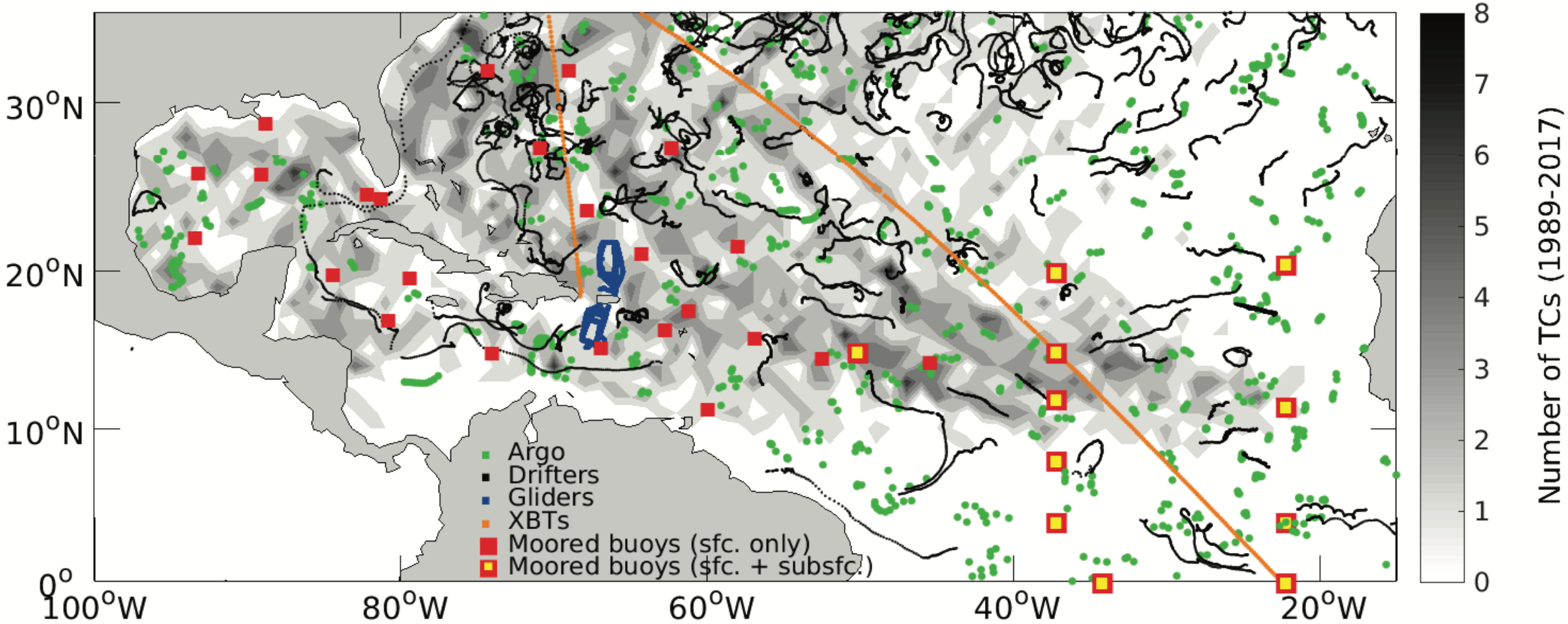
The tropical Atlantic observing system and its value for hurricane research and forecasting

Greg Foltz (Physical Oceanography Division, NOAA/AOML)



National Hurricane Center seminar, 18 July 2019

frontiers in Marine Science

REVIEW
published: 10 May 2019
doi: 10.3389/fmars.2019.00206

Check for updates

The Tropical Atlantic Observing System

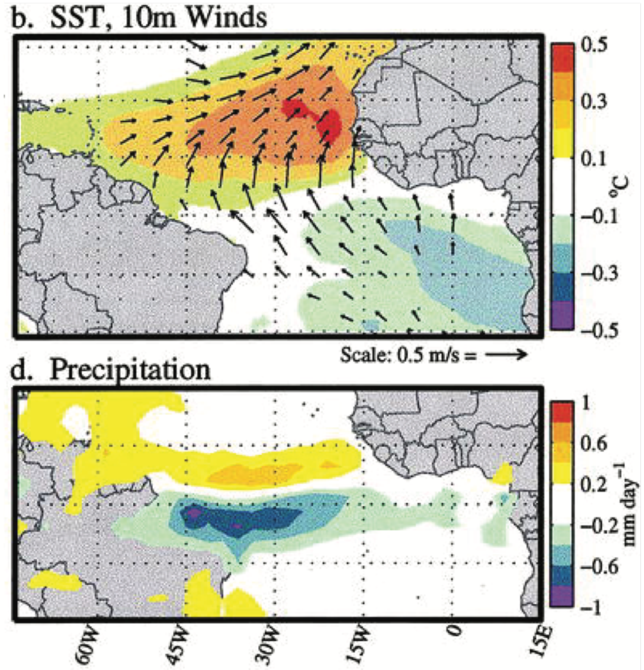
G. R. Foltz[1*], P. Brandt[2,3], I. Richter[4], B. Rodríguez-Fonseca[5,6], F. Hernandez[7,8], M. Dengler[2], R. R. Rodrigues[9], J. O. Schmidt[10], L. Yu[11], N. Lefevre[12], L. Cotrim Da Cunha[13], M. J. McPhaden[14], M. Araujo[8], J. Karstensen[2], J. Hahn[2], M. Martín-Rey[15], C. M. Patricola[16], P. Poli[17], P. Zuidema[18], R. Hummels[2], R. C. Perez[1], V. Hatje[19], J. F. Lübbecke[2,3], I. Polo[5], R. Lumpkin[1], B. Bourlès[20], F. E. Asuquo[21], P. Lehodey[22], A. Conchon[22], P. Chang[23,24], P. Dandin[25], C. Schmid[1], A. Sutton[14], H. Giordani[25], Y. Xue[26], S. Illig[27,28], T. Losada[5], S. A. Grodsky[29], F. Gasparin[30], T. Lee[31], E. Mohino[5], P. Nobre[32], R. Wanninkhof[1], N. Keenlyside[33,34], V. Garcon[27], E. Sánchez-Gómez[15], H. C. Nnamchi[2], M. Drévillon[30], A. Storto[35,36], E. Remy[30], A. Lazar[37], S. Speich[38], M. Goes[1,39], T. Dorrington[40], W. E. Johns[18], J. N. Moum[41], C. Robinson[42], C. Perruche[30], R. B. de Souza[32], A. T. Gaye[43], J. López-Parages[5], P.-A. Monerie[44], P. Castellanos[45], N. U. Benson[46], M. N. Hounkonnou[47], J. Trotte Duhá[48], R. Laxenaire[38] and N. Reul[49]

Domingues et al., 2019: **Ocean Observations in Support of Studies and Forecasts of Tropical and Extratropical Cyclones**. *Front. Mar. Sci.*, accepted.

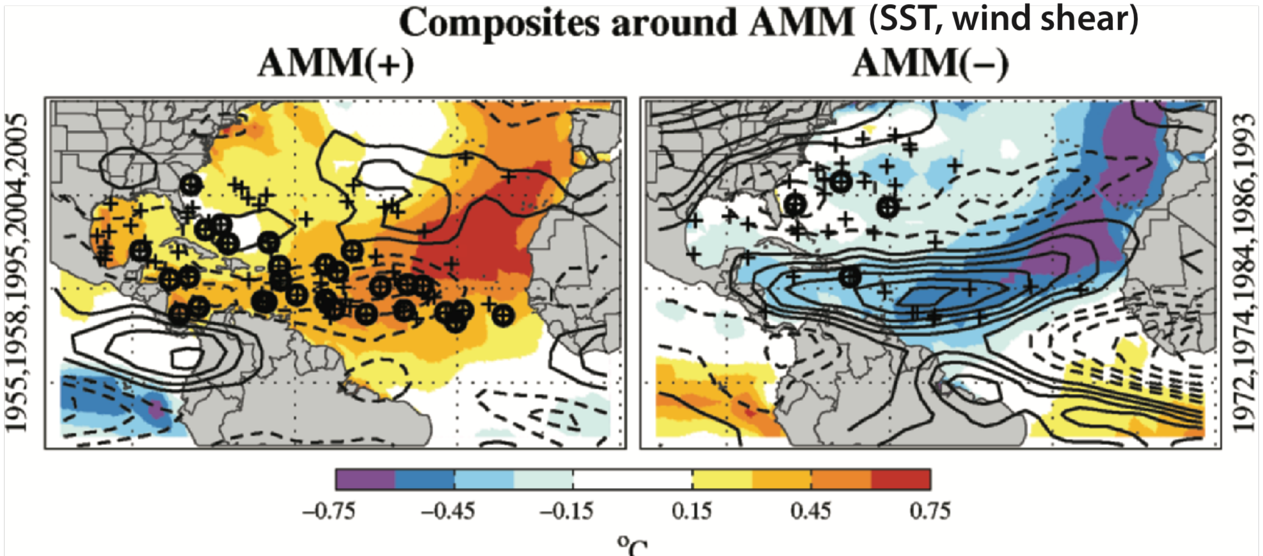
Outline

- Importance of the ocean (weekly to multidecadal)
- Existing sustained observing system
- Recommendations for the future observing system
- Importance of salinity for hurricane rapid intensification

Atlantic Meridional Mode and hurricanes

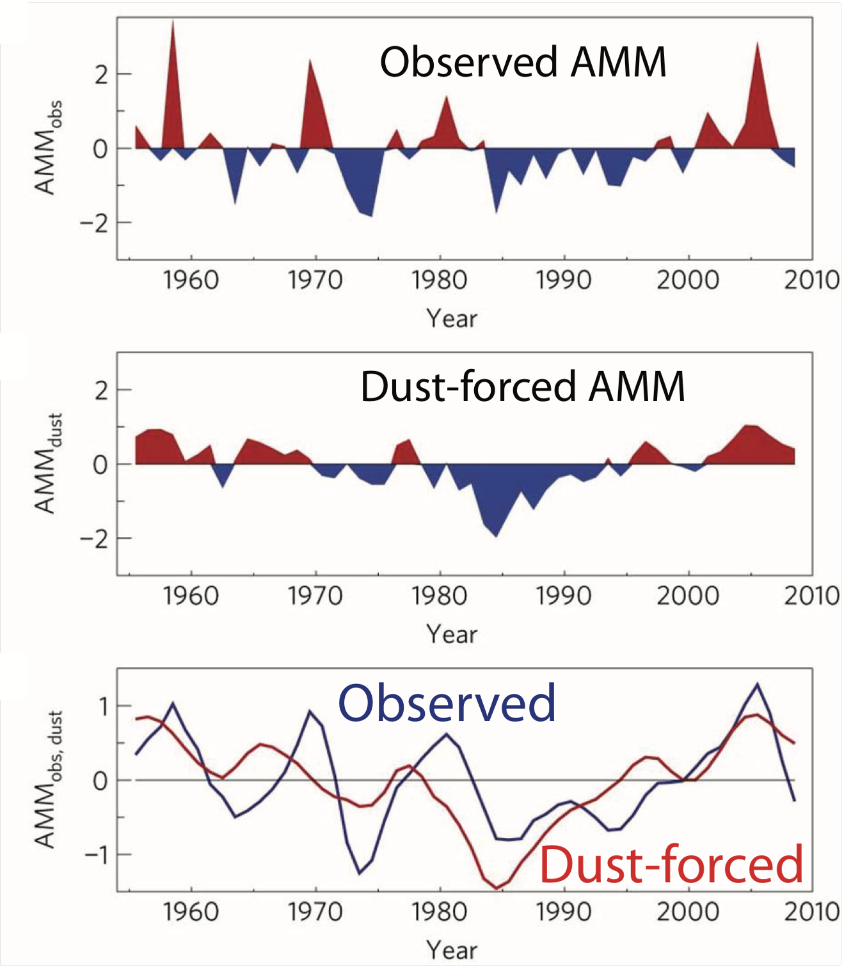


Chiang and Vimont 2004



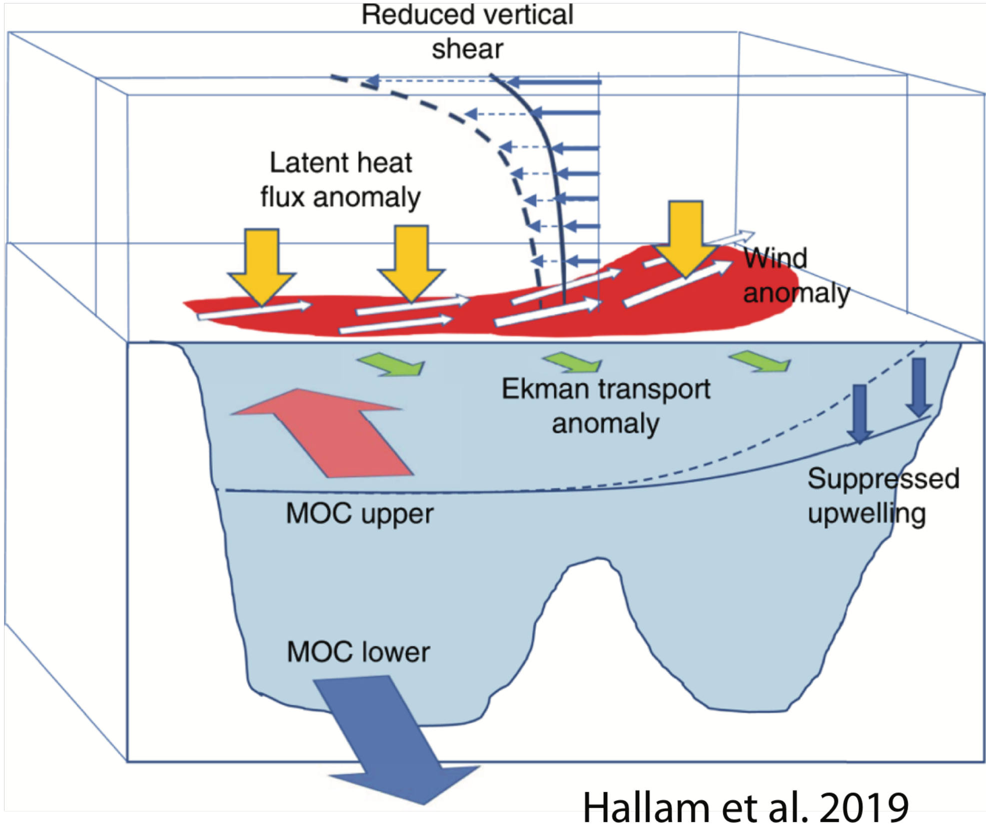
Kossin and Vimont 2007

Aerosols and ocean circulation



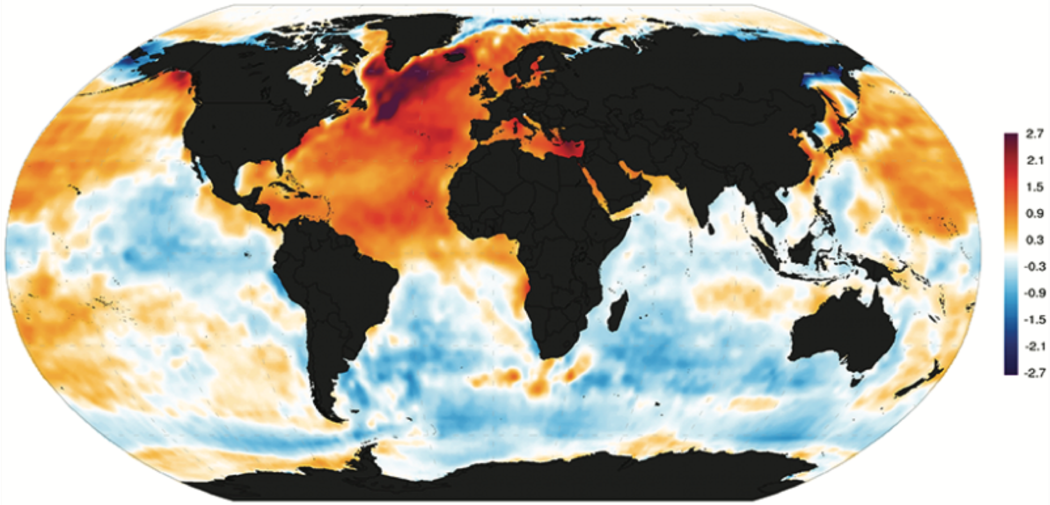
Evan et al. 2011

Importance of surface heat flux, ocean circulation

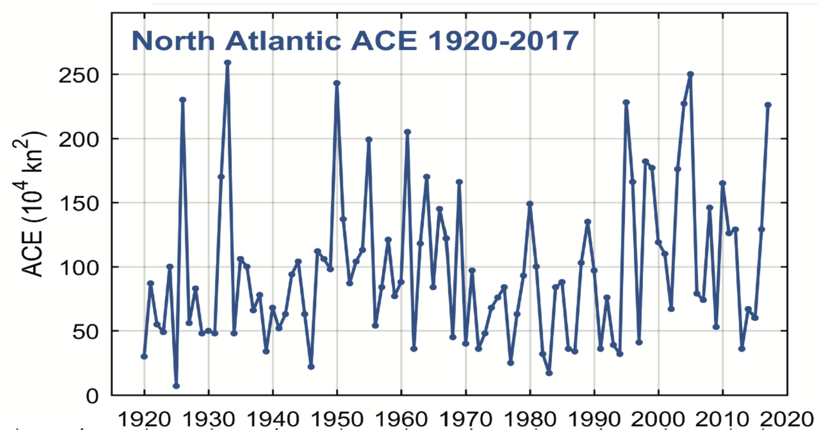


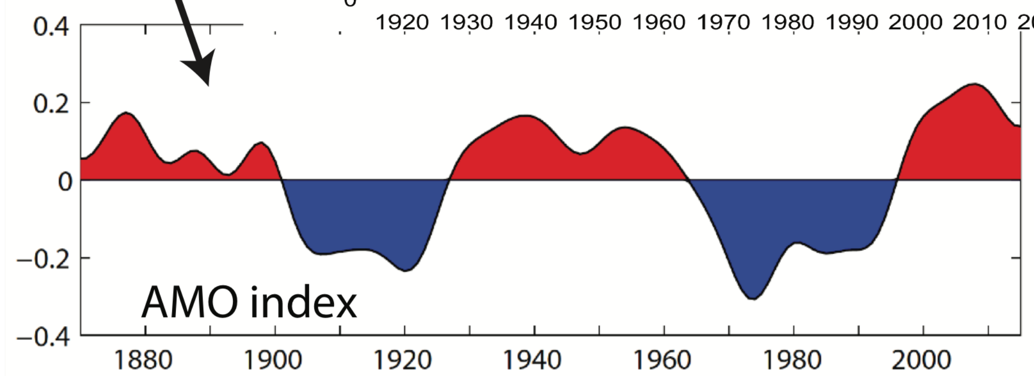
Hallam et al. 2019

Atlantic Multidecadal Oscillation



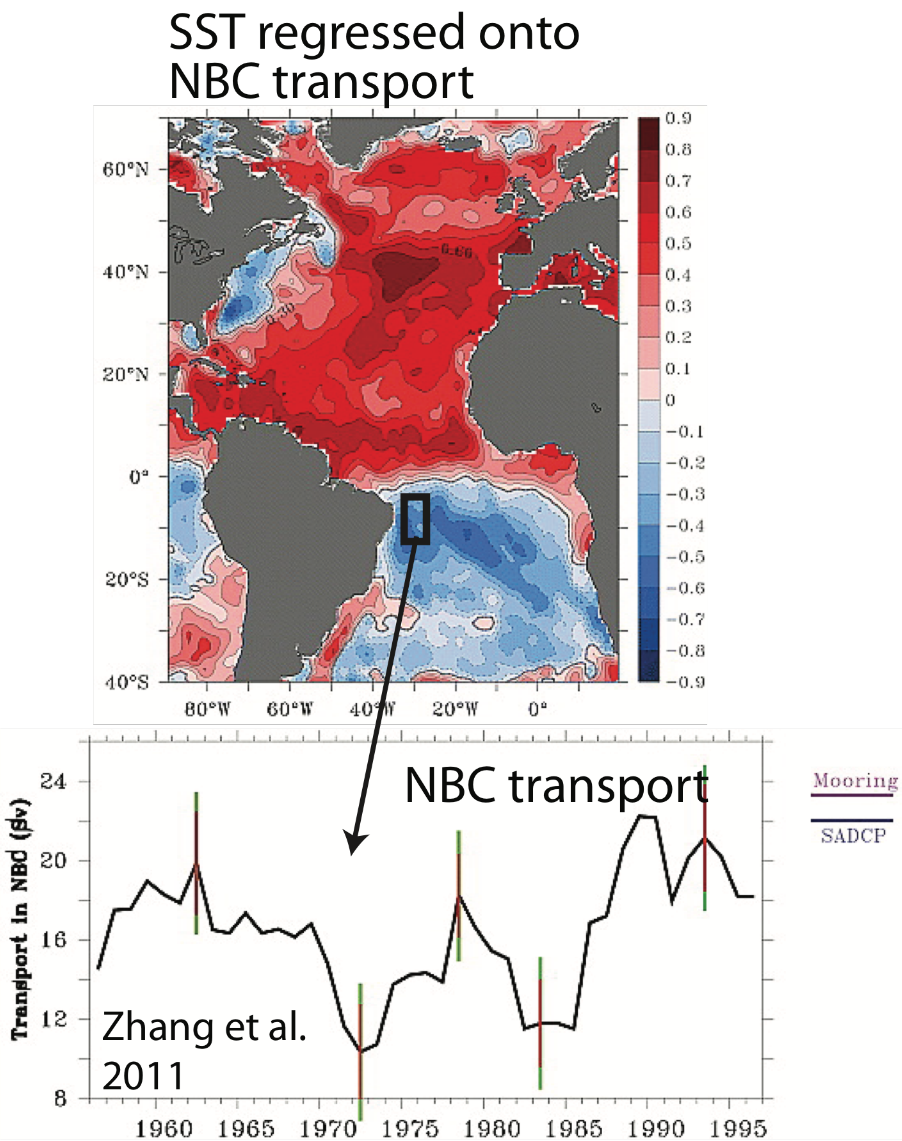
AMO SST pattern

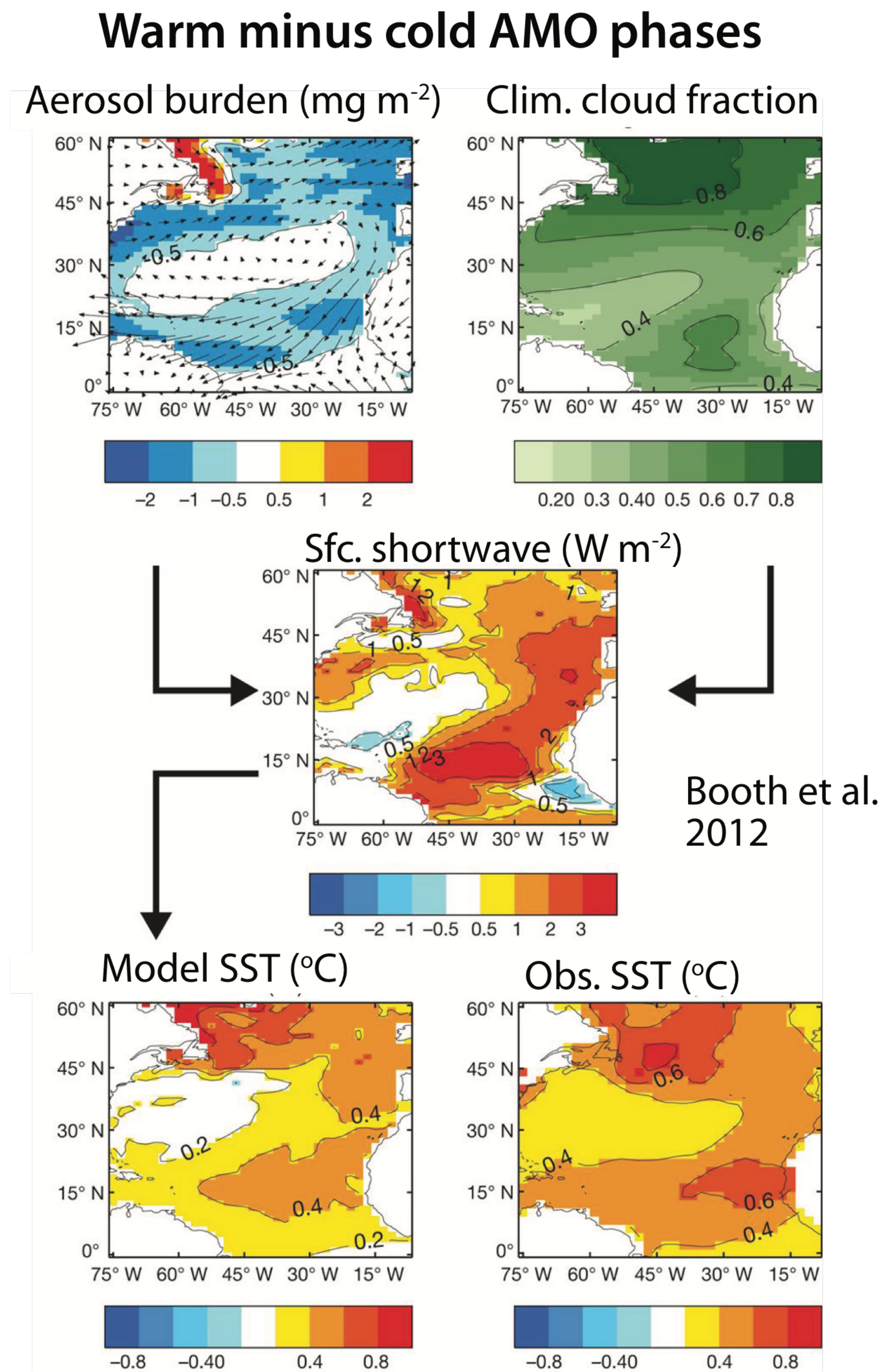




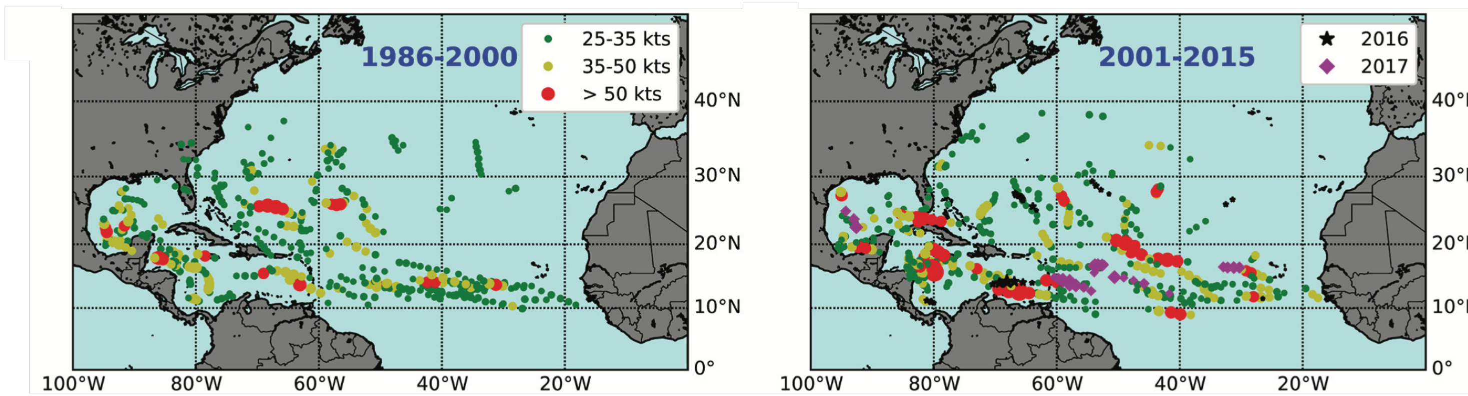
Goldenberg et al. 2001

Aerosols and ocean circulation



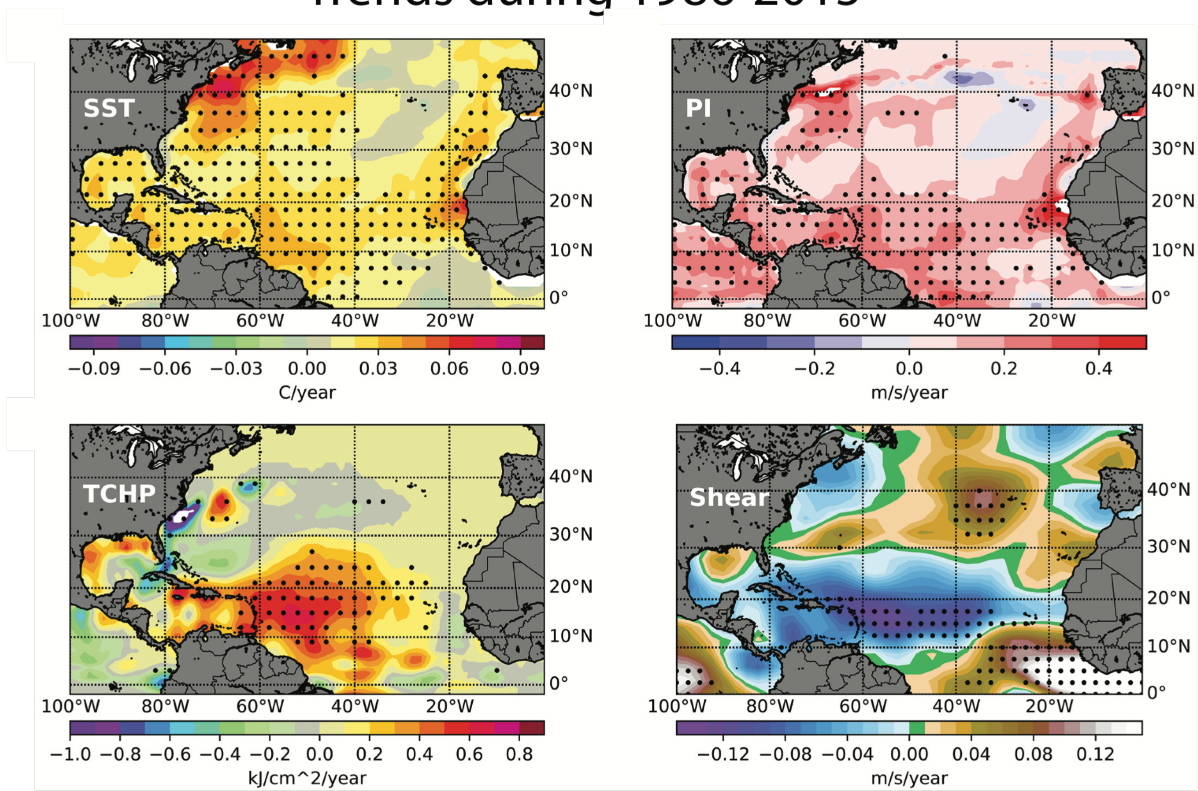


Locations with rapid intensification



Trends during 1986-2015

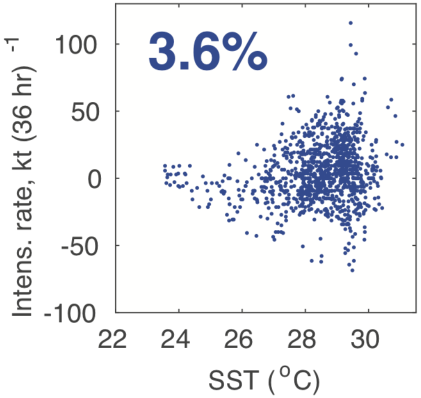
Increasing magnitude of RI during 1986-2015



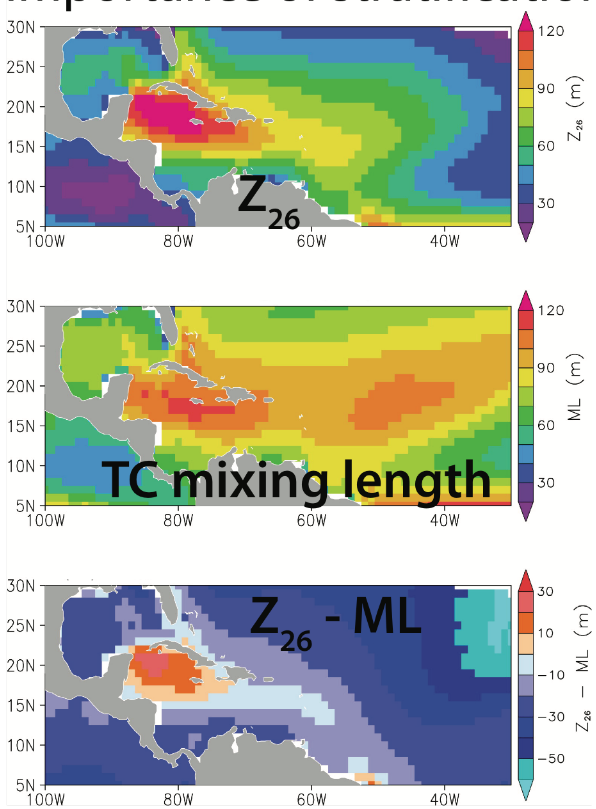
Balaguru et al. 2018

Monitoring and Prediction

Atl. pre-strom **SST** vs. **intens. rate**

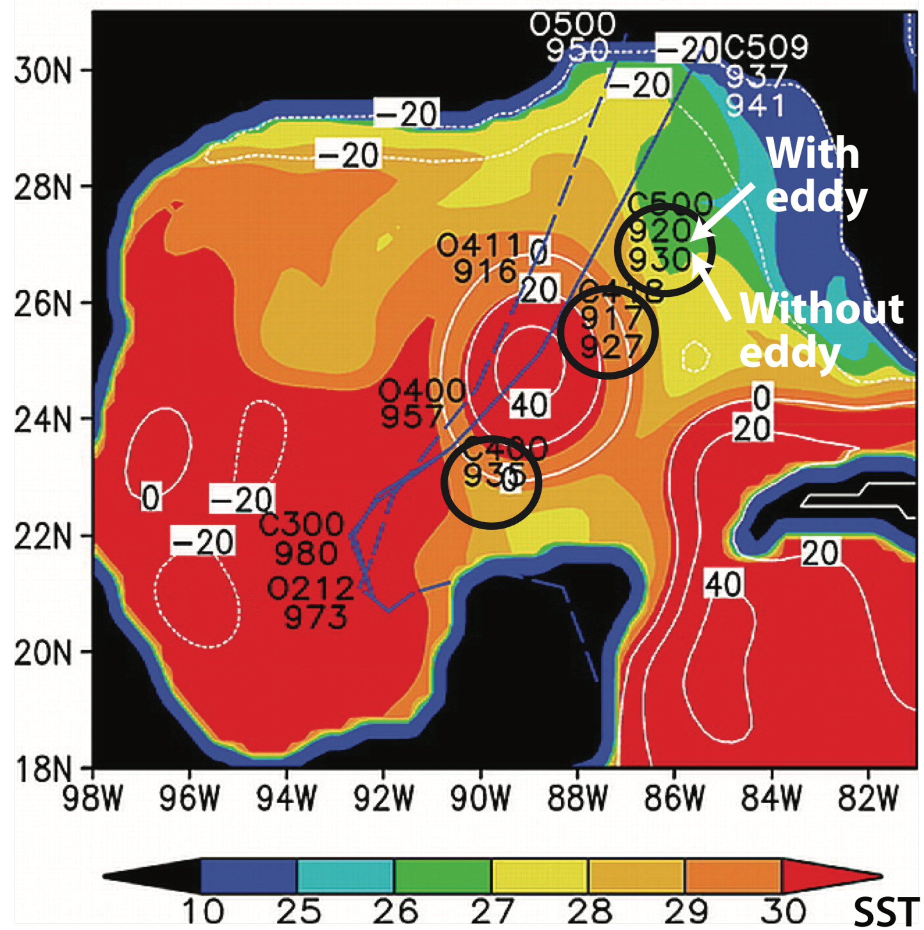


Importance of stratification



Balaguru et al. 2018

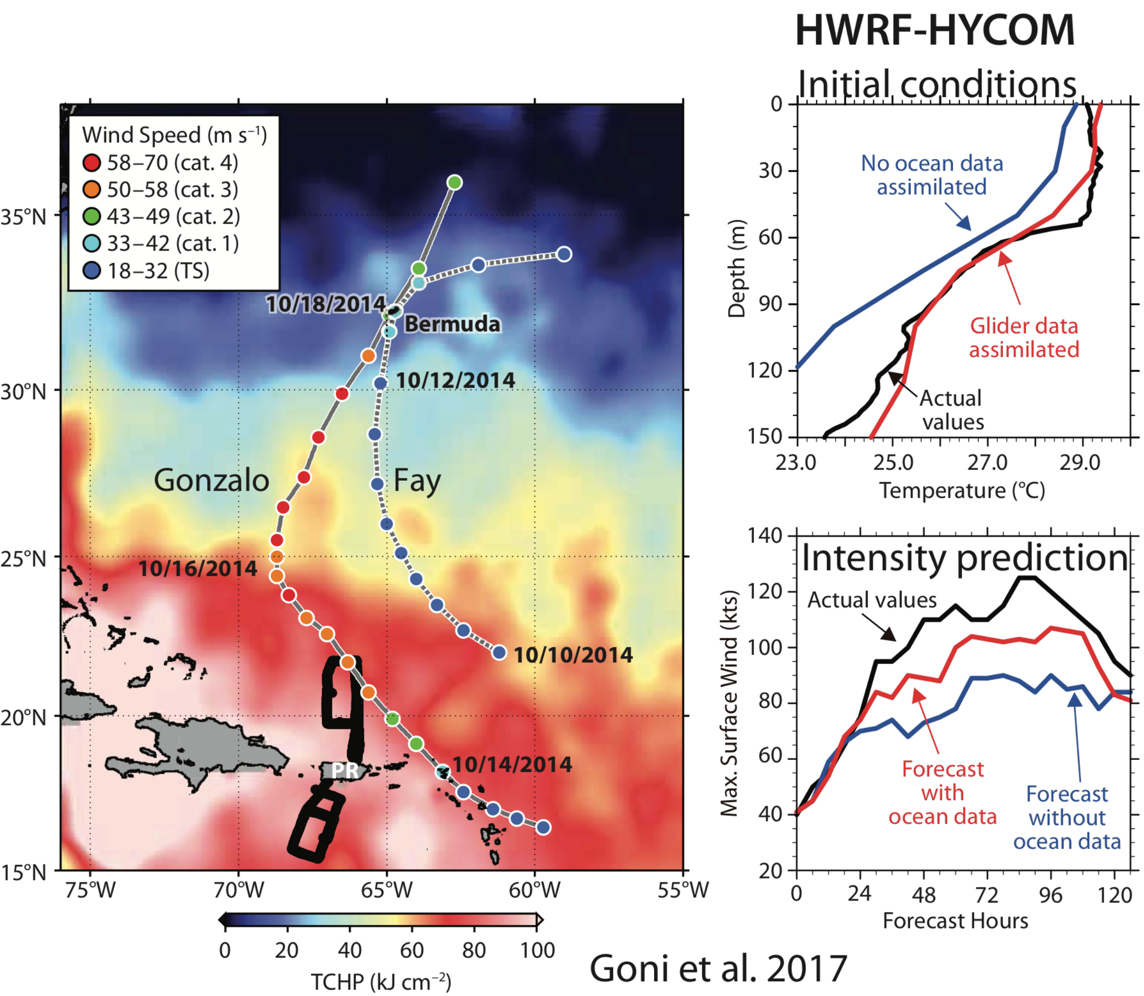
Impact of warm eddy on Hurricane Opal



Hong et al. 2000

Model initialization

Importance of subsurface measurements



Goni et al. 2017

Importance of sfc. atmos. measurements

ECMWF: Moored buoys (PIRATA) sfc. pressure and wind represent 0.000055% of the data assimilated and account for 0.006076% of the 24-hr forecast error reduction (Poli 2018).

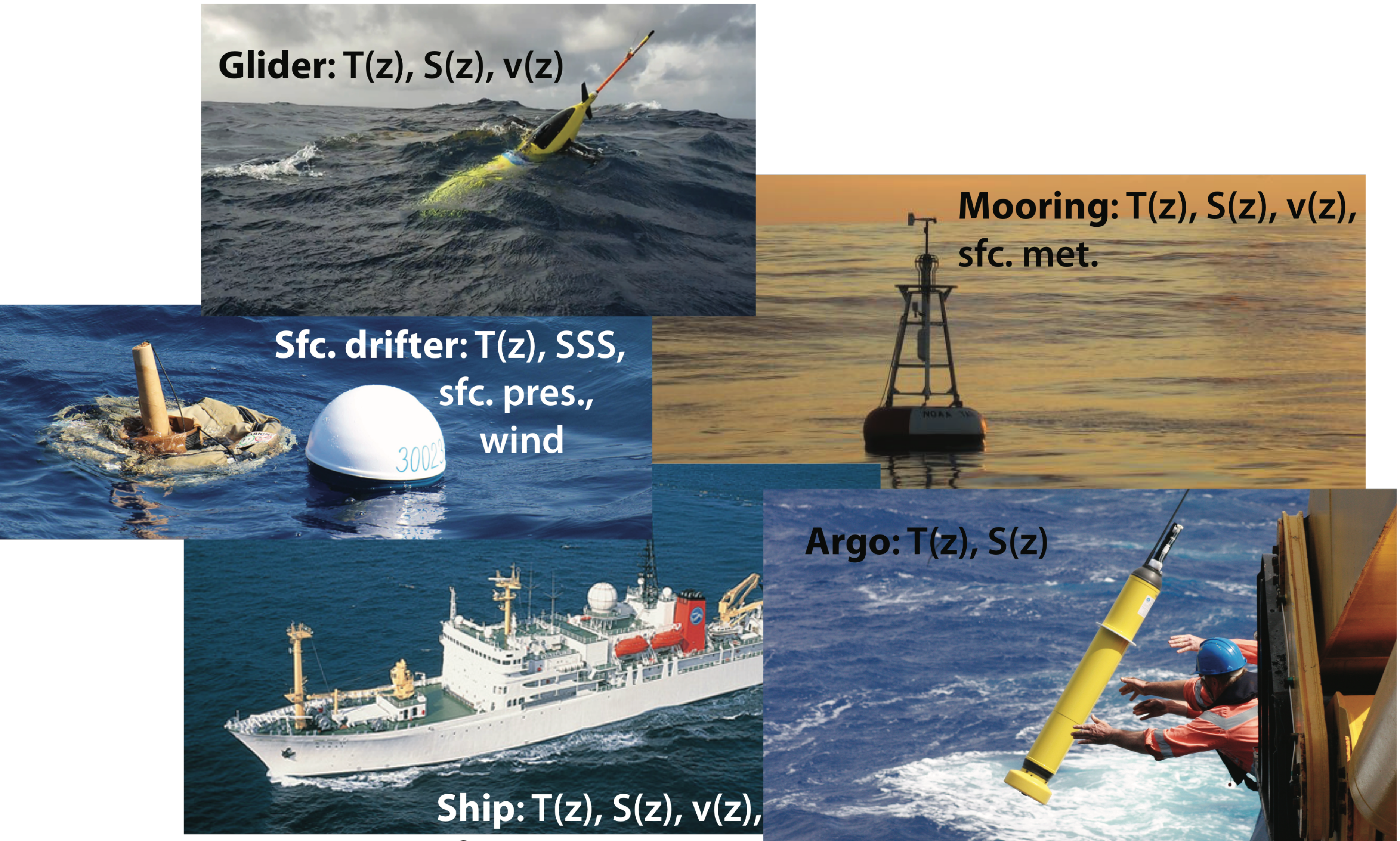
Validation of satellite data

- Satellite coverage is global with high resolution (0.1°-0.25°) and daily-weekly repeat cycles.

- Satellite retrievals are indirect measurements and can be biased (atmospheric composition, aerosols, sensor/orbit drift, ...).

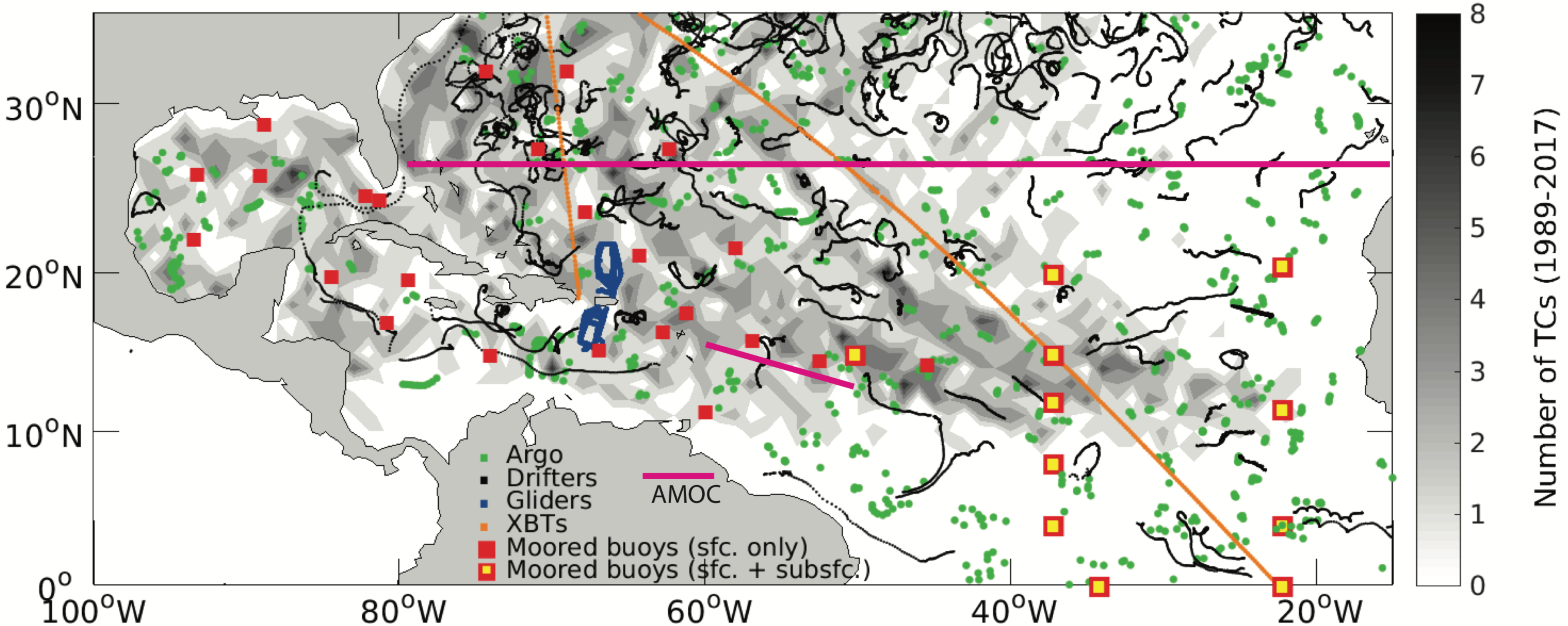
- High-quality in situ measurements are needed to validate and calibrate data from satellites, preferaby in real-time.

The tropical Atlantic (in situ) observing system



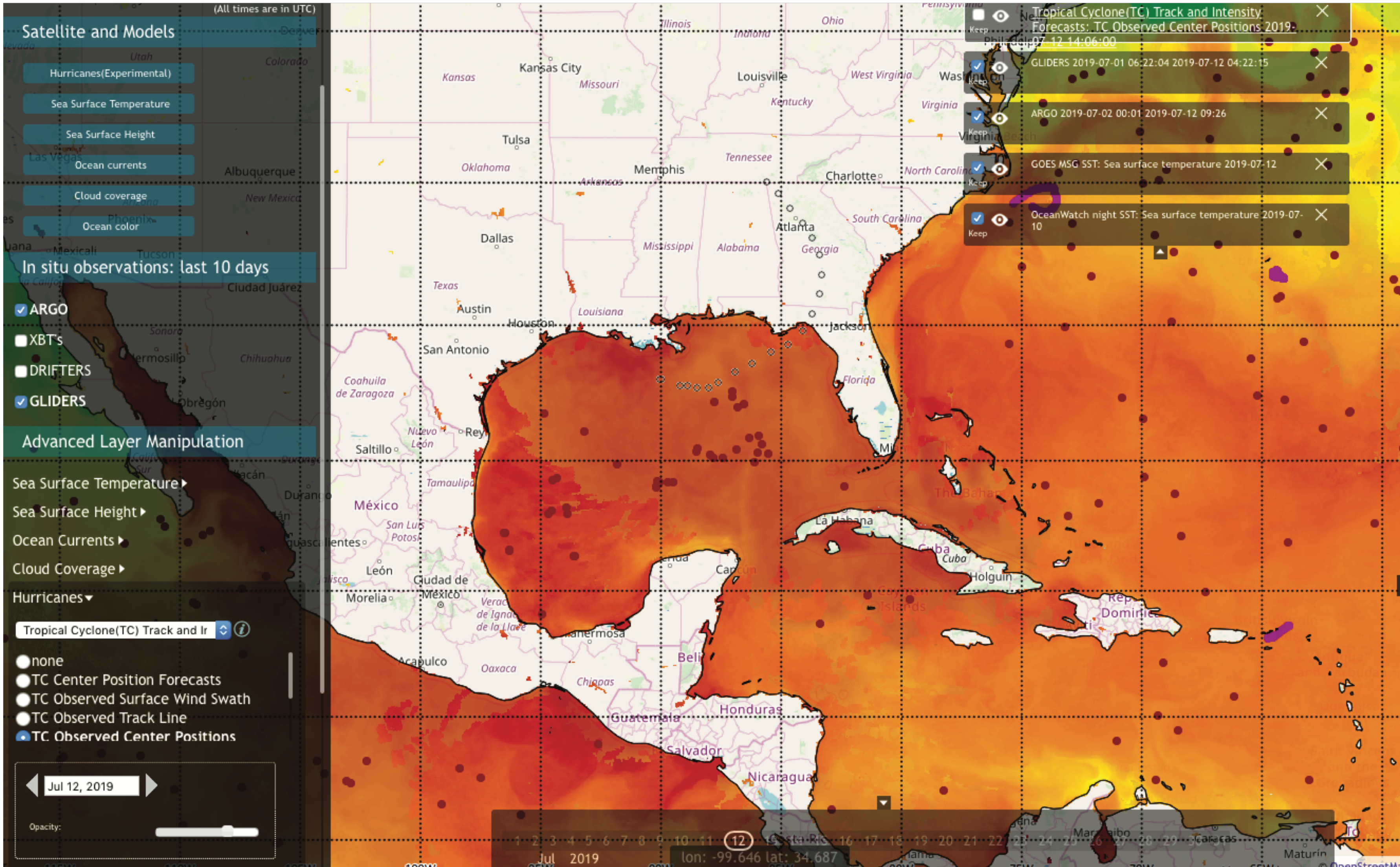
Current tropical North Atlantic observing system

- Data transmitted in real-time
- Limited subsurface obs. in Gulf, Caribbean, Gulf Stream



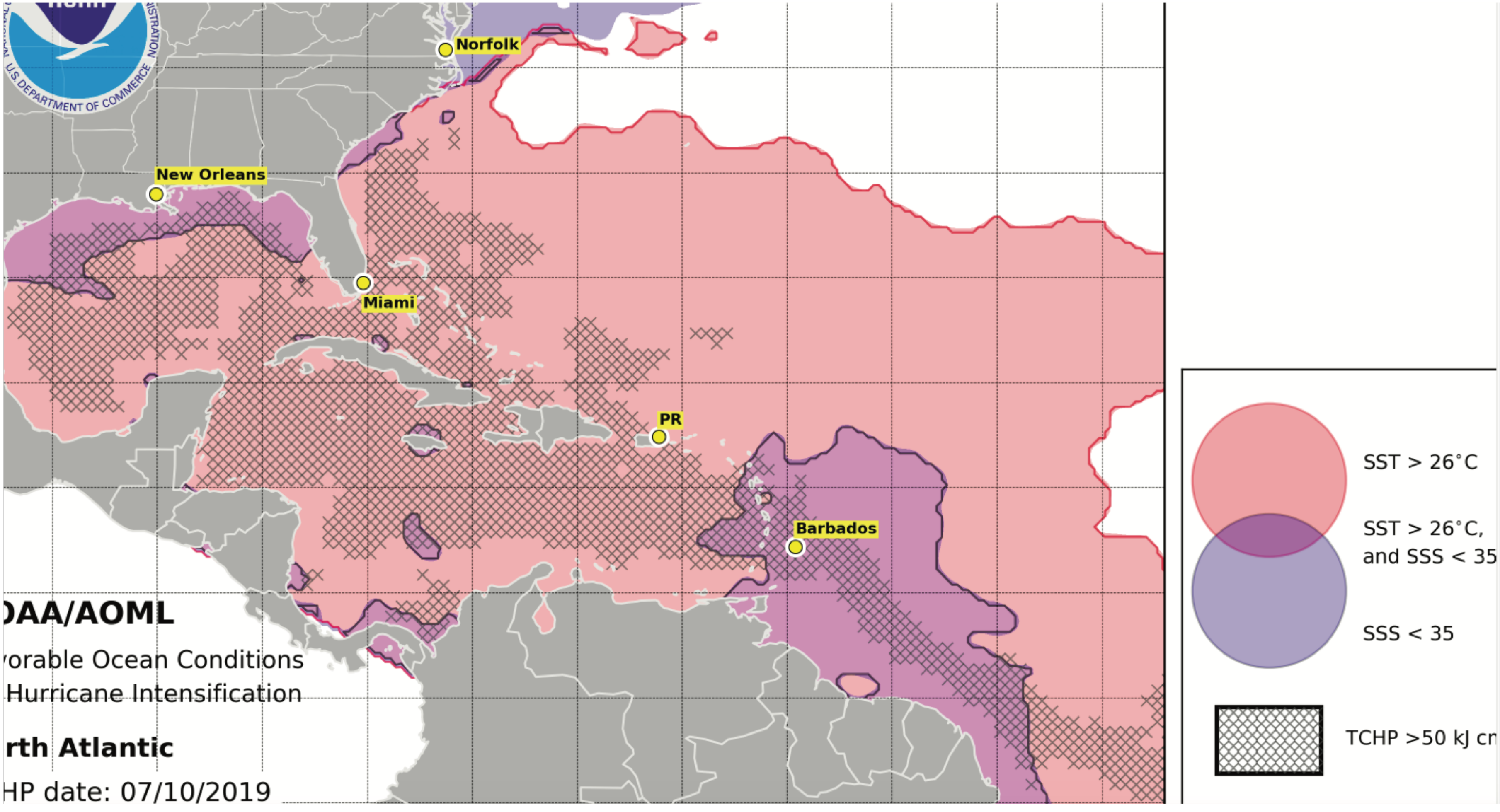
Real-time ocean data viewer

https://cwcgom.aoml.noaa.gov/cgom/OceanViewer/



Current ocean conditions

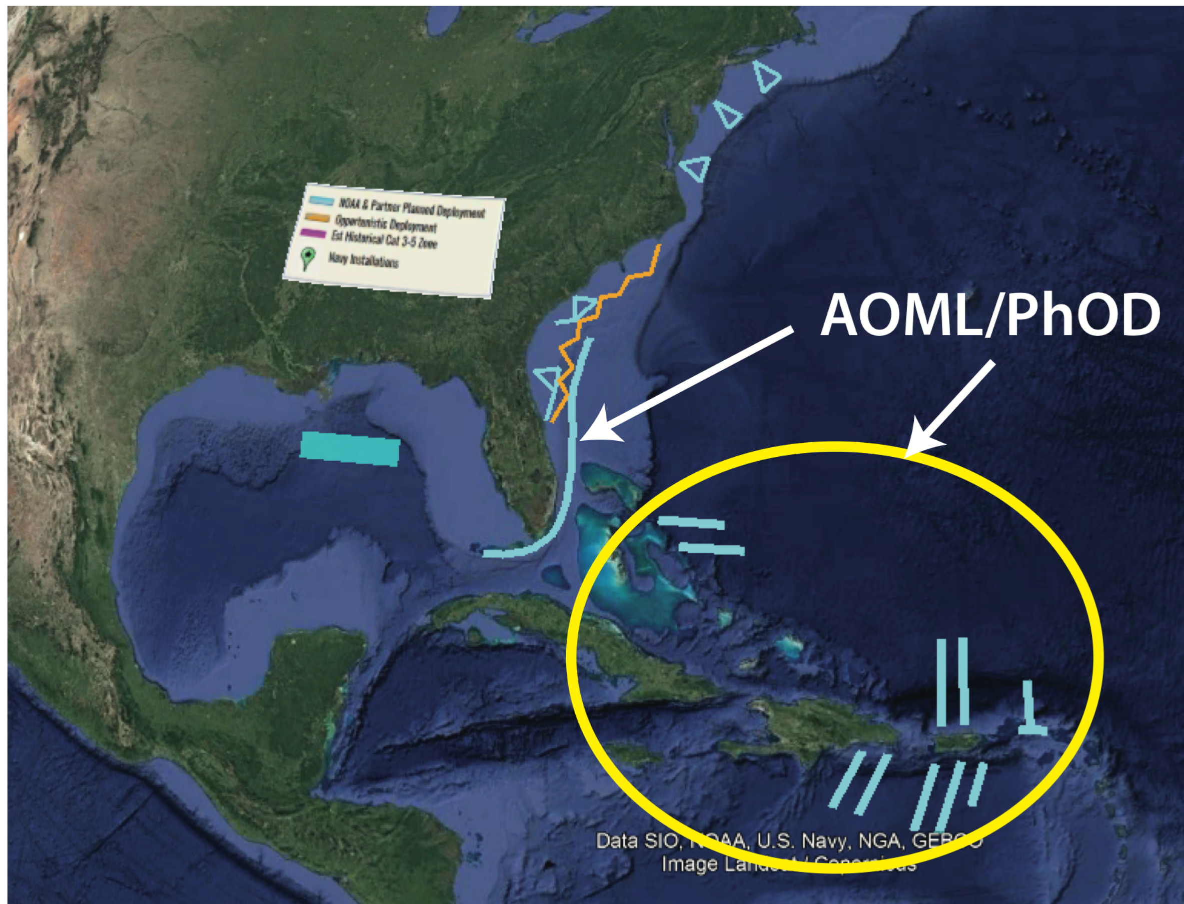
https://www.aoml.noaa.gov/phod/goos/gliders/view_large.php?id=hurr_sat_ocean_conditions_latest.png



Ocean gliders

- Measure temperature and salinity in the upper 400 m along pre-programmed paths

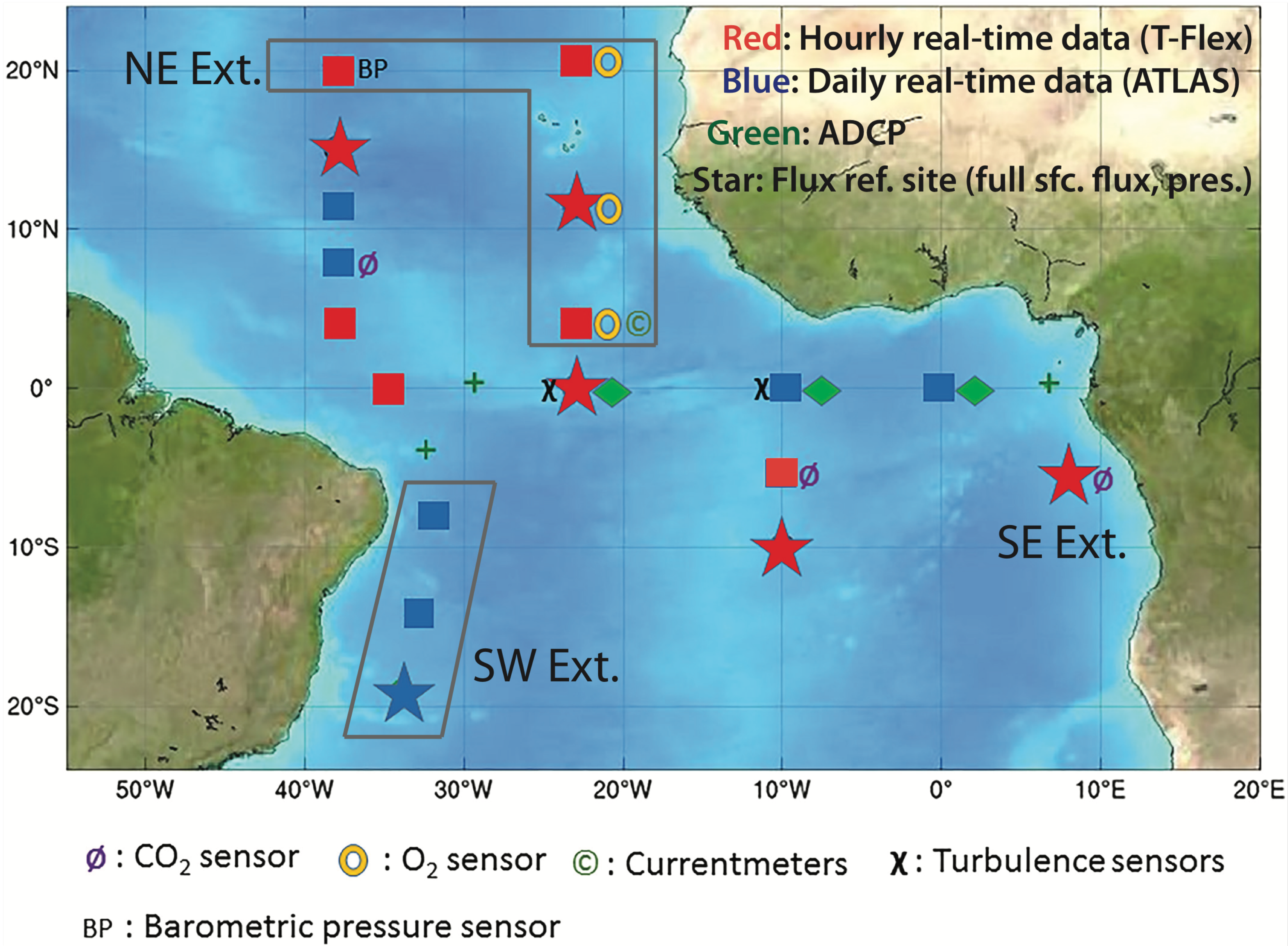
Plans for 2019 hurricane season



PIRATA: Prediction and Research Moored Array in the Tropical Atlantic

- 18 surface moorings measuring the upper ocean and near-surface atmosphere, hourly data transmitted
- Ocean **temp**. (every 5-20 m in upper 140 m), **salinity** (5-80 m in upper 120 m), **velocity** (12 m)
- **Air temp.**, **rel. humidity**, **wind vel.**, **rain**, **solar radiation**, **longwave radiation**, **sfc. atmos. pressure** (3-4 m)
- Measurements begin in 1997 (backbone), 2005 (SW Ext.), 2006 (NE Ext.), 2013 (SE Ext.)

PIRATA buoy locations



PIRATA

- Partnership between **U.S.** (NOAA/PMEL/AOML/OOMD), **Brazil** (DHN, INPE), **France** (IRD/Meteo-France)

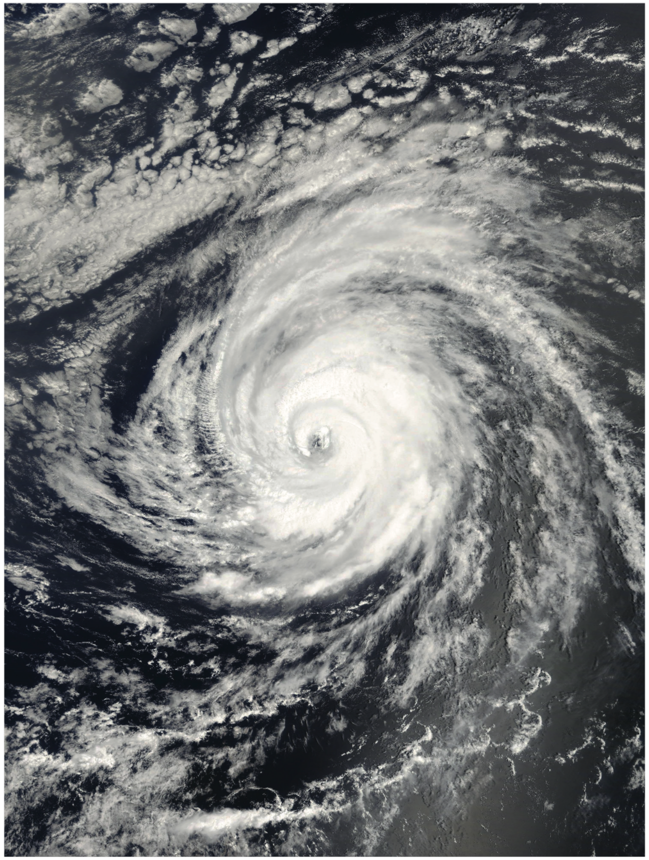
- **NOAA/PMEL** provides moorings, sensors, related technical expertise

- **NOAA/AOML** runs NE Ext. cruises (~ once per year), conducts 50-70 CTD casts along 23^{o}W, acquires other measurements (AEROSE, enhanced current meters,...)

- **Brazil, France** run other mooring servicing cruises, conduct CTD casts, and acquire other measurements

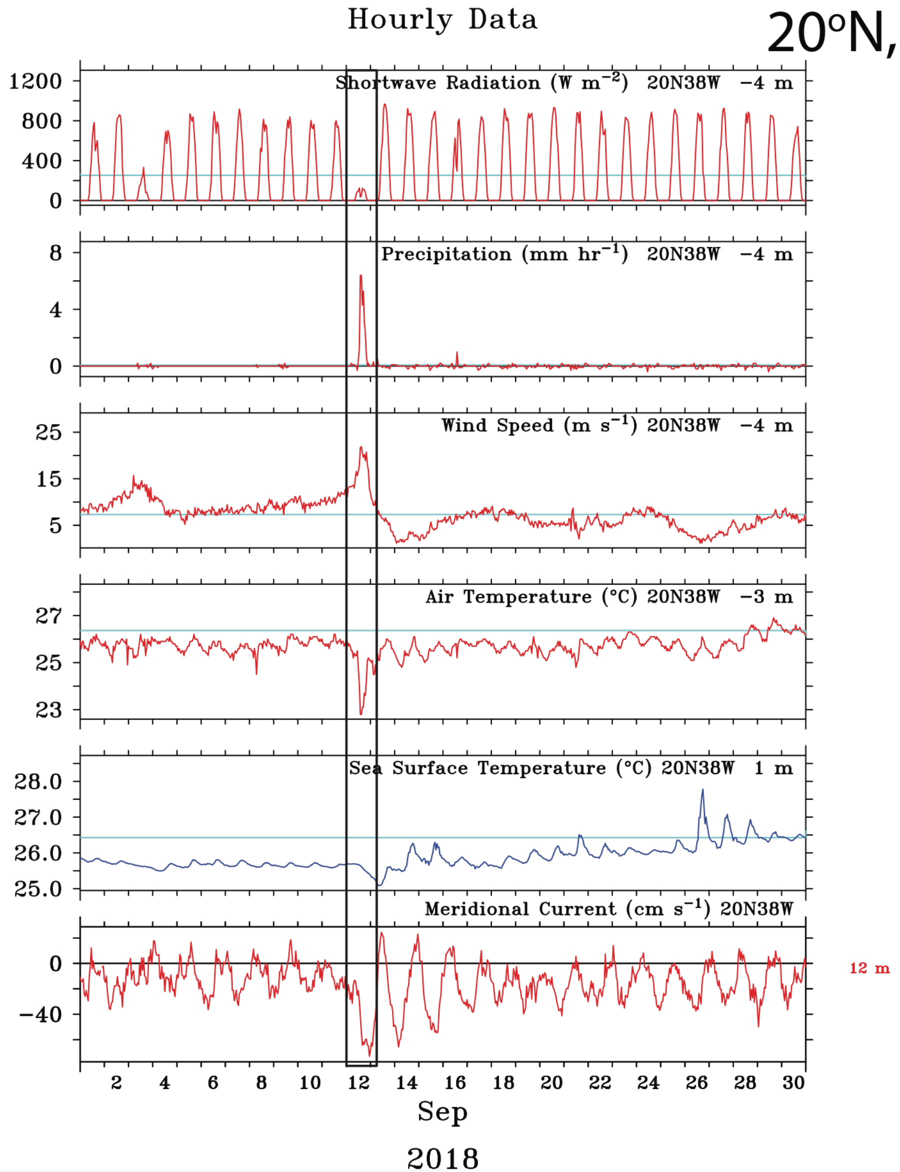
Hurricane Helene

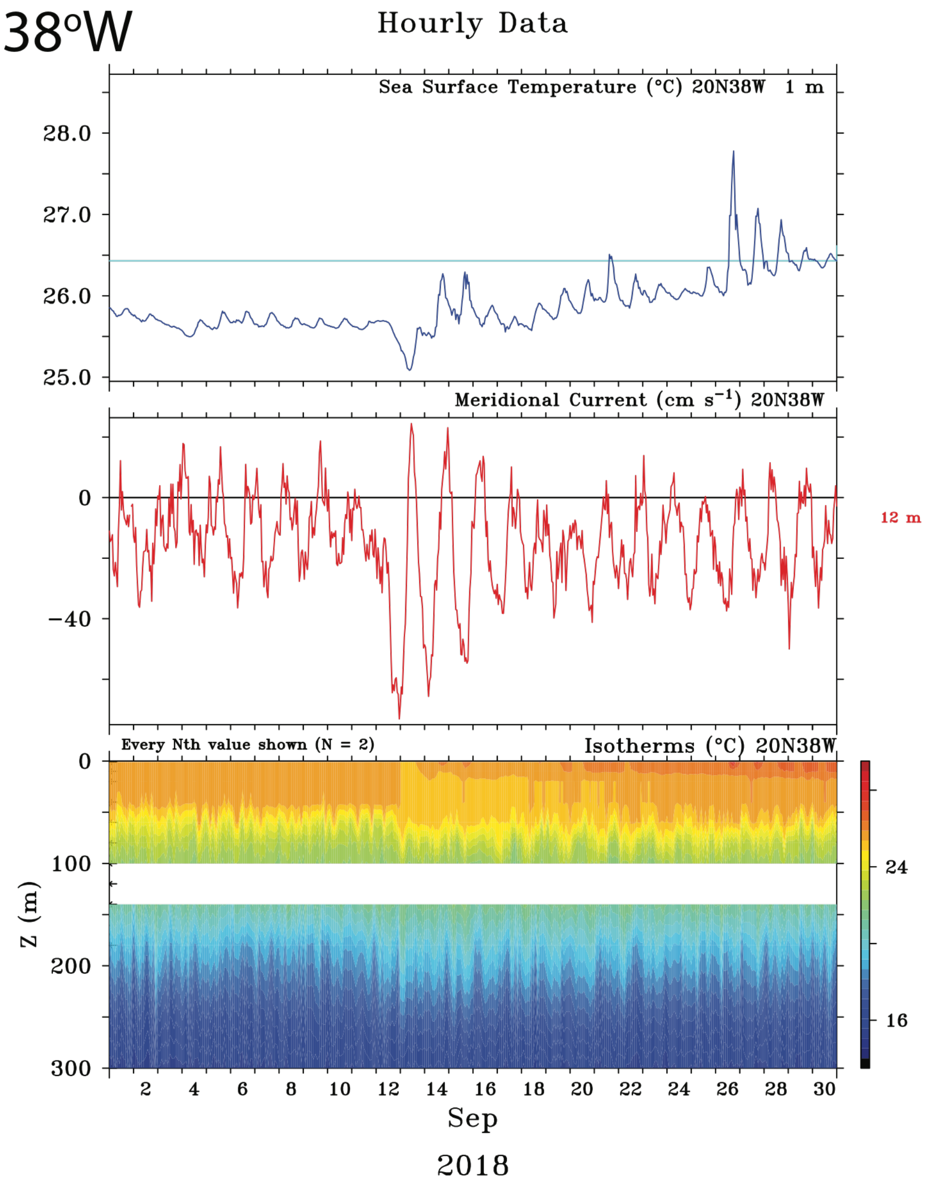
Passed about 150 km east of the 20°N, 38°W PIRATA buoy with max. wind of 80 kt



Data from PIRATA during Helene

20°N, 38°W

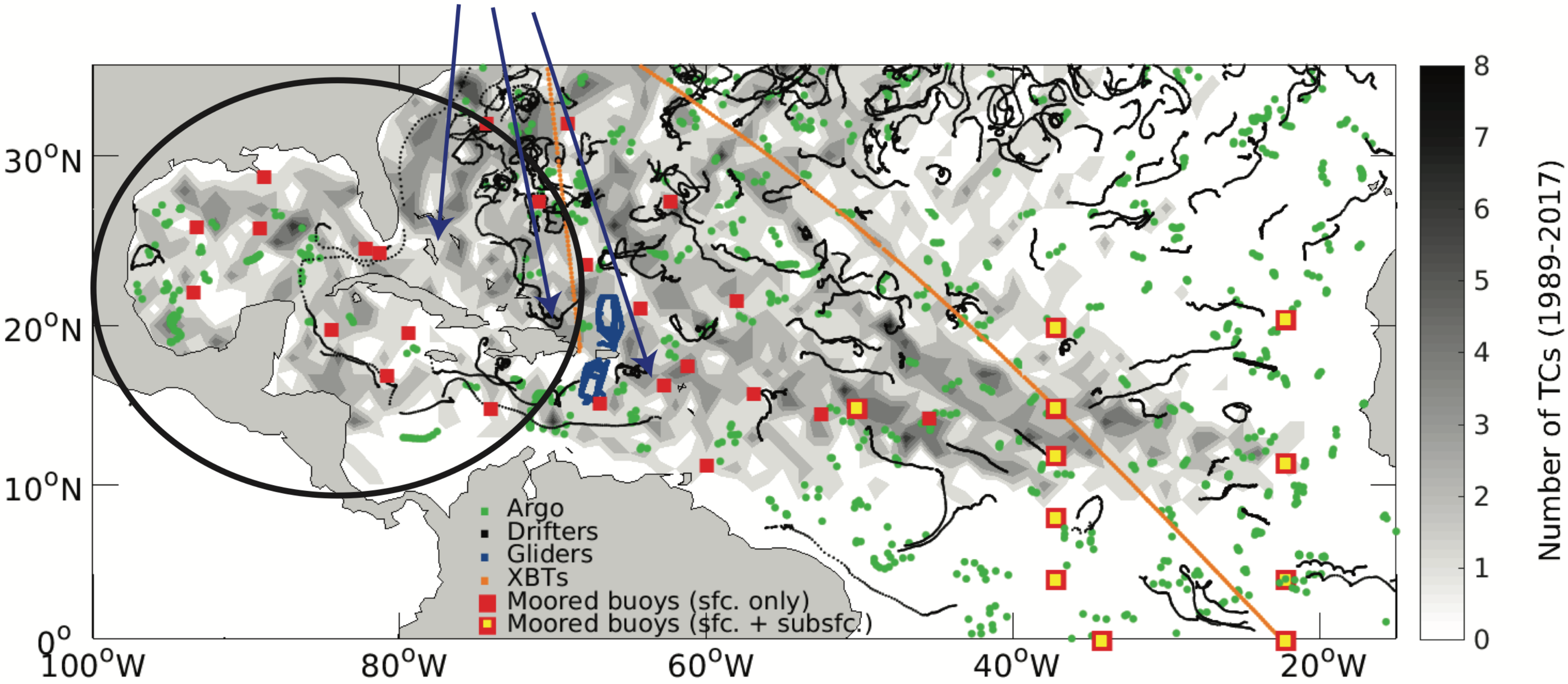




Future observing system needs

- Enhancement of Argo float coverage in Gulf, Caribbean underway

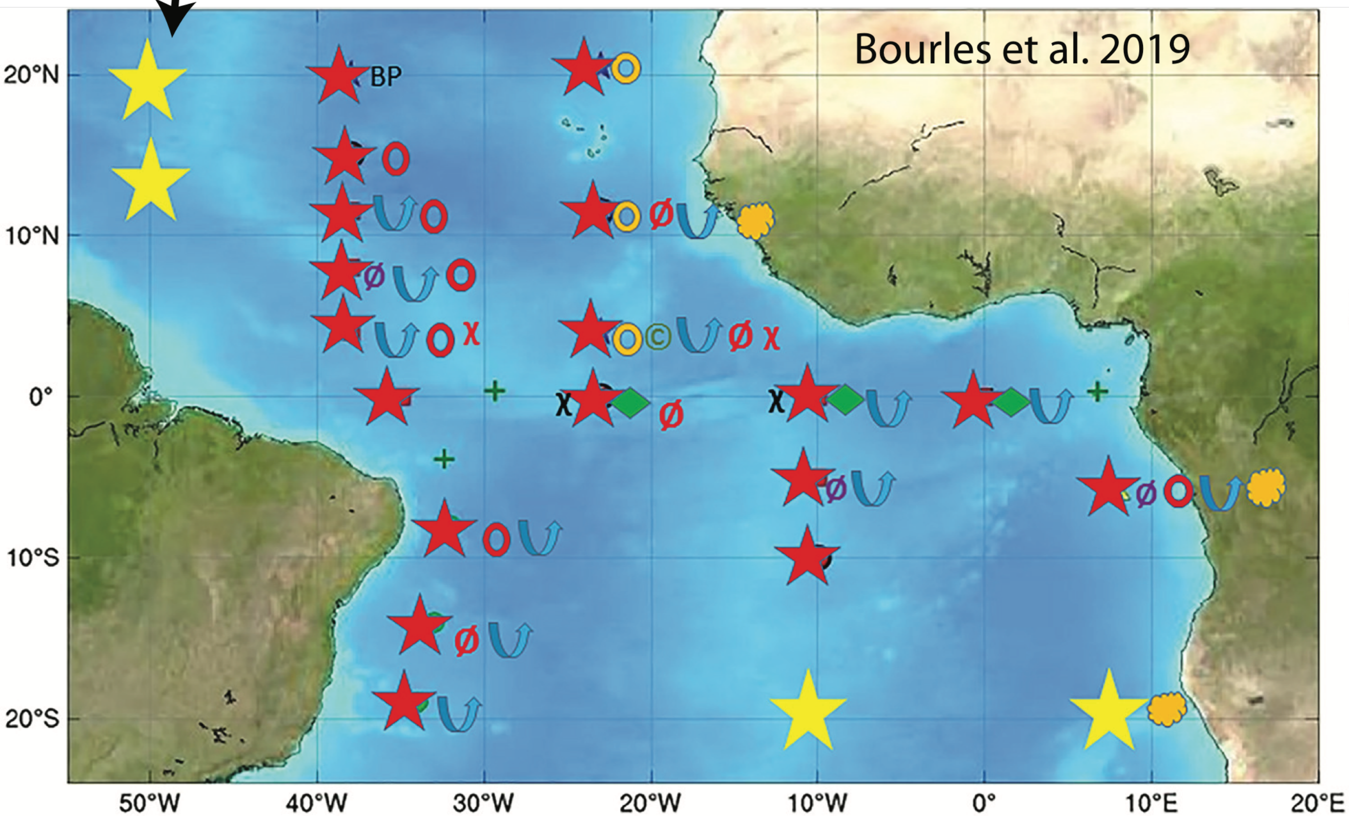
- Additional gliders planned for Bahamas, Dom. Repub., U.S. Virgin Islands (NOAA/AOML's Phys. Oceanogr. Div.)



Desired enhancements to PIRATA

Additional buoys in hurricane MDR

Additional temp., salin., velocity measurements in ocean mixed layer



Existing sensors:

- ø : CO_2 sensor
- O : O_2 sensor
- © : Currentmeters
- χ : Turbulence sensors
- BP : Barometric pressure sensor

Potential additionnal moorings or sensors:

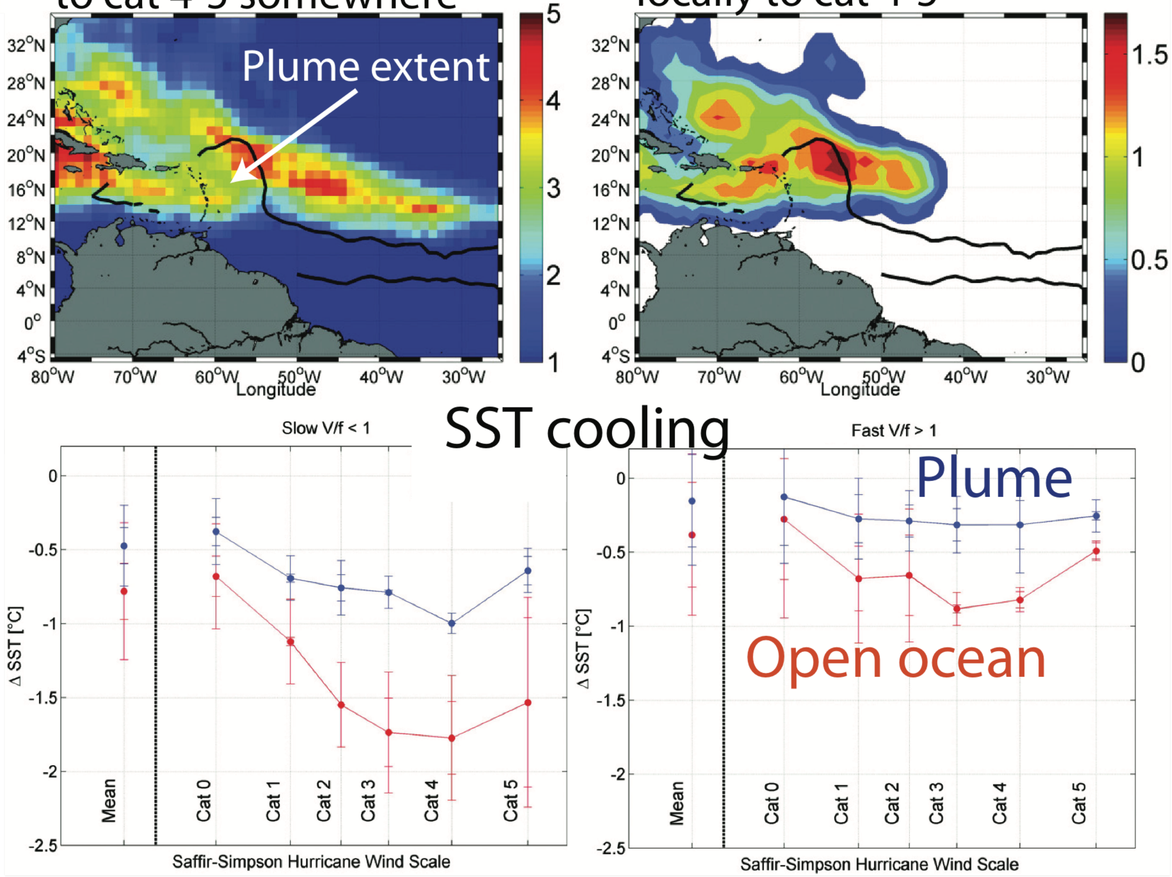
- : Pirata meteo-ocean moorings
- : T/C & current in the Mixed Layer
- ø : CO_2 sensor
- : Aerosols
- O : O_2 sensor
- χ : Turbulence sensors

Role of salinity in hurricane intensification

Enhanced measurements needed in western Atlantic, eastern Caribbean

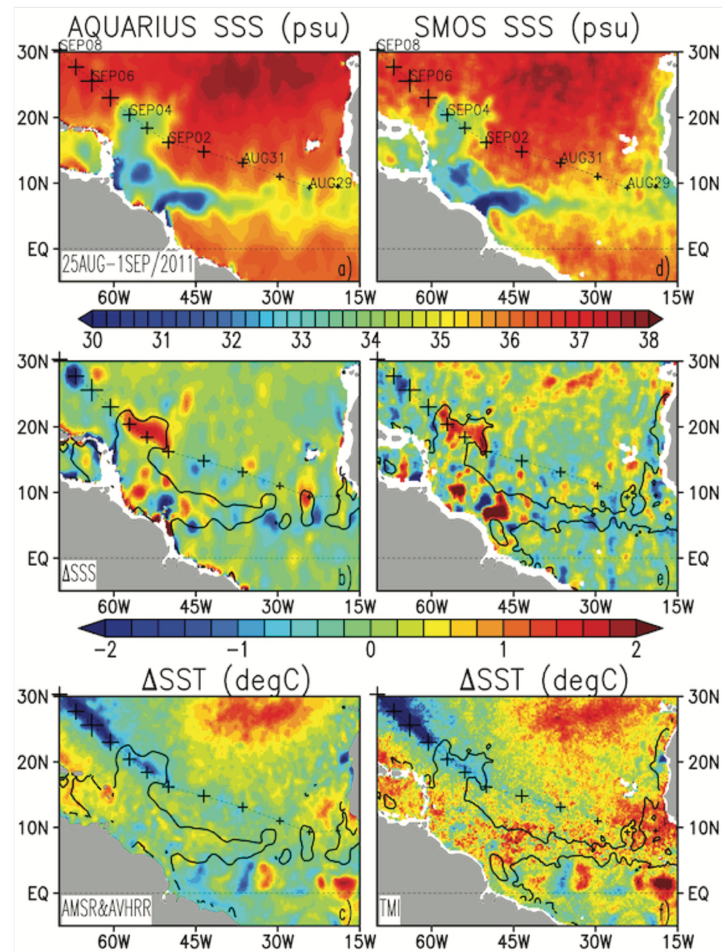
Number of TCs that evolve to cat 4-5 somewhere

Number of TCs that intens. locally to cat 4-5



Reul et al. 2014

SST, SSS responses to Hurricane Katia

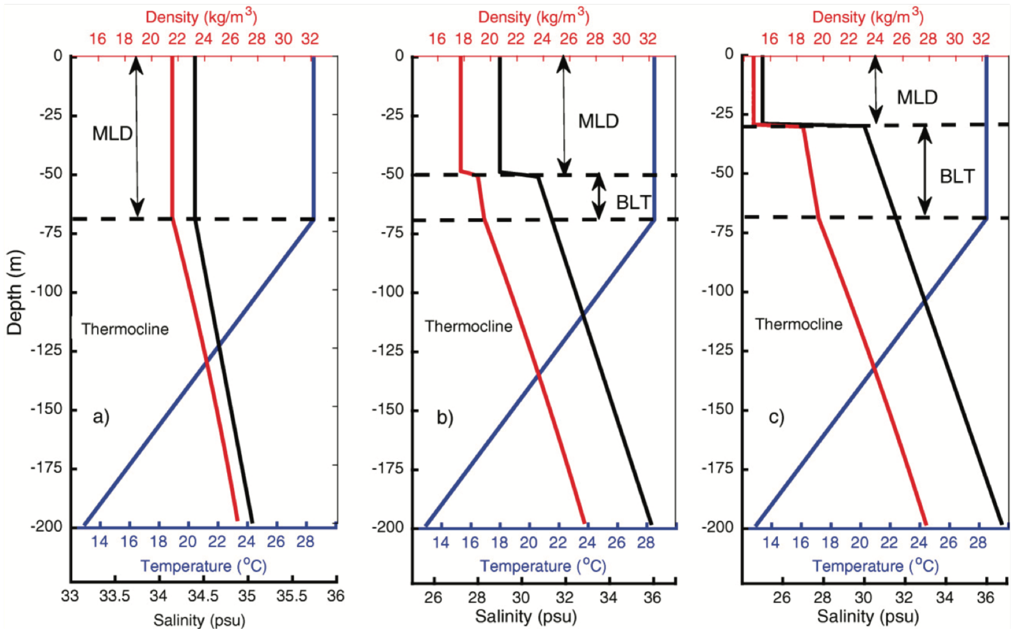


Grodsky et al. 2012

Role of salinity in hurricane rapid intensification

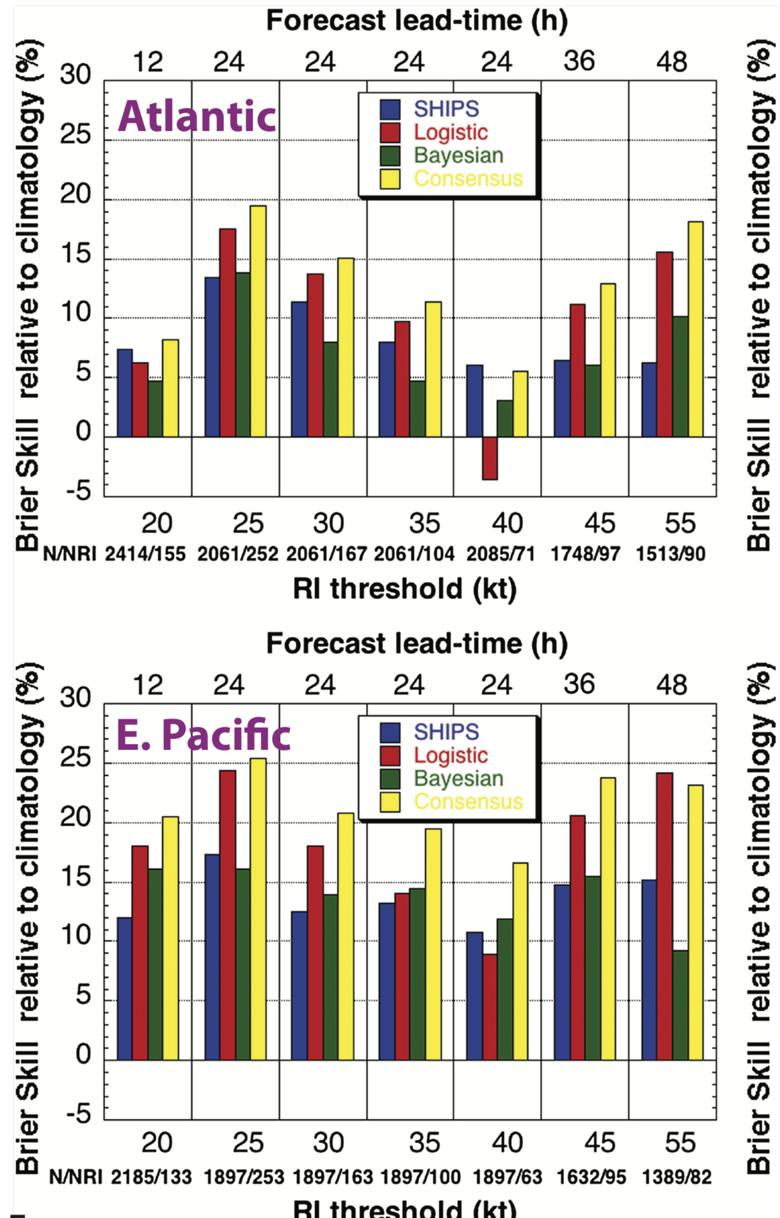
- Previous studies show that salinity stratification can reduce storm-induced mixing and cooling of SST, generating conditions more conducive to intensification (Balaguru et al. 2012, Yan et al. 2017, Hlywiak et al. 2019)

- Unclear whether salinity effect varies with intensification rate and could be useful predictor of RI



RI prediction skill

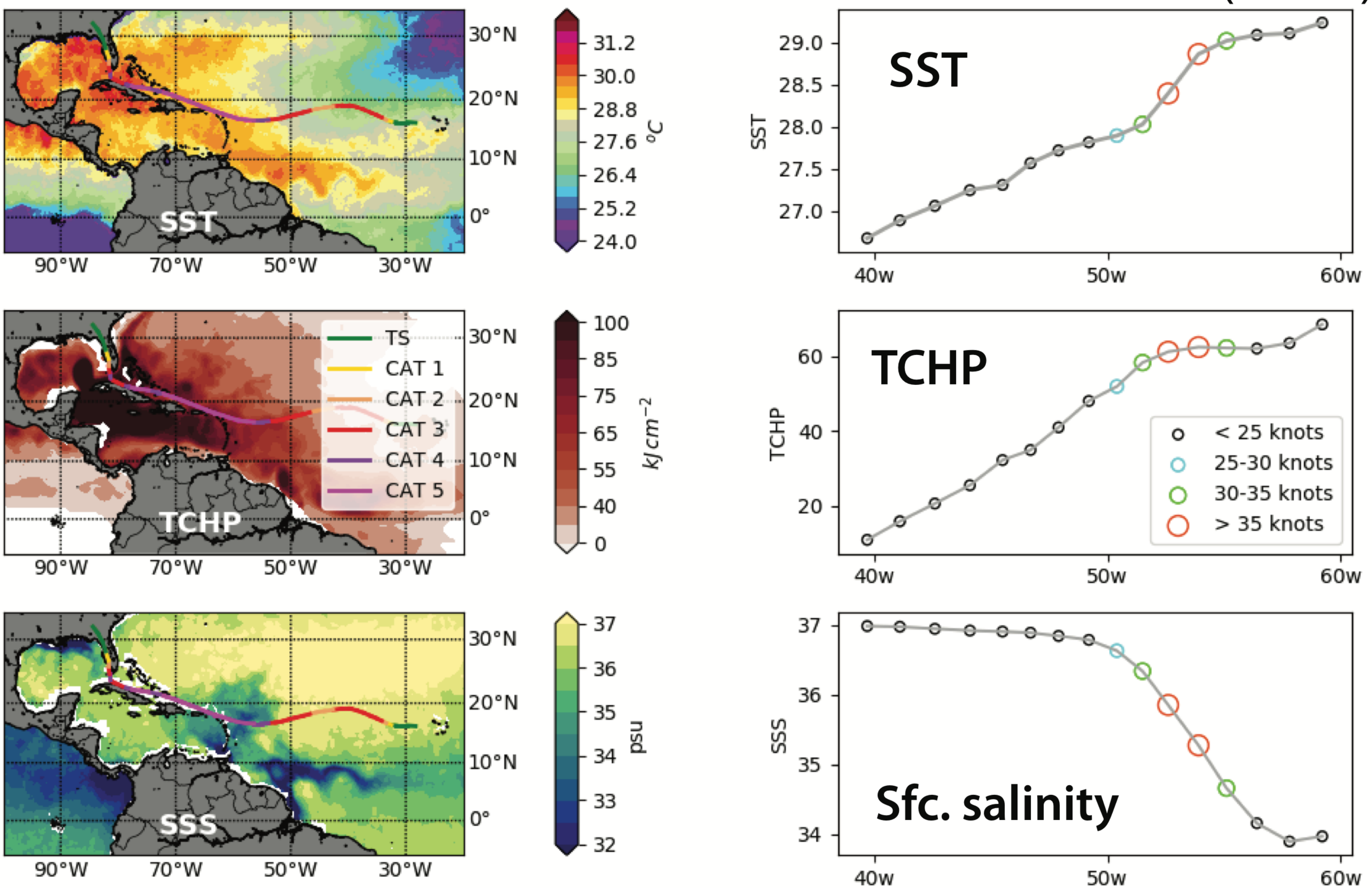
RI prediction skill is lower in the **Atlantic** compared to the **eastern Pacific**

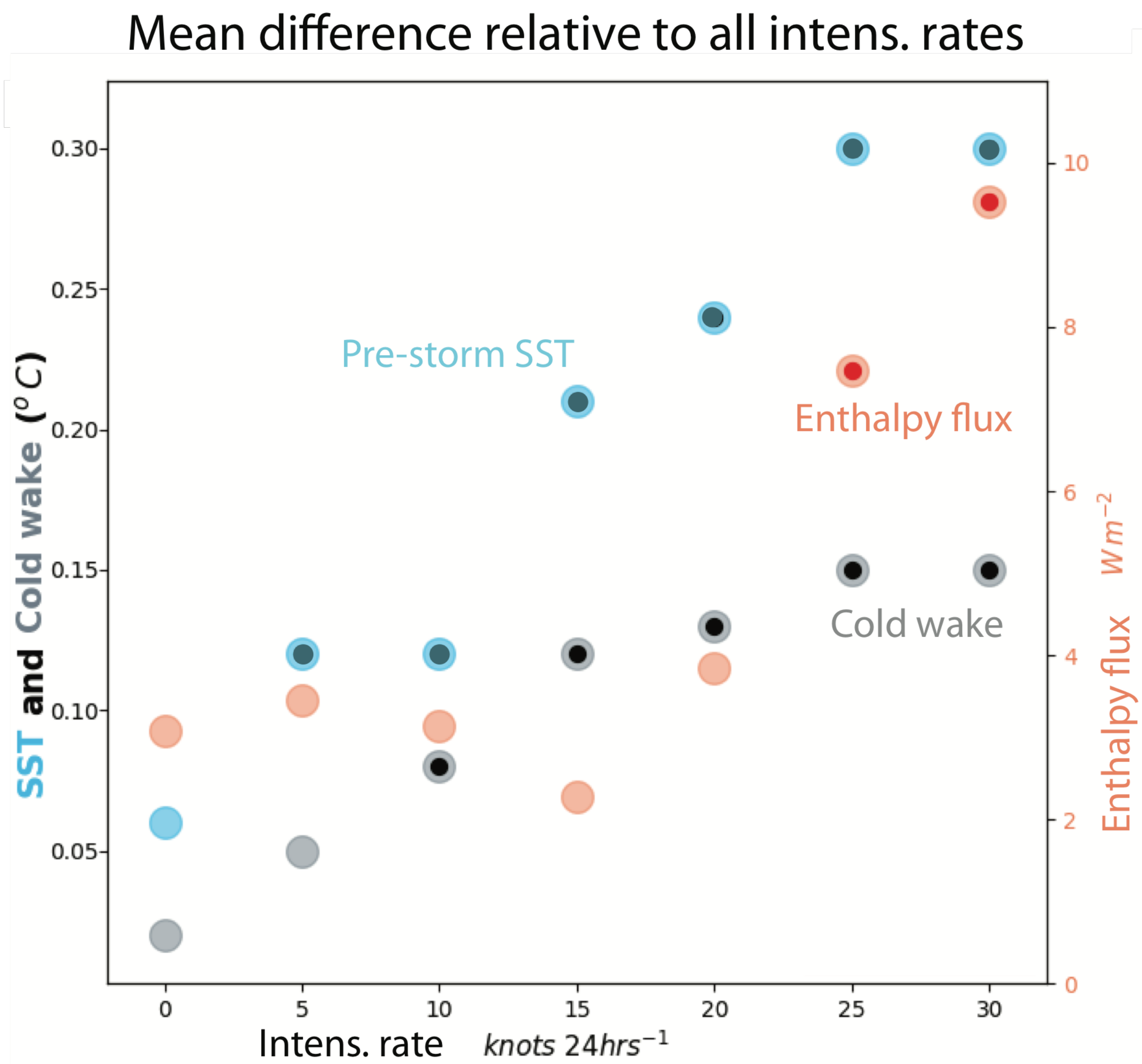


Kaplan et al. 2015

Hurricane Irma

Along-track ocean conditions and 24-hr intens. rate (colors)





Importance of SST, air-sea flux increases with intens. rate

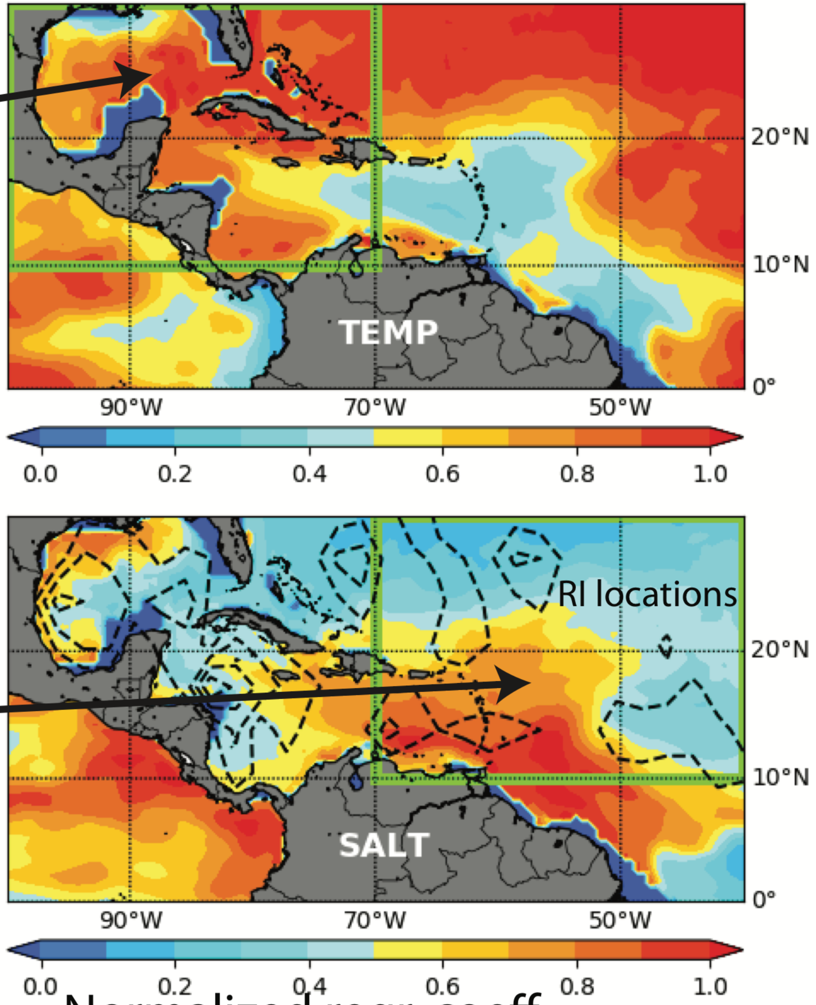
Increase in SST, enthalpy flux; reduction in cold wake

Regimes of ocean temp. and salinity stratification

Temp. and salin. strat. regressed onto density strat. at 100 m

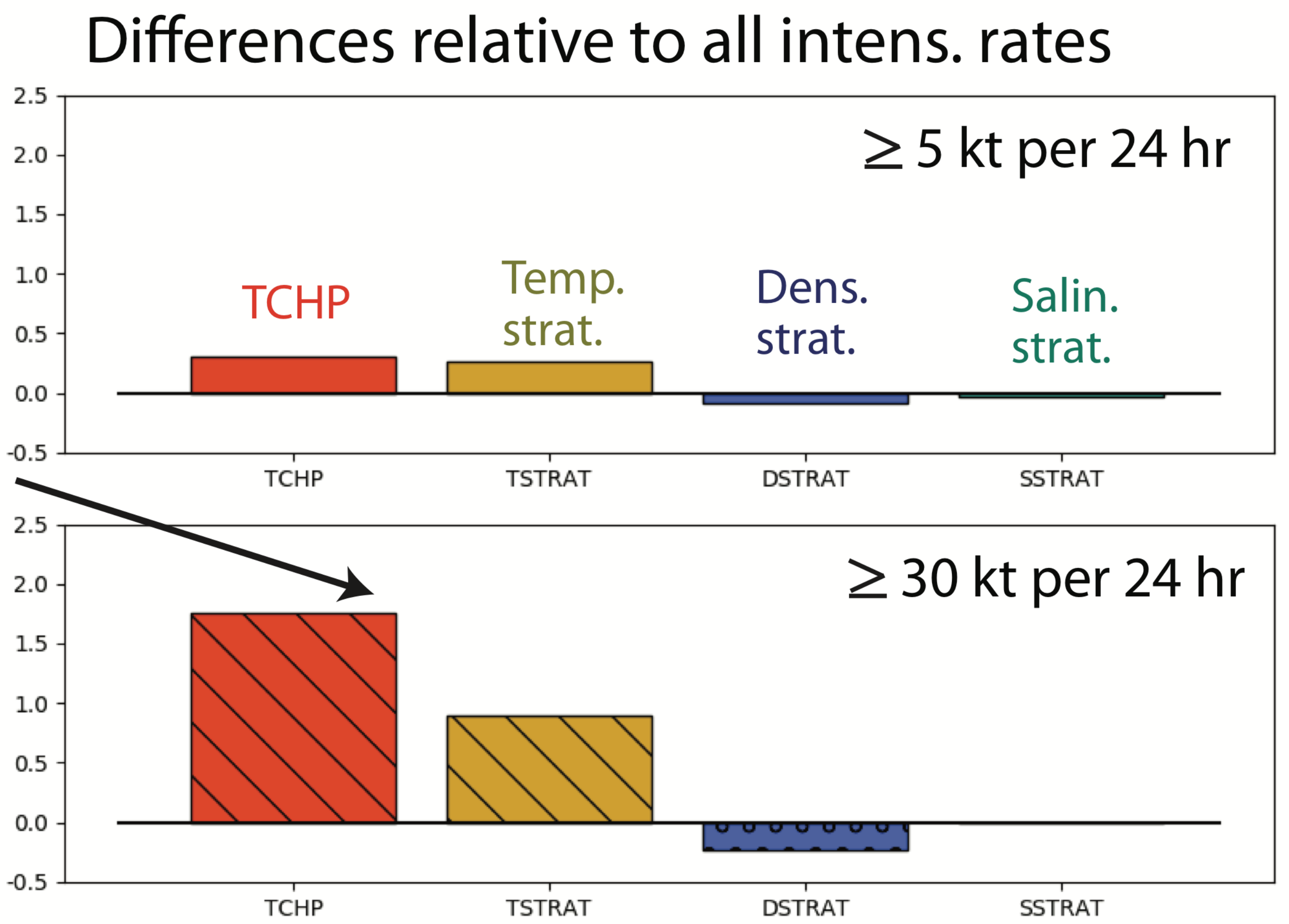
Temperature dominates in western region

Salinity is more important in eastern region



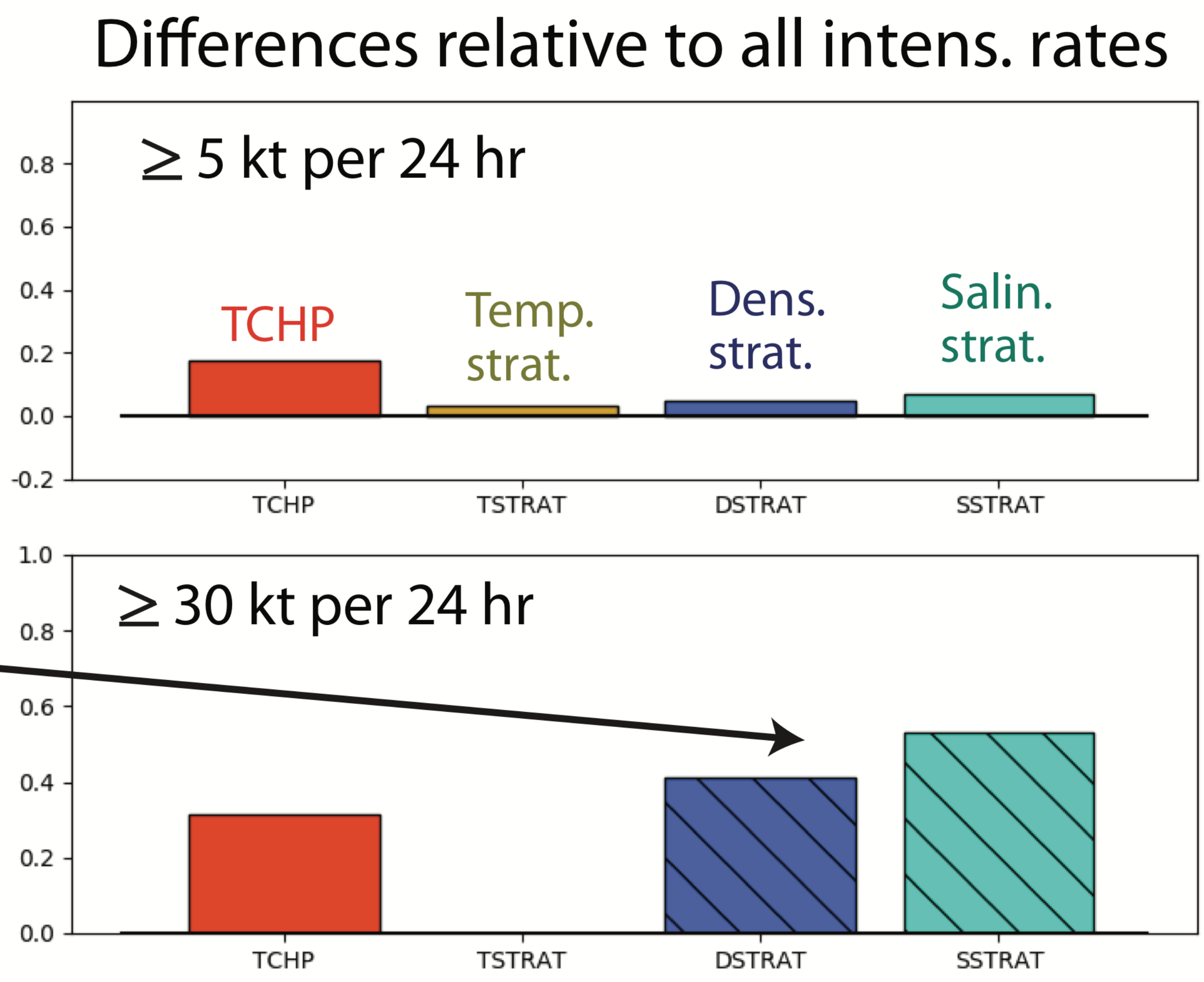
Western region

Significantly larger TCHP., weaker temp. strat. for RI cases

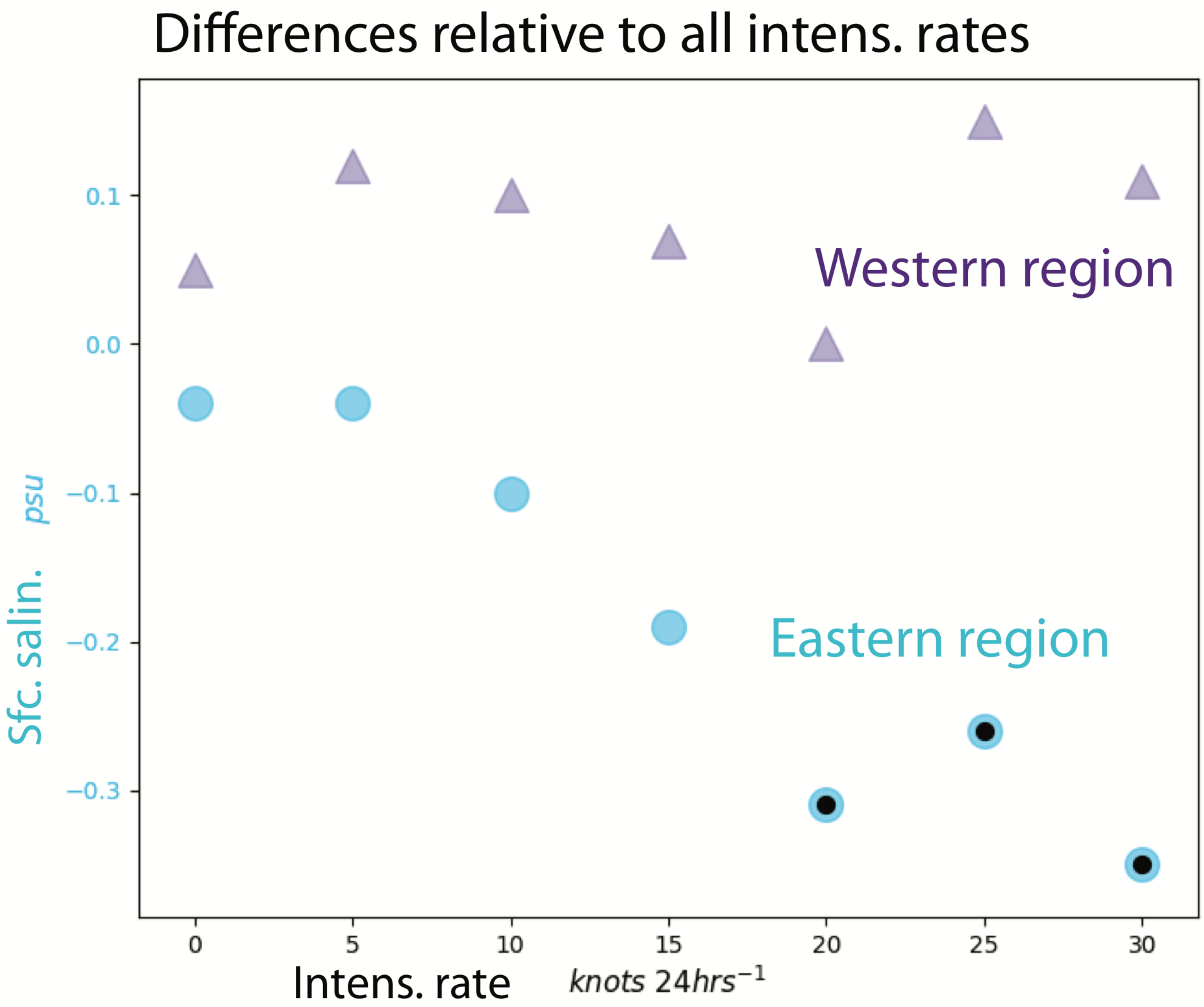


Eastern region

Significantly stronger salin., density strat. for RI cases



Differences in sfc. salinity



For higher intens. rates in the east, ocean is significantly fresher

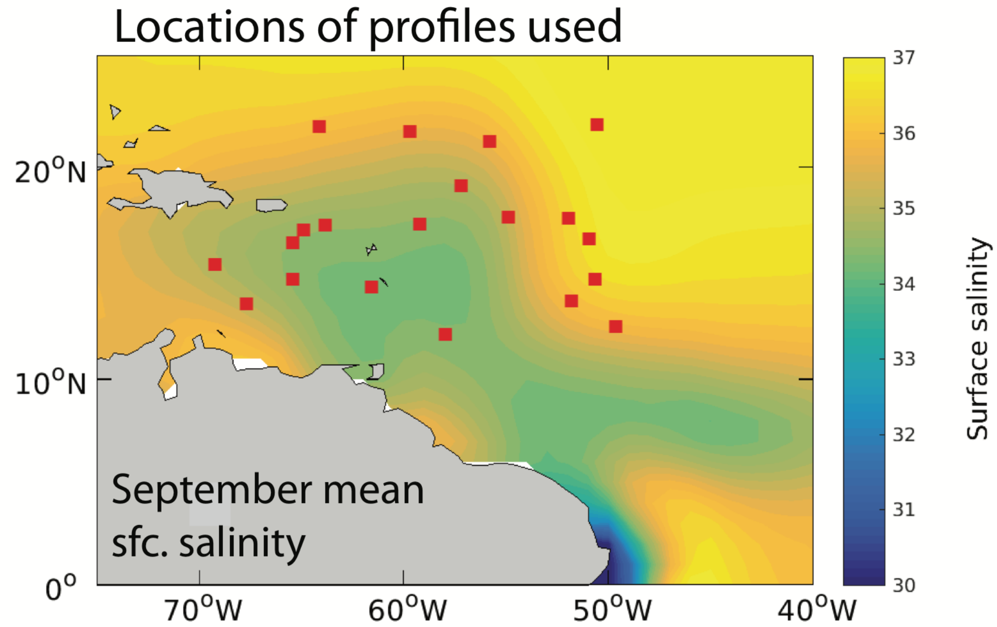
Why is salinity more important for RI?

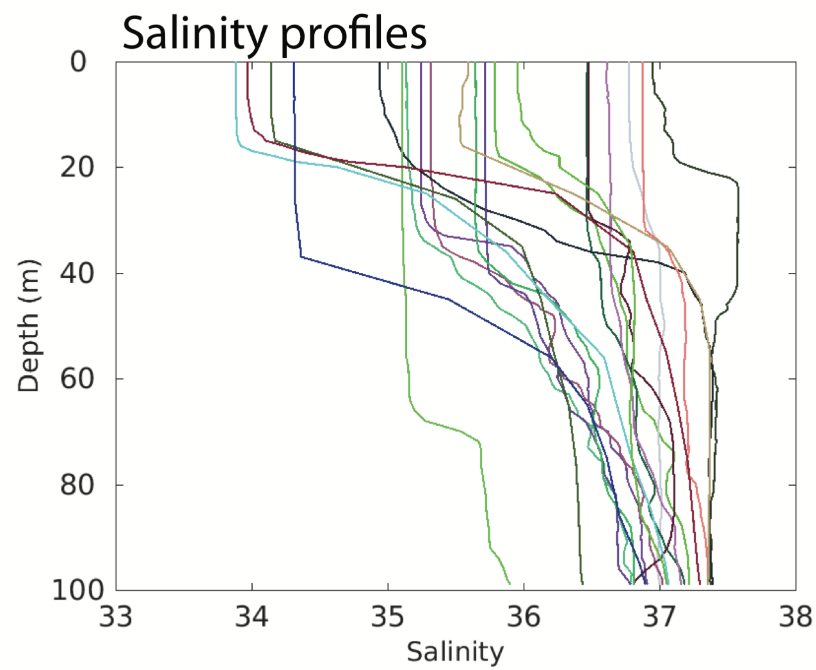
- Cold wake is weaker for RI, and salinity affects wake magnitude.
- TCs undergoing RI have a higher mean intensity and therefore capable of generating stronger mixing.
- Stronger mixing (and cooling) allows for greater potential reduction in cold wake magnitude.

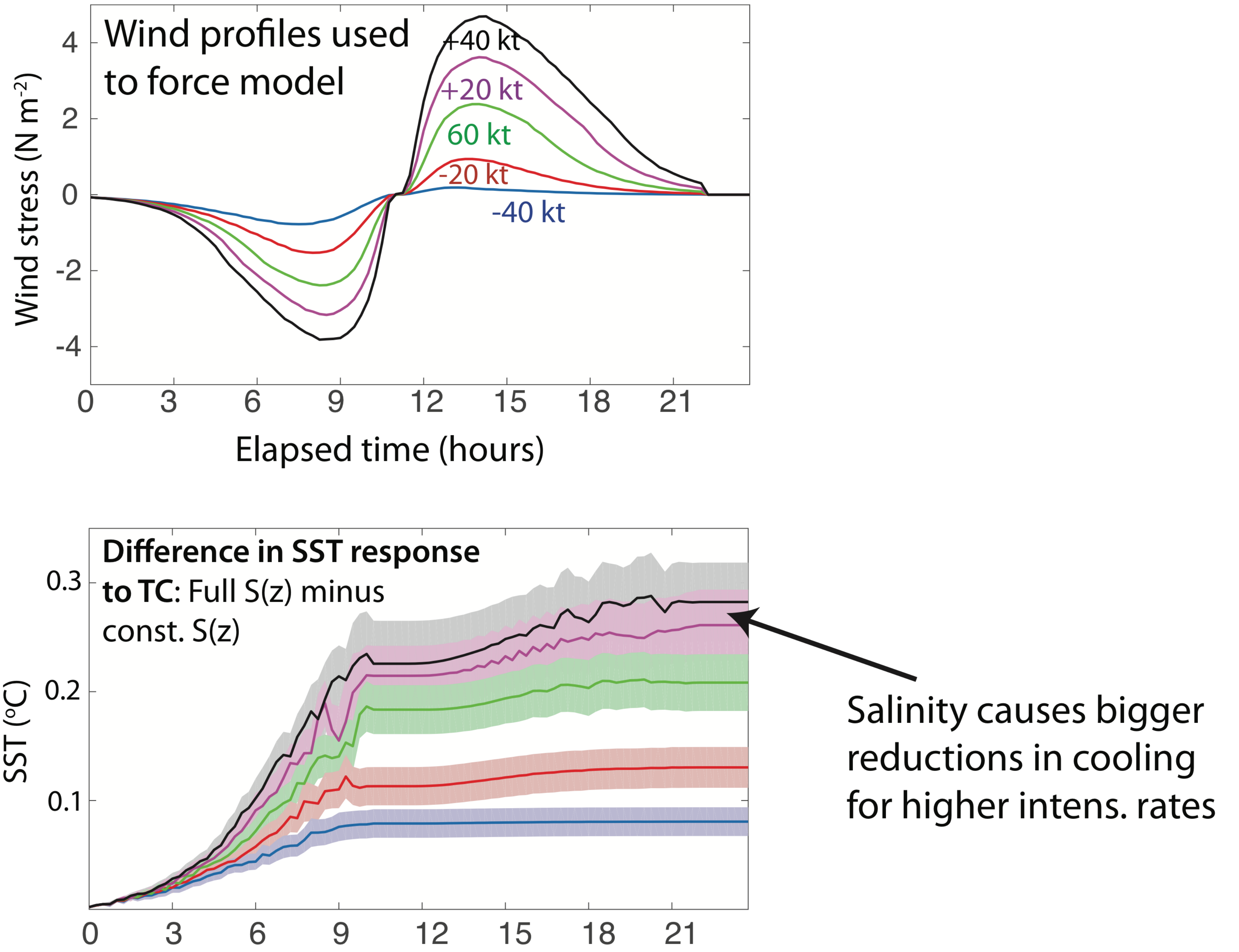
1-d ocean model experiments

Initialize PWP model with realistic temp., salin. profiles from Argo floats and look at difference in cold wake between experiments with realistic salin. and const. salin.

Axisymmetric wind profile,
5 m/s translation, intensity of 60 kt (control) with decreases of 20 kt and 40 kt and increases of 20 kt and 40 kt between t=0 and 2nd RMW.






Wind profiles used to force model
+40 kt
+20 kt
60 kt
-20 kt
-40 kt
Wind stress (N m-2)
4
2
0
-2
-4
0
3
6
9
12
15
18
21
Elapsed time (hours)
Difference in SST response to TC: Full S(z) minus const. S(z)
SST (°C)
0.3
0.2
0.1
0
3
6
9
12
15
18
21
Salinity causes bigger reductions in cooling for higher intens. rates

Summary

- Sustained ocean observations are valuable for hurricane model initialization and forcing, satellite validation, seasonal hurricane outlooks, and improved scientific understanding.
- **The present observing system is not optimized for hurricane research and forecasts**, especially in the western tropical Atlantic, Caribbean, Gulf.
- Enhancements underway: **Increased Argo float coverage, expanded underwater glider network.**

- **Lower surface salinity (stronger stratification) appears to favor hurricane rapid intensification** in the eastern Caribbean and western Atlantic.

- Real-time satellite surface salinity may improve RI prediction, based on preliminary tests.

Please let me know if you have any ideas for improving/enhancing the observing system that could lead to improved operational forecasts.