Unmanned observations of the upper ocean and near-surface atmosphere for improved hurricane intensity prediction

Proposal for **Unmanned Marine Systems (UMS)** submitted to:
Advancing NOAA Application of Unmanned Systems (UxS) Internal NOAA FY2020 Request

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Collaborators: Jun Zhang[1,4], Frank Marks[1], Joe Cione[1], Chidong Zhang[2], Julio Morell[5,6], Ulises Rivero[1]

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Period of Performance: June 1, 2020 - May 31, 2023

Total Requested Budget: **$1,224K** (Y1: $331K, Y2: $444K, Y3: $449K)

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Abstract
Improving the accuracy and ultimate value of NOAA's operational hurricane forecasts requires more complete real-time knowledge of atmospheric and oceanic conditions and more realistic representation of key physical processes in hurricane forecast models. This proposal seeks to address these needs through the deployment of saildrones during the peak of the Atlantic hurricane season. These unmanned autonomous marine systems will continuously measure the near-surface atmosphere (temperature, humidity, wind velocity, solar and longwave radiation, and pressure) and upper ocean (sea surface temperature, salinity, surface and subsurface ocean currents, wave height and period) and transmit one-minute averaged data in real-time. Key parameters will be assimilated into NOAA's operational hurricane forecast models to aid prediction. The saildrones will follow repeated tracks north of Puerto Rico, a region of high hurricane track density where storms often intensify before making U.S. landfall. **A planned coordination with underwater glider observations will provide the first collocated measurements of the upper ocean and atmosphere from unmanned vehicles during a hurricane event.** The saildrones will be directed opportunistically to measure ahead of and inside of any approaching tropical cyclone. Saildrone measurements in tropical cyclones will be coordinated with other elements of NOAA's Hurricane Field Program to provide valuable collocated observations of the ocean and atmospheric boundary layer for coupled data assimilation. In addition, analysis will be conducted to quantify air-sea heat and momentum fluxes, assess hurricane model errors, improve model parameterizations, and determine the value of saildrone observations for data assimilation. The proposed saildrones will serve as a proof of concept for making regular autonomous measurements across the air-sea interface during the hurricane season. **The cross-line office (OAR, NWS, NOS) commitment to the proposal illustrates the significant value the proposed measurements would likely bring to NOAA and the high potential for transitioning to routine operations.**

1 Purpose/Objective

The National Hurricane Center (NHC) provides official U.S. hurricane intensity forecasts, with input from a suite of operational numerical forecast models and statistical guidance products from NOAA's Environmental Modelling Center (EMC) and Atlantic Oceanographic and Meteorological Laboratory (AOML). Together with academic and government research institutions, NOAA AOML leads the collection of in-situ measurements through the NOAA Hurricane Field Program. This program fully supports National Weather Service (NWS) operational hurricane observing requirements. AOML also conducts key components of the research used to improve tropical cyclone (TC) numerical forecast models. Operational forecast models rely on accurate atmospheric and oceanic data obtained from reconnaissance flights, ocean observing platforms at the surface and subsurface, and satellite observations and products, to correctly represent the main atmospheric and oceanic parameters.

Accurately forecasting TC intensity remains a challenge given the complexity of the oceanic and atmospheric processes involved and the limited number of observations for analysis (Shay et al. 2000; Balaguru et al. 2012, 2020; Kaplan et al. 2010). The identification and correct representation of these features have improved TC intensity forecasts within NOAA statistical schemes (Mainelli et al. 2008; Kaplan et al. 2015) and operational forecast models (Dong et al. 2017; Domingues et al. 2019). Though progress has been made, many gaps remain, particularly in ocean-atmosphere initial conditions that are critical for intensity forecasts, and for air-sea interactions within TCs (Tallapragada et al. 2014; Zhang et al. 2017). **For this proposal, we have put together for the first time a team from multiple NOAA line offices (OAR, NWS, NOS) to acquire measurements from collocated autonomous vehicles for real-time assimilation into hurricane forecast models.**

Currently, measurements from NOAA's hurricane reconnaissance flights are made directly by sensors on the aircraft and by dropsondes, XBTs, and ALAMO floats deployed from the flights. These instruments provide profiles of the atmosphere and upper ocean that have enabled improved TC forecasts. However, there has been a lack of continuous high-quality measurements at the air-sea interface ahead of and within TCs. Our proposed atmospheric and oceanic observations from unmanned saildrones (https://www.saildrone.com/news/what-is-saildrone-how-work) will provide unique and critical in situ measurements of the upper ocean and near-surface atmosphere to improve Atlantic TC intensity forecasts. The measurements will sample the large-scale environment ahead of approaching TCs and the conditions within TCs while leveraging complementary observations from other NOAA TC observing systems such as hurricane gliders, small unmanned aerial systems (sUAS), reconnaissance aircraft, surface drifters, Argo floats, and moored buoys. This approach is aimed at providing NOAA operational centers such as NHC and EMC with additional information to aid in operational TC intensity forecasting. The main objectives of this proposal are to:

(1) For the first time, use saildrones as a proof of concept to collect concurrent and collocated observations of upper-ocean temperature and salinity, surface waves, currents, and air-sea heat and momentum fluxes from unmanned platforms in regions of the Atlantic and Caribbean with high TC track densities (Figure 1).

(2) Obtain continuous measurements of ocean-atmosphere conditions outside and within TCs, coordinating saildrone measurements with those from underwater hurricane gliders, aircraft, surface drifters, Argo floats, and sUAS.

(3) Assess the quality of saildrone measurements, and the feasibility of acquiring them routinely, through objective quality-control procedures and intercomparing autonomous, aircraft, and buoy measurements.

(4) Provide real-time high-resolution surface wind, temperature, humidity, pressure, and wave observations to aid NOAA operational analyses and forecasts.

(5) Quantitatively evaluate deficiencies and biases in TC forecast models associated with structure and physics; assess the value of saildrone measurements for data assimilation.

3 Technical Project Plan

We propose to measure several atmospheric and oceanic variables from one to eight saildrones (Table 1). All of these parameters are needed to quantify ocean-atmosphere conditions that affect TC intensification. The 20 Hz wind measurements will be used for direct calculations of the momentum flux from the atmosphere to the ocean through the eddy correlation method (French et al. 2007, Zhang et al. 2008). Note that previous direct flux calculations have been made in winds up to ~ 60 kt. We propose to collect wind data for flux calculations in hurricane-force wind conditions (>64 kt). All data are transmitted in real-time as one-minute averages every 5 to 10 minutes and are accessible via a dedicated Saildrone mission portal. High-resolution data will be downloaded after recovery.

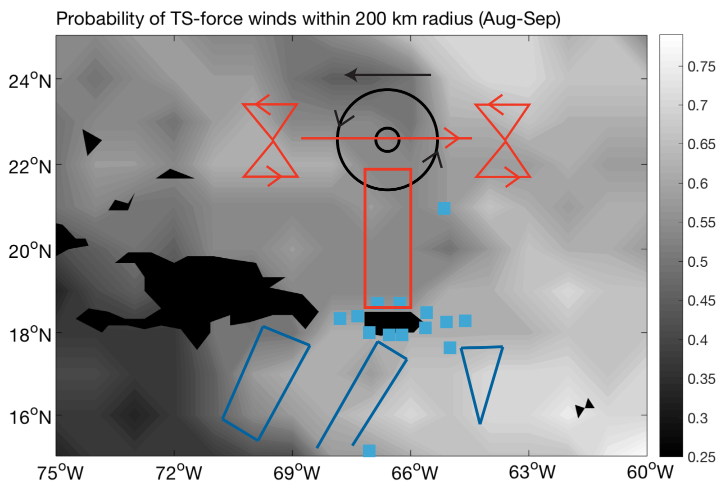

Figure 1 *Shading: probability of sustained TS-force winds within 200 km of each location during August-September. Orange rectangle shows repeated saildrone and glider track when no TC is near. Blue lines show other glider tracks. Schematic above rectangle shows planned saildrone tracks (orange) when TC (black circles, with arrow indicating translation direction) is predicted to pass nearby: before TC arrival (bow-tie pattern on left), during passage (transect through middle of TC), and after (bow-tie pattern on right). Blue squares show locations of long-term moored met. buoys.*

As stated in the previous section, two primary objectives of this proposal are to (1) obtain measurements from saildrones coincident and collocated with underwater hurricane glider measurements, and (2) measure ocean-atmosphere conditions within one or more TCs, coordinated with reconnaissance aircraft and sUAS. To achieve Objective (1), one to eight saildrones will be deployed in early August 2020 and acquire measurements for two months during the peak of the Atlantic hurricane season. These deployments will be repeated in August 2021 and 2022. During each year, the saildrones will be programmed to follow ocean gliders. Hurricane gliders that belong to the NOAA funded Hurricane Glider Picket Fence measure ocean temperature and salinity between the sea surface and 400 m and have been operating during each Atlantic hurricane season (June-November) since 2014 (https://www.aoml.noaa.gov/phod/goos/ gliders/index.php). The Hurricane glider project is led by NOAA AOML, in partnership with several U.S. and international academic and governmental institutions. All glider data is made available continuously in real-time for assimilation into TC forecast models. Since saildrones travel more quickly than gliders, they will likely cross back and forth over the glider locations.

Table 1 Proposed saildrone measurements.

Measurement	*Sensor*	*Meas. Height*
3D wind speed, direction (20 Hz)	Gill Windmaster 3D ultrasonic	5.0 m
Air temperature, humidity	Rotronic HC2 - S3 with rad. shield	2.2 m
Atmospheric pressure	Vaisala Barocap PTB210	0.2 m
Shortwave radiation (5 Hz)	Sunshine Pyranometer SPN1	2.2 m
Longwave radiation	Eppley PIR	2.2 m
Visible camera (360^o)	Saildrone custom	2.2 m
Ocean temperature, salinity	SBE 37, RBR conductivity	-0.5 m
Ocean skin temperature	Heitronics CT15.2 IR pyrometer	2.2 m
Wave height, period	VectorNav VN300	0.2 m
Ocean currents	Teledyne Workhorse ADCP 300KHz	-6 to -100 m

To achieve Objective (2), if a 48-hr forecast predicts a TC will pass within approximately 200 km of a saildrone (or 72-hr forecast within 300 km), we will program the saildrone to move to a location in the TC's predicted path. The saildrone will then travel in a repeated bow-tie pattern until the TC arrives (Figure 1). Upon arrival, the saildrone will be directed near the center of the storm (Figure 1). Saildrone speeds will depend on winds. The saildrone will then obtain measurements for 2-3 days after TC passage before rejoining its rectangular track with the glider. The saildrone measurements in TCs will be coordinated with those from reconnaissance aircraft and sUAS when possible. To validate saildrone data before and after deployments into TCs, we will also take advantage of high-quality measurements of near-surface winds, air temperature, humidity, SST, and waves from several moored buoys that CARICOOS and NDBC maintain in the Caribbean and northwestern tropical Atlantic (blue squares in Figure 1). Based on statistics from the months of August and September 1995-2018, positioning saildrones off Puerto Rico will give approximately a 90% chance of measuring in TS force winds during August-September 2020-2022. This assumes a search radius of 200 km for the saildrones (based on a 48-hr forecast) and an average radius of TS-force winds of 190 km (Quiring et al. 2011).

During **Year 1** of the proposal (August 2020 - May 2021), saildrone data will be analyzed to gauge the success of the missions, including comparisons to available Stepped Frequency Radiometer, dropsonde, ocean glider, sUAS, and buoy measurements. Surface turbulent heat and moisture fluxes will be calculated using bulk formulas, and their dependence on atmospheric stability will be investigated. During **Year 2**, prior to deployment we will reposition and possibly modify, add, or remove sensors based on results from Year 1. When possible, we will coordinate with sUAS deployments, led by Dr. Cione, in order to simultaneously measure the atmosphere above the surface at altitudes as low as 100 m (Cione et al. 2016; Cione et al. 2019). We will leverage work outlined in a complementary proposal submitted by Drs. Cione and Zhang to the FY20 *Advancing NOAA Unmanned Aircraft Systems (UAS) Applications* call. The in-situ data acquired will be compared to output from TC forecasts to identify possible errors in the model physics and parameterizations. We will focus on model validation, data assimilation, and parameterizations of turbulent fluxes in TC forecast models following Zhang et al. (2012). In **Year 3** we will have learned from previous years' deployments and will further modify the deployment locations, saildrone sensors, and coordination with other measurement platforms as needed. We anticipate that after three years of deployments, we will have co-located upper-ocean and atmospheric measurements within a TC from the gliders, saildrones, aircraft, and sUAS. This unique dataset will be analyzed to quantify air-sea exchanges of enthalpy and momentum and the upper-ocean response to TCs, and to determine the value of the observations for data assimilation and TC forecasts. In **Years 2 and 3**, saildrone ocean data will be assimilated in real-time into the HWRF-HMONS model at EMC for operational hurricane prediction (please see attached letter of support on p. 26).

This work will assess how saildrones perform under strong hurricane wind conditions. We are confident that they will perform well in TS-force winds, based on past field tests performed by Saildrone in the Gulf of Alaska and in cross proximity to the track of a typhoon in the Pacific Ocean. Another risk, not unique to this proposal, is the ongoing COVID-19 pandemic. We will continue to be in close communication with Saildrone. If, due to late funding availability and situations external to the PIs, the saildrones cannot be deployed during the 2020 hurricane season, our plan is to perform analysis with synthetic real-time data from satellites and model analyses. The saildrones not deployed in 2020 would then be deployed the following year.

This project will provide for the first time coordinated operations of unmanned marine and atmospheric systems during hurricane events. The close collaboration currently in place between the project PIs and the PIs of the hurricane glider operations is key to the implementation of this project. **Note: To greatly increase the positive impact from the proposed measurements, the PIs recommend deploying 1 to 8 saildrones for 90 days each during the 2021 hurricane season at a cost of $350K-2.5M, instead of the one proposed here for 60 days at a cost of $245K. This would enable broader spatial and temporal coverage, increasing the chances of obtaining measurements ahead of and inside hurricanes that threaten landfall.**

4 Management Plan

Dr. Foltz works in AOML's Physical Oceanography Division and has expertise in using ocean observations for analyses of TC-ocean interaction. He will oversee the project and contribute with analysis of the ocean's response to TCs. Drs. J. Zhang, Cione, and Marks are part of AOML's Hurricane Research Division (HRD) and have extensive experience conducting hurricane field operations and analyzing in situ data. Dr. Marks is the HRD Division Leader and Dr. Cione is leader of sUAS hurricane research projects. Dr. J. Zhang regularly flies on NOAA hurricane reconnaissance flights and is an expert on hurricane air-sea interaction and model physics. Drs. D. Zhang and C. Zhang are part of PMEL's Ocean Climate Research Division (OCRD). They have extensive experience with oceanic and atmospheric measurements, large field campaigns, and saildrone deployments. Dr. Meinig leads the Engineering Development Division at PMEL and has decades of experience designing, testing, and deploying ocean observing platforms. U. Rivero is the leader of the engineering division at AOML and oversees underwater glider development and deployments. J. Morell is a Research Professor of Marine Science at the University of Puerto Rico Mayaguez. He leads the U.S. IOOS sponsored Caribbean Coastal Ocean Observing System (http://caricoos.org).

The entire team will have regular teleconferences prior to and during the August-September saildrone deployments in order to refine the deployment plans and make decisions about whether to direct the saildrones into an approaching TC. Team members from AOML/HRD will provide regular updates on anticipated reconnaissance aircraft missions in order to coordinate with saildrone measurements. One in-person meeting is planned for October-November of Years 2 and 3 in order to make rapid progress on data analysis. Marine Scientific Research authorization requests and saildrone shipping and deployments/recoveries will be handled by Saildrone.

The three main outcomes of this proposed work will be to 1) Conduct a coordinated across-NOAA operation of unmanned vehicles for hurricane forecasts; 2) Obtain collocated

subsurface ocean and near-surface atmospheric observations to be incorporated in real-time into forecast models; 3) Assess data impact to understand ocean-atmosphere observations that are most valuable during hurricane events and have a strong potential for transition into routine operations. The specific timeline is as follows (green indicates key milestones, red is for deliverables):

2020

Aug-Sep	Deploy 1-8 saildrones, coordinate with gliders	Saildrone, Morell, Rivero
	Coordinate with TC aircraft measurements	Marks, J. Zhang

2 months of collocated upper-ocean and sfc. flux measurements from autonomous vehicles, made available to EMC, NHC, and other operational centers on the GTS.

Success criteria: Saildrones able to stay with gliders for co-located sampling; all saildrone and glider data transmitted successfully; ocean data included in EMC's TC prediction models.

Real-time data streams to forecast centers via GTS.

Oct-Dec	Conf. call to evaluate mission, data	All
	Begin saildrone, glider data analysis	J. Zhang, D. Zhang

2021

Jan-Jul	Analysis: sfc. fluxes, evaluation of models	J. Zhang, D. Zhang
Aug-Sep	Deploy saildrones to follow gliders, sample TC	Saildrone, Morell, Rivero
	Coordinate with TC aircraft, sUAS	Marks, Cione, J. Zhang

Real-time data streams to forecast centers via GTS; assimilation in HWRF/HMONS.

Oct-Dec	Recover saildrone, in-person meeting, analysis	All

2022

Jan-Jul	Analysis: sfc. fluxes, params., model valid.	J. Zhang, D. Zhang

Post-mission quality-controlled dataset of co-located upper-ocean and near-surface atmospheric data from saildrones and gliders.

Identification of model deficiencies in predicting TC intensity in HWRF and/or HAFS in terms of air-sea coupling process.

Aug-Sep	Deploy saildrones to follow glider, sample TC	Saildrone, Morell, Rivero
	Coordinate with other aircraft, sUASs	Marks, Cione, J. Zhang

Real-time data streams to forecast centers via GTS; assimilation in HWRF/HMONS.

Continuous near-surface ocean-atmosphere measurements in sustained tropical storm-force winds.

Success criteria: One or more saildrones directed into TC; most saildrone sensors continue returning high-quality data in real-time.

Oct-Dec	Recover saildrone, in-person meeting, analysis	All

2023

Jan-May	Analysis: sfc. fluxes, ocean response to TCs,	J. Zhang, D. Zhang, Foltz

Post-mission quality-controlled data for public use.

Written report of model discrepancies, error statistics, and recommendations for model improvement for HWRF and/or HAFS.

Report on value of saildrone obs., and coordinated obs. with gliders, aircraft, sUAS, for data assimilation and TC intensity prediction.

Final project report describing mission accomplishments, setbacks, and recommendations for sustained autonomous measurements.

Quarterly progress report briefings will be provided as requested by program managers.

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5 AOML Budget

(a) Salaries

Funds are requested to cover two months per year of salary, benefits, and indirect costs for Dr. Jun Zhang, a Senior Researcher at AOML. Dr. Zhang will be responsible for research related to air-sea heat, moisture, and momentum fluxes and hurricane model validation and improvement. Funds are also requested during Years 2 and 3 to cover four months per year of salary and related costs for a TBD research scientist at AOML. This research scientist will be responsible for analysis of the value of saildrone atmospheric measurements for data assimilation and aiding in the analysis of the oceanic response to TCs, using data from ocean gliders and saildrones. The costs associated with Dr. Jun and the TBD research scientist will be paid through a subcontract to the Cooperative Institute for Marine and Atmospheric Studies (CIMAS) at the University of Miami. The current benefits rate at CIMAS is 38.3% of contracted salary, and indirect costs are 26% of salary and benefits. There is a 3% fee on all funds transferred to CIMAS. Dr. Foltz will contribute two months per year at no cost to the proposal. He will be responsible for overseeing the project and the analysis of the oceanic response to TCs. An annual inflation rate of 3% has been applied to all expenses listed in Years 2 and 3.

(b) Equipment

Funds are requested in all years for the rental of one saildrone for 60 days at a cost of $2575 per day, plus saildrone shipping expenses and travel for Saildrone employees to deploy and recover the saildrones.

(c) Publications and Supplies

Funds are requested for the publication of one full-length article in an AGU/AMS journal during Years 2 and 3 of the proposal.

(d) Travel

In Year 2, funds are requested for Foltz, Marks, Cione, and Zhang to attend an in-person meeting with PMEL participants in Seattle. Funds are also requested to attend the Fall AGU meeting in San Francisco to present results. In Year 3, funds are requested to attend the Fall AGU meeting.

AOML YEAR 1

		mo	AOML In Kind	**UxS Req.**
G. Foltz (AOML)	PI	2	$21,099	
F. Marks (AOML)	Sen. Res.	1	$14,660	
J. Cione (AOML)	Sen. Res.	1	$14,263	
J. Zhang (CIMAS)	Sen. Res.	2		**$16,840**
TBD (CIMAS)	Res. Sci.	0		**$0**
TOTAL SALARIES			$50,022	**$16,840**
BENEFITS (NOAA 33%; CIMAS 38.3% in Y1)			$16,507	**$6,450**
TOTAL SALARIES & BENEFITS			$66,529	**$23,290**
Saildrone expenses				
Rental	60days @$2575/day			**$154,500**
Shipping				**$20,000**
Travel				**$10,000**
Travel (meetings)				
Travel (conferences)				
Publication costs				**$0**
Modified Total Direct Costs:			$66,529	**$207,790**
Indirect Costs (NOAA 53%; CIMAS 26%)			$35,260	**$54,025**
3% Management Fee on CIMAS transfer				**$7,854**
TOTAL AOML COSTS: YEAR 1			$101,790	**$269,670**

AOML YEAR 2

		mo	AOML In Kind	**UxS Req.**
G. Foltz (AOML)	PI	2	$21,731	
F. Marks (AOML)	Sen. Res.	1	$15,100	
J. Cione (AOML)	Sen. Res.	2	$29,383	
J. Zhang (CIMAS)	Sen. Res.	2		**$17,345**
TBD (CIMAS)	Res. Sci.	4		**$30,900**
TOTAL SALARIES			$66,214	**$48,245**
BENFITS (NOAA 33%; CIMAS 38.3% in Y1)			$21,851	**$18,960**
TOTAL SALARIES & BENEFITS			$88,065	**$67,206**
Saildrone expenses				
Rental	60days @$2575/day			**$159,135**
Shipping				**$20,600**
Travel				**$10,300**
Travel (meetings)				**$10,000**
Travel (conferences)				**$12,000**
Publication costs				**$3,000**
Modified Total Direct Costs:			$88,065	**$282,241**
Indirect Costs (NOAA 53%; CIMAS 26%)			$46,674	**$69,444**
3% Management Fee on CIMAS transfer				**$10,096**
TOTAL AOML COSTS: YEAR 2			$134,739	**$361,781**

AOML YEAR 3

		mo	AOML In Kind	**UxS Req.**
G. Foltz (AOML)	PI	2	$22,383	
F. Marks (AOML)	Sen. Res.	1	$15,553	
J. Cione (AOML)	Sen. Res.	2	$30,264	
J. Zhang (CIMAS)	Sen. Res.	2		**$17,866**
TBD (CIMAS)	Res. Sci.	4		**$31,827**
TOTAL SALARIES			$68,200	**$49,693**
BENFITS (NOAA 33%; CIMAS 38.3% in Y1)			$22,506	**$20,026**
TOTAL SALARIES & BENEFITS			$90,706	**$69,719**
Saildrone expenses				
Rental	60days @$2575/day			**$163,909**
Shipping				**$21,218**
Travel				**$10,609**
Travel (meetings)				
Travel (conferences)				**$12,000**
Publication costs				**$3,000**
Modified Total Direct Costs:			$90,706	**$280,455**
Indirect Costs (NOAA 53%; CIMAS 26%)			$48,074	**$70,580**
3% Management Fee on CIMAS transfer				**$10,261**
TOTAL AOML COSTS: YEAR 3			$138,781	**$361,296**

6 PMEL Budget

(a) Salaries

Funds are requested for salary support for co-PI Dr. Dongxiao Zhang (2 months per year in Years 2 and 3), Data Scientist Kevin O'Brien (1 month in Year 1 and 0.5 months per year in Years 2 and 3), and TBD Engineer (1 mo in yr1 and 0.75 mo/yr in yr2 and yr3) of JISAO/University of Washington. D. Zhang will serve as the saildrone mission manager and be responsible for saildrone data QC and analysis. O'Brien will be responsible for real time data transmission to PMEL data server and GTS. The TBD engineer will be responsible for modifying and calibrating the radiometers before and after each saildrone mission. The benefits rate at JISAO/UW is 32.1%. The off-campus overhead rate for JISAO/UW employees working at PMEL is 26%, the PMEL overhead rate is 18.5% of salary, benefits, and JISAO overhead. There is a 2.8% fee on all funds transferred to JISAO. A 4% COLA is included in the Year 2 and 3 budgets.

(b) Travel and publications

Funds are requested for 3 domestic trips per year for Drs. D. Zhang, C. Zhang, and C. Meinig to attend conferences and in person meetings with collaborators at AOML and Saildrone, Inc. Computer charges, internet connection, and publication charges are also included in the budget.

(c) Leveraged NOAA costs

In-kind contributions include NOAA PMEL federal salaries for C. Zhang (1 month per year) and C. Meinig (1 month per year), and JISAO/UW salaries for D. Zhang (2 months in Year 1).

Budget category	**FY20**	**FY21**	**FY22**	**3-Year Total**
JISAO/Univ. of Washington Salaries and Benefits	$25,431	$45,461	$47,279	$118,171
Equipment: 1 Eppley PIR + 1 Sunshine Pyranometer SPN1	$10,550	$0	$0	$10,550
Sensor Calibration: Radiometer calibration and shipping	$1,000	$1,000	$1,000	$3,000
Computer IT connection	$700	$1,138	$1,138	$2,976
Publication Charge	$0	$0	$3,000	$3000
Travels: 3 Domestic trips / yr	$9,900	$9,900	$9,900	$29,700
OH/ Ind. Cost	$13,603	$24,317	$25,290	$63,210
Total	$61,184	$81,816	$87,607	**$230,607**

6 Curriculum Vitae

Gregory R. Foltz

Professional Experience

2010-present *Oceanographer*
NOAA/Atlantic Oceanographic and Meteorological Laboratory
Physical Oceanography Division, Miami, FL

2006-2010 *Research Scientist*
Joint Institute for the Study of the Atmosphere and Ocean
University of Washington, Seattle, Washington

2003-2006 *National Research Council postdoctoral fellow*
NOAA/Pacific Marine Environmental Laboratory
Ocean Climate Research Division, Seattle, Washington

Education

2003 University of Maryland, Ph.D., Meteorology
Dissertation title: "Tropical Atlantic Seasonal Variability"

1999 Colby College, B.A., Physics, magna cum laude

Awards and Professional Service

Member, CLIVAR Atlantic Region Panel, 2020-present
Member, PIRATA Scientific Steering Group, 2017-present
Editor, *Journal of Physical Oceanography*, 2015-present
Member, Editorial Board, *Climate*, 2012-present
Member, CLIVAR Process Study and Model Improvement Panel, 2016-2019
Co-chair, U.S. CLIVAR Workshop: Atmospheric Convection and Air-sea Interactions over the Tropical Oceans, May 2019
Member, 2018 IUGG Early Career Scientist Award Committee
Session Chair, "Tropical Cyclone-Ocean Interactions: from Weather to Climate," AGU Ocean Sciences Meeting, 2016, 2018, 2020
Member, U.S. Group on Earth Observations (USGEO) 2nd Earth Observation Assessment (EOA2), 2015-2016
International Union of Geodesy and Geophysics (IUGG) Early Career Scientist Award, 2015

Other Professional Activities

Principal Investigator, Prediction and Research moored Array in the Tropical Atlantic (PIRATA) Northeast Extension, 2010-present
Chief Scientist, PIRATA Northeast Extension cruise, 7 Mar - 14 Apr 2018, 11 Nov - 8 Dec 2013
Past/present advisor/mentor for 2 Ph.D. students, 2 postdoctoral researchers, 6 undergraduate/graduate interns, 1 high school intern

Selected Refereed Publications

Balaguru, K., G. R. Foltz, L. R. Leung, J. Kaplan, W. Xu, N. Reul, and B. Chapron, 2020: Pronounced impact of salinity on rapidly intensifying tropical cyclones, *Bull. Am. Meteorol. Soc.*, doi:10.1175/BAMS-D-19-0303.1, in press.

Domingues, R., et al., 2019: Ocean observations in support of studies and forecasts of tropical and extratropical cyclones, *Front. Mar. Sci*., 6, 446, doi:10.3389/fmars.2019.00446.

Rodrigues, R. R., A. S. Tashetto, A. Sen Gupta, and G. R. Foltz, 2019: Common cause for severe droughts in South America and marine heatwaves in the South Atlantic, *Nature Geosci*., 12, 620-626, doi:10.1038/s41561-019-0393-8.

Foltz, G. R., et al., 2019: The Tropical Atlantic Observing System, *Front. Mar. Sci*., 6, 206, doi:10.3389/fmars.2019.00206.

Bourles, B., M. Araujo, M. J. McPhaden, P. Brandt, G. R. Foltz, et al., 2019: PIRATA: A sustained observing system for tropical Atlantic climate research and forecasting, *Earth and Space Sci.*, 6, 577-616, doi:10.1029/2018EA000428.

Balaguru, K., G. R. Foltz, and L. R. Leung, 2018: Increasing magnitude of hurricane rapid intensification in the central and eastern tropical Atlantic. *Geophys. Res. Lett*., 45, doi:10.1029/2018GL077597.

Foltz, G. R., K. Balaguru, and S. Hagos, 2018: Interbasin differences in the relationship between SST and tropical cyclone intensification. *Mon. Wea. Rev*., 146, 853-870, doi:10.1175/MWR-D-17-0155.1.

Balaguru, K., G. R. Foltz, L. R. Leung, S. Hagos, and D. R. Judi, 2018: On the use of ocean dynamic temperature for hurricane intensity forecasting. *Wea. Forecasting*, 33, 411-418, doi:10.1175/WAF-D-17-0143.1.

Foltz, G. R., C. Schmid, and R. Lumpkin, 2018: An enhanced PIRATA data set for tropical Atlantic ocean-atmosphere research. *J. Climate*, 31, 1499-1524, doi:10.1175/JCLI-D-16-0816.1.

Wang, X., H. Liu, and G. R. Foltz, 2017: Persistent influence of tropical North Atlantic wintertime sea surface temperature on the subsequent Atlantic hurricane season. *Geophys. Res. Lett.*, 44, doi:10.1002/2017GL074801.

Balaguru, K., G. R. Foltz, L. R. Leung, and K. A. Emanuel, 2016: Global warming-induced upper-ocean freshening and the intensification of super typhoons. *Nature Comm*., 7, 13670, doi:10.1038/ncomms13670.

Foltz, G. R., and K. Balaguru, 2016: Prolonged El Nino conditions in 2014-15 and the rapid intensification of Hurricane Patricia in the eastern Pacific. *Geophys. Res. Lett*., 43, 10,347-10,355, doi:10.1002/2016GL070274.

Balaguru, K., G. R. Foltz, L. R. Leung, E. A. D'Asaro, K. A. Emanuel, H. Liu, and S. E. Zedler, 2015: Dynamic Potential Intensity: An improved representation of the ocean's impact on tropical cyclones. *Geophys. Res. Lett*., 4, 6739-6746, doi:10.1002/2015GL064822.

Balaguru, K., S. Taraphdar, L. R. Leung, G. R. Foltz, and J. A. Knaff, 2014: Cyclone-cyclone interactions through the ocean pathway. *Geophys. Res. Lett.*, 41, 6855-6862, doi:10.1002/2014GL061489.

Balaguru, K., S. Taraphdar, L. R. Leung, and G. R. Foltz, 2014: Increase in the intensity of post-monsoon Bay of Bengal tropical cyclones. *Geophys. Res. Lett*., 41, 3594-3601, doi:10.1002/2014GL060197.

Evan, A. T., G. R. Foltz, D. Zhang, and D. J. Vimont, 2011: Influence of African dust on ocean-atmosphere variability in the tropical Atlantic. *Nature Geosci*., 4, 762-765, doi:10.1038/ngeo1276.

Foltz, G. R., S. A. Grodsky, J. A. Carton, and M. J. McPhaden, 2003: Seasonal mixed layer heat budget of the tropical Atlantic Ocean. *J. Geophys. Res. Oceans*, 108, 3146, doi:10.1029/2002JC001584.

CURRICULUM VITAE: Dongxiao Zhang

NOAA/PMEL and JISAO/University of Washington
7600 Sand Point Way, NE. Seattle, WA 98115
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Education

1999 Ph.D., RSMAS/University of Miami, Physical Oceanography.
1993 M.S., Chinese Academy of Science, China, Physical Oceanography.
1990 B.S., Ocean University of China, China, Physical Oceanography.

Professional Experience

2009–present Senior Research Scientist, GTMBA Principal Investigator and Supervisor, JISAO
2001–2009 Research Scientist, JISAO
2000–2001 Postdoctoral Research Associate, JISAO, University of Washington

Selected Relevant Publications

Zhang, D., M.F. Cronin, C. Meinig, J.T. Farrar, R. Jenkins, D. Peacock, et al. 2019: Comparing Air-sea flux measurements from a new unmanned surface vehicle and proven platforms during the SPURS-2 Field Campaign. ***Oceanography***, 32(2): 122-133, https://doi.org/10.5670/oceanog.2019.220, 2019.

Hogikyan, A., M. F. Cronin, D. Zhang, and S. Kato, 2020: Uncertainty in Net Surface Heat Flux due to Differences in Commonly Used Albedo Products. ***J. Clim.***, 33(1), 303–315.

Cronin, M.F., et al. 2019: Air-sea fluxes with a focus on heat and momentum. OceanObs'19, ***Front. Mar. Sci.***, doi: 10.3389/fmars.2019.00430.

Meinig, C., et al. 2019: Public private partnerships to advance regional ocean observing capabilities: A Saildrone and NOAA-PMEL case study and future considerations to expand to global scale observing. ***Front. Mar. Sci***., doi: 10.3389/fmars.2019.00448, 2019.

Todd, R.E., et al. 2019: Global perspectives on observing ocean boundary current systems. Front. Mar. Sci., 6:423. doi: 10.3389/fmars.2019.00423.

Centurioni, L.R., et al. 2019: Global in situ Observations of Essential Climate and Ocean Variables at the Air–Sea Interface. ***Front. in Mar. Sci.***, 6:419. DOI 10.3389/fmars.2019.00419.

Moltmann, T., et al. 2019: A Global Ocean Observing System (GOOS), delivered through enhanced collaboration across regions, communities, and new technologies. ***Front. Mar. Sci***. 6:291. doi: 10.3389/fmars.2019.00291

Cheng, W., W. Weijer, W. Kim, G. Danabasoglu, S. G. Yeager, P. R. Gent, D. Zhang, J.C.H. Chiang, and J. Zhang, 2018: Can the salt-advection feedback be detected in internal variability of the Atlantic Meridional Overturning Circulation? ***J. Clim***., 31, 6649-6667

Zhang, D., M. F. Cronin, C. Wen, Y. Xue, A. Kumar, and D. McClurg, 2016: Assessing surface heat fluxes in atmospheric reanalyses with a decade of data from the NOAA Kuroshio Extension Observatory, ***J. Geophys. Res. Oceans***, doi:10.1002/2016JC011905.

Wang, F., J. Wang, C. Guan, Q. Ma, and D. Zhang, 2016: Mooring observations of equatorial currents in the upper 1000 m of the western Pacific Ocean during 2014, ***J. Geophys. Res. Oceans***, *121*(6), 3730–3740, doi:10.1002/2015JC011510.

Zhang, D., M. J. McPhaden, and T. Lee, 2014: Observed Interannual Variability of Zonal Currents in the Equatorial Indian Ocean Thermocline and Their Relation to Indian Ocean Dipole. ***Geophys. Res. Lett.***, 41, 7933-7941, doi: 10.1002/2014GL061449.

Cheng, W. J. Chiang and D. Zhang, 2013: Atlantic Meridional Overturning Circulation (AMOC) in CMIP5 models: RCP and Historical Simulations, ***J. Clim***.*,26,* 7187-7197.

Evans, A., G. Foltz, D. Zhang 2012: Physical response of the tropical-subtropical North Atlantic Ocean to decadal-multidecadal forcing by African dust. ***J. Clim****, 25,* 5817-5829.

Zhang, D., R. Msadek, M.J. McPhaden, and T. Delworth 2011: Multidecadal variability of the North Brazil Current and its connection to the Atlantic meridional overturning circulation. ***J. Geophys. Res*.,** 116, 201110.1029/2010JC006812.

Evans, A., G. Foltz, D. Zhang, and D. Vimont 2011: Influence of African dust on ocean–atmosphere variability in the tropical Atlantic. ***Nature Geoscience****, 4,* 762-765.

Huang, B, Y. Xue, D. Zhang, A. Kumar, and M.J. McPhaden 2010: The NCEP GODAS ocean analysis of the tropical Pacific mixed layer heat budget on seasonal to interannual time scales. ***J. Clim****., 18,* 4901-4925.

Zhang, D., and M.J. McPhaden 2006: Decadal variability of the shallow Pacific meridional overturning circulation: relation to tropical sea surface temperatures in observations and climate change models. ***Ocean Modelling***, *15*, 250-273.

McPhaden, M. J., and D. Zhang 2004: Pacific Ocean circulation rebounds. ***Geophys. Res. Lett.***, *31*, L1830, doi:10.1029/2004GL020727.

Zhang, D., W.E. Johns, T.N. Lee, 2002: The seasonal cycle of meridional heat transport at 24°N in the North Pacific and in the global ocean. ***J. Geophys. Res.,*** *107*, 10.1029/2001JC001011.

McPhaden, M.J., and D. Zhang 2002: Slowdown of the meridional overturning circulation in the upper Pacific Ocean, ***Nature,*** *415*, 603-608.

Selected Awards

• NOAA Outstanding Scientific Paper, 2004

Synergistic Activities

• Member: US CLIVAR AMOC science team (2010–present)

• Mentor to NOAA Hollings Scholars (2016, 2020)

• Advising Saildrone, Inc. to integrate ocean and meteorological sensors with the Autonomous Surface Vehicles (2016-present)

• Supervising the Tropical Atmosphere and Ocean JISAO project scientists and engineers for developing and maintaining NOAA Global Tropical Moored Buoy Array (2004-present)

• Serving as a co-PI and advising the air-sea flux measurements and calculations of the NOAA Ocean Climate Stations project (2014-present)

CURRICULUM VITAE

Christian Meinig
NOAA/Pacific Marine Environmental Laboratory
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Seattle, Washington 98115
P: 206-526-6149
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Professional Experience
Leads a team of 18 engineers and technicians specializing in the research, development, deployment and transition of ocean and atmospheric instruments and observing platforms. Supported programs are global in scope and include moorings, ships, ROVs and unmanned and autonomous vehicles. Duties include all leadership and management responsibilities including recruiting and retention of employees, and performance management duties to ensure that all systems are designed, developed and transitioned on time, within budget and meet all of the requirements.

- 2000 – present Director of Engineering, NOAA-PMEL
- 1998 – 2000 Project Engineer, NOAA-PMEL
- 1994 – 1998 Mechanical Engineer, NOAA-PMEL
- 1988 – 1994 Commissioned Officer, NOAA Corps

Field Experience
Thirty major research cruises totaling over 550 days at sea, in polar, equatorial and coastal waters. Roles as a ship's officer, project engineer and chief scientist. 12 cruises involved submersibles, ROVs, AUVs, USVs and underwater gliders.

Education
1998 M.S., Mechanical Engineering, University of Washington
1987 B.S., Mechanical Engineering, University of Maryland

Professional Activities
- Washington State Maritime Blue Advisory Committee, 2019 – present
- Intergovernmental Oceanographic Commission (IOC), International Tsunameter Partnership Group,
  2007 – present
- NOAA UxS Strategic Planning and Implementation Committee, 2019-present
- NOAA Ecosystems Monitoring Working Group SME, 2019
- NOAA-OAR Engineering Forum Lead, 2019
- Oceans 2018 Lithium Battery Workshop Chair, 2018
- ITU-WMO-UNESCO IOC Joint Task Force, Engineer Chair, 2012 – 2014
- Journal of Operational Oceanography, Editorial Staff, 2007 – 2012
- National Sea Grant Technology Advisory Board, 2000 - 2002

Honors and Awards

- NOAA Administrator's Award: *For creating the nation's first, comprehensive, underwater sound sensing network including all U.S. coastal regions and several marine national parks, 2019*
- U.S. Department of Commerce Gears of Government Award (Group): *Created the newest system for detecting a tsunami, allowing more time to alert potentially impacting citizens, 2019*
- U.S. Department of Commerce Bronze Medal (Group): *For strengthening NMSF-OAR collaborations through the pioneering use of a Saildrone for next-generation ecosystem surveys in the Bering Sea, 2018*
- U.S. Department of Commerce Silver Medal (Group): *For the successful deployment and recovery of acoustic mooring and first long-term record of ambient sound at Challenger Deep, 2017*
- U.S. Department of Commerce Silver Medal*: For developing a multi-platform observing array to collect data on ocean acidification in the Gulf of Alaska, 2015*
- NOAA Technology Transfer Award: *For developing a sensor to measure CO2 and transferring the design to industry, 2011*
- NOAA Technology Transfer Award: *For the invention of DART tsunami technology, which allows NOAA to produce accurate forecasts through a patent license and generate new US jobs, 2008*
- U.S. Department of Commerce Bronze Medal: *For personal and professional excellence as the Nation's experts and spokespersons on tsunamis following the December 26, 2004 Indian Ocean tsunami, 2007*
- U.S. Department of Commerce Gold Medal: *For research and development leading to the creation of a tsunami forecasting capability, 2005*
- U.S. Department of Commerce Gold Medal: *For the creation and use of a new moored buoy system to provide accurate and timely warning information of tsunamis, 2004*
- NOAA Administrator's Award: *"New Millennium Observatory Network", 2003*

Patents

U.S. Patent 7,244,155; Nye, Milburn, Meinig*: Mooring line for an oceanographic buoy system, issued August 21, 2006*

U.S. Patent 7,289,907; Meinig, Stalin, Nakamura, Milburn: *System for reporting high resolution ocean pressures in near realtime for the purpose of tsunami monitoring, issued October 30, 2007*

Relevant Media Coverage

- Seattle Times*, 'Sneaky' underwater robot spent 18 days recording sea creatures — and noisy humans, too, Dec 2019*
- NBC KTUU Anchorage, *Saildrones return from the Arctic after milestone research mission, Nov 2019*
- Seattle Times, *Saildrones go where humans can't — or don't want to — to study the world's oceans, July 2018*

- Science Daily, "*Seven miles deep, ocean still a noisy place*", *Mar 2016*
- Newsweek, *"Scientists Find Ocean Floor Noisier Than Expected", Mar 2016*
- New York Times, *"No Sailors Needed: Robot Sailboats Scour the Oceans for Data", Sept 2016*
- Government Computer News, *"NOAA Aquatic Bots Break the Ice on Climate Research", Nov 2012*
- NPR-Earthfix, "*The Five Coolest things about Ocean-Exploring Robots", Nov 2011*
- IEEE Spectrum, Philip E. Ross*, "Waiting and Waiting for the Next Killer Wave", March 2005*
- American Museum of Natural History, *"Fear the Future Tsunami?", October 2005*
- Newshour with Jim Lehrer*, "Tsunami Alert", January 11, 2005*
- Modern Marvels, History Channel, *"Nature Tech:Tsunamis", July 8, 2003*

Selected Recent Publications

Meinig, C., E.F. Burger, N. Cohen, E.D. Cokelet, M.F. Cronin, J.N. Cross, S. de Halleux, R. Jenkins, A.T. Jessup, C.W. Mordy, N. Lawrence-Slavas, A.J. Sutton, D. Zhang, and C. Zhang (2019): Public private partnerships to advance regional ocean observing capabilities: A Saildrone and NOAA-PMEL case study and future considerations to expand to global scale observing. *Front. Mar. Sci., 6*, 448, Oceanobs19: An Ocean of Opportunity, doi: 10.3389/fmars.2019.00448.

Haxel, J.H., H. Matsumoto, C. Meinig, G. Kalbach, T.-K.A. Lau, R.P. Dziak, and S. Stalin (2019): Ocean sound levels in the northeast Pacific recorded from an autonomous underwater glider. *PLoS One, 14(11)*, e0225325, doi: 10.1371/journal.pone.0225325.

Alex De Robertis, Noah Lawrence-Slavas, Richard Jenkins, Ivar Wangen, Calvin W Mordy, Christian Meinig, Mike Levine, Dave Peacock, Heather Tabisola, Long-term measurements of fish backscatter from Saildrone unmanned surface vehicles and comparison with observations from a noise-reduced research vessel, *ICES Journal of Marine Science*, , fsz124, https://doi.org/10.1093/icesjms/fsz124

Haver, S.M., J. Gedamke, L.T. Hatch, R.P. Dziak, S. Van Parijs, M.F. McKenna, J.P. Barlow, C. Berchok, E. DiDonato, B. Hanson, J. Haxel, M. Holt, D. Lipski, H. Matsumoto, C. Meinig, D.K. Mellinger, S.E. Moore, E.M. Oleson, M.S. Soldevilla, and H. Klinck (2018): Monitoring long-term soundscape trends in U.S. waters: The NOAA/NPS Ocean Noise Reference Station Network. *Mar. Policy, 90*, 6–13, doi: 10.1016/j.marpol.2018.01.023.

Dziak, R.P., J.H. Haxel, H. Matsumoto, T.-K. Lau, S. Heimlich, S. Nieukirk, D.K. Mellinger, J. Osse, C. Meinig, N. Delich, and S. Stalin (2017): Ambient sound at Challenger Deep, Mariana Trench. *Oceanography*, *30*(2), 186–197, doi: 10.5670/oceanog.2017.240.

Matsumoto, H., A. Turpin, J. Haxel, C. Meinig, M. Craig, D. Tagawa, H. Klinck, and B. Hanson (2016): A real-time acoustic observing system (RAOS) for killer whales. In *Oceans '16 MTS/IEEE*, Marine Technology Society and Institute of Electrical and Electronics Engineers, IEEE, Monterey, Calif., 19–23 September 2016

Cokelet, E.D., R. Jenkins, C. Meinig, N. Lawrence-Slavas, C.W. Mordy, P.J. Stabeno, H. Tabisola, and J.N. Cross (2015): The use of Saildrones to examine spring conditions in the Bering Sea: Instrument comparisons, sea ice meltwater and Yukon River plume studies. In *Oceans 2015 MTS/IEEE*, Marine Technology Society and Institute of Electrical and Electronics Engineers, Washington, DC, 19–22 October 2015.

Cross, J.N., C.W. Mordy, H. Tabisola, C. Meinig, E.D. Cokelet, and P.J. Stabeno (2015): Innovative technology development for Arctic exploration. In *Oceans 2015 MTS/IEEE*, Marine Technology Society and Institute of Electrical and Electronics Engineers, Washington, DC, 19–22 October 2015.

Dziak, R.P., J.H, Haxel, H. Matsumoto, C. Meinig, N. Delich, J. Osse, and M. Wetzler (2015): Deployment and recovery of a full-ocean depth mooring at Challenger Deep, Mariana Trench. In *Oceans 2015 MTS/IEEE*, Marine Technology Society and Institute of Electrical and Electronics Engineers, Washington, DC, 19–22 October 2015.

Fassbender, A.J., C.L. Sabine, N. Lawrence-Slavas, E.H. De Carlo, C. Meinig, and S. Maenner Jones (2015): Robust sensor for extended autonomous measurements of surface ocean dissolved inorganic carbon. *Environ. Sci. Tech.*, doi: 10.1021/es5047183.

Meinig, C., R. Jenkins, N. Lawrence-Slavas, and H. Tabisola (2015): The use of Saildrones to examine spring conditions in the Bering Sea: Vehicle specification and mission performance. In *Oceans 2015 MTS/IEEE*, Marine Technology Society and Institute of Electrical and Electronics Engineers, Washington, DC, 19–22 October 2015.

Osse, J., S. Stalin, C. Meinig, and H. Milburn (2015): The PRAWLER, a vertical profiler: Powered by wave energy. In *Oceans 2015 MTS/IEEE*, Marine Technology Society and Institute of Electrical and Electronics Engineers, Washington, DC, 19–22 October 2015.

Thomson, J., J. Talbert, A. de Klerk, A. Brown, M. Schwendeman, J. Goldsmith, J. Thomas, C. Olfe, G. Cameron, and C. Meinig (2015): Biofouling effects on the response of a wave measurement buoy in deep water. *J. Atmos. Oceanic Tech.*, *32*(6), 1281–1286, doi: 10.1175/JTECH-D-15-0029.1.

Peralta-Ferriz, C., J.H. Morison, S.E. Stalin, and C. Meinig (2014): Measuring ocean bottom pressure at the North Pole. *Mar. Technol. Soc. J.*, *48*(5), 52–68, doi: 10.4031/MTSJ.48.5.1.

Rudnick, D.L., C. Meinig, K. Ando, S. Riser, U. Send, and T. Suga (2014): TPOS White Paper #12: Emerging technology. In *Proceedings of the Tropical Pacific Observing System 2020 Workshop, A Future Sustained Tropical Pacific Ocean Observing System for Research and Forecasting*, WMO and Intergovernmental Oceanographic Commission, La Jolla, CA, 27–30 January 2014.

Dr. Joseph J. Cione – NOAA/AOML/Hurricane Research Division (1997-)

Education: Ph.D., 1996, North Carolina State University, Meteorology

Leadership: NOAA Senior Scientist and Project Manager for small UAS Research and Operations in Tropical Cyclones

USWRP Deputy Director (1995-1996)

Coordinated USWRP initiatives with federal agencies and academia

NOAA/NASA UAS Field Program Director & Lead PI (2004-2008)

Hurricane Forecast Improvement Project (HFIP) Oceanic and Atmospheric

Operational Model Physics Evaluation Lead (2012-)

NOAA Executive Leadership Program Graduate

John A. Knauss National Sea Grant Fellow

2010 National Oceanic and Atmospheric Administration Bronze Medal

2015 US Department of Commerce Silver Medal

Selected Relevant Experience:

Two areas of expertise include analysis of atmospheric and oceanic boundary layer thermodynamic processes in hurricanes and extratropical winter storms. Throughout his career, Cione has explored difficult to observe regions and demonstrated an ability to incorporate promising research results into improved forecast operations. In late 2005 and again in November 2007, Cione led a NOAA/NASA team that successfully utilized unmanned aircraft systems (UAS) to fly into the core of two tropical systems. The 2005 mission (Tropical Storm Ophelia) was the first-ever UAS flight into a tropical cyclone while the 2007 flight (Hurricane Noel) established records for duration (17.5h) and minimum altitude (82m). Both flights collected critical near-surface wind measurements that were reported to NOAA's NHC in real time, enabling the observations to be used in subsequent public forecasts and warnings. Using NOAA's manned P-3 aircraft, two Coyote UAS, each measuring 13 pounds and 5 feet across were successfully air-deployed into the atmospheric boundary layer of Major Hurricane Edouard in 2014. Follow-on P-3/Coyote sUAS hurricane missions were also successfully conducted in Major Hurricanes Maria in 2017 and Michael in 2018.

Selected Relevant Publications and Presentations:

Cione, J.J., G. Bryan, R. Dobosy, J. A. Zhang, G. de Boer, A.Aksoy, J. Wadler, E.Kalina, B. Dahl, K. Ryan, J. Neuhaus, E. Dumas, F. Marks, A. Farber, T. Hock and X. Chen 2019: Eye of the Storm: Observing Hurricanes with a Small Unmanned Aircraft System. *Bull. Amer. Meteor. Soc. https://doi.org/10.1175/BAMS-D-19-0169.1*.

Cione, J. J., E. Kalina, E. Uhlhorn, and A. Damiano 2016: Coyote Unmanned Aircraft System Observations in Hurricane Edouard (2014). Earth Space Sci., doi:10.1002/2016EA000187

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Cione, J.J., E. A. Kalina, J. A. Zhang, E. W. Uhlhorn 2013: Observations of air-sea interaction and intensity change in hurricanes. Mon. Wea. Rev., 141, 2368–2382.

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RELEVANT PUBLICATIONS:

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UNITED STATES DEPARTMENT OF COMMERCE
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April 15, 2020

Dear Dr. Foltz,

I believe the unique measurements from your proposed project "**Unmanned observations of the upper ocean and near-surface atmosphere for improved hurricane intensity prediction**" have great potential to improve hurricane forecasts at NCEP/EMC and the physical parameterizations within our models. The collocated ocean and atmospheric measurements from saildrones and gliders will be especially valuable for validating our models and assessing errors in surface heat, moisture, and momentum fluxes. During 2021 and 2022 we will assimilate ocean data from saildrones and gliders into our operational global Real-Time Ocean Forecast System (RTOFS), which feeds into the operational HWRF and HMON hurricane prediction models. We will also test the saildrone/glider data in the ocean domains (MOM6, JEDI) of the planned Hurricane Analysis and Forecast System (HAFS).

We are excited about the prospect of continuous ocean-atmosphere measurements from unmanned vehicles during the hurricane season and look forward to continued communication with you and the other PIs and collaborators of the proposal should it receive funding.

Sincerely,

Avichal Mehra

Avichal Mehra

Chief, Dynamics and Coupled Modeling Group
Modeling and Data Assimilation Branch
NOAA/NWS/NCEP/EMC