NOAA's Atlantic Oceanographic and Meteorological Laboratory
U.S. Department of Commerce

Impact of ocean conditions on hurricane evolution and forecast during Hurricane Maria (2017)

Matthieu Le Hénaff[1,2]

Ricardo Domingues[1,2], George Halliwell[2], Francis Bringas[2], Jun Zhang[1,2], Hyun-Sook Kim[2], and Gustavo Goni[2]

(1) Univ.Miami-CIMAS, Miami, FL
(2) NOAA-AOML, Miami, FL

CIMAS

UNIVERSITY OF MIAMI
ROSENSTIEL SCHOOL of MARINE & ATMOSPHERIC SCIENCE

This work is supported by the NOAA Disaster Related Appropriation Supplemental: Improving Forecasting and Assimilation (DRAS 19 IFAA)

UNITED STATES NAVY

IOOS Integrated Ocean Observing System

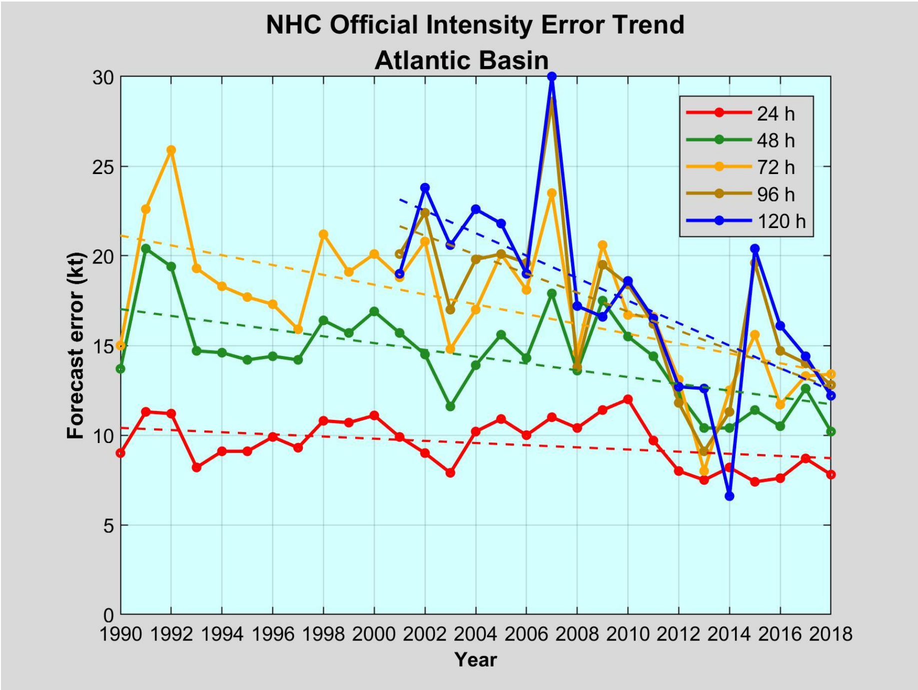
CARICOOS

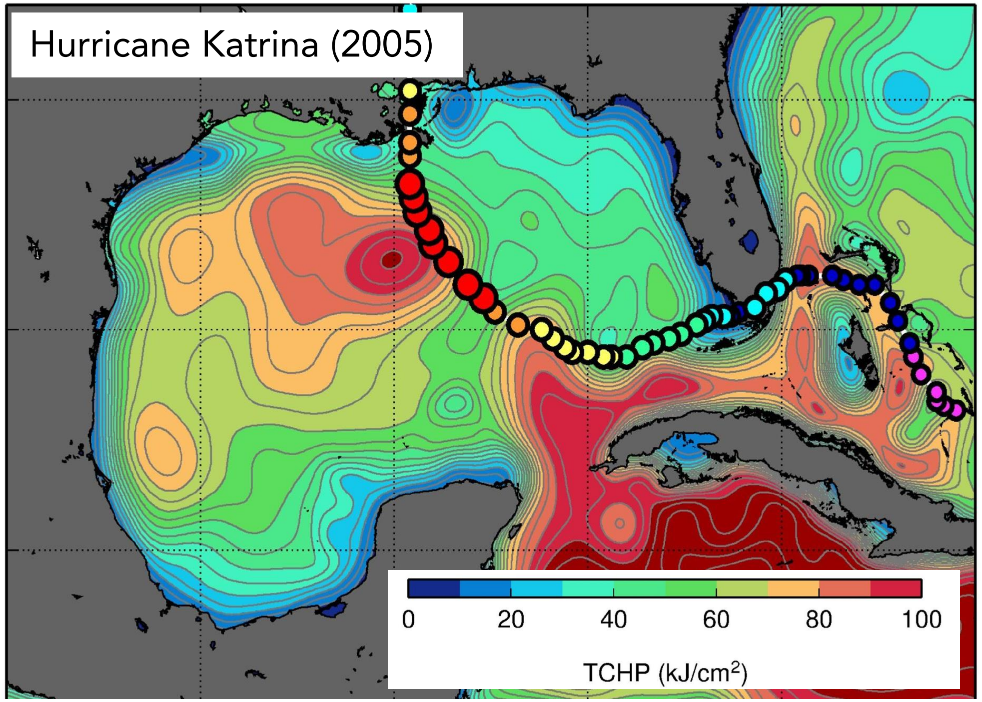
SECOORA Southeast Coastal Ocean Observing Regional Association

MARACOOS Ocean Information for a Changing World
Mid-Atlantic Regional Association Coastal Ocean Observing System

Motivation

- The skill of **hurricane intensity forecasts** has remained relatively **unchanged** over the past decades





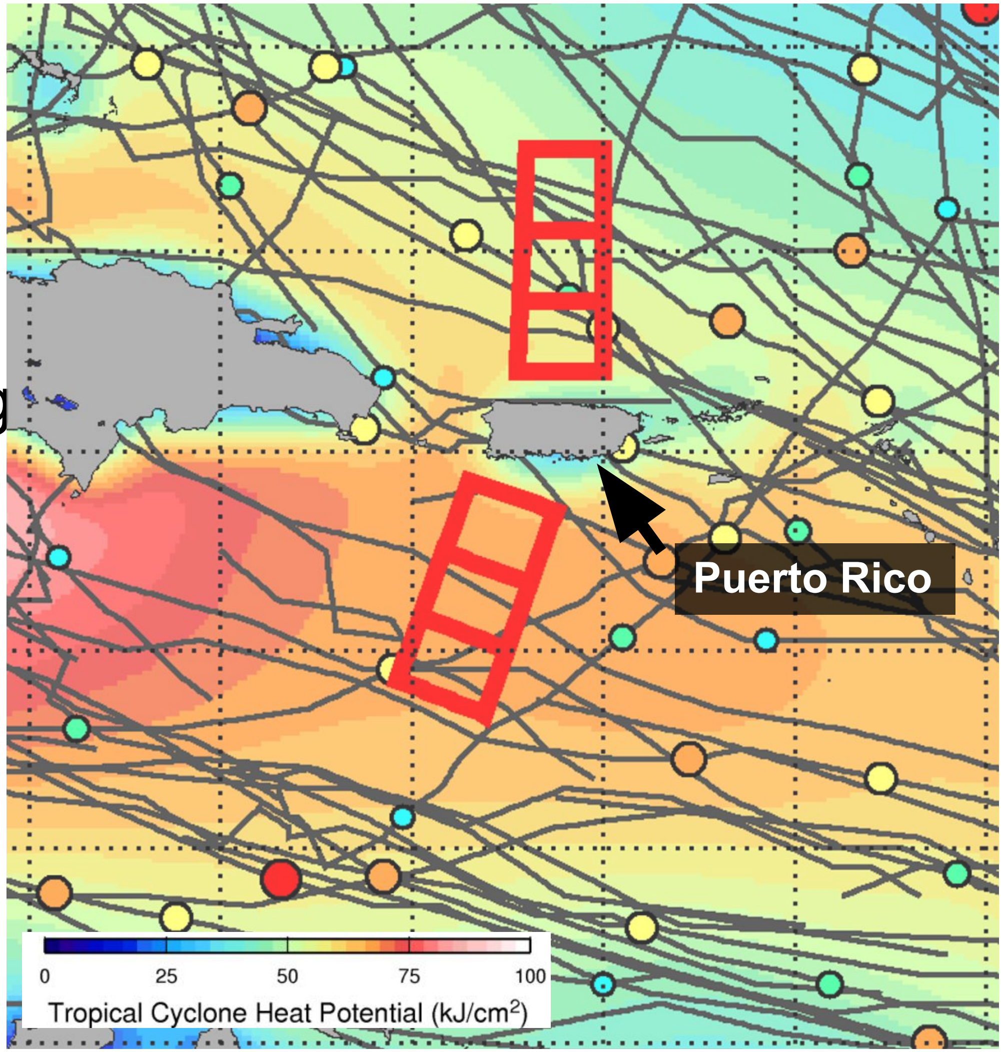
- **Ocean conditions** can **favor** hurricane **intensification**: the **upper ocean heat content** provides an **energy reservoir** that can help fuel and sustain hurricane intensification

Tropical Cyclone Heat Potential and Intensity of Hurricane Katrina in 2005.

NOAA Hurricane Glider Operations in the Tropical Atlantic

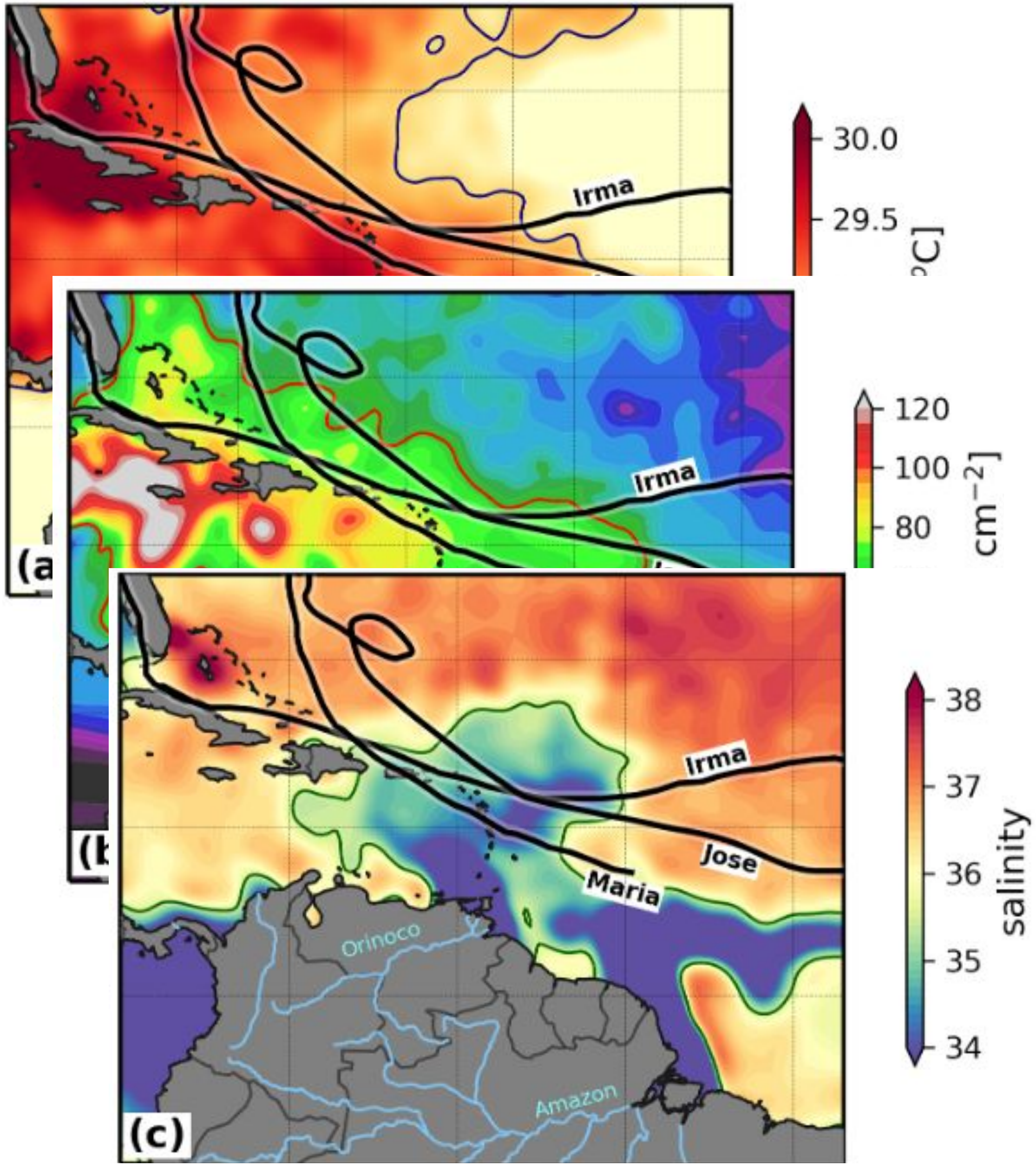
<u>Goal</u>: Help improve the accuracy of hurricane intensity forecasts

- Implement a **network of underwater gliders** to collect and transmit in real-time ocean observations from **areas where hurricanes intensify**
- **Assess the impact** of such observations in helping improve **hurricane intensity forecasts**
- ~35,000 T and S profiles since 2014
- 2014: Trop. Storm Bertha, Hurricane **Gonzalo**
- 2015: Trop. Storm Erika
- 2016: Hurricane Matthew
- **2017**: Hurricanes Harvey, **Irma, Jose** and **Maria**
- 2018: Hurricane Isaac
- 2019: Hurricane **Dorian**, Trop. Storm Karen
- 2020: Hurricane Isaias and Laura



Typical Tropical Cyclone Heat Potential around Puerto-Rico, with the glider coverage

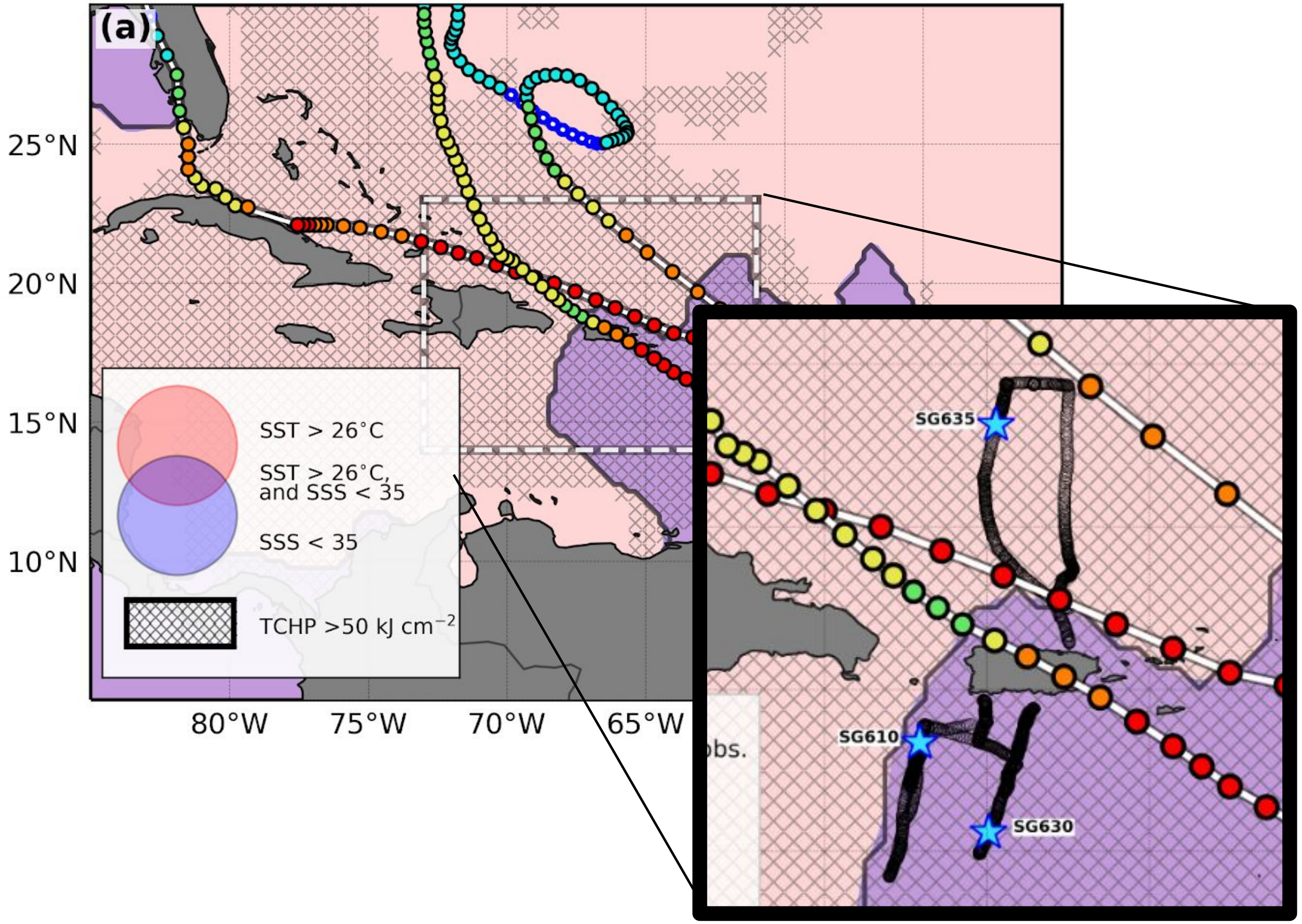
Major Atlantic Hurricanes of 2017: Irma, Jose, and Maria



Ocean Conditions in August 2017:

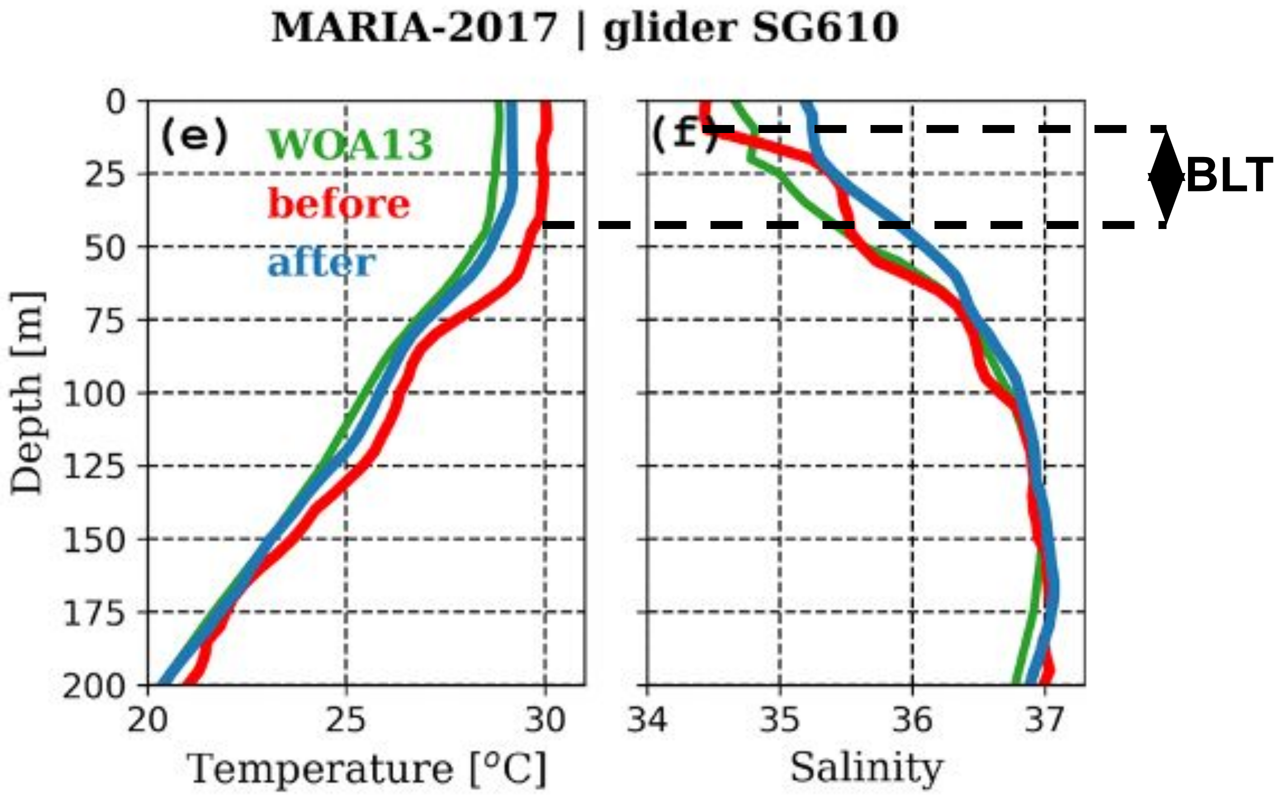
- **Warm SSTs** with values ranging from 28-30°C (values above above 26°C are required to sustain genesis and intensification)
- **Tropical Cyclone Heat Potential** (TCHP) values were consistently **above 50 kJ cm^{-2}**, which is threshold required for intensification
- Widespread **low-salinity plume** (<35) associated with the Amazon and Orinoco riverine plumes, which are generally associated with **barrier layers** that favor intensification

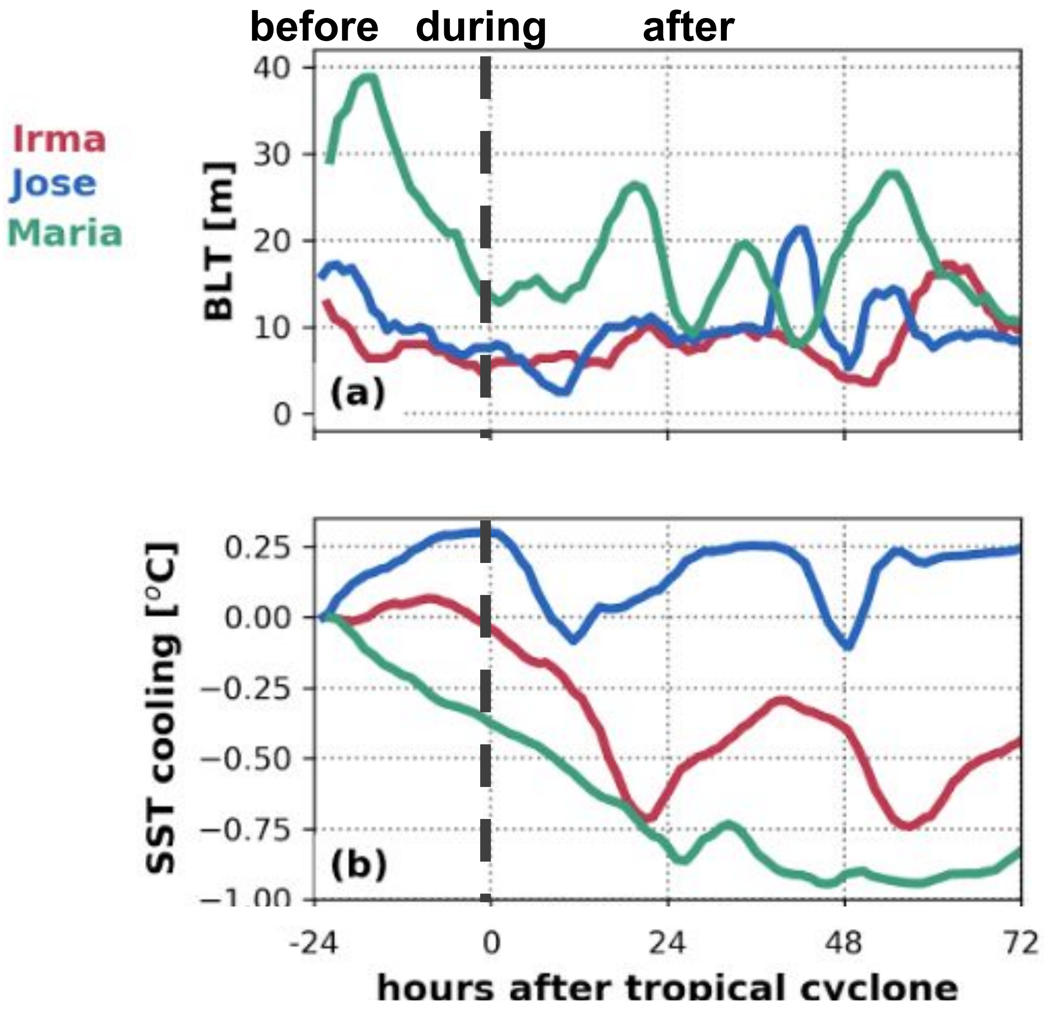
Major Atlantic Hurricanes of 2017: Irma, Jose, and Maria



- Hurricanes Irma, Jose, and Maria **reached their peak intensity** while traveling over ocean **areas with conditions more favorable than normal**
- **3 NOAA-AOML gliders** surveyed the areas **in the vicinity of** where **the hurricanes** travelled

Subsurface Ocean Conditions Sampled by the Hurricane Gliders





- Ocean **warmer than usual**
- Presence of a **barrier layer** before the passage of Hurricane Maria

- Maria: **largest Barrier Layer Thickness**
- **Limited cooling for all storms** (<1°C)

Impact of glider motion

- **Pre-existing ocean conditions** (warm SSTs, large TCHP, low SSS) helped **maintain SSTs warmer than 28°C** throughout the passage of Irma, Jose, and Maria, which likely contributed to **sustaining and favoring** further **intensification**.

Questions:

- *How much did these ocean conditions contribute to the intensification of these three hurricanes?*
- *What is the specific contribution of different components of the ocean observing system to improving their intensity forecast?*

Ocean Observing System Experiments (OSEs) and Coupled Hurricane Forecasts

Ocean OSEs
Model: HYCOM

Baseline simulations carried out for Jan.-Oct. 2017

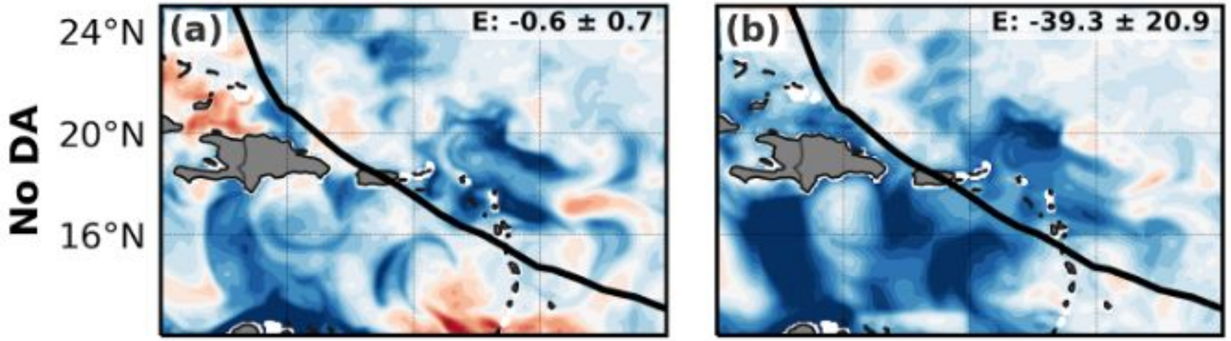
OSEs	Ocean data assimilation
No DA	No ocean data
Add Alt	Satellite-altimetry only
Add Argo	Argo profiling data only
Add gliders	Glider profiling data only
All Obs	Satellite altimetry + satellite SST +Argo profiling data + glider profiling data

Coupled Hurricane Forecats
Model: HWRF-HYCOM

- Adapted from **operational NOAA EMC** HWRF-HYCOM
- **HWRF H218** version (**3 domains** of resolution 13.5/4.5/1.5 km)
- **Initial ocean conditions** provided by the different ocean OSEs
- Atmospheric initial conditions provided by NOAA EMC reference HWRF simulation (same for all)
- Simulations: “**cycles**” of **5-day forecast** using the coupled model

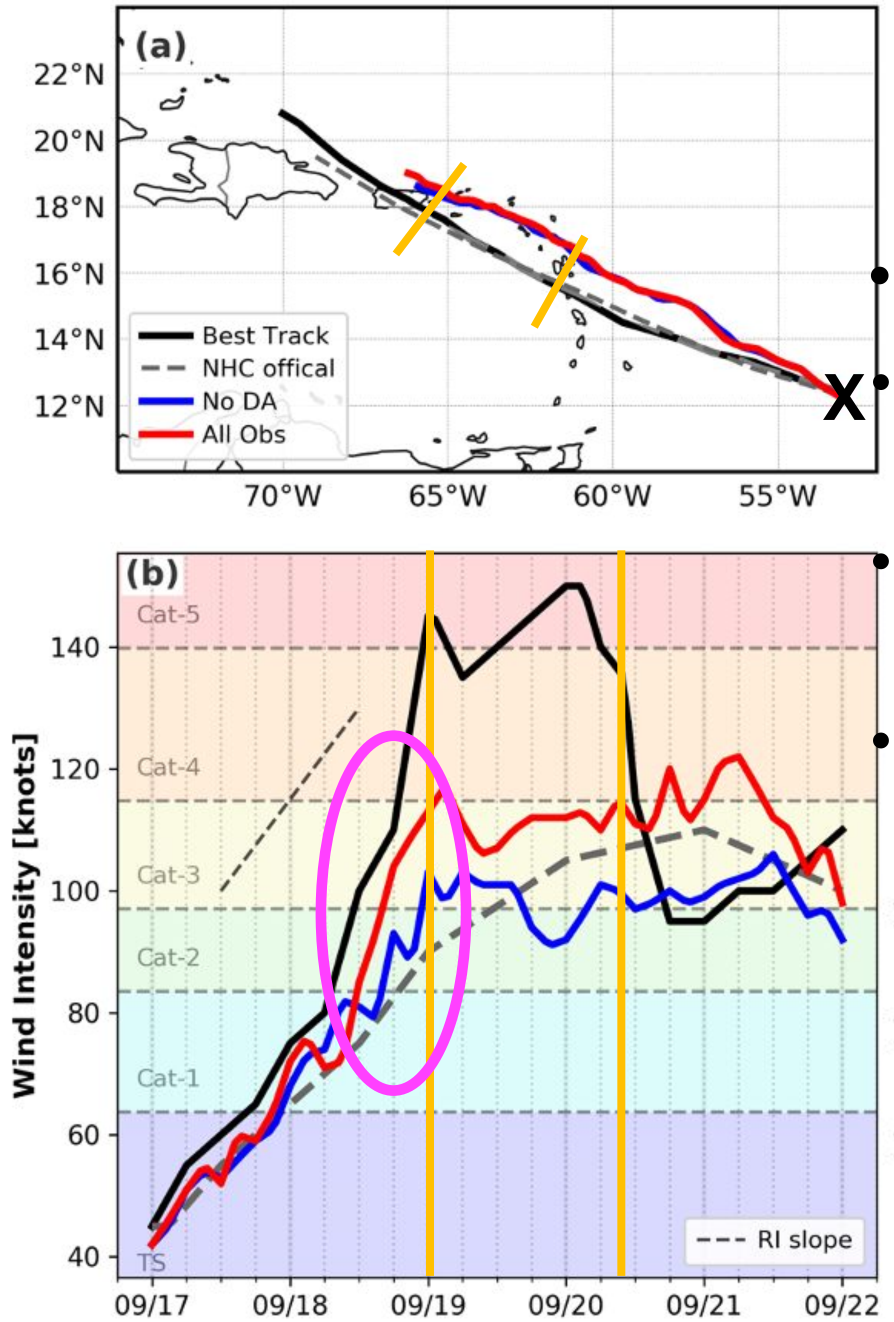
Impact of Ocean Data Assimilation on HYCOM outputs

Spatial distribution of biases



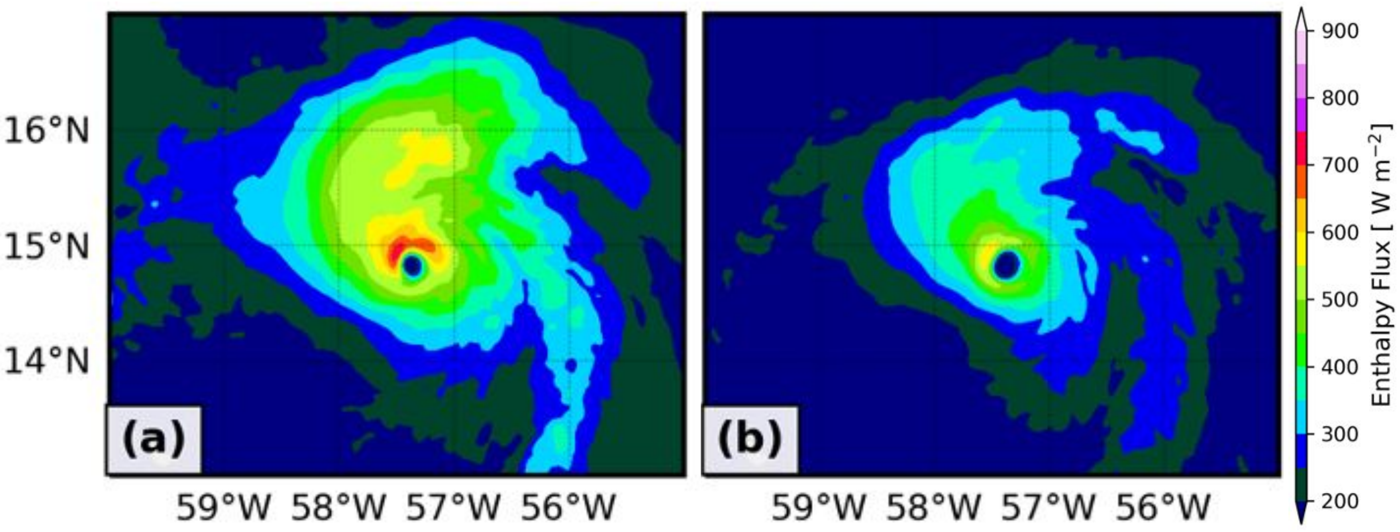
- **Without ocean data assimilation**, initialization of coupled-forecasts will generally include **cold temperature biases** in the upper-ocean

Hurricane Maria (2017): example of a coupled simulation



(a) Observed track (grey), with simulated tracks for the All Obs (red) and No DA (blue) simulations starting on 17 Sept., 00Z. (b) Wind intensities. Official forecast from NHC also included.

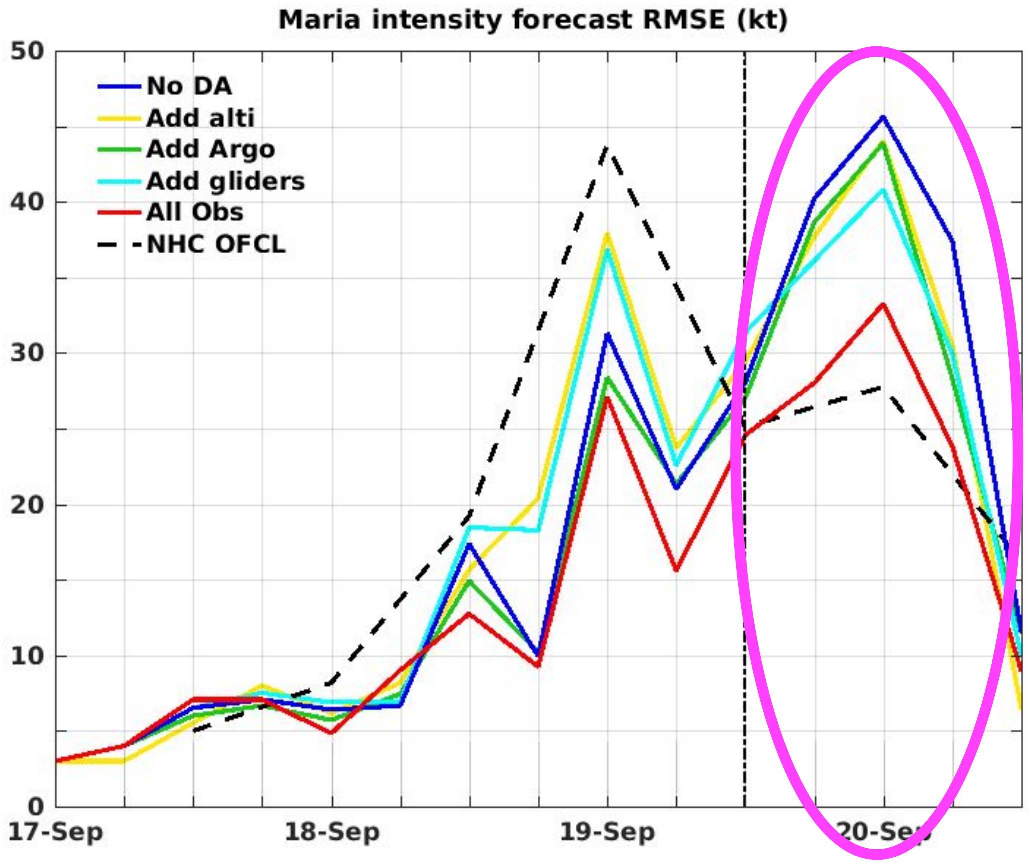
- Trajectories **north of observed** one
- "**All Obs.**" case is able to **better reproduce** the **rapid intensification than** the "**No DA**" case
- **Larger** wind intensity when **assimilating ocean observations**
- Ocean DA leads to **higher enthalpy fluxes**



Total enthalpy flux over 24-30 hours (a: All Obs, b: No DA)

Hurricane Maria (2017): ensemble statistics

- Wind intensity **Root Mean Square Error** (RMSE) over **6 forecast cycles** (start every 12 hrs during 17-19 Sept. 2017)
- Assimilation of all ocean observations ("**All Obs**", red): 20% error reduction in the 3-day intensity forecasts of Maria



24 hours preceding landfall:

- "**No DA**" (blue): **largest error** (33.7 kts)
- "**All Obs.**" (red): **lowest error** (23.5 kts **= 30% total error reduction**)
- "**Add glider**" (cyan): 44% of total error reduction, **largest contributor**
- Corresponds to the period when **the storm is over the Caribbean Sea close to Puerto-Rico**: impact of **localized glider observations**
- **High spatial density** of profiles necessary for **efficient model constraint**

Conclusions

- **Pre-existing ocean conditions** (warm SSTs, large TCHP, low SSS) helped **maintain SSTs warmer than 28°C** throughout the passage of Irma, Jose, and Maria, which likely contributed to **sustaining and favoring** further **intensification**
- **Assimilation of ocean observations** enabled an **overall 20% improvement** in the 72-hr intensity forecasts of Maria
- The **correct representation of upper ocean conditions** produced a **more realistic** characterization of ocean-atmosphere **enthalpy fluxes** for Hurricane Maria, leading to a **~30% reduction in intensity error** during the **24 hrs preceding landfall**
- Assimilation of **glider observations** alone provided **~40% of the error reduction** (largest contributor) achieved by assimilating all observations over that time window.
- **Without ocean data assimilation**, the ocean component of coupled forecasts is generally **too cold to sustain further intensification**

Reference:

- Domingues, R., M. Le Hénaff, G. Halliwell, J.A. Zhang, F. Bringas, P. Chardon, H.-S. Kim, J. Morell, and G. Goni (2021). The Impact of Ocean Conditions on the Intensification and Forecasts of three Major Atlantic Hurricanes from 2017. *Monthly Weather Review*, *149*(5), pp.1265-1286.