Integrating Ocean Observations to Improve NOAA's Hurricane Intensity Forecasts Workshop

Priority Recommendations for Integrating Ocean Observations to Improve NOAA's Hurricane Intensity Forecasts

Introduction

On September 8, 1900, the great Galveston Hurricane tore through the Texas island, with winds exceeding 130 miles per hour and a 15-foot storm surge. While Isaac Monroe Cline, the Galveston Weather Bureau climatologist, was aware the hurricane had passed over Cuba, wireless ship-to-shore communication was not available in 1900 to provide up-to-date information indicating the hurricane was strengthening and heading toward Texas. As the storm neared, Cline became increasingly suspicious of the weather and attempted to warn the citizenry of the approaching risk by raising the hurricane warning flags atop the Galveston Weather Bureau building the day before the hurricane struck. However, many people stayed on the beach and, to this day, the 1900 Galveston hurricane remains the Nation's deadliest natural disaster, with more than 8,000 people killed and over 3,600 homes and buildings destroyed[1]. This storm focused Cline's research on understanding the physical forces of tropical cyclones and devising rules for forecasts and warning, together resulting in significant contributions to forecasters and the public.

> *"I decided that I could be of greater service to humanity by determining what are the physical forces in the cyclones that develop the storm tides and by devising rules for use in forecasting and warning the public in advance of their arrival"*
> *-Isaac Cline*

The unprecedented 2020 Atlantic hurricane season[2] highlights the massive improvements in hurricane forecasts over the past 120 years — and how important it is to improve them further. Whereas the error in 48-hour track forecasts has been reduced by more than half in the past two decades, intensity forecasts remain a challenge, particularly with storms that rapidly intensify. The unprecedented 2020 hurricane season also highlighted what scientists do, and do not, know about how hurricanes will change as the climate warms.

> Hurricanes increasingly cause significant impacts to the United States (U.S.) coastline as the climate continues to change and both the population near the coast (42% of the U.S. population) and coastal infrastructure and economic activity (estimated at $8 trillion and 48% of US GDP[2]) continue to increase. In 2020, an unprecedented 30 named tropical storms formed in the Atlantic; a record 12 made landfall in the continental U.S. and, together, caused 86 deaths. The seven billion-dollar tropical cyclones (TC) were the most in one year since NOAA started keeping track of billion-dollar disasters in 1980. The combined cost of the seven tropical systems was approximately $40.1 billion, more than 42% of the total U.S. billion-dollar disaster price tag in 2020.

Scientists are increasingly aware of the important role the ocean plays in weather prediction. However, the frequency and density of ocean observations do not match the amount of data available for atmospheric parameters. The 2020 hurricane season underscores the importance of making the following our national priorities for sustained investments: (1) ocean observations; (2) co-location of air-sea observations; and (3) integration of these observations into numerical models. More accurate, and more reliable, forecasts will allow greater lead times for pre-storm mitigation efforts, enhanced protection of life and property, and an overall reduction in the economic impact of damaging storms, potentially saving hundreds of lives and billions of dollars.

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[1] NOAA Celebrates 200 Years
[2] NOAA Billion Dollar Disasters

Priority Recommendations

The recommendations outlined in this report were informed by the 2020 Integrating Ocean Observations to Improve NOAA's Hurricane Intensity Forecasts Workshop. Addressing these recommendations will require coordinated implementation across NOAA mission areas, programs, and service areas and an integrated ocean observing system that can be used to better initialize and validate numerical models.

- **Coordinate efforts to close gaps in ocean and transition zone observations**
  Improving NOAA's hurricane intensity forecasts will require closing gaps in ocean and air-sea observations, as these data are key to better understanding the interaction processes that lead to the formation and intensification of storm systems. However, an integrated multi-platform, coordinated ocean observing system is not currently in place at NOAA. Ocean and air observing systems can be better leveraged and coordinated within NOAA and with external partners to close gaps in observations prior to and during the hurricane storm season (e.g., enhancing co-located ocean-atmosphere observations in the air-sea interface zone and the lower atmospheric boundary layer).

- **Evaluate the impacts of ocean and transition zone observations on hurricane intensity forecasts**
  Assessing the impacts of ocean and co-located air-sea data is necessary to understand the effectiveness of observation types during the course of a storm and to determine the optimal network design when planning a new observing strategy, reorganizing existing observing networks, or investing in future observing systems. Observing System Experiments (OSEs), Observing System Simulation Experiments (OSSEs), and data-denial studies must be done to assess the impacts of different observations and/or combined observations for improving NOAA's ocean observing strategies.

- **Improve assimilation of ocean and transition zone observations into numerical modeling systems**
  Assimilation of more ocean and co-located air-sea data into numerical models is needed to improve hurricane intensity forecasts. Collaboration between NOAA and non-NOAA partners is needed to improve data assimilation (DA) software and development practices to build state-of-the-art assimilation systems; observational targeting practices through analysis of available ensemble model sensitivity patterns; NOAA's current and next generation hurricane modeling systems; understanding of hurricane processes using high-resolution numerical modeling systems; and physical parameterizations in modeling systems.

- **Prioritize and recommend ocean and transition zone observations for future operational investment**
  Improving future observing strategies requires understanding the following questions: What observations are needed? When are these observations needed? Why are these observations needed? Which observing systems are best to gather these data? The evaluation of the impacts of ocean and co-located air-sea observations on hurricane intensity forecasts must be assessed with economic valuation studies to answer these questions, allow NOAA to measure and track the societal contributions of its outputs, and inform future investment decisions that generate a high societal contribution (see also: NOAA's Economic Valuation Guide 2021).

Enabling Frameworks and Infrastructure

The recommendations outlined in this report are designed to bolster coordination across NOAA mission areas, programs, and service areas. Implementing the recommendations requires a coordinated approach from planning to implementation, as well as strengthening and expanding partnerships with academic, private, and international groups, and Federal, State, regional, local, and Tribal governments. The following groups, composed of subject matter experts from across NOAA and external partners, have been set up to coordinate the planning and implementation of the priority recommendations.

Extreme Events Ocean Observations Task Team

The Extreme Events Ocean Observations Task Team (EEOOTT) provides the unifying organizational infrastructure for NOAA and external partners to coordinate efforts for implementing the priority recommendations. The task team meets bi-monthly and consists of NOAA and non-NOAA subject matter experts responsible for observations, forecasts, research modeling, funding, and logistical support.

Due to the breadth of subject matter the priority recommendations encompass, the EEOOTT has also convened working groups of subject matter experts focused on advancing the priority recommendations. Working groups report regularly to, and will coordinate with, the EEOOTT to provide recommendations for future priorities and investments at NOAA to improve hurricane intensity forecasts.

Coordinated Ocean Observations Working Group

Priority Recommendation	Coordinated Ocean Observations Working Group Response
Coordinate efforts to close gaps in ocean observations.	This team will focus on coordinating ocean observations efforts, possibly co-located with atmospheric observations, to improve hurricane intensity forecasting by using an evidence-based approach to determine the optimal spatial and temporal ocean observations required. To close gaps in ocean observations, this group will take advantage of advancements in ocean observing technologies and focus on resolving upper ocean features, such as spatial and temporal variability of meso-scale and synoptic features including eddies, boundary currents, and seasonal water masses.

Aircraft Deployment Working Group

Priority Recommendation	Aircraft Deployment Working Group Response
Coordinate efforts to close gaps in ocean observations.	This team will work with the Coordinated Ocean Observations Team to coordinate aircraft-deployed atmospheric and oceanic observations with surface-based ocean observation efforts. This group will: (1) better understand the process and timelines of different aircraft groups; (2) better understand the how, when, and why priorities are set among competing interests; (3) describe the existing and upcoming technical packages and understand loading, securing, and launching needs and constraints; (4) map out staging

	locations and understand the criteria and constraints for using those staging locations; (5) define the communications chain and points of contact for this chains; (6) build and enhance rapport between aircraft deployment groups.

Integrated Modeling Prediction Assimilation Coordination Team (IMPACT)

Priority Recommendation	IMPACT Response
Evaluate the impacts of ocean observations on hurricane intensity forecasts.	IMPACT will: (1) summarize conclusions from previous model runs and comparisons; (2) outline and conduct the necessary analyses (e.g., OSEs) to evaluate the impacts of ocean observations on hurricane intensity forecasts.
Improve data assimilation of ocean observations into hurricane modeling systems.	IMPACT will evaluate the ocean component of the existing (operational and experimental) coupled atmosphere-ocean hurricane forecasting models. This group will also evaluate the impact of ocean data assimilation on hurricane intensity forecast. Due to maturity or availability of DA systems, data impact studies will be expected to start only when RTOFS-DA and/or ROMS 4DVar are available to EEOOTT members. Because regional MOM6 is in the development stage, the use of Marine JEDI DA in coupled hurricane modeling systems is expected at a later date. The work of this group will benefit from data impact studies performed with available Data Assimilation systems such as COAMPS-TC, HWR-ROMS, and HWRF-HYCOM. A major outcome will be to recommend sampling strategies to improve hurricane intensity forecast.

Prioritization and Resourcing Working Group

Priority Recommendation	Prioritization and Resourcing Working Group response
Prioritize and recommend ocean observations for future operational investment.	This group will work ongoingly to leverage and procure resources to fill gaps in the hurricane intensity forecasting space (observing platforms, data assimilation needs, impact studies, visualization tools, etc.). The group will also work to conduct economic valuation studies of observing systems and combine these results with those from the Coordinated Ocean Observations, Aircraft Deployment, and IMPACT Working Groups to provide NOAA leadership with justifiable, evidence-based recommendations that prioritizes sustained and targeted ocean observations based on cost and relative impact.

Appendix A. Acronyms

ACRONYM	DEFINITION
AOML	Atlantic Oceanographic and Meteorological Laboratory
DA	Data Assimilation
EEOOTT	Extreme Events-Ocean Observations Task Team
GOMO	Global Ocean Monitoring and Observing
HFIP	Hurricane Forecast Improvement Program
IMPACT	Integrated Modeling Prediction Assimilation Coordination Team
IOOS	Integrated Ocean Observing System
JEDI	Joint Effort for Data Assimilation Integration
NOAA	National Oceanic and Atmospheric Administration
NWS	National Weather Service
OSE	Observing System Experiments
OSSE	Observing System Simulation Experiments
RTOFS	Real Time Ocean Forecast System
TC	Tropical Cyclone

Appendix B. Supporting Materials

B1. NOAA Hurricane Forecast Improvement Program (HFIP) Strategic Plan
B2. National Weather Service Weather Ready Nation Strategic Plan 2019-2022
B3. NOAA Administrative Order 212-15: Management of Environmental Data and Information
B4. The FAIR Guiding Principles for Scientific Data Management and Stewardship
B5. 2020 NOAA Data Strategy
B6. NOAA's Economic Valuation Guide 2021
B7. Precipitation Prediction Grand Challenge Strategy
B8. IOOS-OAR Workshop's Two Pager: Hurricanes
B9. IOOS-OAR Workshop's Two Pager: Cloud Computing
B10. IOOS-OAR Workshop's Two Pager: Technology Development and Transition
B11. Weather, Water, Climate Five-Year Strategy
B12. NOAA Climate and Fisheries Initiative
B13. EPIC Strategic Plan
B154 Workshop Crosswalk with NOAA Line Offices and Programs

Appendix C. Crosswalk of Line Office Priorities

	Priority Recommendations for Integrating Ocean Observations to Improve NOAA's Hurricane Intensity Forecasts			
	Coordinate efforts to close gaps in ocean observations	**Evaluate the impacts of ocean observations on hurricane intensity forecasts.**	**Improve assimilation of ocean and transition zone observations into numerical modeling systems**	**Prioritize and recommend ocean observations for future operational investment**
NOS				
IOOS	x	x	x	x
COMT			x	
OAR				
GOMO	x	x	x	x
AOML	x	x	x	x
GFDL				
PSL	x	x	x	x
PMEL	x			x
WPO				
NWS				
NHC				
EMC		x	x	
OPC				x
STI				
Dissemination				
NWS Observations Portfolio	x			x
Cooperative Institutes				
CIMES				
CIMAS	x	x	x	x
CINAR	x	x	x	x
CIMEAS	x	x	x	
OMAO				
	x			
NESDIS				

Appendix D. Crosswalk of Intra-Agency Efforts

	Priority Recommendations for Integrating Ocean Observations to Improve NOAA's Hurricane Intensity Forecasts			
	Coordinate efforts to close gaps in ocean observations	**Evaluate the impacts of ocean observations on hurricane intensity forecasts.**	**Improve assimilation of ocean and transition zone observations into numerical modeling systems**	**Prioritize and recommend ocean observations for future operational investment**
Precipitation Prediction Grand Challenge				
Objective 1. Enhance and sustain user engagement				
Objective 2. Improve precipitation prediction products and applications				
Objective 2. Improve precipitation prediction products and applications				
Objective 3. Improve prediction systems for precipitation			x	
Objective 4. Sustain, enhance, and exploit observations	x			
Objective 5. Improve process-level understanding and modeling		x		
Objective 6. Advance understanding of precipitation predictability				
IOOS-OAR Workshops				
Hurricanes	x	x		x
Cloud Computing				
Techonology Development and Transitions				
Climate Fisheries Initiaitive				
Action // Enhance the utility of existing climate information				
Action // Advance NOAA's regional modeling system				
Action // Establish regional teams and a national community of practice				
Action // Fuel innovation and applications through targeted research				
WWC Strategy (2022-2026)				
4.1 Service delivery				
4.2 Decision support				
4.3 Modeling and prediction	x	x	x	x
4.4 Research and development	x	x	x	x
4.5 Observations	x	x	x	x
EPIC Strategic Plan				
3.1 Accurate and reliable operational models	x		x	
3.2 Community contributions to operational modeling systems				
3.3 Community engagement				

Appendix E. Who's Who of Hurricane Intensity Forecasting

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