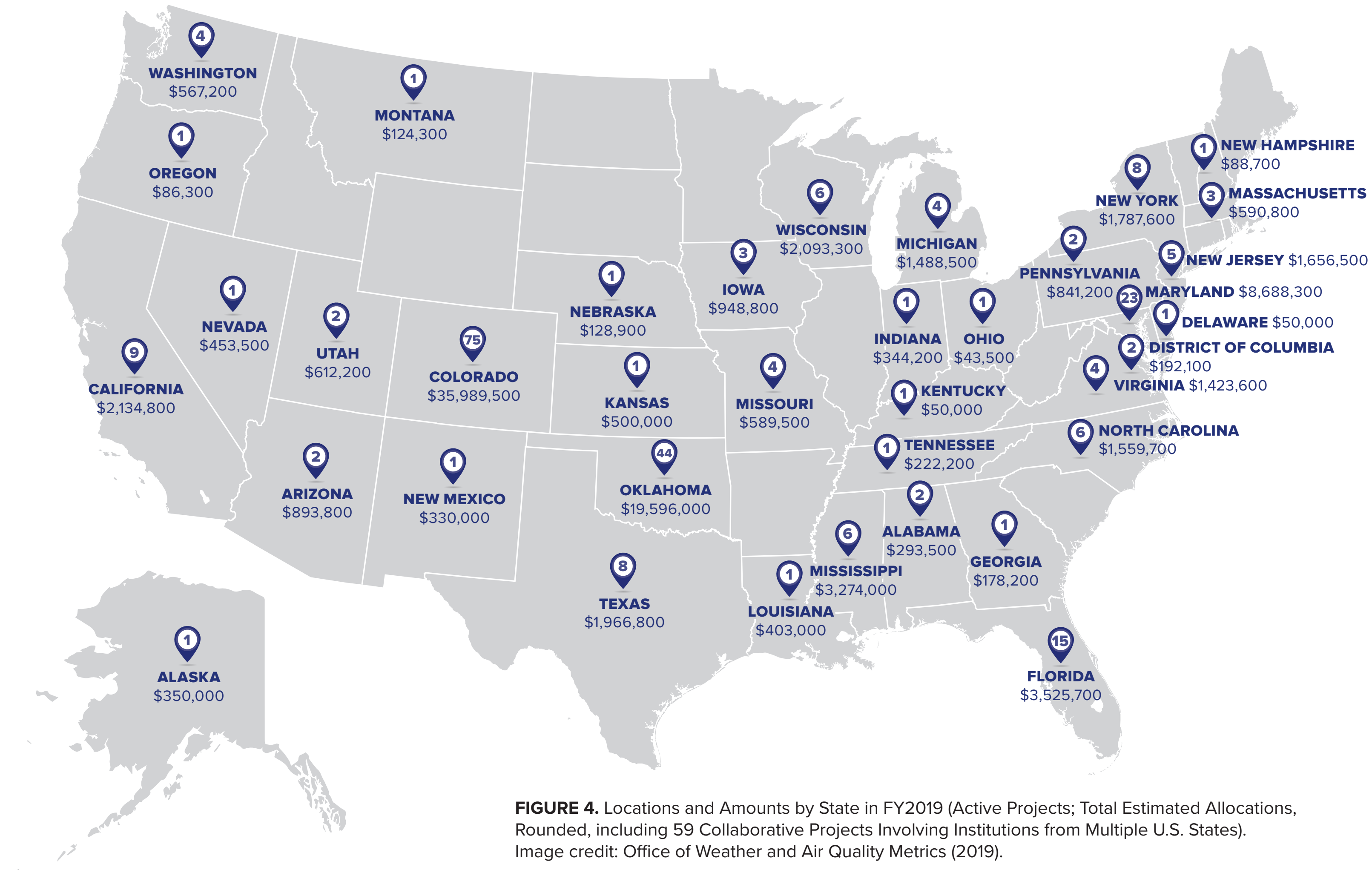

FIGURE 4. Locations and Amounts by State in FY2019 (Active Projects; Total Estimated Allocations, Rounded, including 59 Collaborative Projects Involving Institutions from Multiple U.S. States). Image credit: Office of Weather and Air Quality Metrics (2019).

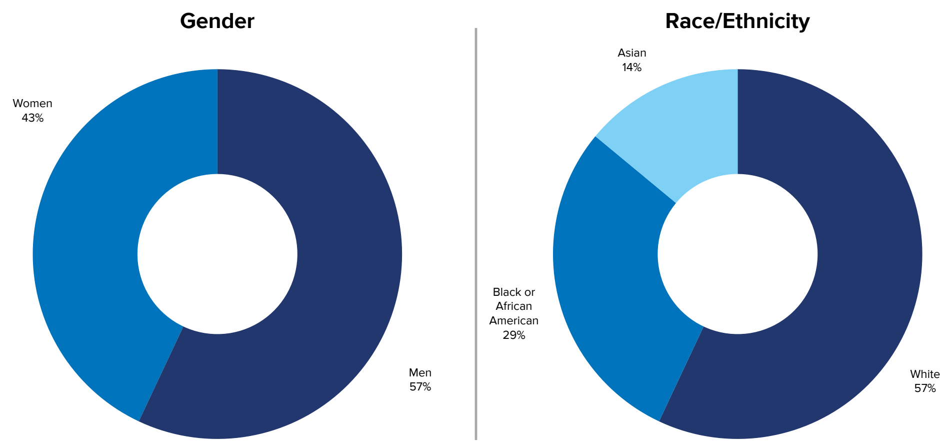

FIGURE 5. OWAQ Diversity Profiles (Federal Employees at the end of FY2019). Image credit: Office of Oceanic and Atmospheric Research's Equal Employment Opportunity Program Office (2019).

in the NOFO that each applicant discuss efforts to support diversity, inclusion, and outreach as part of the project proposal.

- **Engagement.** Served as judges for the NOAA Hollings and Educational Partnership Program Scholar Symposium.
- **Awards.** Among other awards, the Acting Director was acknowledged by the American Meteorological Society for her work on diversity, inclusion, and equity during the hiring process and a risk communications expert was honored for her dedication to embedding social science in the weather enterprise.

Transitioning the Research that Informs World-Class Forecasts. Of the 184 active projects in FY2019, 58 projects already have signed transition plans, which means they already have an explicit operational owner and a path into operations. OWAQ is preparing those projects for transitions by enabling evaluation in NOAA's testbeds and proving grounds. Moreover, OWAQ continues to invest in a dedicated transition manager to improve the transition process itself while ensuring that the underlying transition conversations continue throughout the life of the research project. Throughout this document, projects with signed transition plans per the FY2019 Annual Operating Plan Metric Tracker are denoted with .

RESEARCH FOCUS AREA 1

Tropical Cyclones

(includes Hurricanes, Typhoons, and Cyclones)

Tropical cyclones, in which winds reach 74 miles per hour or more (119 kilometers per hour or more),[6] are known variously as hurricanes (Atlantic and Eastern Pacific Oceans), typhoons (Northwestern Pacific), and tropical cyclones (South Pacific and Indian Ocean).[7,8] The impacts of tropical cyclones can be devastating; winds and storm surge can cause deaths and devastating property losses ranging from damaged roads and bridges to destroyed homes and businesses.

As of October 2019, there had been 12 named storms in the North Atlantic, including five hurricanes and three major hurricanes.[9] Two of the major hurricanes, Dorian and Imelda, caused the loss of life for fifteen people[10] and extensive damage to communication, transportation, and utility infrastructures as a result of heavy rains, strong winds, and waves.

The FY2019 funding priorities follow:[11]

1. Improve operational analysis of the surface wind field in tropical cyclones.
2. Identify new applications of ensemble modeling systems for track, intensity, and structure forecasting.
3. Improve tropical cyclone intensity guidance.
4. Improve guidance for tropical cyclone genesis.
5. Advance coastal inundation modeling and/or applications, visualization, and/or dissemination technology.
6. Develop probabilistic wave height forecasts.
7. In each research area, apply and integrate relevant social and behavioral science methodologies to improve forecasters' use of convection allowing/resolving data, techniques, and guidance, as well as end-users' ability to receive, assess, understand, and respond to forecasts and warnings. For additional examples of projects funded by the Social Science Program, **see also Research Focus Area 5 - Social Science**.

In FY2019, approximately 1 out of every 10 total projects funded by OWAQ contributed to tropical cyclone research, among them:

Producing Reliable Tropical Cyclone (TC) Forecasts

Adding Tropical Cyclone (TC) Genesis Verification Capabilities to the Model Evaluation Tools - TC Software | Daniel Halperin | Embry-Riddle | See Figure 6

In order to verify deterministic and probabilistic forecasts of tropical cyclone formation (genesis), researchers intend to add a new tropical cyclone genesis tool to the Model Evaluation Tools (MET) software package. This will allow the National Hurricane Center to directly compare probabilistic Tropical Weather Outlook (TWO) forecasts against forecasts from various guidance tools and, ultimately, will help improve the National Hurricane Center's ability to produce reliable tropical cyclone genesis forecasts. This new tool will also help NOAA's scientists evaluate tropical cyclone genesis forecasts in new versions of the Global Forecast System model.

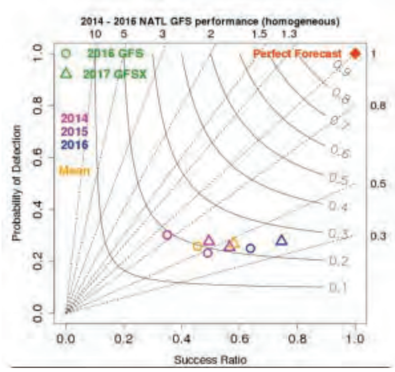

FIGURE 6. Identification of the problem: Performance diagram showing the 2014-2016 annual and mean verification statistics for TC genesis forecasts from the 2016 GFS (circle) and 2017 GFS (triangle) configurations. This diagram shows the success ratio (x-axis), probability of detection (y-axis), frequency bias (dashed lines), and critical success index (curved lines). Image credit: Provided by Daniel Halperin per Research Proposal, Figure 3 (2018).

Improving Tropical Cyclone Genesis (TC) Prediction

Improvements and Extensions to an Existing Probabilistic Genesis Forecast Tool Using an Ensemble of Global Models | Robert Hart | Florida State University | See Figure 7

To enhance the probabilistic TC genesis forecast tool, researchers have developed a more calibrated, skillful, and compatible forecast tool for the National Hurricane Center. This will allow forecasters to utilize well-calibrated TC genesis guidance well in advance (up to five days) of tropical cyclone formation. Improvements have included a Python version of the tool and graphical output, improved consensus tracking (matching) algorithm, addition of the NAVGEM and ECMWF guidance to lead to four and five model consensus equations, and extensions of the guidance itself to the Central Pacific Basin.

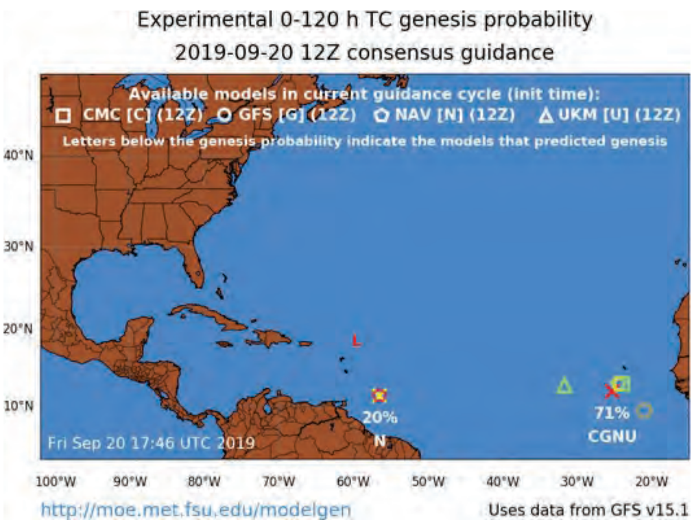

FIGURE 7. Sample graphic of regression-based 120 hour consensus TC genesis probabilities from the updated version of the guidance tool (constructed in Python) showing two disturbances with 20% (71%) consensus probabilities of formation, supported by one (four) models, respectively. Image credit: Guidance tool experimental web site: http://moe.met.fsu.edu/modelgen.

Supporting Tropical Cyclone (TC) Pre-Genesis Watches and Warnings

Ensemble-Based Pre-Genesis Watches and Warnings for Atlantic and North Pacific Tropical Cyclones | Russell Elsberry | University of Colorado-Colorado Springs

To understand where and when a TC forms, researchers will develop guidance products that combine the environmental forcing that is relatively well-forecasted and the precise timing and location of TC genesis that depend on mesoscale convective systems and convective-scale systems that are not well-observed or well-forecasted. Based on the NOAA Global Ensemble Forecast System and the European Center for Medium-range Weather Forecasts, researchers will provide guidance products for the NHC, the Central Pacific Hurricane Center, and the Joint Typhoon Warning Center (JTWC) to support pre-genesis watches and warnings of Atlantic and eastern North Pacific, central North Pacific, and western North Pacific, respectively.

Improving Tropical Cyclone (TC) Forecasts with Machine Learning

Transition of Machine-Learning Based Rapid Intensification Forecasts to Operations | Andrew Mercer | Mississippi State University-Northern Gulf Institute | See Figure 8

To improve Atlantic tropical cyclone rapid intensification (RI) forecasts, researchers are transitioning an ensemble of artificial-intelligence-based prediction models to operations. They found vorticity to be a useful predictor for RI, an increase in the maximum sustained winds of a TC of at least 30 knots in a 24-hour period. The resulting, configurable product could predict upcoming RI events and is currently providing probabilistic RI output as part of the 2019 Joint Hurricane Testbed.

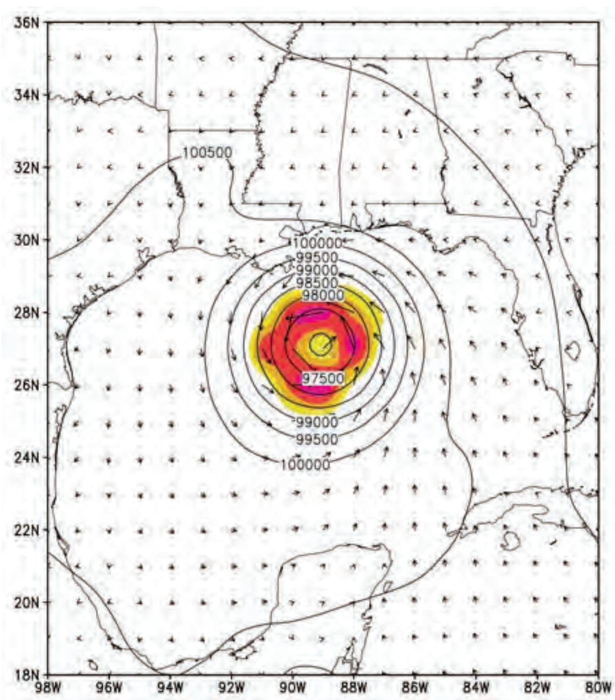

FIGURE 8. Hurricane Katrina wind field with absolute vorticity. Image credit: Global Forecast System (GFS) Analysis provided by Andrew Mercer.

Improving Tropical Cyclone (TC) Predictions with Improved Understanding of Microphysics

Improving the Microphysics Parameterization in High-Resolution FV3GFS Nested Modeling System for Tropical Cyclone Predictions | S. G. Gopalakrishnan & Xuejin Zhang | NOAA's Atlantic Oceanographic and Meteorological Laboratory

Using observations from *in situ* and longitudinal rain and ice data collected by NOAA and National Aeronautics and Space Administration (NASA) over the years, researchers intend to improve the characterizations of the microphysics (i.e., the level of molecules, atoms, and subatomic particles) that make up hurricane models. This could lead to revisiting the microphysics observations in the Hurricane Analysis and Forecast System and in the Finite-Volume Cubed Global Forecast System (FV3GFS).

RESEARCH FOCUS AREA 2

Hazardous Weather

(includes Thunderstorms, Severe Wind and Hail Storms, Tornadoes, Heavy Rainfall, Winter Weather, and Flooding)

The term "hazardous weather" is used to describe local, intense, often-damaging storms such as thunderstorms, severe wind and hail storms, and tornadoes, as well as heavy rainfall, winter weather such as heavy snow and ice, and flooding such as coastal, inland, and flash flooding. Annually, the U.S. is struck by 100,000 thunderstorms, 10,000 severe thunderstorms, 5,000 floods or flash floods, and 1,000 tornadoes; 90 percent of all presidentially-declared disasters are hazardous-weather-related, representing 500 deaths and nearly $15 billion in damages per year.[12]

FY2019 priorities follow:[11]

1. Identify and validate concepts and techniques to improve NOAA's convection-allowing/resolving ensemble forecast system performance.
2. Identify and validate innovative post-processing and verification techniques for NOAA's deterministic models and ensembles across spatial and temporal scales to create skillful and reliable probabilistic thunderstorm and severe hazard threat guidance.
3. Identify and validate new or improved methods, models, or decision-support tools to improve probabilistic winter precipitation forecasts for snowfall amounts and/or ice accumulation.
4. Identify and validate new or improved ways of enhancing forecaster use of probabilistic precipitation or ice accumulation short-range and medium-range forecasts.
5. Identify and validate new or improved methods, observations, decision-support tools, and models to improve understanding or evaluate forecast performance of extreme precipitation events.
6. Improve numerical weather prediction modeling through data assimilation, post-processing, and verification capabilities.
7. Improve extreme precipitation forecasting.
8. Demonstrate how infrasound information can enhance tornado threat predictive capability.
9. Compare infrasound from tornadic storms with other measures and data to identify the radiating mechanisms.
10. Study infrasound propagation in complex atmospheric environments associated with severe weather.
11. Collect infrasonic data to leverage ancillary environmental observations.
12. Develop improved algorithms for real-time processing and subsequent display of infrasonic data.
13. Advance technologies that characterize boundary layer vertical profiles of water vapor, temperature, pressure, and winds.
14. In each research area, apply and integrate relevant social and behavioral science methodologies to improve forecasters' use of convection allowing/resolving data, techniques, and guidance, as well as end-users' ability to receive, assess, understand, and respond to forecasts and warnings. For additional examples of projects funded by the Social Science Program, **see also Research Focus Area 5 - Social Science**.

In FY2019, approximately 3 out of every 10 total projects funded by OWAQ contributed to hazardous weather research, among them:

Evaluating Forecast Tools

Intelligent Post-Processing of Convection-Allowing Model (CAM) Output to Inform Weather Prediction Center (WPC) Outlooks and Forecasts | Russ Schumacher | Cooperative Institute for Research in the Atmosphere | See Figure 9

This project will generate continental US-wide guidance on the probability of locally excessive rainfall on Day One based on post-processing of the operational High Resolution Ensemble Forecast Version 2 and other available operational convection-allowing model outputs. Researchers seek to objectively and subjectively evaluate forecast tools in the Flash Flood and Intense Rainfall Experiment (FFaIR) and in other Weather Prediction Center (WPC) evaluation projects.

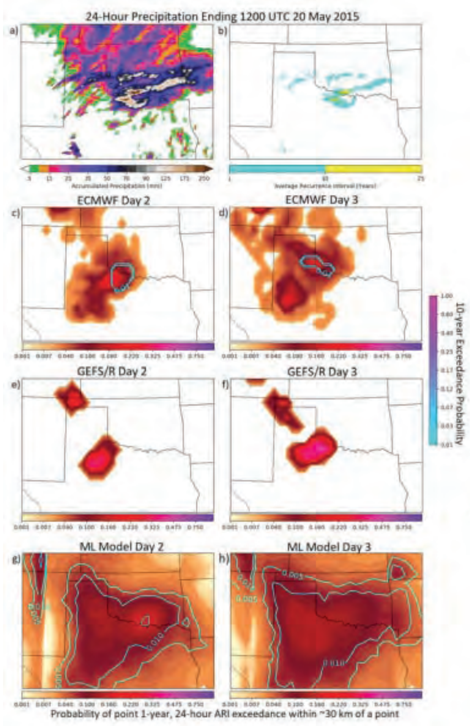

FIGURE 9. Case study depicting forecasts from the final machine learning model and both reference ensembles for the 24-hour period ending 1200 UTC 20 May 2015: (a) 24-hour Stage IV QPE ending at 1200 UTC 20 May 2015 and (b) associated 1-(cyan) and 10-year (yellow) 24-hour ARI exceedances. (c) ECMWF ensemble neighborhood ARI exceedance probabilities in the filled (1-year) and unfilled (24-year) contours for the 36–60 hour forecast initialized 0000 UTC 18 May 2015 and (d) for the 60–84 hour forecast initialized 0000 UTC 17 May 2015. Panels (e) and (f) depict analogous fields as panels (c) and (d), respectively, except for forecasts from the raw GEFS/R QPFs. Panels (g) and (h) similarly show respectively 36–60 and 60–84 hour forecasts, except for from the final version of the machine learning model trained in this study. Image credit: Adapted from Herman and Schumacher[13] and used with permission of © American Meteorological Society.

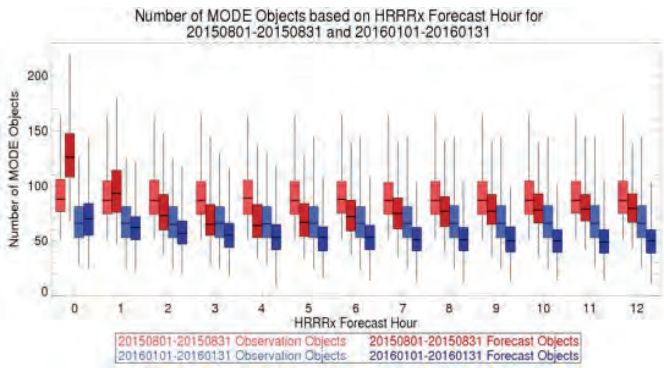

FIGURE 10. Box plot diagram depicting the range of the number of observed (lighter colors) and forecast (darker colors) cloud objects in the upper troposphere identified using the Method for Object-based Diagnostic Evaluation (MODE) system during August 2015 (red boxes) and January 2016 (blue boxes). The results are plotted as a function of forecast hour along the x-axis. Data from all forecast cycles and hours during each of these months were used when producing the box plot diagram. Image credit: Provided by Jason Otkin et al. per Research Proposal, Figure 1 (2019).

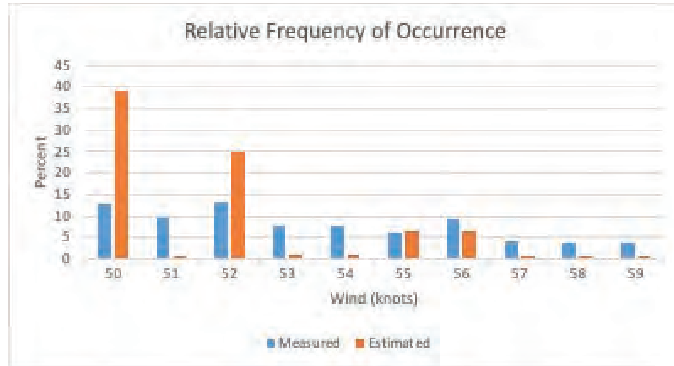

FIGURE 11. Relative frequency of occurrence (out of roughly 180,000 reports from 2007-2018) of measured and estimated winds in the Storm Events Database for values between 50 and 59 knots, demonstrating human-influenced peaks at 50 and 52 knots (60 mph) for estimates. Image credit: Provided by William Gallus.

Using Reanalysis to Improve Forecasting

Implementing Convective Storm Statistics from a Large Reanalysis of WSR-88D Data for Model Verification and Forecasting Probabilistic Uncertainty | Travis Smith | University of Oklahoma - Cooperative Institute for Mesoscale Meteorological Studies

To continue the research-to-operations (R2O) transition process for key aspects of the Forecasting a Continuum of Environmental Threats (FACETs) effort for convective hazards, researchers will elevate the readiness levels (RLs) of two physical concepts and methodologies in support of probabilistic hazards information for the National Weather Service: (1) Model verification using a large, reanalysis dataset of convective storms using WSR-88D data; and (2) Providing storm-based probabilistic trends and historical distributions of convective storm features for use in the Probabilistic Hazard Information (PHI) Tool.

Simulating Convection Accurately

Advancing Forecast Verification Efforts for Unified Forecast System Advanced Physics Testing using Spatial Verification Methods | Jason Otkin, Tara Jensen & Patrick Skinner | University of Wisconsin-Cooperative Institute for Meteorological Satellite Studies, National Center for Atmospheric Research & University of Oklahoma - Cooperative Institute for Mesoscale Meteorological Studies | See Figure 10

To advance the METplus verification system, researchers are developing new use cases for testing various physics suites in current and future versions of operational CAMs to produce accurate convection simulations. This will be completed using output from a suite of model simulations produced during the 2019 and 2020 Hazardous Weather Testbed Spring Experiments. The research outcomes will support advanced physics testing in the Finite-Volume Cubed (FV3) model, improvement of the convection representation in future versions of the standalone regional FV3 model, and enhancement of severe weather forecasting accuracy.

Leveraging Machine Learning to Diagnose Severe Winds

Improved Diagnosis of Severe Wind Occurrence through Machine Learning | William Gallus | Iowa State University | See Figure 11

The objective of this research is to construct a tool to better detect severe wind events from storm reports using advanced clustering, spatial statistics, and machine learning methodologies. The resulting product can be applied to historical archives and in real-time to give users probability values that thunderstorm winds are exceeding severe and significant severe threshold values. Researchers intend to use the diagnostic tool to accept a storm report as input from the Storm Events Database and then estimate the posterior probability distribution of a severe wind event using machine learning techniques. The research outcome will be a machine-learning-based diagnostic product that NOAA can use to enhance severe thunderstorm warning validation and forecasting.

Enhancing Extreme Winter-Weather Precipitation Forecasts for the Great Lakes Region

Improving Lake-Effect Snow Forecasting Capabilities via Advanced Coupling Techniques in NOAA's Unified Forecast System (UFS) | Christiane Jablonowski & Philip Chu | University of Michigan - Cooperative Institute for Great Lakes Research & Great Lakes Environmental Research Laboratory (GLERL) | See Figure 12

This research seeks to advance the Unified Forecast System's (UFS) capabilities related to lake interactions, which, although absent from the UFS, are essential for providing the Great Lakes Region with accurate forecasts of extreme winter-weather precipitation. The researchers will resolve this by advancing the operational status of NOAA's 3D lake hydrodynamic-ice model, FVCOM-CICE; loosely coupling FVCOM-CICE to NOAA's high-resolution weather prediction models in the UFS; working with regional Weather Forecast Offices to objectively evaluate the coupling technique and configuration via the

Hydrometeorology Testbed (HMT) and participation in the Winter Weather Experiment; and evaluate the potential for transitioning the modeling and coupling advances toward operational use at National Centers for Environmental Prediction's Environmental Modeling Center.

Informing Uncertainty with Physical Processes

Development of Process-Level Parameterizations of Model Uncertainty in the Global Forecast System / Global Ensemble Forecast System | Jeffrey S. Whitaker & Jian-Wen Bao | NOAA's Earth System Research Laboratory

Using cellular automata, here defined as gridded cells with a defined set of rules for affecting neighboring cells over time, researchers simulate uncertainty physical processes. This means that the models of the physical processes are directly informed by observations and simulations and that the information about the underlying uncertainties is clearer. Following testing, this may support the upcoming FV3-based Global Ensemble Forecasting System and is being developed in collaboration with the Environmental Modeling Center's ensemble team.

Improving Longer-range Prediction of Specific Hazards

Medium-range to Subseasonal-to-Seasonal Prediction at Convective Scales | Lucas Harris | NOAA's Geophysical Fluid Dynamics Laboratory | See Figure 13

Historically, NOAA's research for medium-range to extended-range severe weather prediction has combined statistical prediction methods and coarse-resolution global ensemble systems, which provide insufficient information about the specific type of hazard (e.g., tornado, flooding, etc.). Using the zooming capability in a global weather model based on the GFDL Finite-Volume Cubed-Sphere Dynamical Core (FV3) to be able to predict individual severe thunderstorms, researchers plan to improve longer-range prediction (with probabilities) of specific hazards. This work benefits the Unified Forecast System community by improving Subseasonal-to-Seasonal (S2S) predictions and could inform longer-term dynamical models. Additionally, this work could inform S2S prediction of significant cold-season events, such as heavy snowfall or ice storms.

Improving Rainfall Forecasts by Understanding Eddy Activity

Sensitivity of NMME Seasonal Predictions to Ocean Eddy Resolving Coupled Models | Ben Kirtman & Dr. Robert Burgman | University of Miami & Florida International University | See Figure 14

Hypothesizing that fronts and eddies in the ocean (oceanic mesoscale features) affect the exchange of heat, water vapor, and momentum between the air and the sea and in turn affect the representation of climatic features in models, this research seeks to identify improvements to the North American Multi-Model Ensemble (NMME) by:

- Increasing the resolution in NMME retrospective predictions with increased resolution in the ocean and ice component model (i.e., 0.1 degree versus 1 degree) and increased resolution in the atmospheric component model (i.e., 0.5 degree versus 1 degree);
- Assessing forecast quality using both deterministic and probabilistic measures; and
- Examining how including this model affects the multi-model forecast quality.

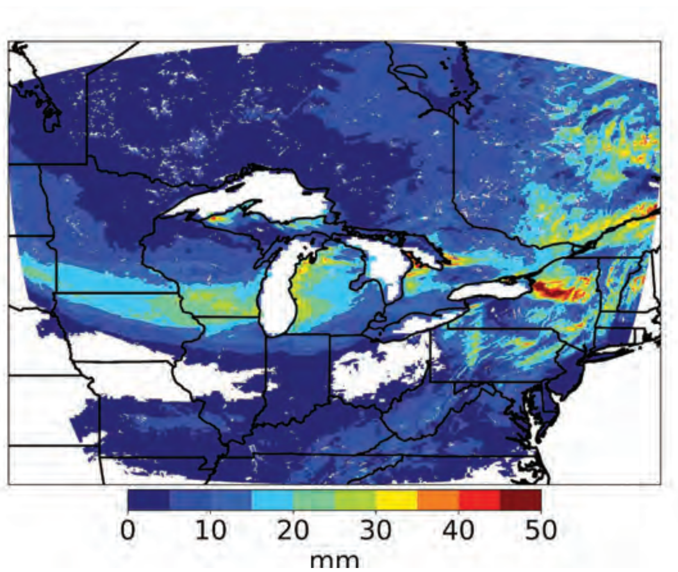

FIGURE 12. Example of a stretched, variable-resolution grid configuration (called C768s5) of the global UFS weather prediction model FV3GFS, which provides high-resolution grid spacings of about 3 km over the Great Lakes Region (left). Right panel depicts the forecasted precipitation (here shown as the snow water equivalent SWE) which accumulated from January 27 to February 1, 2019. This shows the ability of the variable-resolution configuration of UFS-FV3GFS to create lake-effect snowfall downwind of the Great Lakes. Image credit: Provided by Christiane Jablonowski.

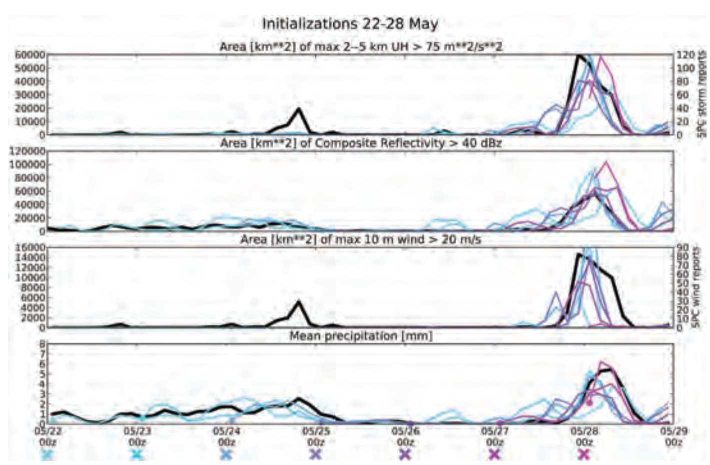

FIGURE 13. Predictions from an FV3-based convective-scale model of various proxies for severe weather at different lead times versus observations (black) for the "Triple Derecho" of 27-28 May 2017. Image credit: Provided by Lucas Harris et al.;[16] publisher confirms that the work is in the public domain.

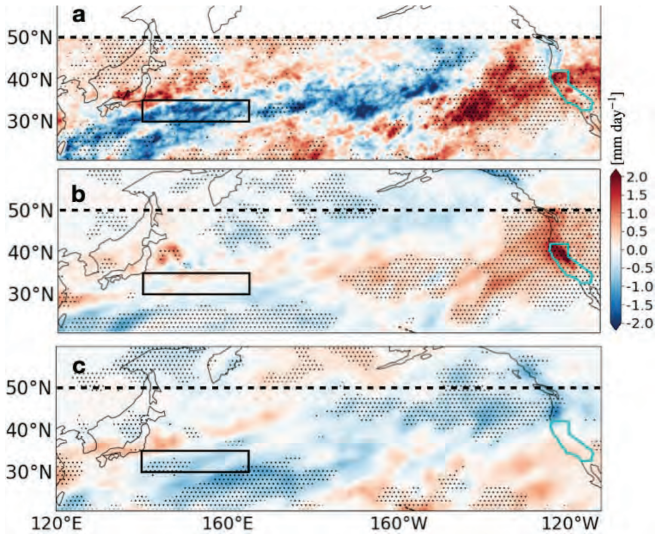

FIGURE 14. Difference in January through March rainfall composites between Inactive Eddy Years (IEY) and Active Eddy Years (AEY) for: (a) TRMM 3B42 (5 years each); (b) ensemble average HR hindcast (7 years each); and (c) ensemble average LR hindcast (7 years each). IEY and AEY are taken from observational estimates. Rainfall difference is significant at 95% confidence level based on a two-sided Wilcoxon rank-sum test is shaded by gray dots. Image credit: Provided by Benjamin Kirtman and Robert Burgman.

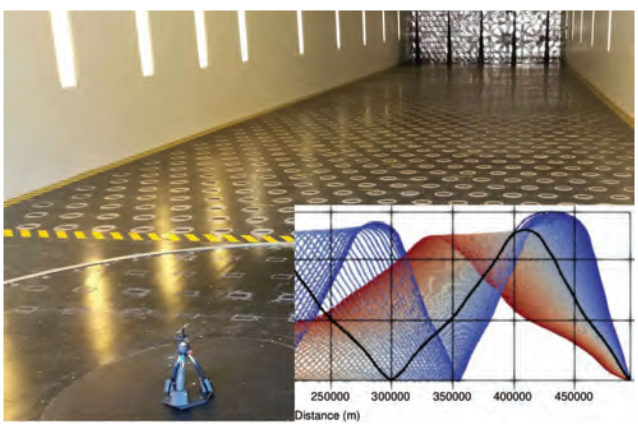

FIGURE 15. University of Florida Boundary Layer Wind Tunnel. Acoustic measurements that interact with the scaled acoustic sources propagate through the tunnel. Lower right image shows alteration of acoustic solver via coefficients modified by measurement. Image credit: Provided by Steve Miller.

Improving Tornado Detectability

Prediction and Measurement of Infrasound Propagation in the Turbulent Atmosphere | Steven Miller | University of Florida | See Figure 15

To improve the use of infrasound for detecting tornadoes, researchers plan to quantify the impacts on the propagation of ultrasound under various conditions of turbulence in the boundary layer. By integrating current theories, measurements, and field tests—and by obtaining coordinated measurements from infrasound, StickNet, and mobile radar during tornadoes—researchers intend to develop a propagation code that considers atmospheric turbulence.

RESEARCH FOCUS AREA 3

Flooding

(Hydrological)

Flooding is the result of an overflow or inundation from a river or other body of water that causes or threatens damage. Coastal storms, heavy rain, and melting snow (addressed in previous sections) are all potential causes. When flooding is on coastal lands, it is termed "coastal inundation." Although it could be caused by wave action, it is usually the result of riverine flooding, spring tides, severe storms, or underwater seismic activity resulting in a tsunami. Flooding can endanger life, property, and economies.

FY2019 priorities follow:[11]

1. Identify and validate new or improved methods, models, or decision-support tools to improve flash-flood monitoring and forecasting.
2. Identify and validate new or improved methods, data assimilation, models, or decision-support tools to improve utilization of precipitation forecasts and production of streamflow forecasts.
3. Improve water prediction capabilities to include efforts to enhance hydrologic prediction through improved data assimilation and model extension for hydrological data sets.
4. Focus on advancements leading to improved surface-based or airborne-based observing capabilities of snow depth (snow water equivalent) and soil moisture.
5. Improve observations of snow depth and soil moisture.
6. Improve data assimilation and physics parameterization of snow depth and soil moisture.

7. In each research area, apply and integrate relevant social and behavioral science methodologies to improve forecasters' use of convection allowing/resolving data, techniques, and guidance, as well as end-users' ability to receive, assess, understand, and respond to forecasts and warnings. For additional examples of projects funded by the Social Science Program, **see also Research Focus Area 5 - Social Science**.

In FY2019, approximately 1 out of every 10 total projects funded by OWAQ contributed to hydrological research priorities, among them:

Helping the Public Understand Uncertainty

Making Sense of Uncertainty: Improving the Use of Hydrologic Probabilistic Information in Decision Making | Rachel Carr | Nurture Nature Center | See Figure 16

This research builds on a series of studies conducted by the research team since 2012, each of which is centered on how professional and residential users understand flood and hydrologic forecasts, including those representing uncertainty and probabilistic information. Deliverables include a series of user-tested prototype products, developed in cooperation with operational offices and advanced toward operational use, as well as a final report with findings, general recommendations for probabilistic communication, and an explanatory video about the project's findings.

Incorporating Snowmelt into the National Water Model

Improving Subseasonal Water Supply Prediction across the Western United States through Assimilation of Remotely Sensed Snow Cover, Snow Albedo, and Snow Water Equivalent in the NOAA National Water Model | Karl Rittger, Aubrey Dugger & Edward Bair | University of Colorado, National Center for Atmospheric Research & University of California Santa Barbara | See Figure 17

To address current shortcomings in subseasonal water supply prediction, researchers intend to assimilate a new, near-real-time (NRT) suite of remote-sensing-based snow products into the National Water Model. Reducing uncertainties in streamflow forecasts using large scale spatially and temporally complete observations of snow surface properties previously unavailable may increase the likelihood that water managers and resource managers will use the 30-day forecast in the National Water Model (NWM). Assimilating these high-quality, high-impact observations from the snow suite provided by the Institute for Arctic and Alpine Research (INSTAAR) will make substantial improvements in the accuracy and relevance of the NWM seasonal forecasts for water resource managers.

Improving Snowmelt Runoff Prediction

Improving National Water Model (NWM) Snowmelt Runoff Prediction | Guo-Yue Niu & Michael Barlage | University of Arizona, National Center for Atmospheric Research | See Figure 18

The current snow model in the National Water Model (NWM) requires improved representations of snow/rain partitioning, heat advected (carried) by rainfall, and topographic shading and scattering of light. The researchers seek to improve snowpack (snow-water equivalent) physics parameterization in NWM/WRF-Hydro and will advance snow data assimilation

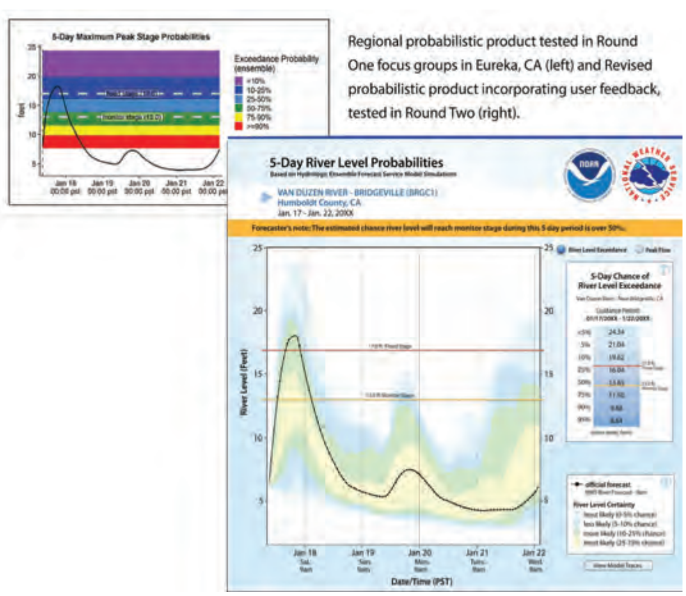

FIGURE 16. Comparison of pre- and post- focus group products. Image credit: Nurture Nature Center.

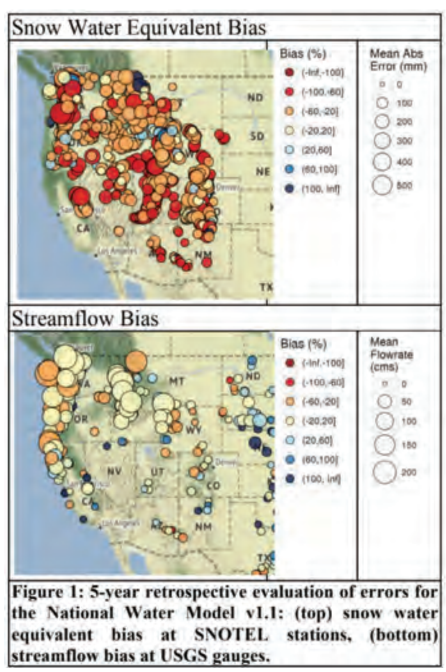

FIGURE 17. 5-year retrospective evaluation of errors for the National Water Model v1.1: snow water equivalent bias at SNOTEL stations (top); and streamflow bias at USGS gauges (bottom). Image credit: Provided by Karl Rittger et al. per Research Proposal, Figure 1 (2018).

for hydrologic prediction. Researchers will deliver the snow-enhanced version of the NWM and the daily snow dataset (from 1982 to present) to the National Weather Service's Office of Water Prediction; the National Centers for Environmental Prediction's Environmental Modeling Center; and the National Center for Atmospheric Research's NWM development team.

Understanding Atmospheric Rivers to Improve Snowmelt Processes in the National Water Model (NWM)

Evaluation and Improvement of Snowmelt Processes in the NWM during Extreme Atmospheric River Events in the Western U.S. | Martin Ralph | Scripps Institute, University of California - San Diego | See Figure 19

To improve water prediction, this project proposes to study extreme atmospheric river events, which can be visualized as the rivers in the sky that transport most of the water vapor. This requires *in situ* and remote sensing of the snowpack and soil moisture to understand how warm atmospheric rivers lead to rapid snowmelt and therefore high river flows. Researchers will assess the underlying meteorological and hydrological processes and landscape variables that are linked to rapid snowmelt in the current model and will quantify the National Water Model's simulation performance for the changes in snowpack. This simulation, and attendant opportunities for improvement, will be informed by machine learning techniques. Finally, and in support of the National Water Model, researchers also will develop a situational awareness tool for the Sierra Nevada and Cascades that could identify potential extreme snowmelt conditions for hydrologic forecasters.

RESEARCH FOCUS AREA 4

Air Quality

In many areas of the country, the public is still exposed to unhealthy levels of air pollutants and sensitive ecosystems are damaged by air pollution. Both wildfires in the West and high surface ozone episodes during heat waves in the East contribute

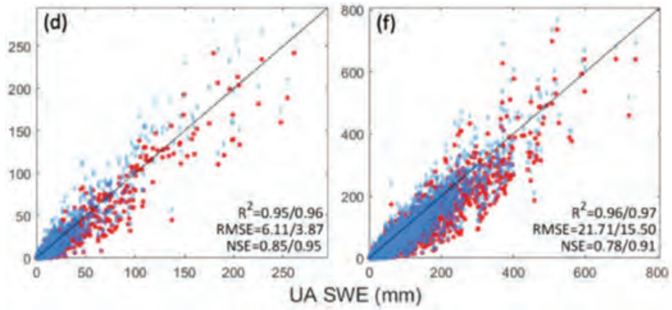

FIGURE 18. Comparison of the NWM model skill in snow water equivalent (SWE) climatology at each 0.125° grid in two USGS HUC2 basins. Also shown in the legends are three model skill scores (correlation, root mean square error, Nash-Sutcliffe efficiency) in the order of TDRY / TWET. Image credit: Wang et al.;[17] Figure 3 used with permission from the publisher.

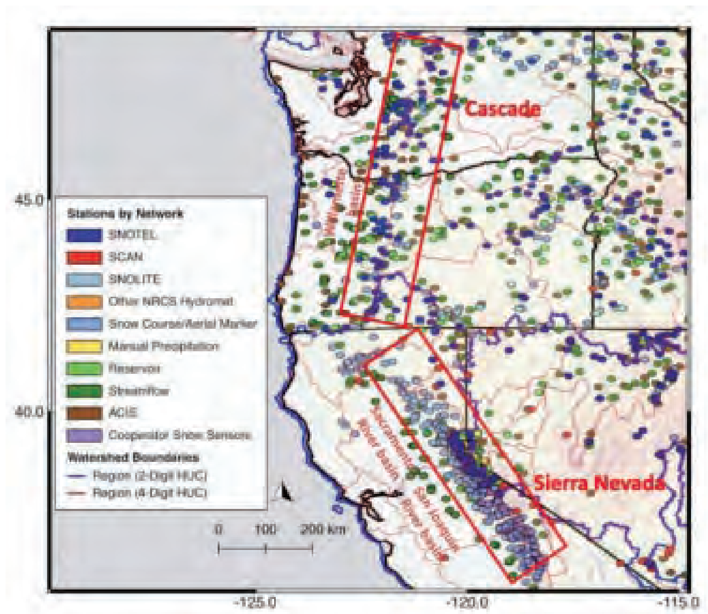

FIGURE 19. Study area, and snow network data (collected by Natural Resources Conservation Service (NRCS)). Image credit: Provided by Martin Ralph per Research Proposal, Figure 1 (2019).

FIGURE 20. Flooding. Credit: NOAA's Center for Operational Oceanographic Products and Services (2019).

to poor air quality. NOAA works with the Environmental Protection Agency, state and local air quality agencies, academia, and the private sector to provide an air quality forecast capability for the nation called the National Air Quality Forecasting Capability.

FY2019 priorities follow:[11]

1. Develop and evaluate high-resolution (1-4 km) air quality forecast capabilities that are consistent with NOAA weather forecast models at these resolutions.
2. Incorporate the Finite Volume Cubed-Sphere Dynamical Core (FV3) model-driven meteorological predictions in the National Air Quality Forecasting Capability with on-line coupling in the near future.
3. Improve spatial and temporal estimates of anthropogenic and natural pollutant emissions.
4. Explore and quantify the potential value of ensemble model approaches and post processing to operational air quality forecasting.
5. Improve model representation in the FV3 model of physical/chemical processes for long-range transport.
6. In each research area, apply and integrate relevant social and behavioral science methodologies to improve forecasters' use of data, techniques, and guidance, as well as end-users' ability to receive, assess, understand, and respond to forecasts and warnings. For additional examples of projects funded by the Social Science Program, **see also Research Focus Area 5 - Social Science**.

In FY2019, approximately 1 out of every 10 projects funded by OWAQ contributed to air quality research priorities, noting that air quality research projects run for three years compared to the typical two years for other research projects.

Improving Air Quality Prediction

Post-Processing of Community Air Quality Multi-scale Model Air Quality Predictions: Research to Operations | Irina Djalalova | NOAA's Earth System Research Laboratory & Cooperative Institute for Research in Environmental Sciences/University of Colorado | See Figure 21

Researchers improved the accuracy of particulate matter (PM2.5) and surface ozone air quality forecasts for the public: Updated ozone post-processing code was delivered to the National Centers for Environmental Prediction (NCEP) that included site-specific weighting of ozone forecasts. In addition, an updated version of the post-processing code that provides improved skill at forecasting extreme events for both ozone and PM2.5 was developed, tested, and evaluated against the NCEP Community Multiscale Air Quality forecasts. Based on this testing, NCEP approved the new ozone post-processing scheme, as well as updates to the PM2.5 scheme, for the next operational model implementation upgrade. By the end of Fiscal Year 2019, the South Coast Air Quality Management District had begun issuing new hourly air quality forecasts that are based on NOAA's bias-correct air-quality predictions developed and implemented operationally, in part, through this research.

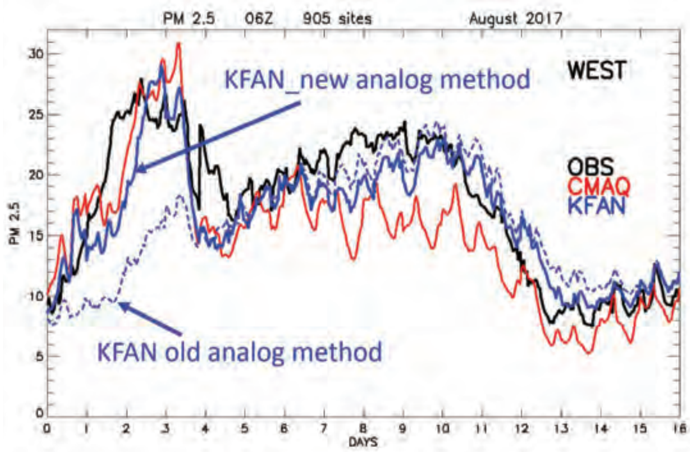

FIGURE 21. This image shows a 16-day time-series of observed and forecast PM2.5, spatially averaged over 905 sites in the western third of the U.S. Early in the time period there were numerous fires burning in Washington and Oregon states and western Canada, leading to high PM2.5 values during the first 5 days of August. Whereas the raw CMAQ forecasts (red line) reached PM2.5 values as high as those observed during this period, the original KFAN method (blue dashed line) predicted values that were much too low, as it did not find a sufficient number of good analogs with high PM2.5 values. In contrast, the new KFAN method modified for extreme events (solid blue line) does a much better job of matching the observed high PM2.5 values. Image credit: Provided by Irina Djalalova.

Increasing Accuracy of Air Quality Forecasting Related to Wildfires

A Novel Method for Improving Fine Particulate Matter Air Quality Forecasts during Wildfires | Rajesh Kumar | National Center for Atmospheric Research | See Figure 22

This research seeks to improve accuracy of the daily fine particulate matter forecasts generated by the Community Multiscale Air Quality (CMAQ) model, which is employed by NOAA's National Air Quality Forecasting Capability (NAQFC), especially during wildfires. The new approach may increase the precision of these forecasts through enhancing initialization of the NAQFC using chemical data assimilation and by producing a long-term forecast archive with refined accuracy that is used to train current post-processing methods. Researchers will then evaluate the resulting air quality forecasting system by comparing it to the U.S. Environmental Protection Agency's AirNOW network and in field campaigns that will statistically examine U.S. wildfires. The product from this research is intended to positively affect public health and air quality decision-making as well as numerical weather prediction through compatibility with the Joint Effort for Data Assimilation Integration (JEDI) framework.

Advancing Scientific Modules in FV3-CMAQ to Improve Operational Forecasting Skill

Towards Optimal Configurations of NAQFC Chemistry and Aerosol Representations | Yang Zhang & Daniel Tong | North Carolina State University & George Mason University | See Figure 23

Researchers propose to test gas-phase chemistry and secondary organic aerosol (SOA) modules in FV3-CMAQ [Community Air Quality Multi-scale Model] v5.3; minimize systematic, persistent time- and region-specific, and gaseous precursor biases; and employ a novel bias reduction method (i.e., M2K3) to enhance the model's accuracy. This research will advance the skill of operational forecasting from local to national levels, and inform the U.S. Environmental Protection Agency's (EPA) CMAQ stakeholders as they determine research priorities.

Advancing Aerosol Forecasting using Data Assimilation

Development of the National Global Data Assimilation Ensemble-based System for Forecasting of Aerosols | Mariusz Pagowski | Cooperative Institute for Research in Environmental Sciences/University of Colorado

Researchers intend to build a global aerosol data assimilation system for purposes of real-time aerosol forecasting at the national level. Given the role of atmospheric aerosols in air pollution, weather and climate, this research aims to enhance estimation of these aerosols through data assimilation. Such progress could contribute to the establishment of aerosol-sensitive physical parameterizations and to the advancement of subseasonal to seasonal (S2S) prediction. Because the aerosol component is one of the six Earth system components of the Next Generation Global Prediction System and the unified modeling system, this research could contribute to each of those endeavors.

Advancing Emission R2O Using a Community Testbed System

NAQFC Community Emission Testbed (NCET): Accelerating Anthropogenic Emission Updates for NAQFC FV3-CMAQ through Community Collaboration | Bok Baek & Daniel Tong | University of North Carolina & George Mason University | See Figure 24

Researchers intend to advance the National Air Quality Forecast Capability (NAQFC) Community Emission Testbed (NCET) to eventually serve as a platform for the emissions community to submit new datasets for use in NAQFC and FV3-chem. The researchers will employ NCET to expedite anthropogenic emission inventory processing and to reduce uncertainties related to wildfire emissions. In addition to producing a community platform for emission modeling, other outcomes include model-ready emission datasets to support NAQFC testing, products for use by emission sector stakeholders, and recommendations for NAQFC deployment.

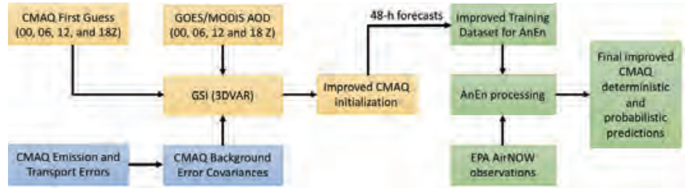

FIGURE 22. Conceptual framework proposed to improve NAQFC PM2.5 forecasts during wildfires. Orange boxes corresponds to the tasks aimed at improving CMAQ PM2.5 deterministic forecasts, blue boxes represent tasks aimed at better representing uncertainties in emissions input to CMAQ, and the green boxes aim to improve the post-processing algorithms currently used by NAQFC to improve accuracy of the forecasts. Image credit: Provided by Rajesh Kumar per Research Proposal, Figure 2 (2019).

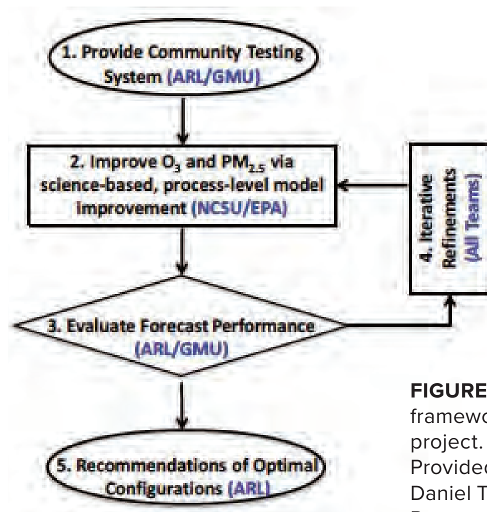

FIGURE 23. Conceptual framework of the proposed project. Image credit: Provided by Yang Zhang and Daniel Tong per Research Proposal, Figure 1 (2019).

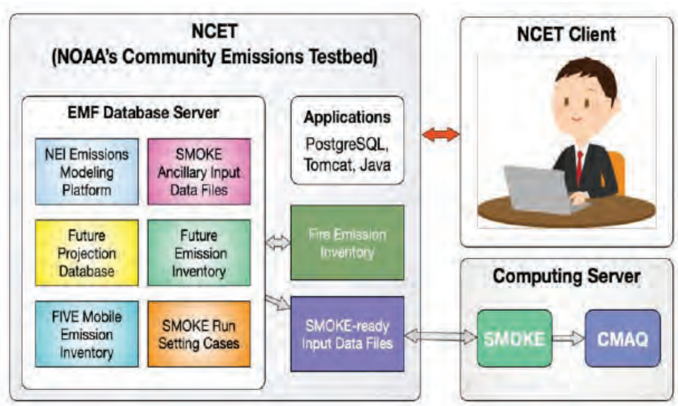

FIGURE 24. NAQFC Community Emission Testbed Flow Diagram based on EMF [Emissions Modeling Framework]. Image credit: Provided by Bok Baek and Daniel Tong per Research Proposal, Figure 1 (2019).

RESEARCH FOCUS AREA 5

Social Science

NOAA must communicate clear and simple weather information that serves the public, which is why social science must inform every aspect of weather forecasting and effective warnings, from effective research practices to communicating uncertainty. OWAQ and partners coordinate social, behavioral, and economic science research needs; determine approaches to translating social, behavioral, and economic science research into application; and learn from the operational community to understand the next research challenges.

FY2019 priorities were informed by OWAQ's goals, especially the goal to improve effective communication of weather information to strengthen decision-making and forecasting ability (OWAQ Goal 1). As noted for each of the preceding research focus areas, this required OWAQ to apply and integrate relevant social and behavioral science methodologies to improve forecasters' use of convection allowing/resolving data, techniques, and guidance, as well as end-users' ability to receive, assess, understand, and respond to forecasts and warnings. Because of that integration of research priorities and funding, approximately 2 out of every 10 projects funded by OWAQ contributed to social science research priorities, among them:

Understanding How the Public Responds to Forecasts and Warnings

Communicating Forecast Uncertainty and Probabilistic Information: Experimenting with Social Observation Data in the Hazardous Weather Testbed | Carol Silva | University of Oklahoma

Researchers seek to improve communication of forecast uncertainty and probabilistic information by building upon the Severe Weather and Society Survey, a new data collection capacity that provides generalizable, longitudinal, and experimental data on how members of the U.S. public receive, understand, and respond to uncertainty and probabilistic information in severe weather forecasts and warnings. Although still in development, current data are available here: https://crcm.shinyapps.io/WxDash/. To ensure a smooth transition from research to operations, researchers will engage with the National Weather Service's Warning Decision Training Division before, during, and after the Hazardous Weather Testbed experiment.

Understanding National Weather Service (NWS) Messaging

Joint Project: Social Media Message Amplification and Attentional Networks | Jeannette Sutton & Carter Butts | University of Kentucky & University of California - Irvine | See Figure 25

This project will identify factors that are predictive of social media message amplification of NWS messages, taking into account hazard type and level of risk. The project combines human and automated coding to identify engagement

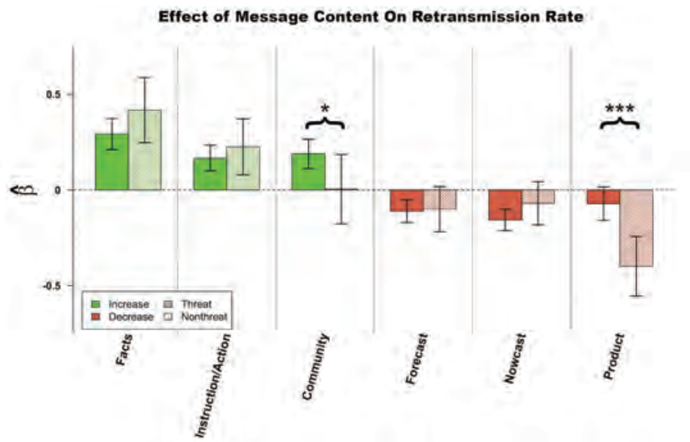

FIGURE 25. Message content features are shown with their corresponding model estimates, which here represent the expected log count of message passing. Green bars indicate features that positively impact message passing while red bars indicate features that negatively impact message passsing. Solid colored bars represent the feature in the nonthreat period while cross-hatched bars represent features during a threat period. Brackets indicate a feature that differs significantly between nonthreat and threat periods, with ***$p \le 0.001$, **$p \le 0.01$, and *$p \le 0.05$. Image credit: From Sutton et al.;[18] used with permission from the © American Meteorological Society.

content (i.e., information, action, and community building) and microstructure (e.g., directed messages, hashtags, and URLs) in NWS messages over time. These variables are modeled to predict which types of content and microstructure lead to message amplification, or retweeting, of NWS tweets during threat and non-threat periods. The findings from this research will lead to recommendations for message-design strategies. This research is particularly important in the context of meteorological hazards, for which alerts and warnings are vital tools in efforts to protect the public.

Assessing the Public's Consumption of Changing Tropical Cyclone (TC) Forecasts over Time

Wait, That Forecast Changed? Assessing How Publics Consume and Process Changing Tropical Cyclone (TC) Forecasts over Time | Gabrielle Wong-Parodi, Rebecca Morss & Leysia Palen | Leland Stanford Junior University

To learn more about how the public consumes and processes tropical cyclone information in the modern information environment, this project will investigate how people at risk process, understand, and use the complex collection of evolving forecast and warning information available during a tropical cyclone threat. This includes examining whether and when members of the public anchor on forecast information and how they shift their risk perceptions as updated forecast information emerges.

Improving Websites by Studying the Use of Tropical Cyclone (TC) Information

Optimizing TC Information: A NOAA Hurricane Website User Experience Study from a Public Perspective | Scott Miles | University of Washington | See Figure 26

The goal of this project is to improve the public's experiences when using the National Hurricane Center's (NHC) website

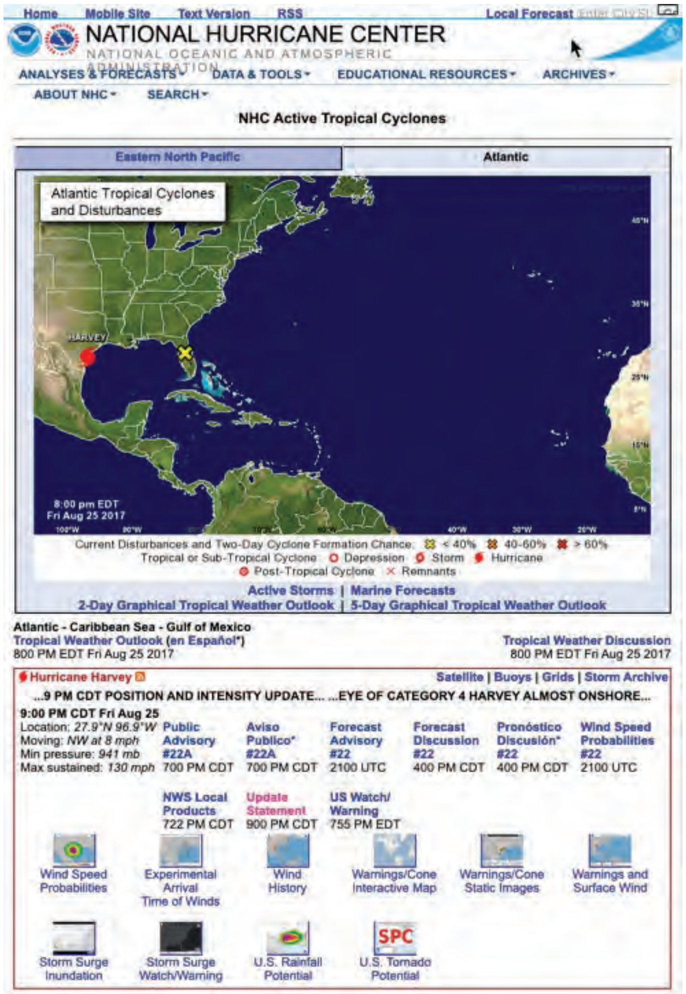

FIGURE 26. Screenshot of National Hurricane Center website on August 25th, 2017. Image credit: NOAA's National Hurricane Center.

to access useful information during a tropical cyclone event. The project will characterize the public's information needs for making related decisions and determine best practices for presenting such information using web design. Results of this project will include a range of webpage design prototypes that improve upon relevant portions of the NHC website, as well as recommendations for implementing these prototypes.

Improving Products by Evaluating Information Needs

Minding the Gap: Modernizing the Tropical Cyclone (TC) Product Suite by Evaluating National Weather Service Partner Information Needs | Rebecca Morss & Ann Bostrom | University Center for Atmospheric Research

How well are tropical cyclone forecast and warning products meeting the needs of our core partners? This project will investigate whether tropical cyclone products are currently meeting the needs of emergency managers and broadcast meteorologists and how the product suite could be improved to better meet partner needs. The project will build understanding about NWS partners' information needs for decision making and the utility of the current tropical cyclone product suite. It will also assess key information gaps in the product suite, in general, and with respect to potential new products being considered, in particular.

Improving Tropical Cyclone (TC) Products by Assessing Numeracy Skills

There's a Chance of What? Assessing Numeracy Skills of Forecasters, Partners, and Publics to Improve TC Product Uncertainty Communication, Impact-based Decision Support Services, and Training | Joseph Ripberger, Carol Silva, Hank Jenkins-Smith & Edward Cokely | University of Oklahoma

Researchers intend to conduct a baseline assessment of forecaster, NOAA's National Weather Service core partners, and the public's understanding of probabilities (or "numeracy") related to tropical cyclone hazards. This project will focus on the ways in which probabilities and their respective reference class enable forecasters, NWS core partners, and the public as they assess their risk.

RESEARCH FOCUS AREA 6

Additional Interdisciplinary Research

Interdisciplinary research is integrating knowledge and methods from different disciplines and synthesizing approaches. OWAQ interdisciplinary themes include, but are not limited to:

Data and models, including Weather-Water-Climate initiatives. Programs such as the Joint Hurricane Testbed, Hydrometeorology Testbed, and Joint Technology Transfer Initiative support development, testing, and evaluation of mature research that has the potential for improving NWS operational capabilities, particularly in the areas of advancing numerical weather prediction capabilities that seamlessly integrate in the NOAA UFS, water prediction capabilities, and forecasting extreme precipitation and flooding events.

Earth Prediction Innovation Center (EPIC). Consistent with legislative and executive mandates, OWAQ is leading the development of EPIC and the associated scientific workspace that will change the way community integrated environmental modeling is achieved in the U.S. In the near term, EPIC will facilitate improvements in the Unified Forecast System (UFS), which is defined as shared science components and software infrastructure for extreme weather forecasting. In the long-term, EPIC will facilitate community integrated environmental modeling across all phenomenon and time scales. For sample projects inspired by EPIC, **see Research Focus Area 2 - Hazardous Weather**.

FIGURE 27. Ominous wall cloud portending possible violent weather. Credit: Jerry Penry, Registered Land Surveyor (2010).

Forecasting a Continuum of Environmental Threats (FACETs). FACETs supports multiple-hazard research across severe weather, tropical cyclones, precipitation extremes, air quality, flash flooding, hydroclimate extremes, and other hazards. Consistent with NOAA's Weather-Ready Nation initiative to build community resilience, FACETs is a natural hazard forecasting framework that seeks societal benefit through the forecasting and communication of probabilistic hazardous weather, water, and climate information.

National Earth System Prediction Capability (ESPC). NOAA and other federal agencies collaborate within the National ESPC to establish a global prediction system. The National ESPC will improve environmental predictions and help decision makers address critical planning and policy issues by extending the national predictive capability from hours and days to seasonal, annual, and decadal time periods through improved, coupled global environmental prediction.

Subseasonal-to-Seasonal (S2S), including infrastructure support. For S2S, research focuses on baseline understanding of predictability; advancement of community-driven NOAA modeling initiatives; and increasing the utility of multi-model ensembles for end users. FY2019 priorities included improved data assimilation and incorporation of new observation types for individual Earth components; community-based approaches to improving Earth system models; and improving existing ensembles to improve prediction skill and assessments of uncertainty. Together, these begin to fulfill the S2S (two weeks out to two years) requirements of the Weather Research and Forecasting Innovation Act of 2017 while emphasizing the models and components in NOAA's Unified Forecast System (UFS), the North American Multi-Model Ensemble, and ongoing multi-model ensemble efforts on the S2S timescale (e.g., the continuation of the Subseasonal Experiment and support to the S2S datasets at the International Research Institute for Climate and Society's Data Library).

FY2019 interdisciplinary research priorities follow:[11]

1. Identify and validate via quasi-operational testbed demonstrations new high temporal and spatial resolution in-situ and remotely-sensed observation datasets and

dynamically consistent 3-D objective data-analysis techniques to provide the best state of the current environment.
2. Apply and integrate relevant social and behavioral science methodologies into the above testbed priority areas to improve forecasters' use of convection-allowing/resolving data, techniques, and guidance.
3. Apply and integrate relevant social and behavioral science methodologies to improve forecasters' use of convection-allowing/resolving data, techniques, and guidance, as well as end-users' ability to receive, assess, understand, and respond to forecasts and warnings.

In FY2019, approximately 1 out of every 10 projects funded by OWAQ contributed to interdisciplinary research priorities.

Expanding the National Earth System Prediction Capability

Preliminary Steps toward a National Ocean Modeling Capability in Support of the National Earth System Prediction Capability - Phase III | Robert Hallberg & Eric Chassignet | NOAA's Geophysical Fluid Dynamics Laboratory & Florida State University | See Figure 28

The National Earth System Prediction Capability effort seeks to provide improved environmental prediction capabilities for the entire earth climate system on timescales of hours out to thirty years and this requires an advanced global ocean modeling capability. The Modular Ocean Model (MOM6) is being used already by NOAA's Geophysical Fluid Dynamics Laboratory and the National Center for Atmospheric Research for climate projections and by NOAA's National Centers for Environmental Prediction for coupled forecasts. Because MOM6 already incorporates elements of the HYbrid Coordinate Ocean Model (HYCOM) such as C-grid spatial discretization (appropriate at higher resolutions) and the Arbitrary Lagrangian-Eulerian approach to the vertical discretization, researchers are investigating the options for incorporating additional capabilities from HYCOM to become the basis for a unified national large-scale ocean model codebase.

Improving the Prediction of Daily Extremes

A Hybrid Statistical-Dynamical System for the Seamless Prediction of Daily Extremes and S2S Climate Variability | Dan Collins | NOAA's Climate Prediction Center

A critical predictability gap exists for S2S prediction due to the weak influence of initial conditions and the weak signals from larger-scale boundary forcings. By leveraging and combining methods that demonstrate skill at short and long lead times, this project intended to improve the skill of subseasonal forecasts and the skill of predicting daily temperature and precipitation extremes within a seasonal forecast period. By the end of FY2019, and in support of NOAA's Climate Prediction Center's week 3-4 outlook, researchers had implemented an experimental, calibrated multi-model ensemble, subseasonal temperature forecast using Bayesian Joint Probability modeling.

Improving S2S Predictions with Improved MJO Predictions

A New Technique for Improved MJO Prediction | Chidong Zhang & Wanqiu Wang | NOAA's Pacific Marine Environmental Laboratory & NOAA's Climate Prediction Center | See Figure 29

This project seeks to improve Madden-Julian Oscillation (MJO) predictions by tracking the eastward motion of large-scale precipitation anomalies along the equator. This provides accurate definition of parameters such as longitude and time of the initiation and termination; speed and range of the propagation; life span and mean strength; and intervals of neighboring events. This new approach affects both monitoring of MJO events and measuring the prediction skill. This will be applied first in the Climate Forecast System and, if it meets objective standards, also could be expanded to the S2S prediction products or the North American Multi-Model Ensemble. By the end of FY2019, an algorithm for tracking MJO precipitation had been implemented by a Pacific Marine Environmental Laboratory and National Centers for Environmental Prediction team for real-time validation of MJO prediction.

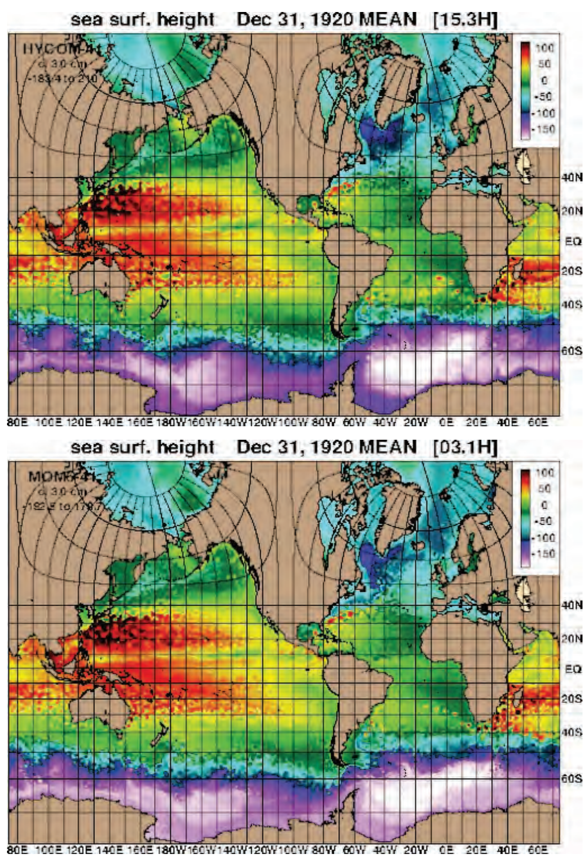

FIGURE 28. Sea surface height (cm) snapshot after 10 model years for twin global 1/12 degree simulations with HYCOM (top left) and MOM6 (bottom right). HYCOM and MOM6 have very similar capabilities. Image credit: Provided by Robert Hallberg and Eric Chassignet.

Improving S2S Predictions by Predicting Atmospheric Rivers and Impacts

Skillfully Predicting Atmospheric Rivers and Their Impacts in Weeks 2-5 Based on the State of the Madden-Julian Oscillation (MJO) and Quasi-Biennial Oscillation (QBO) | Elizabeth Barnes | Colorado State University

This project will examine and transition Mundhenk et al.'s[14] methodology for predicting atmospheric river frequencies and precipitation at two-to-five weeks. After transitioning the atmospheric frequency forecast tool into operations at NOAA's Climate Prediction Center, researchers intend to refine and extend the methodology; leverage additional predictors (e.g., dynamical Madden-Julian oscillation (MJO) forecasts) with the intent of producing skillful forecasts beyond Week 5. By the end of FY2019, researchers were successfully developing an empirical prediction model based on the MJO and the quasi-biennial oscillation (QBO) with the intention of producing skillful forecasts of precipitation at leads of up to six weeks during all seasons and for many regions across the U.S.

Using Unmanned Aircraft to Improve Observations

Toward Obtaining Daily Vertical Profiles of Boundary Layer Temperature and Moisture Fields using Small Unmanned Aircraft Systems | Temple Lee & Bruce Baker | University of Oklahoma/Cooperative Institute for Mesoscale Meteorological Studies & the Army's Research Laboratory | See FIgure 30

Researchers will use small Unmanned Aircraft Systems (sUAS) to gather information about temperature, moisture, pressure, and wind up to one kilometer above ground level and will provide this information consistently to the National Weather Service's (NWS) Weather Forecast Office (WFO) in Morristown, Tennessee to support improvements to forecasting thunderstorms, wind, and other mesoscale phenomena. The data from the sUAS will also be used to validate and improve operational models such as the High-Resolution Rapid Refresh (HRRR). Improvements in forecast products at the Morristown, Tennessee WFO also may inform improvements in forecast products at other WFOs.

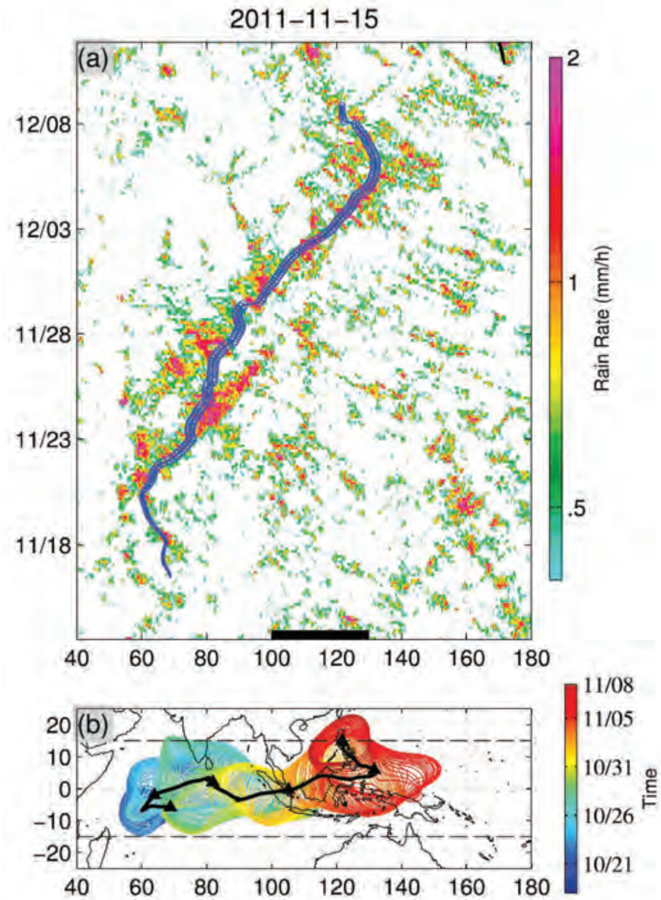

FIGURE 29. Example of tracking MJO large-scale precipitation: (a) Time- longitude diagram of TRMM precipitation with tracked large-scale precipitation centroids marked by blue circles. (b) Tracked large-scale precipitation (contours) with colors representing the time and black line their centroids. Image credit: Kerns and Chen[19] and used with permission from the publisher.

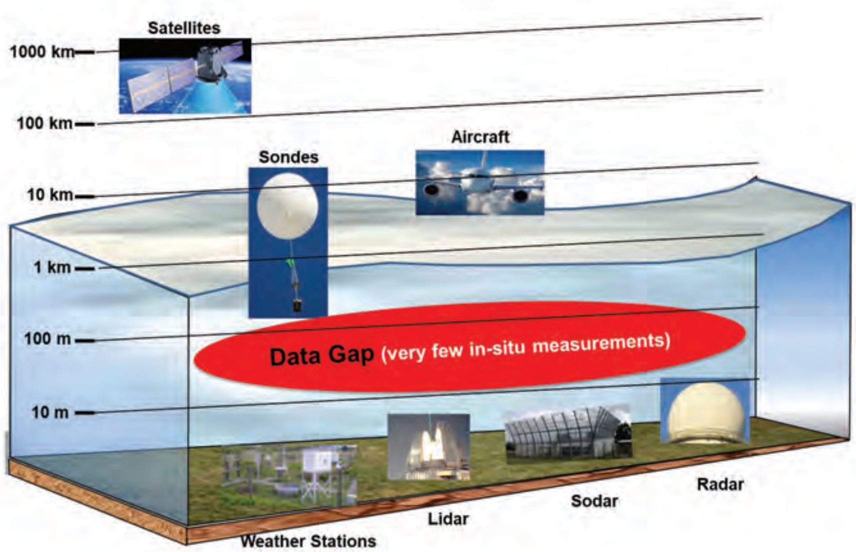

FIGURE 30. Observational data gap in the atmosphere for which small Unmanned Aircraft System can improve sampling. Image credit: Provided by Temple Lee and Bruce Baker.

The Way Forward

Fulfilling the office's vision while meeting the needs of a Weather-Ready Nation requires ongoing innovation and a holistic view of the office's performance and our partners' needs. OWAQ delivered as promised in FY2019 and is ready to deliver again in FY2020. Priorities by research focus area and goals for FY2020 (as of October 2019) include, but are not limited to, the following:[15]

Research Focus Areas.

- Develop improved methods for incorporating data into forecast modeling and for model coupling to improve weather forecasting operations.
- Test the coupled (subhourly to subseasonal timescale) UFS.
- Improve forecasts of extreme weather and high-impact weather events.
- Understand and reduce societal vulnerability to tornadoes.
- Research operational NWS and partners' forecast and warning decision-making process and public response.
- Risk communication, risk perception, and information use in protective decision-making.
- Model post-processing via innovative statistical techniques and the use of Artificial Intelligence (AI)/Machine Learning (ML) methods.
- Accelerate the S2S portion of the UFS.
- Enhance to data assimilation systems that support climate monitoring and prediction.

Goal 1. OWAQ will continue to improve effective communication of weather information to strengthen decision-making and forecasting abilities by:

- **Objectives.** Enhancing the integration of social, behavioral, and economic science (SBES) into weather research and development (Objective 1.1) and, in turn, integrated SBES findings into weather enterprise applications (Objective 1.2).
- **Reports and publications.** Via reports, webinars, and research manuscripts, sharing workshop findings and recommendations, especially from the Social and Behavioral Sciences (SBS) Research-to-Operations (R2O) Workshop. Informed by the SBS R2O Workshop findings and recommendations, producing a work plan.
- **Communications.** Clarifying and expanding the information and resources at http://owaq.noaa.gov and enhancing the office's social media outreach.
- **Events.** Hosting conversations between and among the various Social, Behavioral, and Economic (SBE) researchers throughout NOAA, including representatives from the Chief Economist's Office. Representing NOAA at interagency SBE planning and collaboration meetings. Convening sponsored sessions at national professional conferences, especially for the National Earth System Prediction Capability (ESPC), S2S, SBS, and the Weather Act.

Goal 2. OWAQ will continue to advance models and forecast tools to produce the best weather forecasts and warnings to build a Weather-Ready Nation with an overall focus on improving model physics, developing enhanced hazard mitigation strategies, accelerating the development of capabilities, and incorporating evaluation by:

- **Objectives.** Advancing the development and implementation of the UFS (Objective 2.1), advancing S2S forecasts (Objective 2.2), and improve severe weather prediction capability (Objective 2.3).
- **UFS and EPIC.** Testing for the coupled (hourly to sub-seasonal time scales) UFS. Leveraging high-performance computing resources and machine learning techniques, which includes developing EPIC as a true community-sourced modeling framework and leveraging cloud-computing resources. Published the EPIC FY2020 request for proposals and the report on the EPIC workshop. Leveraging the Cloud to advance models and forecast tools, beginning with a workshop and strategy.
- **S2S.** Developing and maturating the S2S portions of the UFS, with specifics in the Strategic Implementation Plan Emphasis areas.
- **Severe weather.** Improving forecasts of extreme weather and high-impact weather events. Developing improved methods for incorporating data into forecast modeling and for model coupling to improve weather forecasting operations. As requested by the National Severe Storms Laboratory, continuing to support VORTEX-SE and tornado research funding.
- **Air quality.** Continuing to fund improved air quality research and forecasting, especially to improve the NOAA operational forecast for fine particulate matter (PM2.5) and ozone predictions include improving emissions from sources such as wildfire smoke and dust as well as chemical mechanisms.
- **FACETs.** Coordinating with the FACETs program to inform program initiatives and objectives.
- **ESPC.** Hosting the Executive Steering Group Meetings of the National Earth System Prediction Capability (ESPC).
- **Reviewing.** Conducting semi-annual reviews of each OWAQ-funded project. Updating programmatic objectives and science priorities for the FY2021 competition(s). Conducting site visits to NOAA laboratory partners, including visits for FACETs program expansion. Conducting annual U.S. Weather Research Program testbed progress reviews.
- **Tropical Social Science**. Reviewing emergent Tropical Social Science research findings in partnership with NOAA's Atlantic Oceanographic and Meteorological Laboratory and the NWS Tropical Program to work toward a social science transition plan.

Goal 3. To effectively and efficiently manage the advancement and transition of weather research into societal applications, OWAQ will focus on applied research, development, and, in particular, the demonstration and testing of that research in

NOAA's quasi-operational forecasting environment by:

- **Objectives.** Advancing the transition from research to operations (Objective 3.1) while ensuring operations and processes are well-documented (Objective 3.2) and while responding to Congressional mandates (Objective 3.3).
- **Research to operations.** Facilitating the transitions of research to societal application, usually via NOAA's NWS.
- **Operations and processes.** Publishing the EPIC program formulation strategy and the communications strategy documents. Sharing OWAQ research via NOAA's Research and Development Database.
- **Congressional mandates.** Presenting to NOAA's Science Advisory Board's Environmental Information Systems Working Group the activities in support of the Weather Act. In coordination with the Federal Coordinator for Meteorology, drafting the U.S. Weather Research Program Implementation Plan.
- **Overall.** Maturating and implementing data assimilation (DA), monitoring products, and data quality control (QC). Post-processing, diagnostic and verification tools, and innovative statistical techniques leading to improvement of S2S operational predictions. Modeling post-processing via innovative statistical techniques and applications of existing statistical techniques, including Artificial Intelligence (AI)/Machine Learning (ML) methods. Enhancing data assimilation systems to support climate monitoring and prediction, specifically related to ocean, sea ice, and land data assimilation using the Joint Effort for Data-Assimilation Integration.

Goal 4. To develop and support a diverse and inclusive work environment that promotes equal access to the opportunities OWAQ offers, OWAQ will continue to assemble a workforce that understands and responds to OWAQ's partners and stakeholders. Workforce diversity also will ensure that the interdisciplinary demands for weather research and development expertise are continuously met while building a work environment that encourages open communication, provides fair and equitable opportunities, and empowers employees with the resources and support they need to advance and support our mission of science, service, and stewardship. In support of the overall diversity of the weather enterprise, OWAQ will continue to strengthen engagement with underrepresented groups, particularly with NOAA's Cooperative Science Centers, Historically-Black Colleges and Universities, Hispanic-Serving Institutions, and Tribal Colleges and Universities by:

- **Objectives.** Recruiting and maintaining a diverse and highly qualified workforce (Objective 4.1); promoting and enhancing the inclusion of OWAQ's diverse workforce (Objective 4.2); and integrating and promoting diversity and inclusion as a core consideration throughout OWAQ's funding mechanisms.
- **Recruiting and maintaining.** Continuing to recruit and maintain a diverse and highly qualified workforce.
- **Promoting and enhancing.** Continuing to promote and enhance the inclusion of OWAQ's diverse workforce.
- **Integrating and promoting.** Continuing to integrate and promote diversity and inclusion as a core consideration.
- **Informing.** Publishing informational and accessible handouts on each of OWAQ's programs.
- **Evaluating.** Identifying gaps and suggesting methods to improve outreach, diversity, and inclusion relative to OWAQ-funded projects.

FIGURE 31. VORTEX2 field command vehicle in vicinity of thunderstorm. Credit: Mike Coniglio, NOAA's National Severe Storms Laboratory (2009).

Conclusion

Weather is inevitable. Weather forecasts, however, are ever-improving because of OWAQ's prioritized, sustained investments in weather and air quality research. Consistent with our strategic plan and aligned with the OAR strategic plan and our partners' priorities, we will fulfill our vision of a Weather-Ready Nation informed by world-class weather research.

Visit https://owaq.noaa.gov for funding opportunities, student and teacher resources, publications produced by this research, and more.

Research Projects

Below, find the list of research projects that were active in FY2019. denotes projects with signed transition plans per the FY2019 Annual Operating Plan Metric Tracker. For a list of publications and presentations related to this research, visit https://owaq.noaa.gov.

2019 - 2020 Airborne Phased Array Radar (APAR) | Lead PI(s) Vanda Grubišić | National Center for Atmospheric Research | 10/1/18 - 9/30/2020

2020 Airborne Phased Array Radar Preliminary Design and Risk Mitigation | Lead PI(s) Vanda Grubišić | National Center for Atmospheric Research | 9/1/19 - 8/31/2021

Accelerated Implementation, Testing and Evaluation of Optimized Radar Data Assimilation Capabilities within Ensemble-Variational Hybrid GSI for the NOAA Convection-allowing rapidly updated Forecasting System | Lead PI(s) Youngsun Jung, Jeffrey Duda | University of Oklahoma - Center for Analysis and Prediction of Storms, University of Colorado - Cooperative Institute for Research in Environmental Sciences and ESRL/GSD | 10/01/2018 - 09/30/2020

Accelerating the UFS Evaluation Capability | Lead PI(s) Ivanka Stajner and Geoff Manikin, Tara Jensen | EMC, NCAR RAL | 06/15/2019 - 06/14/2020

Accounting for non-Gaussianity in the Background Error Distributions Associated with Cloud-Related Variables (Microwave Radiances and Hydrometeors) in Hybrid Data Assimilation for Convective-Scale Prediction | Lead PI(s) Karina Apodaca | Colorado State University | 10/01/2016 - 09/30/2019

Adding TC Genesis Verification Capabilities to the Model Evaluation Tools - TC Software | Lead PI(s) Daniel Halperin | Embry-Riddle | 09/01/2018 - 08/31/2020

Advancing ADCIRC U.S. Atlantic and Gulf Coast Grids and Capabilities to Facilitate Coupling to the National Water Model in ESTOFS Operational Forecasting | Lead PI(s) Joannes Westerink | University of Notre Dame | 10/01/2018 - 09/30/2020

Advancing Forecast Verification Efforts for Unified Forecast System Advanced Physics Testing using Spatial Verification Methods | Lead PI(s) Jason Otkin, Tara Jensen, Patrick Skinner | University of Wisconsin-Cooperative Institute for Meteorological Satellite Studies, National Center for Atmospheric Research, University of Oklahoma - Cooperative Institute for Mesoscale Meteorological Studies | 09/01/2019 - 08/31/2021

Advancing Frequently-Updating Storm-Scale Ensemble Data Assimilation and Prediction towards Operations | Lead PI(s) Curtis Alexander | OAR/ESRL/GSD | 07/01/2018 - 06/30/2021

Advancing Probabilistic Prediction of High-Impact Winter Storms through Ensemble NWP and Post-Processing | Lead PI(s) Justin Minder, James Steenburgh | SUNY Albany, University of Utah | 07/01/2019 - 06/30/2022

Advancing the Direct Assimilation of Radar Observations to Improve Convective Scale Numerical Weather Prediction through Optimizing the Combined Use of Static and Ensemble Covariances, the Additive Perturbations, and the Assimilation Frequency in the Hybrid EnVar and through Integration with JEDI | Lead PI(s) Xuguang Wang | University of Oklahoma | 09/01/2019 - 08/31/2021

Airborne Phased Array Radar (APAR) Development and Risk Mitigation Project | Lead PI(s) Vanda Grubišić | National Center for Atmospheric Research | 10/01/2017 - 03/31/2019

Airborne Snow Depth Retrieval for Improved Hydrological Modeling | Lead PI(s) Emily Arnold | University of Kansas | 09/01/2019 - 08/31/2021

An Examination of the State of Knowledge on Risk Perceptions and Understanding Response to Uncertainty Information | Lead PI(s) Terri Adams | Howard University | 08/01/2017 - 07/31/2018

Assessing Increased Vulnerability Knowledge and High Temporal Resolution Guidance on Forecaster and Emergency Manager Decision Making | Lead PI(s) Jack Friedman, Daphne LaDue | University of Oklahoma | 07/01/2019 - 06/30/2022

Assessing the Impact of Assimilating Ground-Based Infrared Radiometer Data into Convective-Scale Numerical Weather Prediction Models | Lead PI(s) Timothy Wagner | University of Wisconsin-Cooperative Institute for Meteorological Satellite Studies | 10/01/2016 - 09/30/2019

Assessing the Impact of Stochastic Cloud Microphysics in Convection-Resolving Models using GOES-R Satellite Observations | Lead PI(s) Jason Otkin, Gregory Thompson, Fanyou Kong | University of Wisconsin-Cooperative Institute for Meteorological Satellite Studies, National Center for Atmospheric Research, University of Oklahoma | 08/01/2017 - 07/31/2020

Assessment and Calibration of Extreme Precipitation Probabilities in S2S Forecast Models | Lead PI(s) Chiara Lepore | Columbia University-LDEO | 09/01/2019 - 08/31/2022

Assessment of Hydrologic Forecasts Generated using Multi-Model and Multi-Precipitation Product Forcing | Lead PI(s) Witold Krajewski | University of Iowa | 07/01/2017 - 07/31/2019

Assimilating Novel WSR-88D and GOES-16 Observations to Improve Convection-Allowing Model Forecasts of Convection Initiation and Severe Weather | Lead PI(s) David Stensrud | Pennsylvania State University | 10/01/2018 - 09/30/2020

Assimilation of Lake and Reservoir Levels into the WRF-Hydro National Water Model to Improve Operational Hydrologic Predictions | Lead PI(s) David Gochis, Allen Burton, Lynn Johnson | University Corporation for Atmospheric Research, Great Lakes Environmental Research Laboratory (GLERL), Colorado State University-Cooperative Institute for Research in the Atmosphere | 10/01/2016 - 09/30/2019

Assimilation of Remote Sensing Observations into Convective-scale NWP to Improve 0-6 h Probabilistic Forecasts of High Impact Weather | Lead PI(s) Nusrat Yussouf | Cooperative Institute for Mesoscale Meteorological Studies | 10/01/2016 - 09/30/2019

Benefits of Stochastic Parameterization on the Sub-Seasonal to Seasonal Timescales in Hindcasts with CESM and UFS | Lead PI(s) Judith Berner, Philip Pegion | UCAR/CGD, CU-CIRES/PSD | 09/01/2019 - 08/31/2022

Calibration of Channel Properties to Improve Streamflow Estimates in the National Water Model | Lead PI(s) Toby Minear | University of Colorado | 10/01/2018 - 09/30/2020

Communicating Forecast Uncertainty and Probabilistic Information: Experimenting with Social Observation Data in the Hazardous Weather Testbed | Lead PI(s) Carol Silva | University of Oklahoma | 10/01/2018 - 09/30/2020

Comparison of Model versus Observationally-Driven Water Vapor Profiles for Forecasting Heavy Precipitation Events | Lead PI(s) John Forsythe | Colorado State University-Cooperative Institute for Research in the Atmosphere | 07/01/2017 - 06/30/2020

Continuation of the North American Multi-Model Ensemble (NMME Phase-2): Development, Operation and Seasonal Prediction Science | Lead PI(s) Ben Kirtman, Andrew Robertson | University of Miami, Columbia University | 10/01/2018 - 09/30/2020

Convection-Allowing Ensemble Prediction for Heavy Precipitation in Support of the Hydrometeorology Testbed (HMT): New QPF Products, Data Assimilation Techniques and Prediction Model | Lead PI(s) Ming Xue | University of Oklahoma | 07/01/2017 - 06/30/2019

Coupled Ensemble Prediction and Data Assimilation for UFS | Lead PI(s) Jeffrey S. Whitaker, Thomas Hamill | ESRL/PSD | 07/01/2019 - 06/30/2020

Coupling Infrastructure Integration and User Support for UFS | Lead PI(s) Cecelia DeLuca | GSD/CIRES | 05/01/2019 - 04/30/2020

Critical Steps toward a National Ocean Modeling Capability in Support of the National Earth System Prediction Capability – Phase II | Lead PI(s) Hallberg, Robert | GFDL | 10/01/2018 - 09/30/2019

Demonstration of a Rapid Update Convection-Permitting Ensemble Forecast System to Improve Flash Flood and Winter Weather Prediction | Lead PI(s) Glen Romine | National Center for Atmospheric Research | 07/01/2017 - 06/30/2020

Demonstration of a Rapid Update Convection-Permitting Ensemble Forecast System to Improve Hazardous Weather Prediction | Lead PI(s) Glen Romine | National Center for Atmospheric Research | 07/01/2017 - 06/30/2020

Developing a Unified Online Air Quality Forecasting System Based on CMAQ and NGGPS | Lead PI(s) Georg Grell | NOAA/OAR/ESRL | 06/01/2016 - 05/31/2020

Developing an Objective Evaluation Scorecard for Storm-Scale Prediction | Lead PI(s) Tara Jensen | National Center for Atmospheric Research | 07/01/2017 - 06/30/2020

Developing and Evaluating GSI-based EnKF-Variational Hybrid Data Assimilation for NCEP NAMRR to Improve Convection-Allowing Hazardous Weather Forecast | Lead PI(s) Xuguang Wang | University of Oklahoma | 09/01/2015 - 08/31/2019

Developing New Capabilities and Research Applications for the National Water Model Over the Southeastern United States | Lead PI(s) Jamie Dyer, Andrew Mercer | Mississippi State University | 9/1/2019 - 8/31/2021

Development and Evaluation of Extended Range Ensemble Streamflow and Water Resources Forecast Products for the National Water Model | Lead PI(s) Andrew Wood, Bart Nijssen | National Center for Atmospheric Research, University of Washington | 10/01/2018 - 09/30/2020

Development and Evaluation of New Statistical Calibration Methods for Multi-Model Ensemble Weeks 3-4 Probabilistic Forecasts | Lead PI(s) Nicolas Vigaud | Columbia University | 09/01/2018 - 08/31/2020

Development and Implementation of Probabilistic Hail Forecast Products using Multi-Moment Microphysics and Machine Learning Algorithms | Lead PI(s) Nathan Snook | The University of Oklahoma | 10/01/2016 - 09/30/2019

Development and NWS Forecaster Evaluation of a Convective-scale Ensemble System for Probabilistic Heavy Rainfall and Severe Weather Forecasts | Lead PI(s) Nusrat Yussouf, Michael Erickson | Cooperative Institute for Mesoscale Meteorological Studies, Cooperative Institute for Research in Environmental Sciences | 10/01/2018 - 09/30/2020

Development and Optimization of Radar-Assimilating Ensemble-Based Data Assimilation for Storm-Scale Ensemble Prediction in Support of HWT Spring Experiments | Lead PI(s) Ming Xue | University of Oklahoma - Center for Analysis and Prediction of Storms | 07/01/2017 - 06/30/2019

Development and Testing of a GSI-based Multi-Scale EnKF System for Convection-Allowing Stand-Alone Regional FV3 | Lead PI(s) Youngsun Jung, Ming Xue | University of Oklahoma | 09/01/2019 - 08/31/2021

Development and Testing of Displacement Data Assimilation | Lead PI(s) Thomas Nehrkorn | AER | 10/01/2018 - 09/30/2020

Development of a Multigrid Background Error Covariance Model for High Resolution Data Assimilation | Lead PI(s) Jacob Carley (EMC) | EMC | 06/01/2019 - 05/31/2020

Development of NWS Convective Scale Ensemble Forecasting Capability through Improving GSI-Based Hybrid Ensemble-Variational Data Assimilation and Evaluating the Multi-Dynamic Core Approach | Lead PI(s) Xuguang Wang | The University of Oklahoma | 10/01/2016 - 09/30/2019

Development of Process-Level Parameterizations of Model Uncertainty in the GFS/GEFS | Lead PI(s) Jeffrey S. Whitaker (ESRL/PSD) and Jian-Wen Bao (ESRL/PSD) | ESRL/PSD | 09/01/2019 - 08/31/2020

Development of the National Global Data Assimilation Ensemble-based System for Forecasting of Aerosols | Lead PI(s) Mariusz Pagowski | CIRES-University of Colorado | 06/01/2019 - 05/31/2022

Diagnosing and Improving Unified Forecast System Precipitation through Observationally Constrained Stochastic Parameterizations | Lead PI(s) Prashant Sardeshmukh | CURES-University of Colorado | 09/01/2019 - 08/31/2022

Diode-Laser-Based Remote Sensing for Thermodynamic Profiling of the Lower Troposphere | Lead PI(s) Kevin Repasky, Scott Spuler | Montana State University, National Center for Atmospheric Research | 09/01/2019 - 08/31/2021

Enabling Effective Use of Deterministic-to-Probabilistic Precipitation Forecasts for Heavy and Extreme Events | Lead PI(s) Tara Jensen | National Center for Atmospheric Research | 07/01/2017 - 06/30/2020

End User Understanding of Uncertainty in Higher Spatial and Temporal Hazardous Weather Forecasts | Lead PI(s) Daphne LaDue | University of Oklahoma | 09/01/2019 - 08/31/2021

Enhanced Multi-Radar Multi-Sensor Dual-Polarization Radar Synthetic QPE | Lead PI(s) Stephen Cocks | University of Oklahoma - Cooperative Institute for Mesoscale Meteorological Studies | 09/01/2019 - 08/31/2021

Enhanced Tools for High-Resolution Ensemble Development and Verification | Lead PI(s) Glen Romine | National Center for Atmospheric Research, ESRL/GSD | 09/01/2019 - 08/31/2021

Enhancing CAM Ensemble Forecast System and Improving Ensemble Forecast Products in Support of HMT Winter Weather and Heavy Precipitation Forecasting | Lead PI(s) Keith Brewster | University of Oklahoma | 07/01/2019 - 06/30/2022

Enhancing Observations of Melting Level to Support Forecasts of Rain-Snow Partitioning in the Sierra Nevada | Lead PI(s) Fred Ralph, Andrew Martin | Scripps Institute, UCSD, Portland State University | 09/01/2019 - 08/31/2021

Enhancing the Development of Land Models as a Full Component of the Coupled System | Lead PI(s) Jack Kain (EMC) | EMC @GFDL | 07/01/2019 - 06/30/2021

Enhancing the Prediction of Landfalling Hurricanes through Improved Data Assimilation with the GSI-Based Ensemble-Variational Hybrid System and JEDI | Lead PI(s) Zhaoxia Pu | University of Utah, University of Miami | 09/01/2019 - 08/31/2021

Enhancing the Variational Bias Correction Method to Support the Assimilation of Satellite All-Sky Infrared Brightness Temperatures | Lead PI(s) Jason Otkin | University of Wisconsin-Cooperative Institute for Meteorological Satellite Studies | 09/01/2019 - 08/31/2021

Ensemble Prediction and Predictability of Extreme Weather via Circulation Regimes | Lead PI(s) David Straus, Kathleen Pegion, Stephen Baxter | George Mason University | 09/01/2019 - 08/31/2022

Ensemble-based Pre-genesis Watches and Warnings for Atlantic and North Pacific Tropical Cyclones | Lead PI(s) Russel Elsberry | University of Colorado-Colorado Springs | 07/01/2017 - 06/30/2020

Estimating Inundation Extent and Depth from National Water Model Outputs and High Resolution Topographic Data | Lead PI(s) Paola Passalacqua | University of Texas-Austin | 09/01/2019 - 08/31/2021

Estimating the Economic Benefits of the Tornado Warning Improvement and Extension Program | Lead PI(s) Kimberly Klockow | OU/CIMMS, Austin College | 10/01/2018 - 09/30/2020

Estimating the Value of Economic Resiliency Created By Weather Forecasts | Lead PI(s) Haydar Kurban | Howard University | 10/01/2018 - 09/30/2020

Estimation of Tropical Cyclone Intensity using Satellite Passive Microwave Observations | Lead PI(s) Haiyan Jiang | Florida International University | 07/01/2017 - 06/30/2020

Evaluating Stochastic Physics Approaches within Select Convection Allowing Model (CAM) Members Included in the Community Leveraged Unified Ensemble (CLUE) during the Hazardous Weather Testbed (HWT) Spring Experiment | Lead PI(s) Jamie Wolff, Isidora Jankov | National Center for Atmospheric Research, Colorado State University-Cooperative Institute for Research in the Atmosphere | 07/01/2017 - 06/30/2020

Evaluation and Diagnosis of National Water Model Simulations over CONUS using a Novel Snow Reanalysis Dataset | Lead PI(s) Konstantinos Andreadis | University of California Los Angeles | 09/01/2018 - 08/31/2020

Evaluation and Improvement of Snowmelt Processes in the National Water Model during Extreme Atmospheric River Events in the Western U.S. | Lead PI(s) Martin Ralph | Scripps Institute, UCSD | 09/01/2019 - 08/31/2021

Evaluation and Improvements of Tornado Detection using Infrasound Remote Sensing: Comparative Analysis of Infrasound, Radar, Profiler, and Meteorological Data Sets, and Potential Impacts on NOAA/NWS Operations | Lead PI(s) Hank Rinehart, Kevin Knupp | General Atomics, University of Alabama-Huntsville | 10/01/2017 - 09/30/2019

Evolutionary Programming for Probabilistic Tropical Cyclone Intensity Forecasts | Lead PI(s) Paul Roebber | University of Wisconsin-Milwaukee | 07/01/2017 - 06/30/2020

Experimental Framework for Testing the National Water Model: Operationalizing the Use of Snow Remote Sensing in Alaska | Lead PI(s) Katrina Bennett, Vladmir Alexeev, Aubrey Dugger | Los Alamos National Laboratory, University of Alaska Fairbanks, Research Applications Lab | 10/01/2018 - 09/30/2020

Extending the Rapidly-Updating Real-Time Mesoscale Analysis (RTMA) to Three Dimensions for Whole-Atmosphere Situational Awareness and Analysis of Record | Lead PI(s) Curtis Alexander | NOAA/OAR/ESRL/GSD | 11/01/2017 - 10/31/2020

Extending the Real-Time Multi-Model Sub-Seasonal Predictive Capability | Lead PI(s) Ben Kirtman, Kathy Pegion | University of Miami, George Mason University | 08/01/2019 - 07/31/2020

FACETs: Advancing Physical and Social Science Concepts toward Operational Implementation of Probabilistic Hazard Information | Lead PI(s) Alan Gerard | OAR/NSSL | 07/01/2018 - 06/30/2021

FACETs: Developing Operationally-Ready Hazard Services-Probabilistic Hazard Information (PHI) for Convective Hazards | Lead PI(s) Tracy Hansen | NOAA/OAR/ESRL/GSD | 11/01/2017 - 10/31/2020

Forecast Guidance for Aviation Tactical Operations and Strategic Planning over Alaska | Lead PI(s) Judy Ghirardelli | NOAA/NWS/STI/DFSB | 11/01/2017 - 10/31/2020

Forecast System Development Activities toward a Convective-Scale HRRR Ensemble | Lead PI(s) Glen Romine | National Center for Atmospheric Research | 08/01/2017 - 07/31/2020

Further Improvements and Extensions to the Tropical Cyclone Logistical Guidance for Genesis (TCLOGG) | Lead PI(s) Robert Hart, Daniel Halperin | Florida State University, Embry-Riddle Aeronautical University | 07/01/2019 - 06/30/2022

Generating Operational Guidelines for Use of Probabilistic Hazard Information (PHI) with End Users | Lead PI(s) Kodi Berry, Holly Obermeier | University of Oklahoma - Cooperative Institute for Mesoscale Meteorological Studies, Cooperative Institute for Research in Environmental Sciences | 10/01/2018 - 09/30/2020

Guidelines for Expressing Uncertainty in Impact Decision Support Service Products: Supplement to NSF Award "Improving Public Response to Weather Warnings." | Lead PI(s) Susan Joslyn | University of Washington | 09/01/2016 - 09/01/2019

Hazard Services: National Center Evolve | Lead PI(s) Nathan Hardin | Colorado State University-Cooperative Institute for Research in the Atmosphere; ESRL/GSD | 09/01/2019 - 08/31/2021

Hazards SEES Type 2: Next Generation, Resilient Warning Systems for Tornadoes and Flash Floods, Supplement | Lead PI(s) Brenda Philips, Joseph Trainor | University of Massachusetts - Amherst, University of Delaware | 9/1/2016 - 12/31/2019

A Hybrid Statistical-Dynamical System for the Seamless Prediction of Daily Extremes and Subseasonal to Seasonal Climate Variability | Lead PI(s) Dan Collins | NOAA/CPC | 08/01/2018 - 07/31/2020

Identification of the Fluid Mechanisms Associated with Tornadic Storm Infrasound | Lead PI(s) Brian Elbing | Oklahoma State University | 09/01/2018 - 08/30/2020

The Impact of Ocean Resolution in the Unified Forecast System (UFS) on the Subseasonal Forecast of Extreme Hydrological Events | Lead PI(s) Cristiana Stan | George Mason University | 09/01/2018 - 08/31/2020

Implementation and Testing of Stochastic Perturbations within a Stand-Alone Regional (SAR) FV3 Ensemble using the Common Community Physics Package (CCPP) | Lead PI(s) Jeff Beck, Jamie Wolff | National Center for Atmospheric Research, Colorado State University-Cooperative Institute for Research in the Atmosphere | 07/01/2019 - 06/30/2022

Implementation of a Three-Dimensional Hydrometeor Classification Algorithm within the Multi-Radar/Multi-Sensor System | Lead PI(s) Heather Reeves | University of Oklahoma - Cooperative Institute for Mesoscale Meteorological Studies | 08/01/2017 - 07/31/2020

Implementation of Advanced Multi-Sensor Analysis and Data Fusion Algorithms for Real-Time High-Resolution Quantitative Precipitation Estimation | Lead PI(s) Dong-Jun Seo, Lin Tang | The University of Texas at Arlington, The University of Oklahoma | 10/01/2016 - 09/30/2019

Implementation of an Accurate, Robust and Computationally Efficient Channel Routing Technique for the National Water Model (NWM) | Lead PI(s) Ehab Meselhe | Tulane University | 10/01/2018 - 09/30/2020

Implementation of Multi-Radar Multi-Sensor Dual-Polarization Radar Synthetic QPE | Lead PI(s) Stephen Cocks | University of Oklahoma - Cooperative Institute for Mesoscale Meteorological Studies | 08/01/2017 - 07/31/2020

Implementation of Nested Hyper-Resolution Modeling with Data Assimilation for the National Water Model | Lead PI(s) Dong-Jun Seo | University of Texas-Arlington | 08/01/2017 - 07/31/2020

Implementation of Streamflow Data Assimilator for the National Water Model to Improve Water Prediction and Analysis | Lead PI(s) Seongjin Noh, James McCreight | University of Texas-Arlington, National Center for Atmospheric Research | 08/01/2017 - 07/31/2019

Implementing Convective Storm Statistics from a Large Reanalysis of WSR-88D Data for Model Verification and Forecasting Probabilistic Uncertainty | Lead PI(s) Travis Smith | University of Oklahoma - Cooperative Institute for Mesoscale Meteorological Studies | 10/01/2018 - 09/30/2020

Implementing Snow Data Assimilation Capabilities for the National Water Model and Experimental Assimilation of JPSS Observations of Snow Water Equivalent | Lead PI(s) Yu Zhang, Cezar Kongoli | University of Texas Arlington, University of Maryland | 09/01/2018 - 08/31/2020

Implications of Inconsistent Visual Displays on End User Uncertainty, Risk Perception, and Behavioral Intentions | Lead PI(s) Andrew Grundstein | University of Georgia | 10/01/2018 - 09/30/2020

Improved Diagnosis of Severe Wind Occurrence through Machine Learning | Lead PI(s) William Gallus | Iowa State University | 07/01/2019 - 06/30/2022

Improvement of WRF-Hydro National Water Model Architecture and Calibration Methods for Semi-Arid Environments with Complex Terrain | Lead PI(s) Christopher Castro | University of Arizona | 08/01/2017 - 07/31/2020

Improvements and Extensions to an Existing Probabilistic Genesis Forecast Tool using an Ensemble of Global Models | Lead PI(s) Robert Hart | Florida State University | 07/01/2017 - 06/30/2020

Improvements to Operational Statistical Tropical Cyclone Intensity Forecast Models using Wind Structure and Eye Predictors | Lead PI(s) Galina Chirokova, John Kaplan | Colorado State University-Cooperative Institute for Research in the Atmosphere, NOAA/OAR/AOML | 08/01/2017 - 07/31/2020

Improving Convection-Permitting Ensemble Based Uncertainty Communication for Decision Support using the Weather Archive and Visualization Environment (WAVE) | Lead PI(s) Julie Demuth, Melissa Petty, Jennifer Henderson | National Center for Atmospheric Research, Colorado State University-Cooperative Institute for Research in the Atmosphere, University of Colorado - Cooperative Institute for Research in Environmental Sciences | 10/01/2018 - 09/30/2020

Improving Hail Forecasts through Operational Implementation of the HAILCAST Hail Model | Lead PI(s) Rebecca Adams-Selin, Tara Jensen, Israel Jirak | AER, National Center for Atmospheric Research, NWS | 10/01/2018 - 09/30/2020

Improving Hydrologic Observing Capabilities with Stream Radars | Lead PI(s) Daniel Wasielewski | Cooperative Institute for Mesoscale Meteorological Studies | 10/01/2016 - 09/30/2019

Improving Lake-Effect Snow and Ice Forecasting for the Great Lakes Region | Lead PI(s) Philip Chu | Great Lakes Environmental Research Laboratory (GLERL) | 07/01/2017 - 06/30/2019

Improving Lake-Effect Snow Forecasting Capabilities via Advanced Coupling Techniques in NOAA's Unified Forecast System (UFS) | Lead PI(s) Christiane Jablonowski, Philip Chu | University of Michigan - CIGLR, Great Lakes Environmental Research Laboratory (GLERL) | 07/01/2019 - 06/30/2022

Improving National Water Model Snowmelt Runoff Prediction | Lead PI(s) Guo-Yue Niu, Michael Barlage | University of Arizona, National Center for Atmospheric Research | 09/01/2018 - 08/31/2020

Improving National Weather Service Convection Allowing Hazardous Weather Prediction by using a Cost-Effective Large Background Ensemble in a Regional FV3 Hybrid EnVar Data Assimilation System | Lead PI(s) Xuguang Wang | University of Oklahoma | 07/01/2019 - 06/30/2022

Improving NWS Convection Allowing Hazardous Weather Ensemble Forecasts through Optimizing Multi-Scale Initial Condition (IC) Perturbations | Lead PI(s) Xuguang Wang | University of Oklahoma/Cooperative Institute for Mesoscale Meteorological Studies | 07/01/2017 - 06/30/2020

Improving Operational Hail Prediction through Machine Learning from HREF and CAPSStorm-Scale Ensemble FV3 and WRF ARW Forecasts including Advanced Microphysics | Lead PI(s) Nathen Snook, David Gagne | University of Oklahoma, National Center for Atmospheric Research | 10/01/2018 - 09/30/2020

Improving Probabilistic Forecasts of Extreme Rainfall through Intelligent Processing of High-Resolution Ensemble Predictions | Lead PI(s) Russ Schumacher | Colorado State University | 10/01/2016 - 09/30/2019

Improving Snow and Streamflow Simulation in the National Water Model by Leveraging Advanced Mesonet Observations from the Northeastern United States | Lead PI(s) Justin Minder, David Gochis, Theodore Letcher | SUNY Albany, National Center for Atmospheric Research, USACE CRREL | 09/01/2019 - 08/31/2021

Improving Spread-Skill via Stochastic Physics for Convection Allowing Model Ensembles (SP CAM ENS) | Lead PI(s) Curtis Alexander (GSD) | GSD | 09/01/2019 - 08/31/2020

Improving Subseasonal Water Supply Prediction across the Western United States through Assimilation of Remotely Sensed Snow Cover, Snow Albedo, and Snow Water Equivalent in the NOAA National Water Model | Lead PI(s) Karl Rittger, Aubrey Dugger, Edward Bair | University of Colorado, National Center for Atmospheric Research, University of California Santa Barbara | 10/01/2018 - 09/30/2020

Improving the Design and Utility to Severe Weather Forecasters of Convection Permitting Ensembles through Application of a Probabilistic Object-Based Post-Processing and Verification Technique | Lead PI(s) Aaron Johnson | University of Oklahoma | 07/01/2017 - 06/30/2020

Improving the Microphysics Parameterization in High-Resolution FV3GFS Nested Modeling System for Tropical Cyclone Predictions | Lead PI(s) S. G. Gopalakrishnan, Xuejin Zhang | AOML/HRD | 04/01/2019 - 03/31/2020

Improving the Prediction of Subseasonal Global Rainfall Variability through the Use of a Scale-Adaptive Stochastic Physics Suite | Lead PI(s) Jian-Wen Bao | NOAA/OAR/ESRL/PSD | 11/01/2017 - 08/31/2020

Improving the Quality of Water Forecasts via Bayesian Integration of Multiple Sources of Forecast Information | Lead PI(s) Edwin Welles | Deltares | 10/01/2018 - 09/30/2020

Improving the Use of Dropsondes in NOAA Operations (HWRF) | Lead PI(s) Jason Sippel | AOML | 11/01/2017 - 09/30/2019

Improving Tropical Boundary Layer Structure and Cloud Systems at All Scales | Lead PI(s) Joseph Olson, Georg Grell | GSD | 05/01/2019 - 04/30/2020

Improving Water Cycle Prediction in the National Water Model through Regional Calibration, Meteorological Forcing Improvements, and Coastal Coupling | Lead PI(s) Brad Cardinale | Cooperative Institute for Great Lakes Research | 10/01/2018 - 09/30/2020

Infrasound Detection of Tornadoes | Lead PI(s) Roger Waxler | University of Mississippi | 09/01/2017 - 12/31/2019

Infrasound Detection of Tornadoes (FY2018) | Lead PI(s) Roger Waxler | University of Mississippi | 09/01/2018 - 08/30/2020

Infrasound Observations and Demonstration of Real-Time Tools | Lead PI(s) Brian Elbing | Oklahoma State University | 09/01/2019 - 08/31/2021

INSITE: Integrated Support for Impacted Air Traffic Environments | Lead PI(s) Joshua Scheck | NOAA/NWS/NCEP | 11/01/2017 - 12/31/2020

Integration of Multi-Radar Multi-Sensor Azimuthal Shear into a CONUS Conditional Probability of Tornado Intensity Product in the Hazardous Weather Testbed | Lead PI(s) Matthew Mahalik, Brandon Smith, Alan Gerard | University of Oklahoma/Cooperative Institute for Mesoscale Meteorological Studies, National Severe Storms Laboratory | 07/01/2017 - 06/30/2020

Intelligent Post-Processing of Convection-Allowing Model Output to Inform Weather Prediction Center Outlooks and Forecasts | Lead PI(s) Russ Schumacher | Cooperative Institute for Research in the Atmosphere | 10/01/2018 - 09/30/2020

Inter-Office Collaboration Affecting Severe Weather Warning Services | Lead PI(s) Gregory Stumpf, Darrel Kingfield, Chen Ling | Cooperative Institute for Mesoscale Meteorological Studies, Cooperative Institute for Research in Environmental Sciences, University of Akron | 10/01/2018 - 09/30/2020

Joint Project: Social Media Message Amplification and Attentional Networks | Lead PI(s) Jeannette Sutton, Carter Butts | University of Kentucky, UC Irvine | 10/01/2018 - 09/30/2021

Land Data Assimilation for the UFS | Lead PI(s) Jeffrey Whitaker and Robert Cifelli (ESRL/PSD Federal) and Clara Draper (University of CO/CIRES) | ESRL/PSD | 07/01/2019 - 06/30/2021

Laying the Foundation for Ensemble Prediction and Probabilistic Hazard Tool Development for Winter Weather | Lead PI(s) Heather Reeves | University of Oklahoma - Cooperative Institute for Mesoscale Meteorological Studies | 09/01/2019 - 08/31/2021

Lower-Tropospheric Thermodynamic and Wind Profiling Impact Study | Lead PI(s) Tammy Weckwerth | National Center for Atmospheric Research | 09/01/2019 - 08/31/2021

Maintenance and Development of the Subseasonal to Seasonal Prediction Project (S2S) Database and Tools in IRI Data Library | Lead PI(s) Andrew Robertson | Columbia University | 07/01/2019 - 09/30/2020

Making Sense of Uncertainty: Improving the Use of Hydrologic Probabilistic Information in Decision-Making | Lead PI(s) Rachel Carr | Nurture Nature Center | 10/01/2018 - 09/30/2020

Medium-range to S2S Prediction at Convective Scales | Lead PI(s) Lucas Harris | GFDL | 07/01/2019 - 06/30/2020

Minding the Gap: Modernizing the TC Product Suite by Evaluating NWS Partner Information Needs | Lead PI(s) Rebecca Morss, Ann Bostrom | University Center for Atmospheric Research | 07/01/2019 - 6/31/2021

MJO and QBO Contributions to U.S. Precipitation Skill at S2S Leads | Lead PI(s) Elizabeth Barnes | Colorado State University, University of Colorado - CIRES | 09/01/2019 - 08/31/2022

Modeling of Infrasound Generation from Tornadic Storms | Lead PI(s) Roger Waxler | University of Mississippi | 09/01/2019 - 08/31/2021

Modernizing Observation Operator and Error Assessment for Assimilating In-situ and Remotely Sensed Snow/Soil Moisture Measurements into NWM | Lead PI(s) Ming Pan, Nathaniel Chaney, Clara Draper, Craig Ferguson | Princeton University - CIMES, Duke University, University of Colorado - CIRES, SUNY Albany | 09/01/2019 - 08/31/2021

Multi-Sensor Merged Quantitative Precipitation Estimations for Improved Precipitation Coverage and Accuracy | Lead PI(s) Steven Martinaitis | University of Oklahoma - Cooperative Institute for Mesoscale Meteorological Studies | 08/01/2017 - 07/31/2020

NAQFC Community Emission Testbed (NCET): Accelerating Anthropogenic Emission Updates for NAQFC FV3-CMAQ through Community Collaboration | Lead PI(s) Bok Baek, Daniel Tong | University of North Carolina, George Mason University | 06/01/2019 - 05/31/2022

A New Technique for Improved MJO Prediction | Lead PI(s) Chidong Zhang, Wanqiu Wang | NOAA/PMEL, NOAA/CPC | 08/01/2018 - 07/31/2020

A Novel Ensemble Design for PM2.5 Probabilistic Predictions and Quantification of Their Uncertainty | Lead PI(s) Luca Monache | National Center for Atmospheric Research | 06/01/2016 - 05/31/2020

A Novel Method for Improving Fine Particulate Matter Air Quality Forecasts during Wildfires | Lead PI(s) Rajesh Kumar | National Center for Atmospheric Research | 06/01/2019 - 05/31/2022

NSF Title: Hazards SEES Type 2: Hazard Prediction and Communication Dynamics in the Modern Information Environment | Lead PI(s) Rebecca Morss | NCAR | 10/01/2018 - 09/30/2021

NSF Title: RAPID: Responding to the Risk of Hurricanes Harvey and Irma: Choices and Adjustment Over Time | Lead PI(s) Roxane Silver | UC Irvine | 02/01/2019 - 02/01/2021

Operational Implementation of Near-Real Time High-Temporal Resolution Thermodynamic Retrievals | Lead PI(s) Timothy Wagner | University of Wisconsin-CIMMS | 09/01/2019 - 08/31/2021

Operational Transition of Novel Statistical–Dynamical Forecasts for Tropical Subseasonal-to-Seasonal Drivers | Lead PI(s) Stephen Baxter, Carl Schreck | NOAA/CPC, North Carolina State University | 08/01/2018 - 07/31/2020

Operationalizing an Evaporative Demand Drought Index (EDDI) Service for Drought Monitoring and Early Warning across CONUS | Lead PI(s) Robert Webb, Roger Pulwarty, Michael Hobbins | NOAA/ESRL/PSD, NOAA/ESRL/PSD and National Integrated Drought Information Systems, University of Colorado and Cooperative Institute for Research in Environmental Sciences | 07/01/2016 - 06/30/2019

Optimal Storm-scale Ensemble Configuration for 0–6 h Probabilistic Forecasts of High Impact Weather | Lead PI(s) Nusrat Yussouf (CIMMS/OU and NOAA/NSSL)Co-PIs: Yunheng Wang (CIMMS/OU and NOAA/NSSL), Isidora Jankov (CIRA and NOAA/ESRL/GSD), Youngsun Jung (CAPS/OU) | NSSL/CIMMS | 09/01/2019 - 08/31/2020

Optimizing Geostationary Lightning Mapper Use in AWIPS | Lead PI(s) Scott Rudlosky | NESDIS/STAR | 07/01/2018 - 06/30/2021

Optimizing Tropical Cyclone Information: A NOAA Hurricane Website User Experience Study from a Public Perspective | Lead PI(s) Scott Miles | University of Washington | 07/01/2019 - 6/31/2021

Physics and Improved Vertical Resolution for Improving Hurricane Prediction and Tropical Convection in GFS | Lead PI(s) Lucas Harris | GFDL | 07/01/2019 - 06/30/2020

Post-Processing of CMAQ Air Quality Predictions: Research to Operations | Lead PI(s) Irina Djalalova | NOAA/OAR/ESRL/PSD and CIRES/University of Colorado | 06/01/2016 - 05/31/2019

Prediction and Measurement of Infrasound Propagation in the Turbulent Atmosphere | Lead PI(s) Steven Miller | University of Florida | 09/01/2018 - 08/30/2020

Probabilistic Precipitation Rate Estimates from Ground-Radar for Hydrology | Lead PI(s) Pierre-Emmanuel Kirstetter | University of Oklahoma | 08/01/2017 - 07/31/2020

Probabilistic Warn-on-Forecast System for Heavy Rainfall and Flash Flooding | Lead PI(s) Steven Martinaitis, Jonathan Gourley | University of Oklahoma - Cooperative Institute for Mesoscale Meteorological Studies, NOAA/OAR/NSSL | 10/01/2017 - 09/30/2019

Quantifying Observational Requirements for WRF-Hydro Forcing in the West using Russian River HMT Experience and Data to Inform National Water Center Tools | Lead PI(s) Fred Ralph | University of California San Diego - CIMEC | 07/01/2017 - 06/30/2020

Quantifying Stochastic Forcing at Convective Scales | Lead PI(s) David Randall | Colorado State University | 10/01/2016 - 09/30/2019

Real-time Observations of the Three-Dimensional Hurricane Boundary Layer Winds and Ocean Surface Vector Winds with an Imaging Airborne Profiler | Lead PI(s) Zorana Jelenak, Paul Chang, Stephen Guimond | UCAR, University of Maryland Baltimore County, NESDIS | 09/01/2019 - 08/31/2021

Representing Agricultural Management Processes in the National Water Model | Lead PI(s) Fei Chen, Kristie Franz | National Center for Atmospheric Research, Iowa State University | 10/01/2018 - 09/30/2020

S2S Forecasting of North American Precipitation Anomalies: Using Empirical Forecasts to Challenge Dynamical Forecasts | Lead PI(s) David Randall | Colorado State University | 09/01/2019 - 08/31/2022

Sensitivity of NMME Seasonal Predictions to Ocean Eddy Resolving Coupled Models | Lead PI(s) Benjamin Kirtman, Robert Burgman | University of Miami-RSMAS, Florida International University | 08/01/2018 - 07/31/2020

Skillfully Predicting Atmospheric Rivers and Their Impacts in Weeks 2-5 Based on the State of the MJO and QBO | Lead PI(s) Elizabeth Barnes | Colorado State University | 08/01/2018 - 07/31/2020

Study of Infrasound Propagation from Tornadic Storms in Dynamic Atmospheres over Hilly Terrain | Lead PI(s) Roger Waxler | University of Mississippi | 09/01/2019 - 08/31/2021

Subseasonal to Seasonal Prediction with NCAR's CESM2-WACCM | Lead PI(s) Jadwiga Richter, Dan Collins, Judith Perlwitz | UCAR, NOAA/CPC, NOAA/ESRL/PSD | 08/01/2018 - 07/31/2020

Testing, Refinement and Demonstration of Probabilistic Multi-Model, Calibrated Sub-Seasonal Global Forecast Products | Lead PI(s) Andrew Robertson, Dan Collins | Columbia University, NOAA/CPC | 08/01/2018 - 07/31/2020

There's a Chance of What? Assessing Numeracy Skills of Forecasters, Partners, and Publics to Improve TC Product Uncertainty Communication, IDSS, and Training | Lead PI(s) Joseph Ripberger, Carol Silva, Hank Jenkins-Smith, Edward Cokely | Board of Regents of the University of Oklahoma | 07/01/2019 - 6/31/2021

Top-Down Estimation of Wildfire Smoke Emission Based on HYSPLIT Model and NOAA NESDIS GOES Aerosol/Smoke Products to Improve Smoke Forecasts in the US | Lead PI(s) Tianfeng Chai | University of Maryland | 06/01/2016 - 05/31/2020

Toward Obtaining Daily Vertical Profiles of Boundary Layer Temperature and Moisture Fields using Small Unmanned Aircraft Systems | Lead PI(s) Temple Lee, Bruce Baker | University of Oklahoma/Cooperative Institute for Mesoscale Meteorological Studies, ARL | 09/01/2019 - 08/31/2021

Towards Optimal Configurations of NAQFC Chemistry and Aerosol Representations | Lead PI(s) Yang Zhang, Daniel Tong | North Carolina State University, George Mason University | 06/01/2019 - 05/31/2022

Towards the Improvement of Chemical Lateral Boundary Conditions for the NAQFC | Lead PI(s) Zhining Tao, Huisheng Bian, Daniel Tong | University of Space Research Association/NASA Goddard, University of Maryland, University of Maryland | 06/01/2016 - 05/31/2020

Transition of Machine-Learning Based Rapid Intensification Forecasts to Operations | Lead PI(s) Andrew Mercer | Mississippi State University-Northern Gulf Institute | 07/01/2017 - 06/30/2020

Transition of the Coastal and Estuarine Storm Tide Model to an Operational Model for Forecasting Storm Surges | Lead PI(s) Keqi Zhang | Florida International University | 09/01/2015 - 02/28/2019

Transitioning Ensemble-based TC Track and Intensity Sensitivity to Operations | Lead PI(s) Ryan Torn, Sim Aberson, Jason Dunion | SUNY Albany, NOAA/OAR/AOML, University of Miami | 07/01/2019 - 06/30/2021

UFS Community Modeling Support | Lead PI(s) Arun Chawla, Rusty Benson, Jeff Whitaker, Tom Clune | EMC, GFDL, ESRL/PSD, NASA | 06/01/2019 - 05/31/2020

Understanding the Infrasound Characteristics of Nontornadic and Tornadic Supercells in VORTEX2 and VORTEX-SE Environments using High-Resolution Ensemble Simulations | Lead PI(s) Matthew Parker | North Carolina State University | 09/01/2019 - 08/31/2021

Upgrades and Improvements to MRMS | Lead PI(s) Kenneth Howard, Jennifer Guillot | NOAA/OAR/NSSL, NOAA/NWS | 08/01/2016 - 07/31/2019

Upgrades to the M-PERC and PERC Models to Improve Short Term Tropical Cyclone Intensity Forecasts | Lead PI(s) Derrick Herndon | University of Wisconsin-Madison Cooperative Institute for Meteorological Satellite Studies | 07/01/2019 - 06/30/2021

Use of MRMS-Served Hydrometeor Classification for Determining Initial Hydrometeor Phase in the National Water Model | Lead PI(s) Heather Reeves, Mimi Hughes, David Gochis | University of Oklahoma, Cooperative Institute for Research in Environmental Sciences, National Center for Atmospheric Research | 09/01/2018 - 08/31/2020

Use of the Stochastic-Dynamic Approach in a Single Dynamic-Core Storm-Scale Ensemble for Improved Spread and Reliability of QPF and Surface Variables | Lead PI(s) Isidora Jankov, Judith Berner, Joseph Olson | Colorado State University-Cooperative Institute for Research in the Atmosphere, National Center for Atmospheric Research, Cooperative Institute for Research in Environmental Sciences | 08/01/2017 - 07/31/2020

Using Convective Mode Information for Hazard Prediction with Convection-Allowing Models | Lead PI(s) Ryan Sobash | National Center for Atmospheric Research | 07/01/2019 - 06/30/2022

Using HYSPLIT Ensemble Dispersion Modeling for Forecasting Applications | Lead PI(s) Barbara Stunder | OAR/ARL | 07/01/2018 - 06/30/2021

VSAFE: Verification Services for Aviation Forecast Evaluation | Lead PI(s) Joshua Scheck | NOAA/NWS/NCEP | 07/01/2018 - 06/30/2021

Wait, That Forecast Changed? Assessing How Publics Consume and Process Changing Tropical Cyclone Forecasts over Time | Lead PI(s) Gabrielle Wong-Parodi, Rebecca Morss Leysia Palen | The Leland Stanford Junior University | 07/01/2019 - 6/31/2021

A Web-Based Survey to Estimate the Economic Value of Improved Hurricane Forecasts | Lead PI(s) David Letson | CIMAS | 10/01/2018 - 09/30/2020

Endnotes

1 Weather Research and Forecasting Innovation Act of 2017. Public Law 115-25. https://www.congress.gov/115/plaws/publ25/PLAW-115publ25.pdf

2 National Integrated Drought Information System Reauthorization Act of 2018. Public Law 115-423. https://www.congress.gov/115/plaws/publ423/PLAW-115publ423.pdf

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9 National Oceanic and Atmospheric Administration, National Hurricane Center and Central Pacific Hurricane Center. (2019). 2019 Atlantic Hurricane Season. https://www.nhc.noaa.gov/data/tcr/

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11 Per OWAQ's FY2019 Notice of Federal Funding and the FY2019 Annual Operating Plan. Note that OWAQ may have shared additional priorities in other publications or *fora*.

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15 Per OWAQ's FY2020 Notice of Federal Funding (https://go.usa.gov/xp5pa) (for the Joint Technology Transfer Initiative, Verification of the Origins of Rotation in Tornadoes Experiment in the Southeast U.S., and Climate Testbed) and the FY2020 Annual Operating Plan. Note that OWAQ may share additional priorities in other publications or *fora*.

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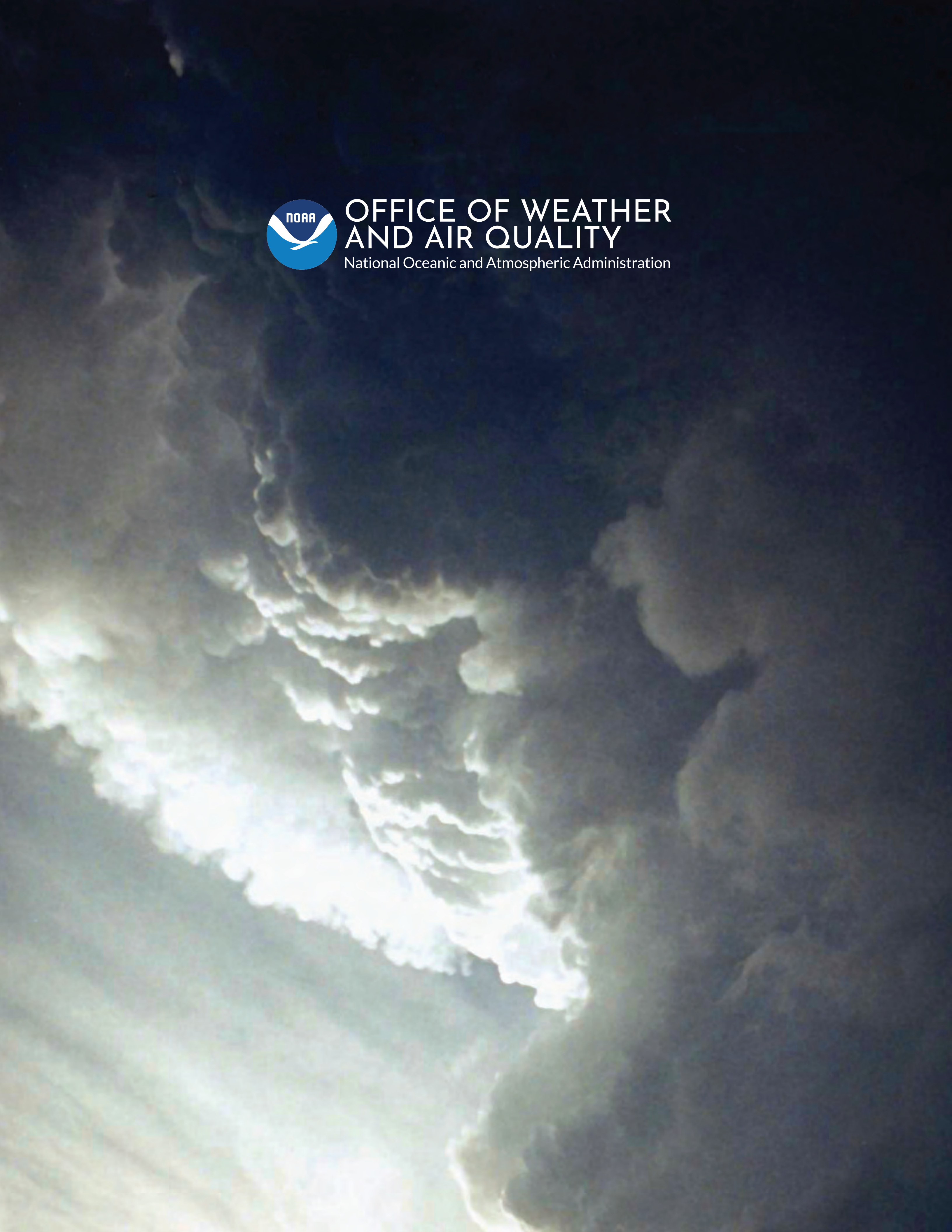
17 Wang, Y.-H., Brotxton, P., Fang, Y., Behrangi, A., Barlage, M., Zeng, X., & Niu, G.-Y. (2019). A wet-bulb temperature-based rain-snow partitioning scheme improves snowpack prediction over the drier Western U.S. *Geophysical Research Letters*, November 2019.

18 Sutton, J., Renshaw, S.L., Vos, S.C., Olson, M.K., Prestley, R., Gibson, B., & Butts, C.T. (2019). Getting the word out, rain or shine: the impact of message features and hazard context on message passing online. Weather, Climate, and Society, October 2019.

19 Kerns, B. W., & Chen, S. (2016). Large-scale precipitation tracking and the MJO over the maritime continent and Indo-Pacific warm pool. Journal of Geophysical Research: Atmosphere, July 2016.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AND AIR QUALITY
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