Satellite-Derived Ocean Heat Content Variability: Implications for Weather and Climate Studies

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Goal: Build a global evaluated OHC product for forecasting tropical cyclone intensity by combining multiple altimeters and in-situ measurements.

Acknowledge NAVO For SHA Fields

UNIVERSITY OF MIAMI
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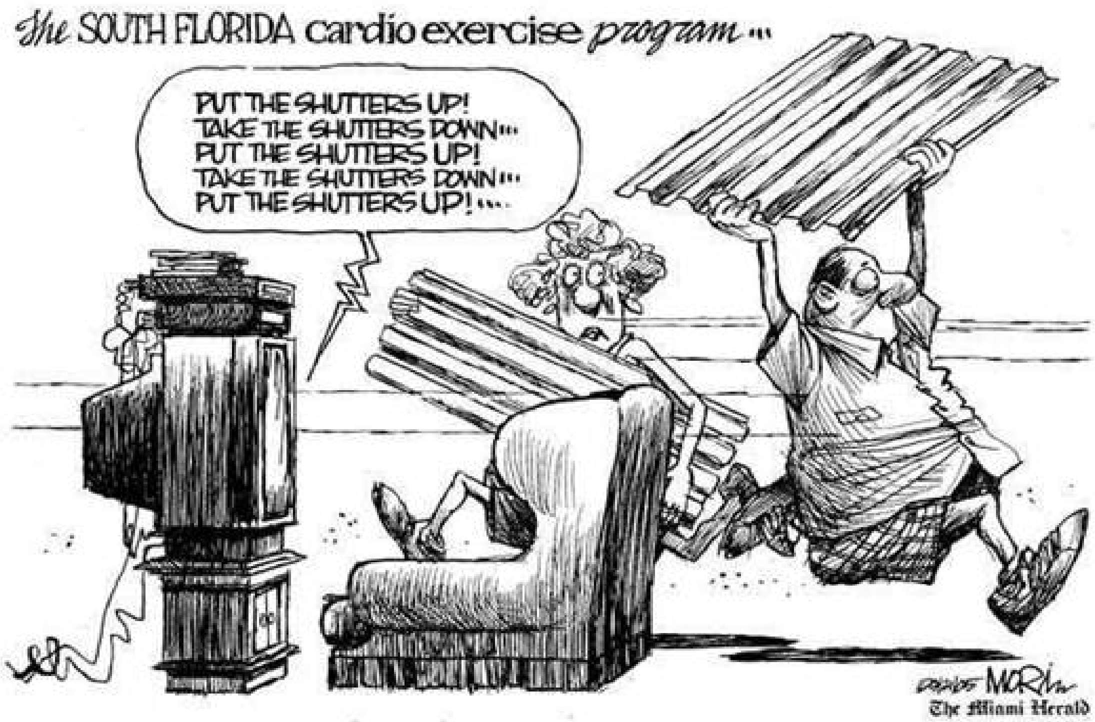
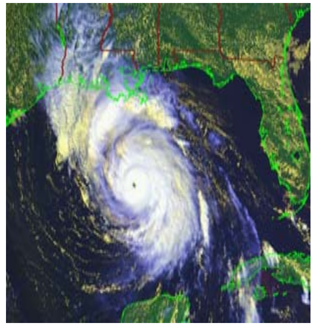

The SOUTH FLORIDA cardio exercise program...
PUT THE SHUTTERS UP!
TAKE THE SHUTTERS DOWN...
PUT THE SHUTTERS UP!
TAKE THE SHUTTERS DOWN...
PUT THE SHUTTERS UP!....
The Miami Herald




ENOUGH WAS ENOUGH!..
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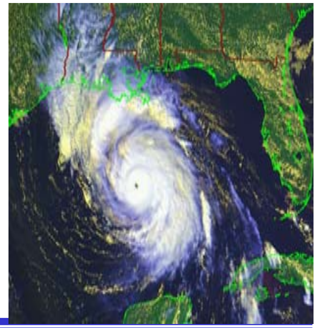
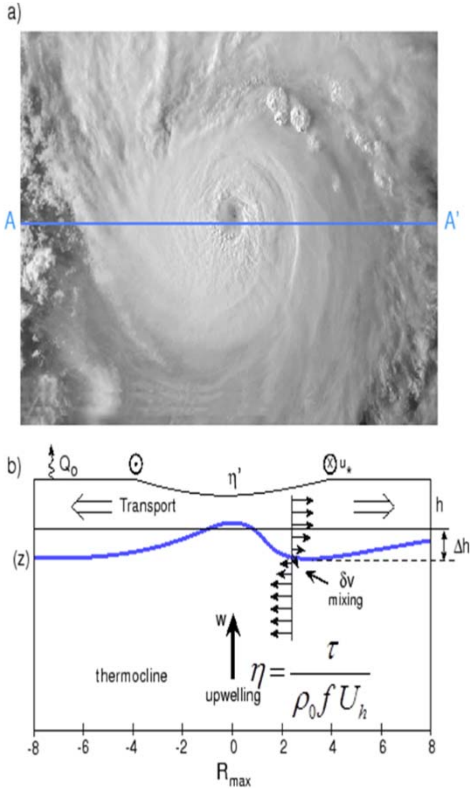


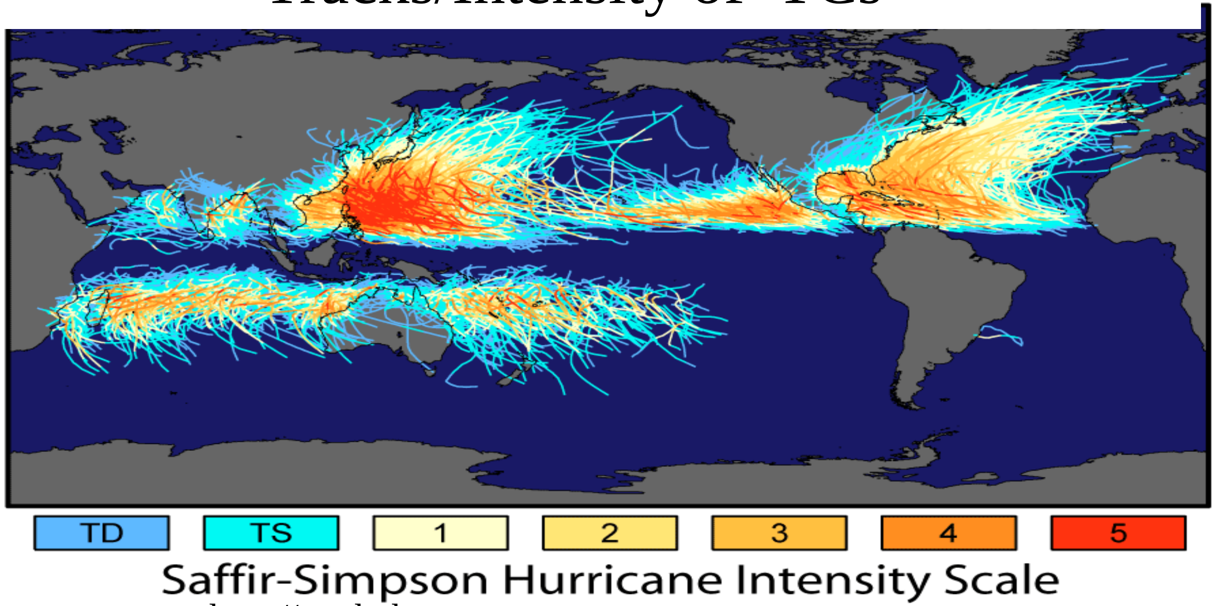
Outline

- Motivation
- Oceanic Heat Content Approach
- East Pacific (El Nino) : Patricia (2015)
- Western Atlantic: Earl (2010); Irma, Maria (2017)
- Gulf of Mexico: Harvey and Nate (2017)
- Future Efforts (New Floats)
- Summary

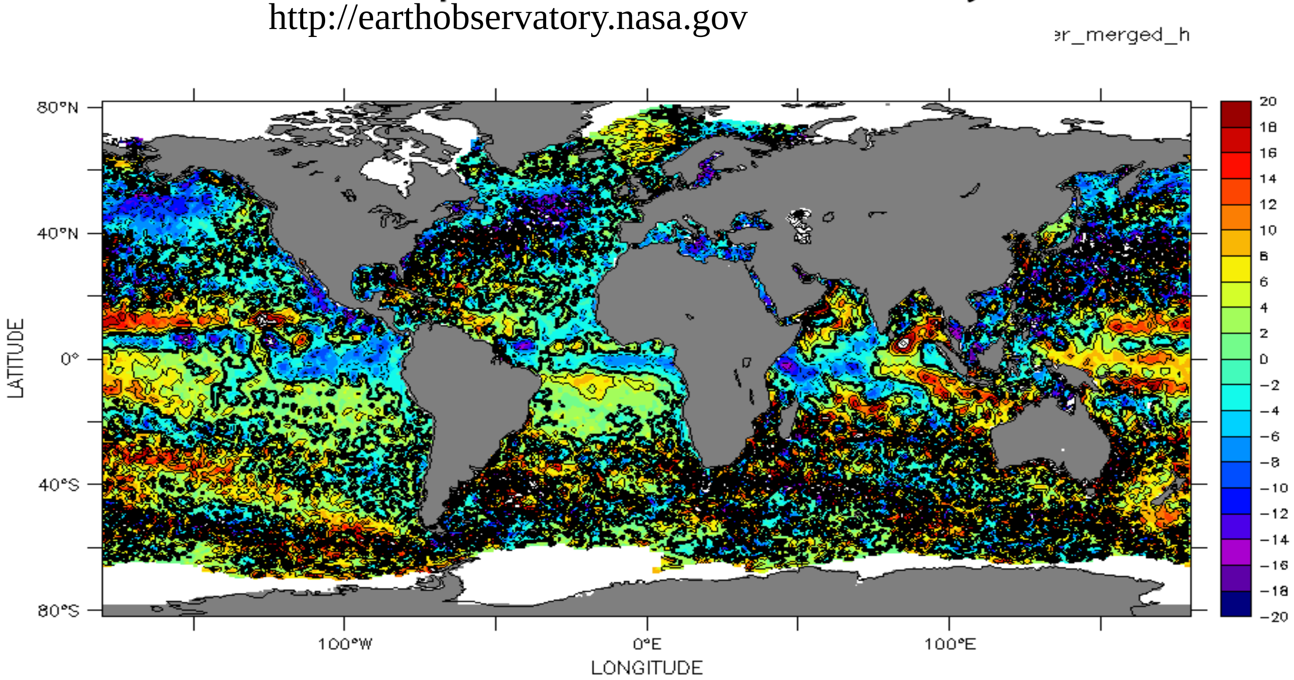


Background ocean fields modulate the level of the upwelling and mixing responses which directly impact the SST and air-sea fluxes and hence intensity change.

Tracks/Intensity of TCs



http://earthobservatory.nasa.gov



Sea surface height anomaly (cm) http://www.aviso.oceanobs.com

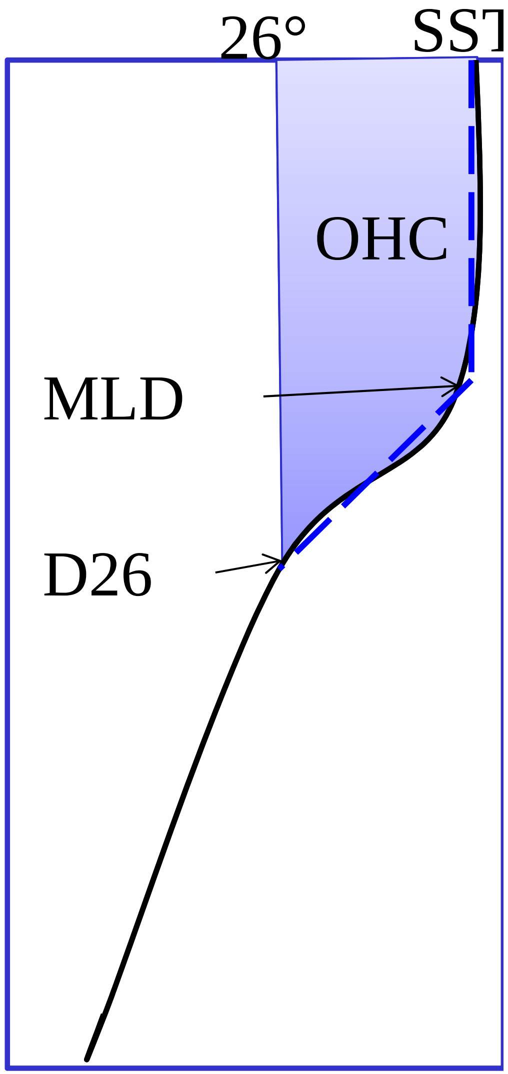
Global Problem of TC-Ocean Interactions!

SST, MLD and OHC Background

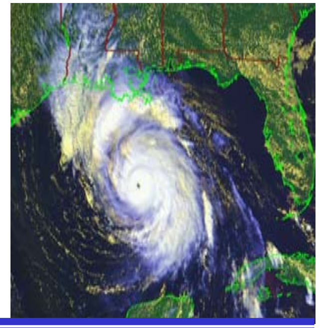
- Minimum sea surface temperature threshold for hurricane formation: SST >26ºC (Palmen, 1948)
- Leipper (JPO, 1972) introduced Ocean Heat Content integrated thermal energy from surface to 26º isotherm:

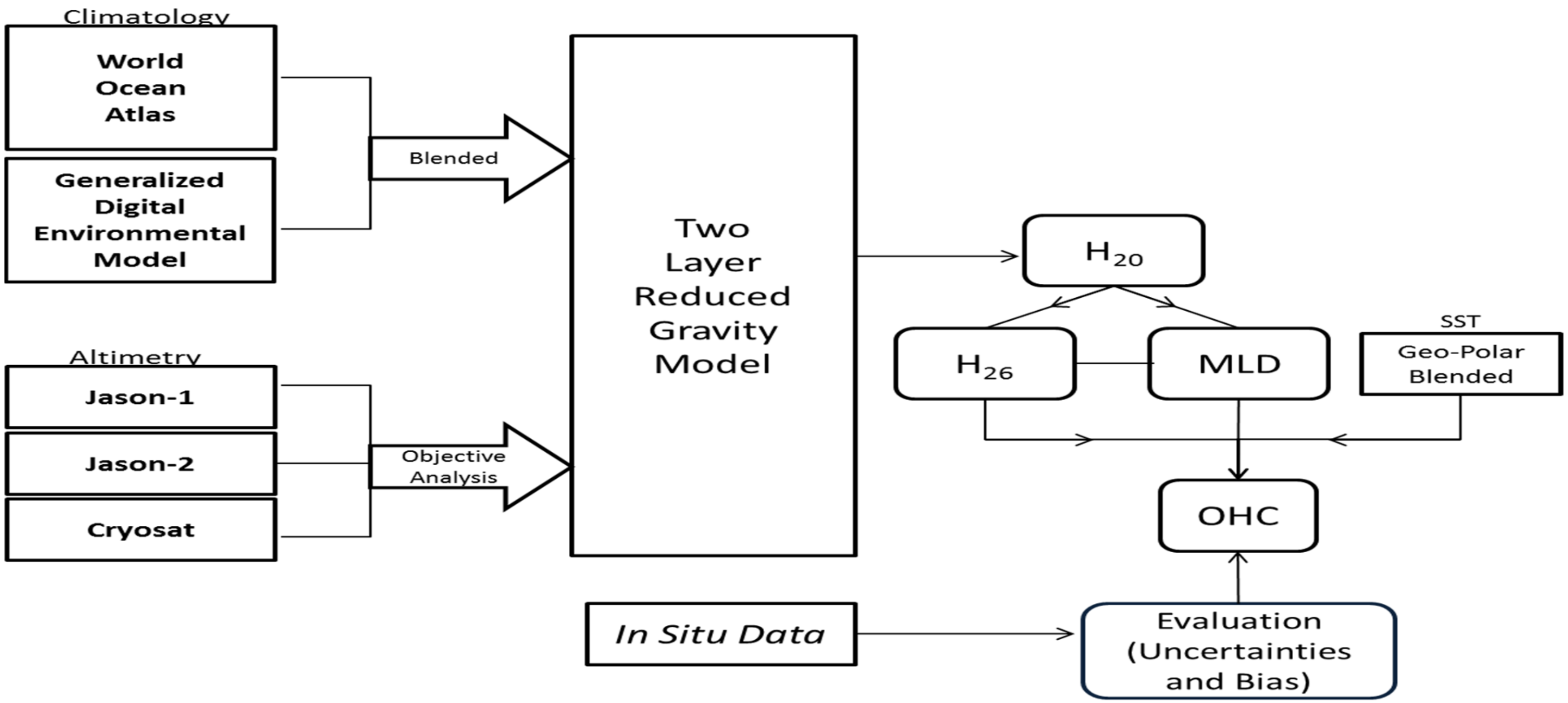
$$OHC = c_p \rho \int_{D26}^{\eta} (T_z - 26°)\, dz$$

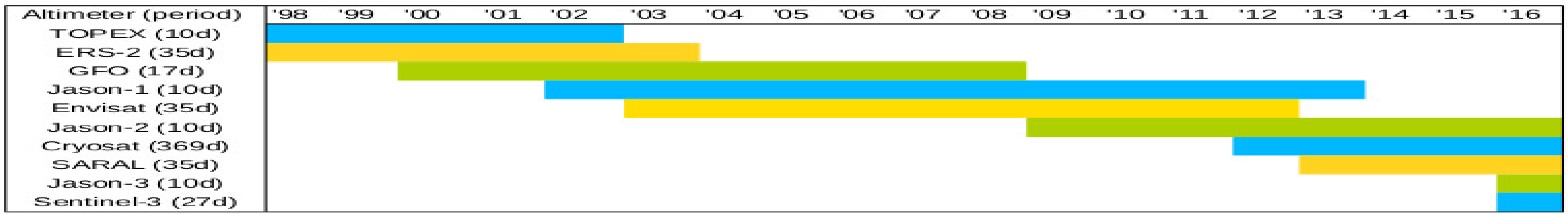
- Approach to estimate OHC from satellite derived SSTs and SSHAs for Operational and Research Products.
- **Operational** Product-Uses NESDIS GeoPolar Blended SST product and updated SHAs each day.
- Used in forecasting intensity (DeMaria et al., WAF, 2005; Mainelli et al., WAF, 2008).
- **Research** Product-Uses GPB (5 km) and MUR SST (1 km) products with weighted SHA field focusing on day of interest (+/- 5 day window for altimeter).
- **Products are evaluated** using measurements (floats, ship transects, mooring, drifters, and aircraft expendables).



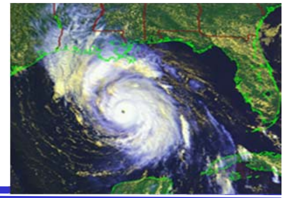
Approach (Shay and Brewster, MWR, 2010; Meyers et al., JAOT, 2014; McCaskill et al. JAOT, 2016)



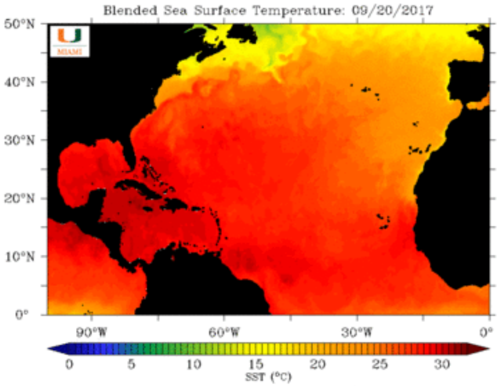


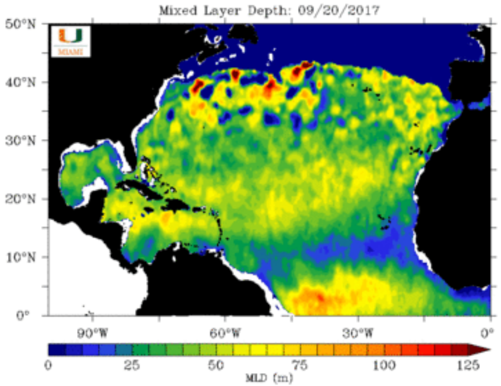


Daily Diagnostic Product Suite:



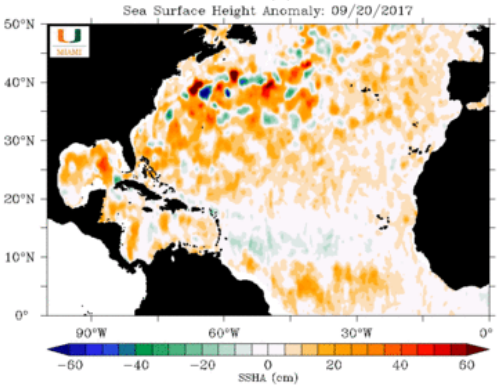
Sea Surface Temperature

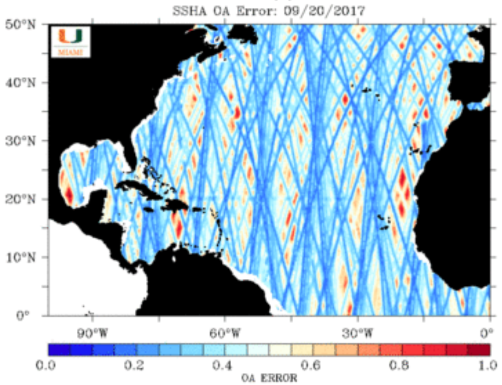




Mixed Layer Depth

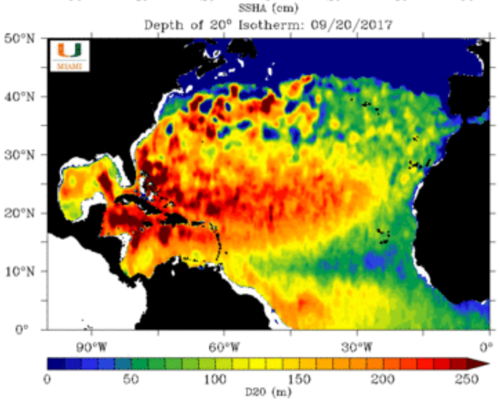
Sea surface Height Anomaly

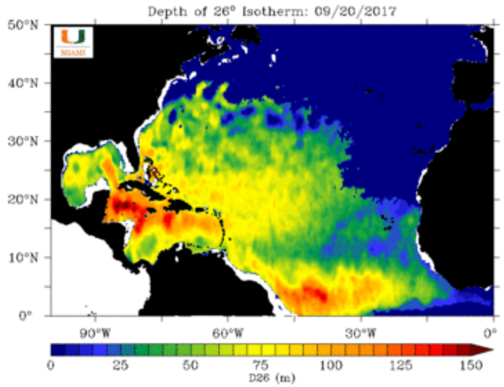




Objective Analysis Error (Mariano and Brown, DSR, 1992)

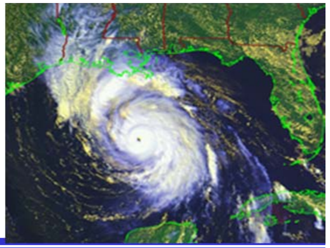
20°C Isotherm

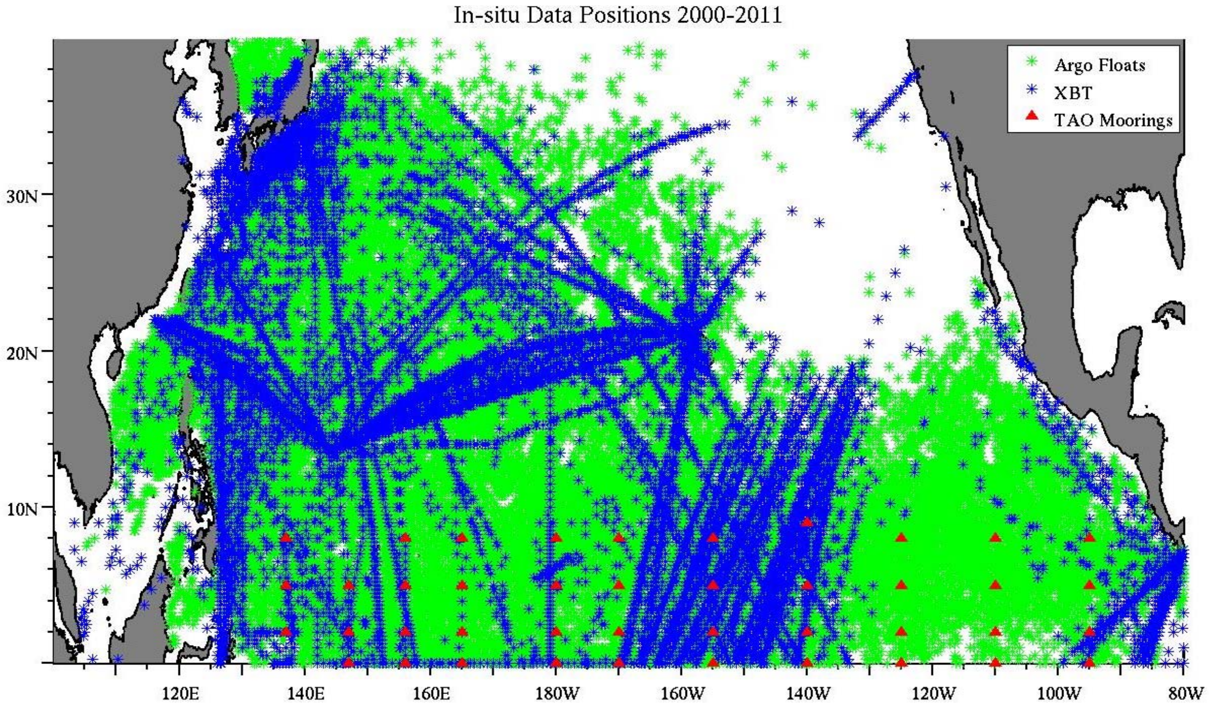


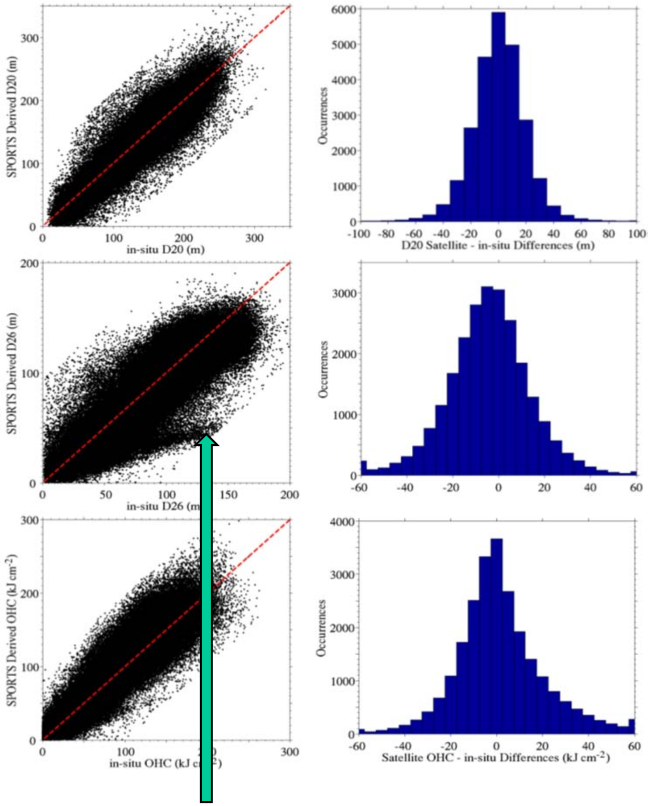


26°C Isotherm

North Pacific Ocean In-situ Evaluation Thermal Profiles From 00 to 13



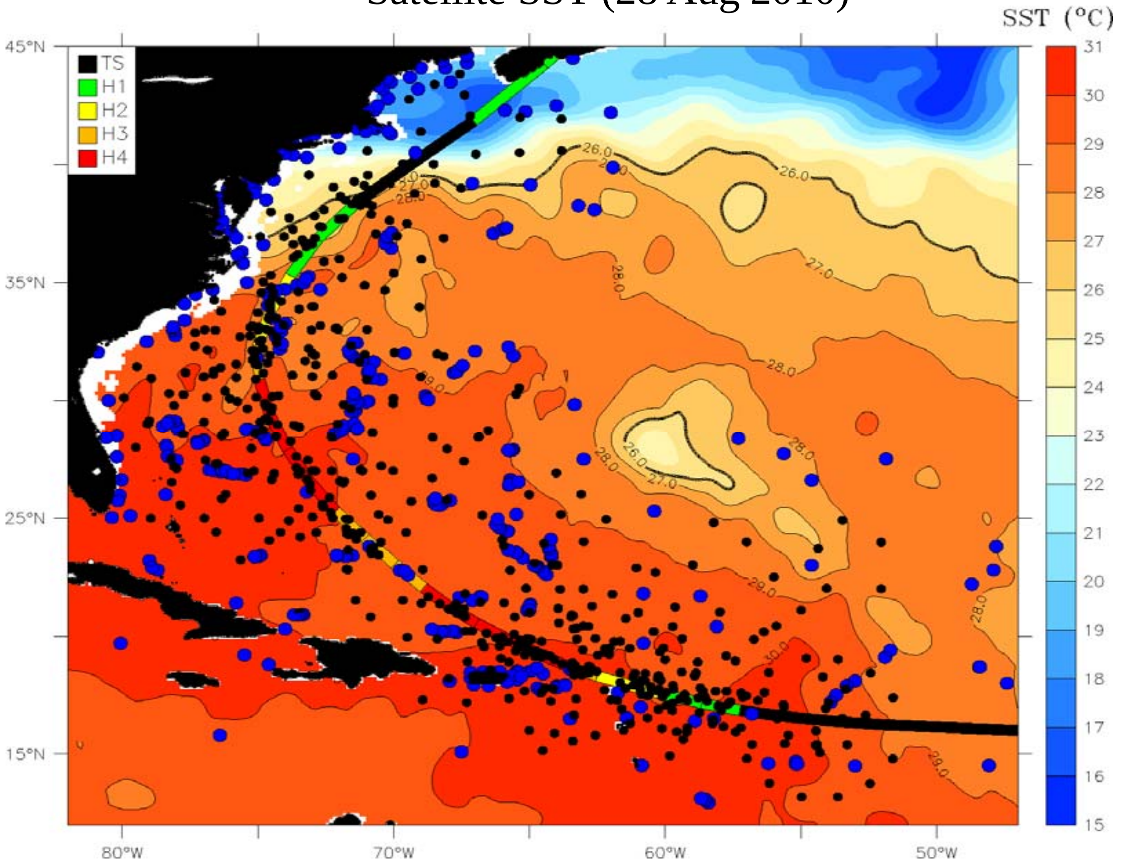


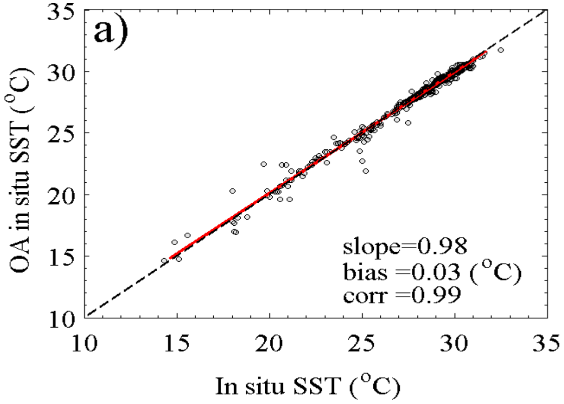


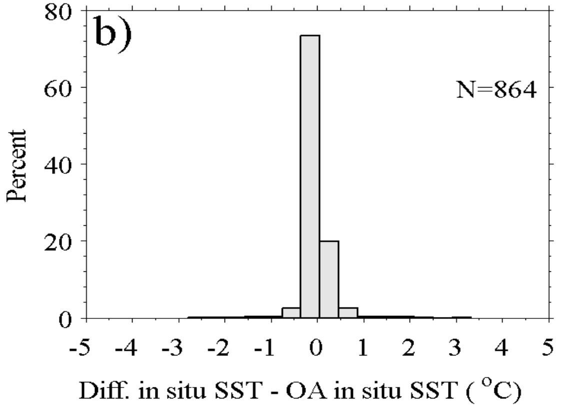
El Nino in **02**, 04, 06, 09

During NASA GRIP In-situ SST data and GPS Dropsondes (Jaimes et al. , MWR, 2014)

Satellite SST (28 Aug 2010)



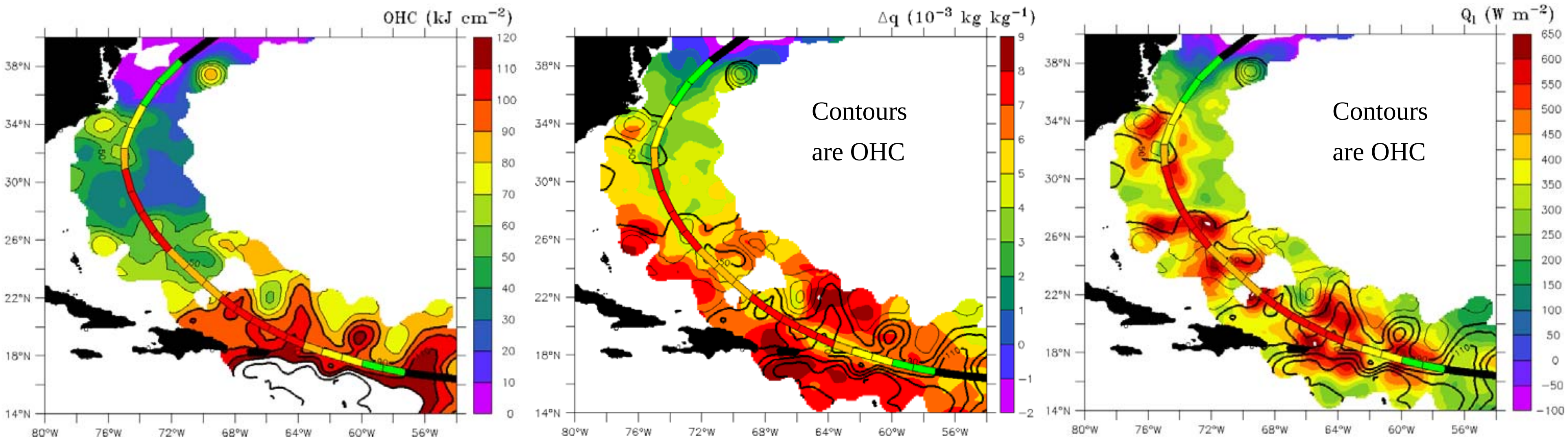




- GPS dropsondes (28 Aug to 3 Sep) from 27 flights
- In-situ SST data points (28 Aug to 3 Sep)

In-situ SST vs. objectively analyzed in-situ SST

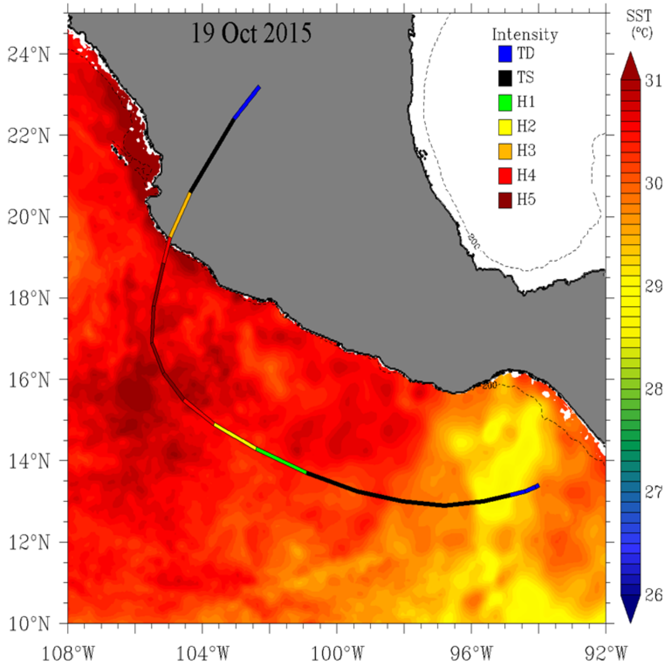
Enthalpy Fluxes Driven by Moisture Disequilibrium

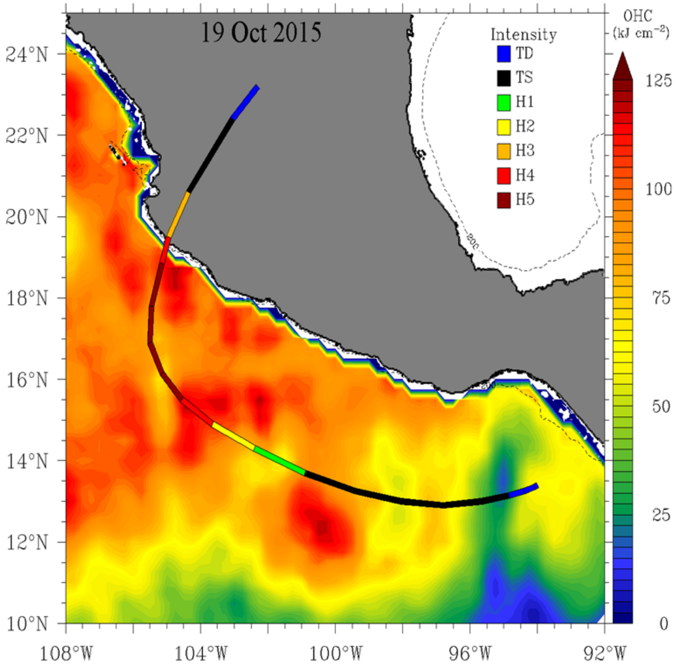


OHC → **Moisture Disequilibrium** → **Moisture Flux**

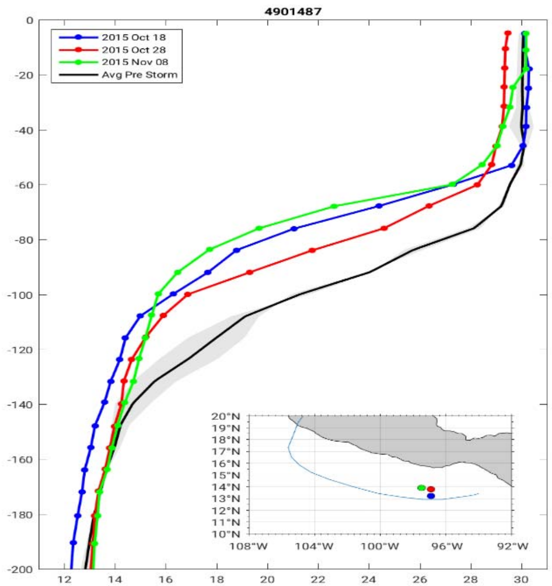
$$Q_l = \rho_a L_\upsilon C_q |\mathbf{U}_{10}| (q_s - q_a)$$

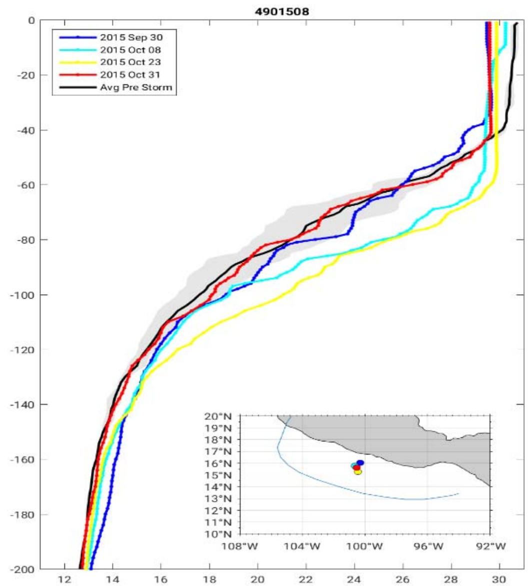
What is the threshold value of OHC for intensity change?



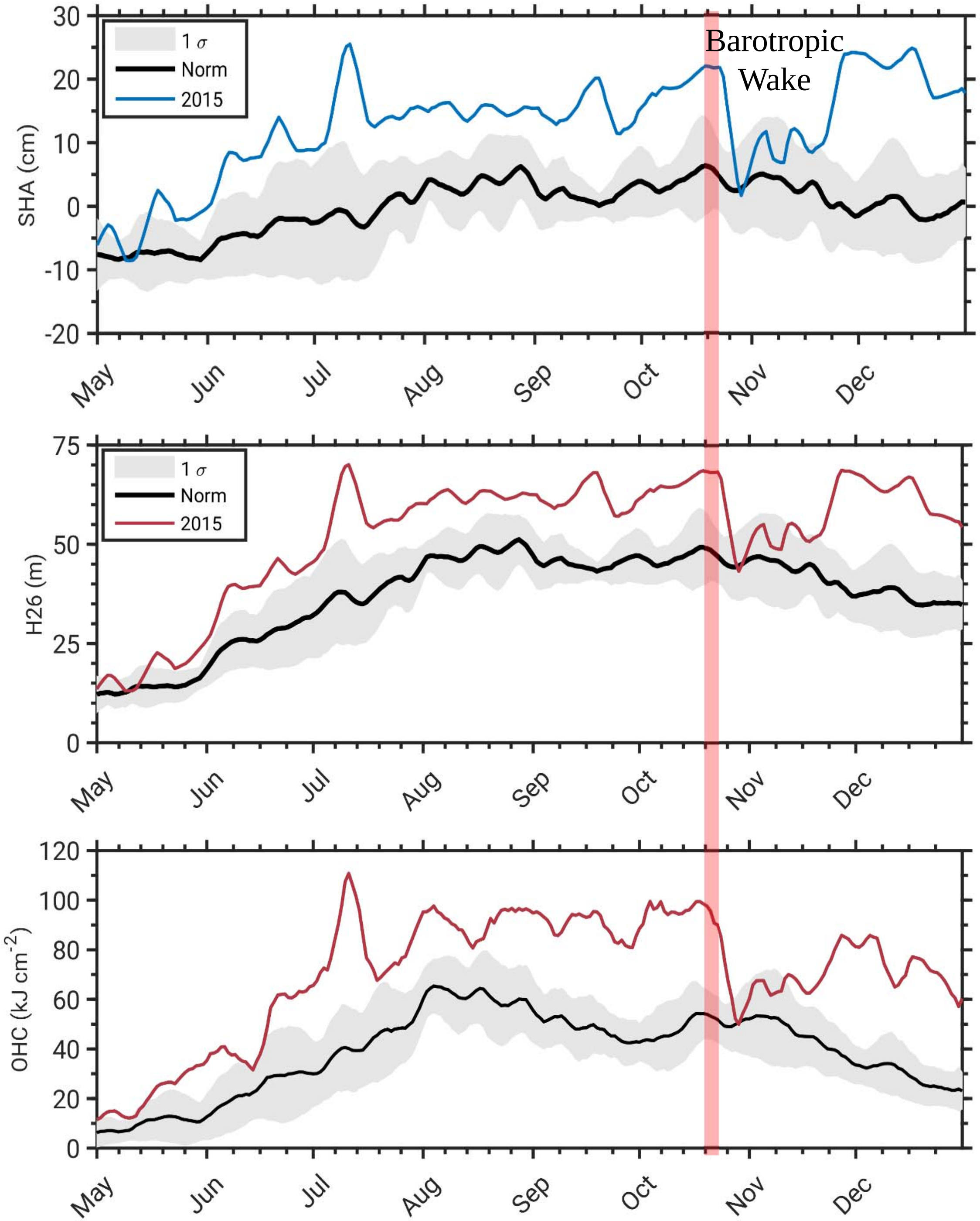


Pre-Patricia SST (left) and OHC (right) relative to the Track on 19 Oct 2015. These OHC levels were a factor of 2-3 times higher due to the 2015 El Nino (Rogers et al., BAMS, 2017).



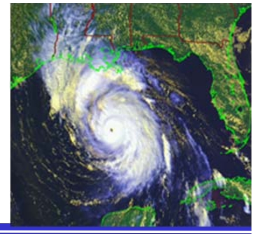


ARGO Floats underneath and on the right side of the track (see inserts) prior to explosive deepening.

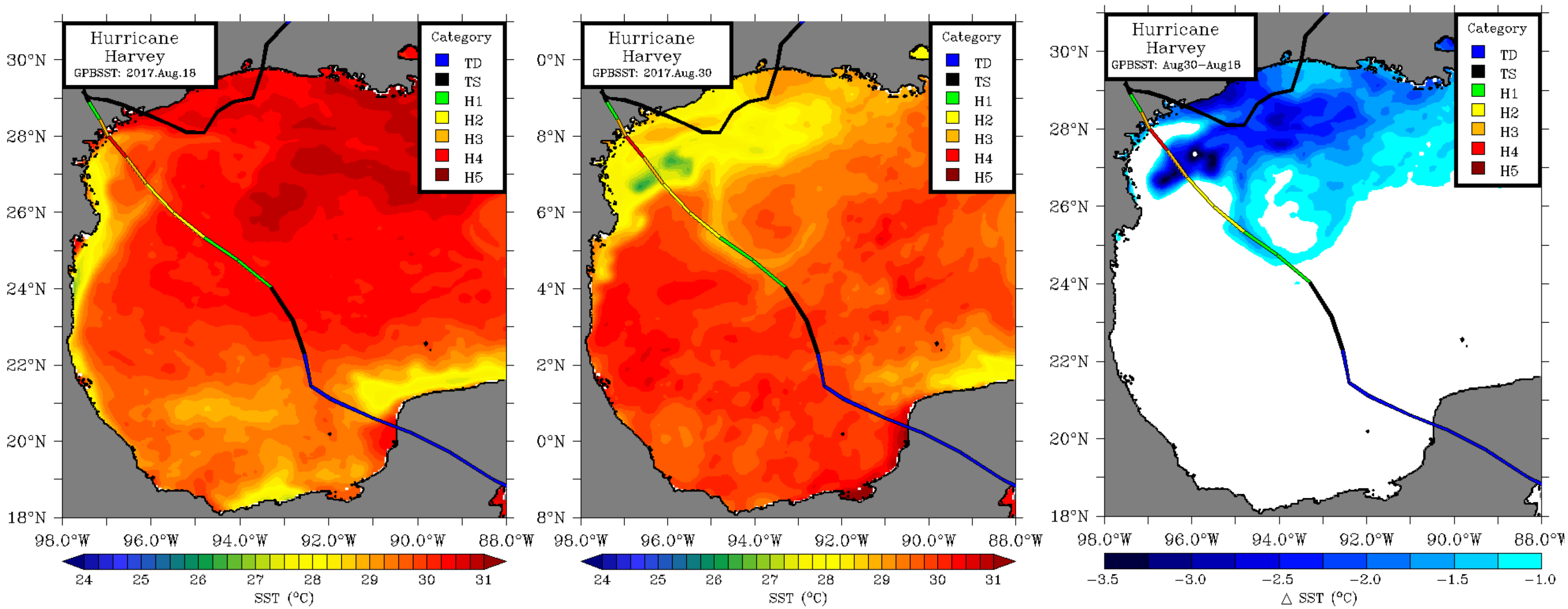


Using **El Nino** years (based on the Nino Ocean Index), average and standard deviation (black and gray) SHA (upper panel), depth of 26C isotherm (center panel) and OHC (lower panel) compared to the 2015 levels at a point along Patricia's track (red). 2015 levels were significantly above the average in the EPac where the average OHC is 35-40 kJ /cm^2 during **Non El Nino years**. (Rogers et al., BAMS, 2017).

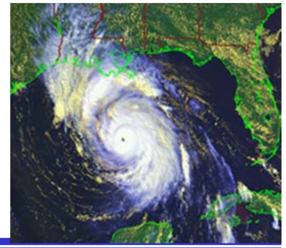
Harvey GeoPolarBlended (GPB) SST



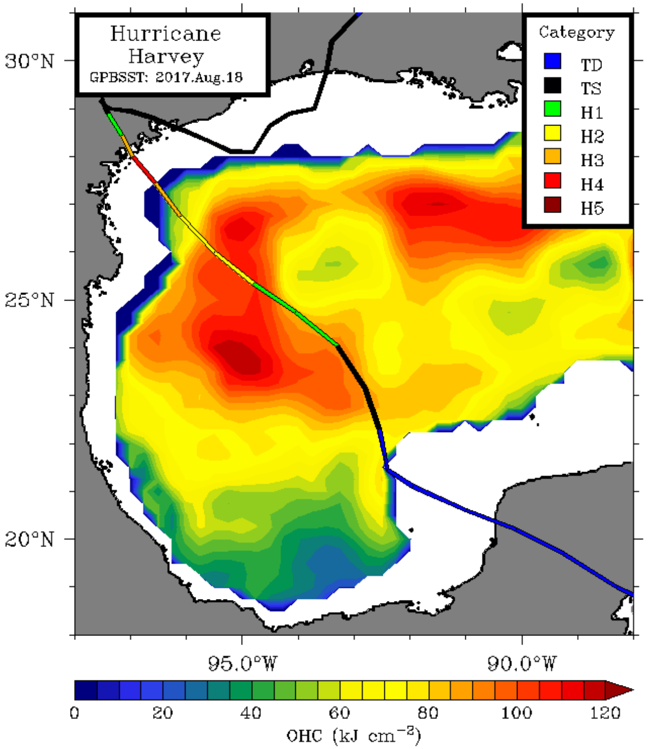
- Daily product
- Resolution 0.05°
- Microwave and Infrared Satellite-blended Fields
- Pre-Storm　　　　Post Storm　　　　Difference



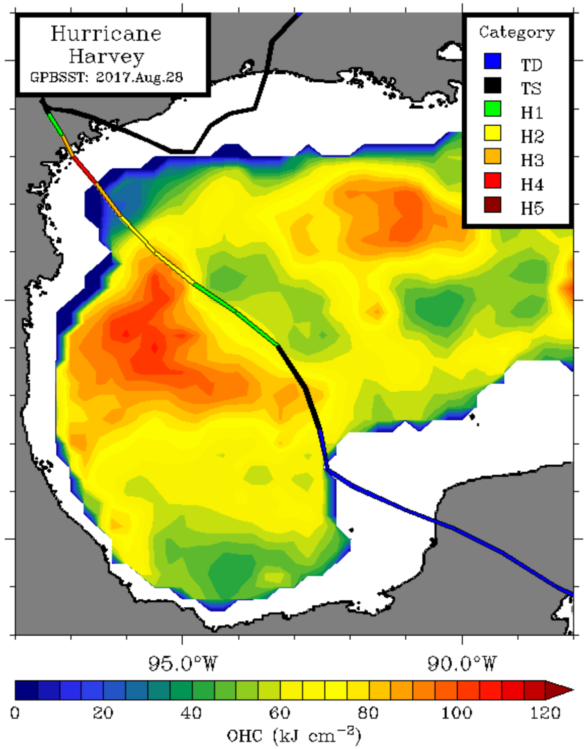
Harvey GPBSST Ocean Heat Content



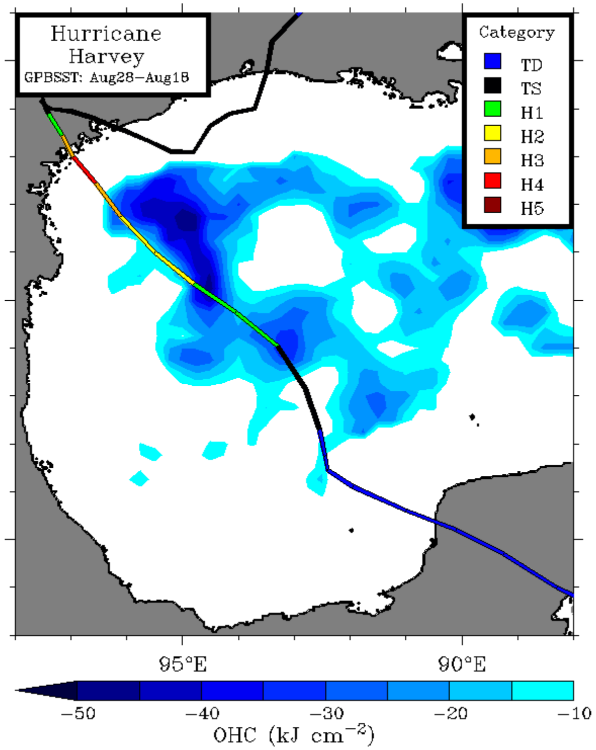
Pre-Storm



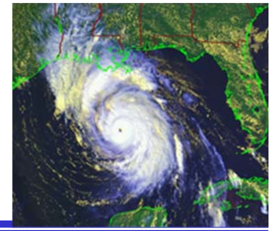
Post Storm



Difference



Surface Geostrophic Flows (Rio et al., GRL, 2014): Pre-Harvey



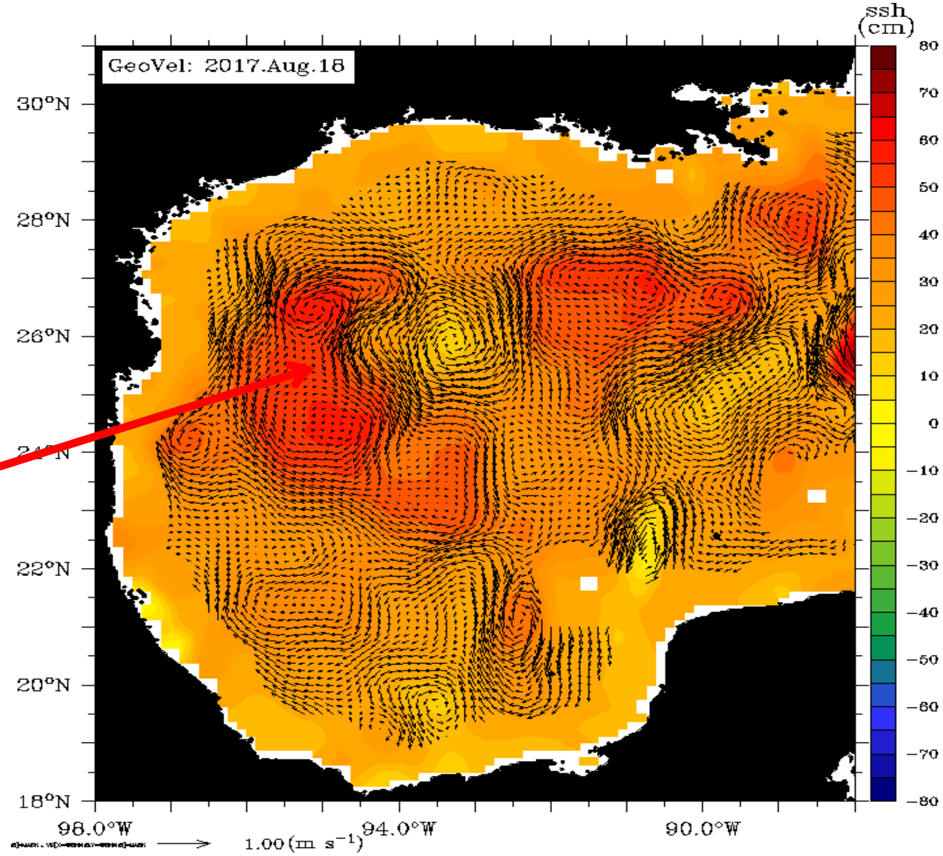
Extended the method of Stern (DSR, 1965) in Hurricane Isaac, assess dominant vorticity balance. Following (Jaimes and Shay, JPO, 2015) we will estimate the following in Harvey:

$$w_s = \mathbf{k} \cdot \frac{\nabla \times \boldsymbol{\tau}}{\rho_0 f} - \frac{h}{f}\left(\mathrm{U_h} \frac{\partial \zeta_g}{\partial y} + \frac{\boldsymbol{\tau} \times \mathbf{k}}{\rho_0 f h} \cdot \nabla \zeta_g \right)$$

Ekman pumping

Non-linear Ekman pumping

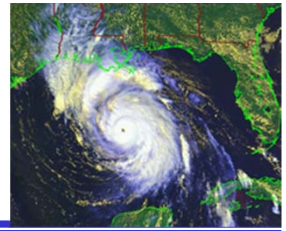
Anticyclonic Warm Eddy



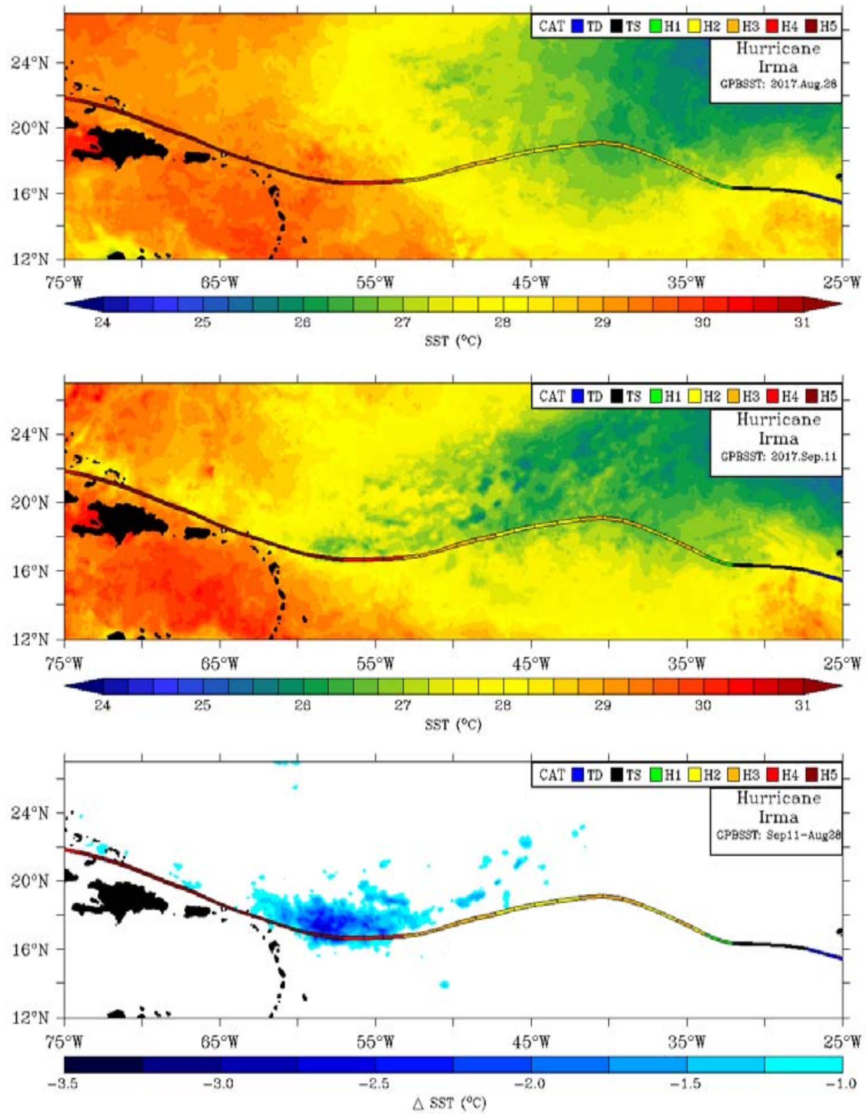
What additional downwelling/upwelling occurred due to these nonlinear-interactions?

1/8 ° resolution

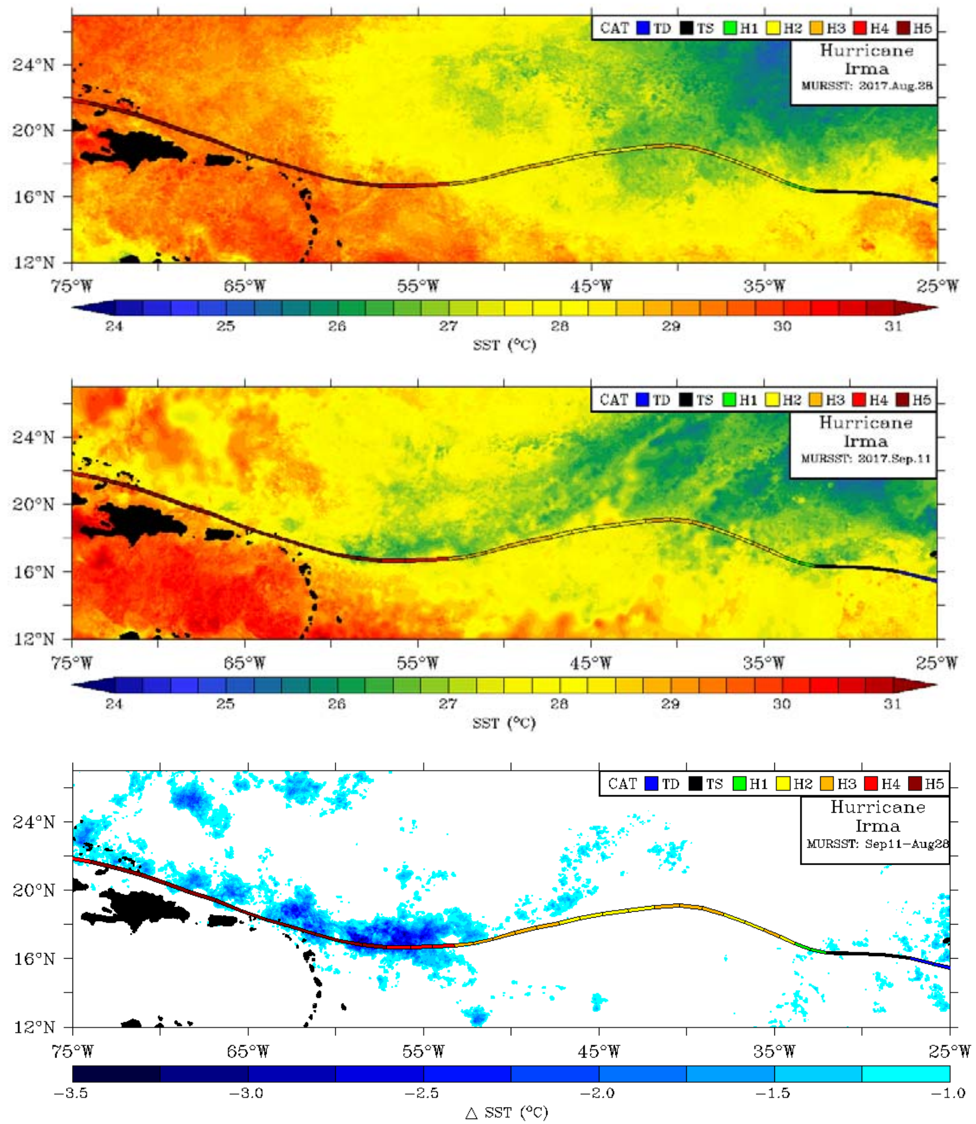
Irma GPB and MURSST Comparison



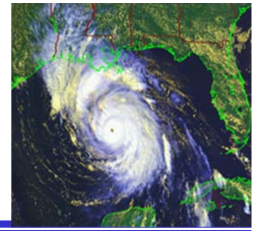
Microwave/Infrared Blended Field, 0.05°



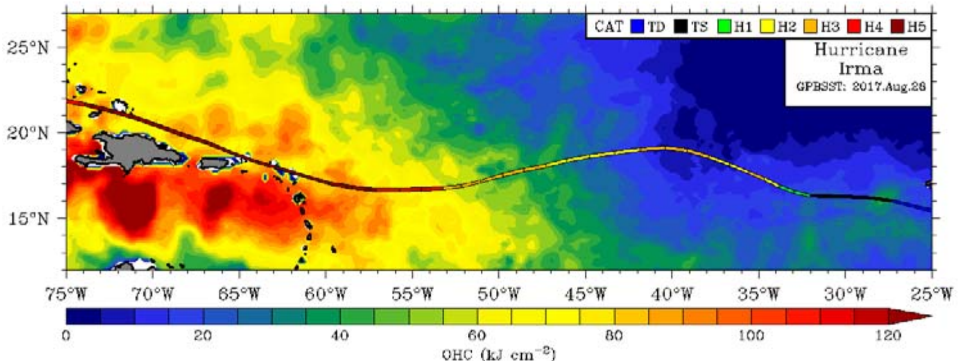
Ultra High Resolution 0.01°



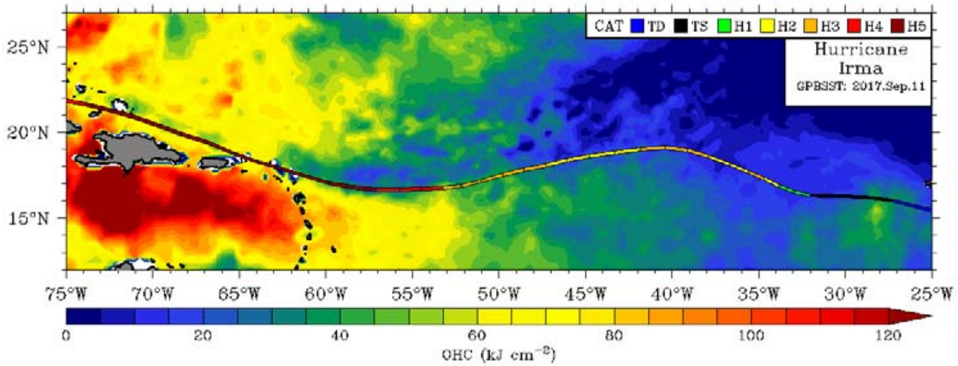
Irma GPBSST Ocean Heat Content



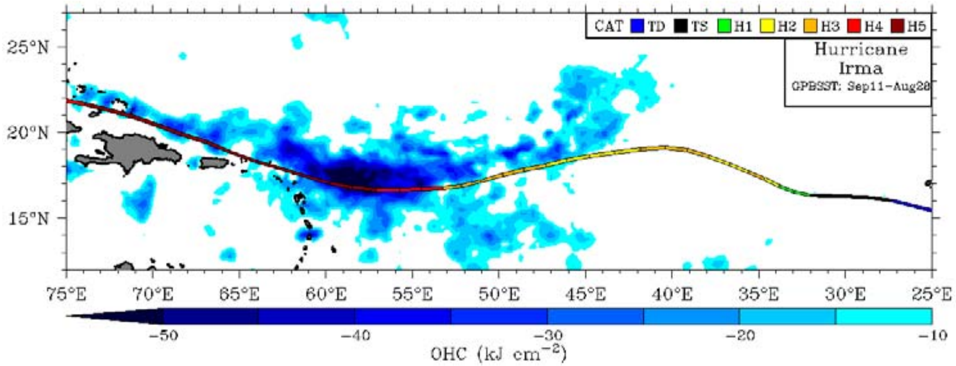
Pre-Storm



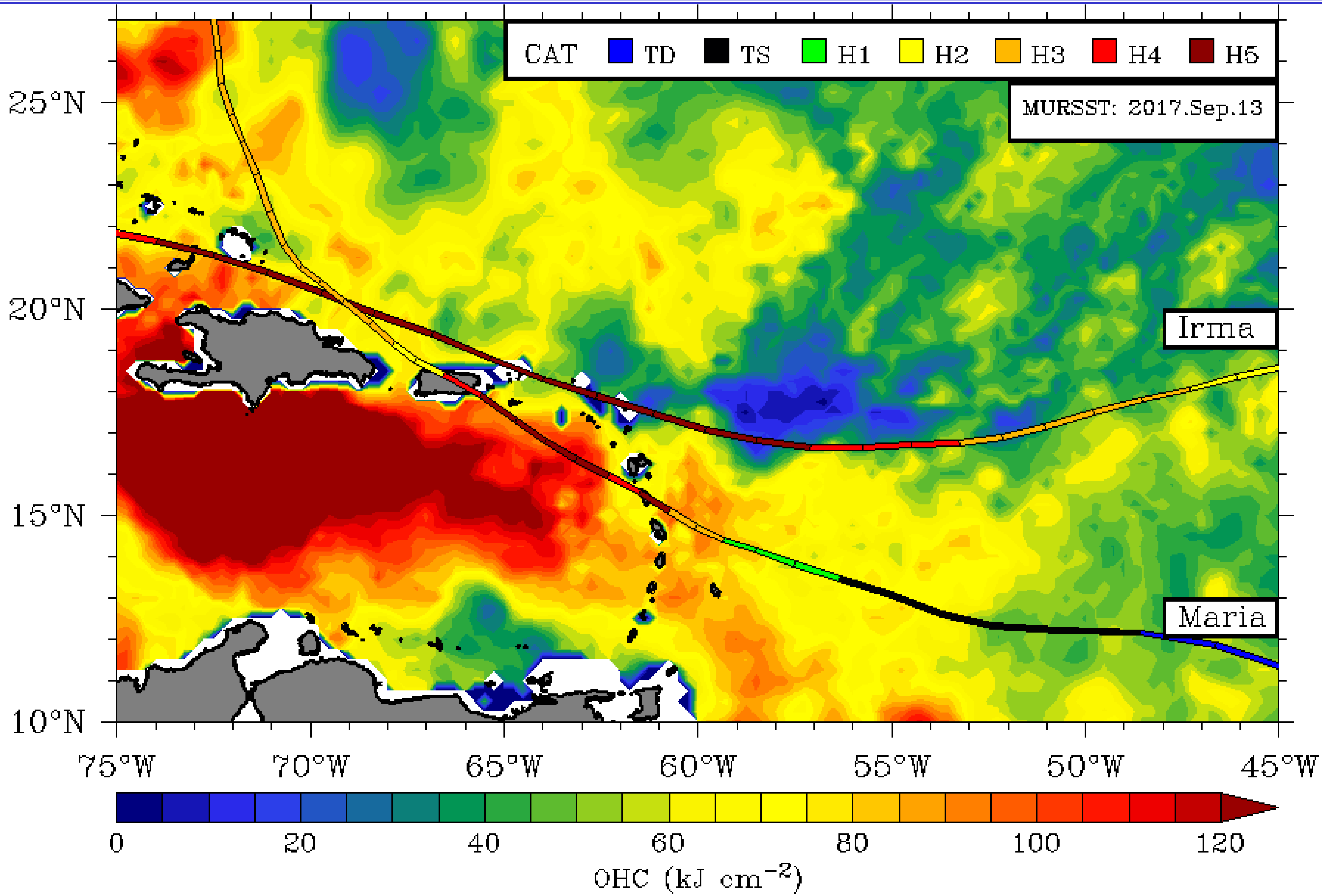
Post-Storm

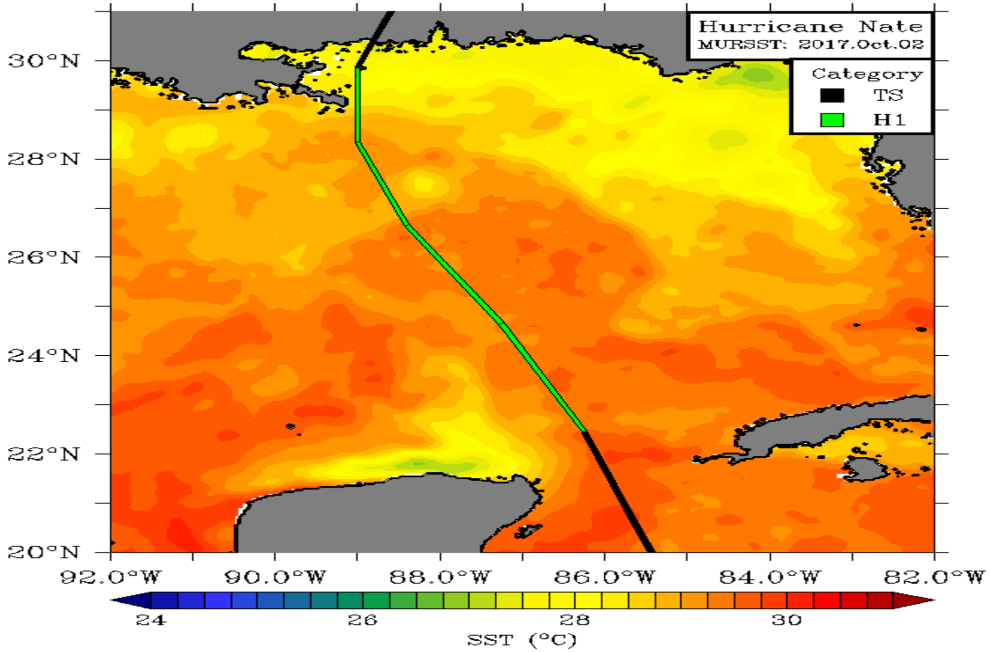


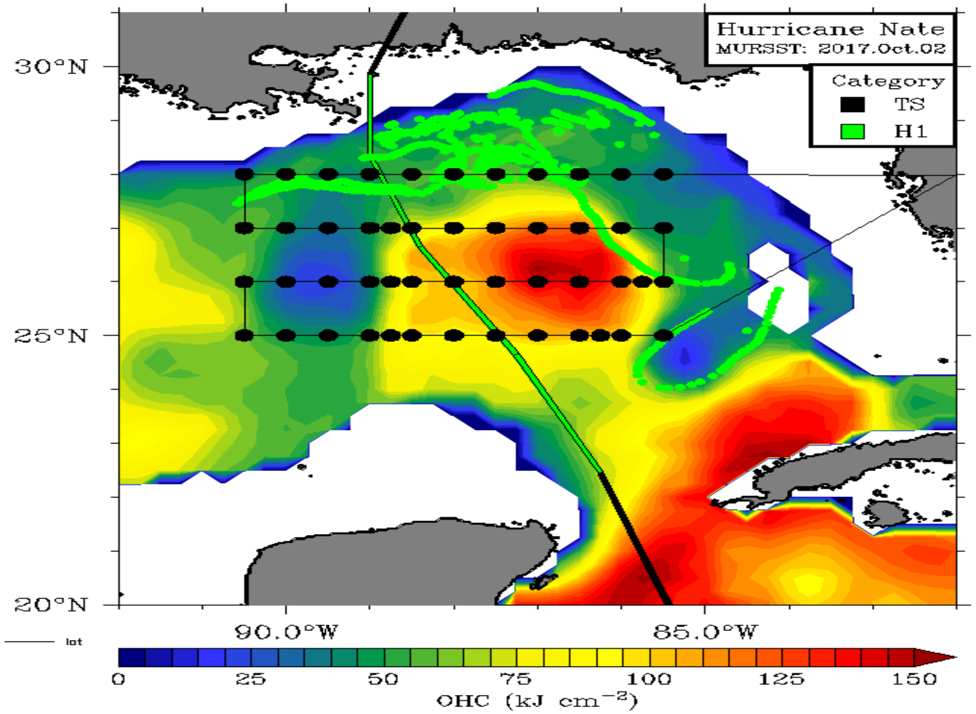
Difference



OHC Post Irma/Pre Maria Using MURSST



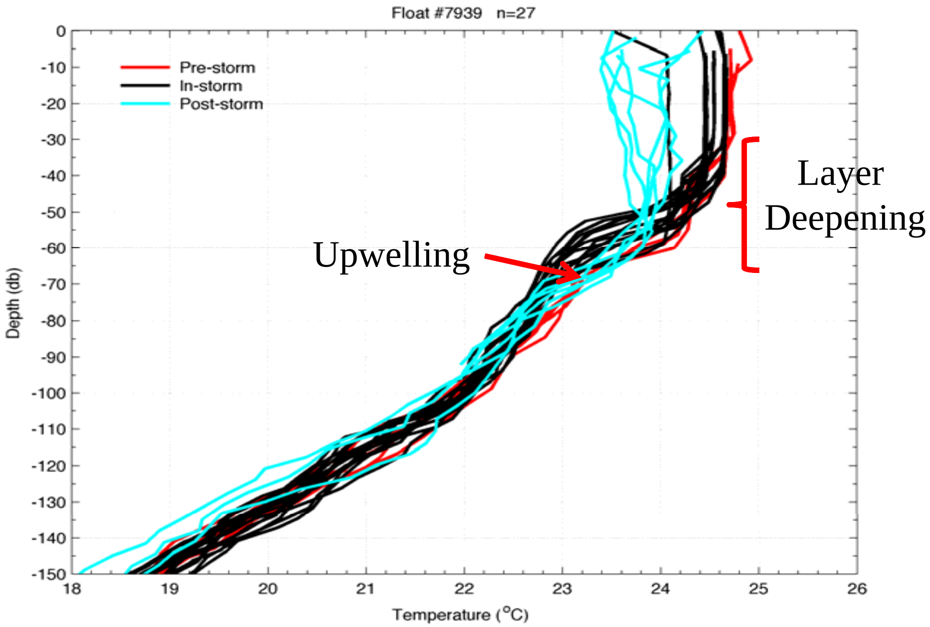


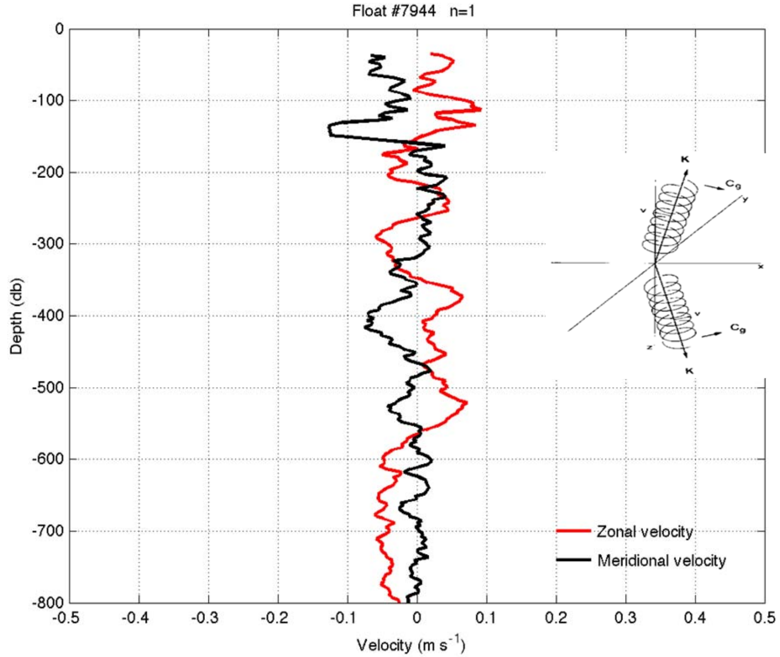


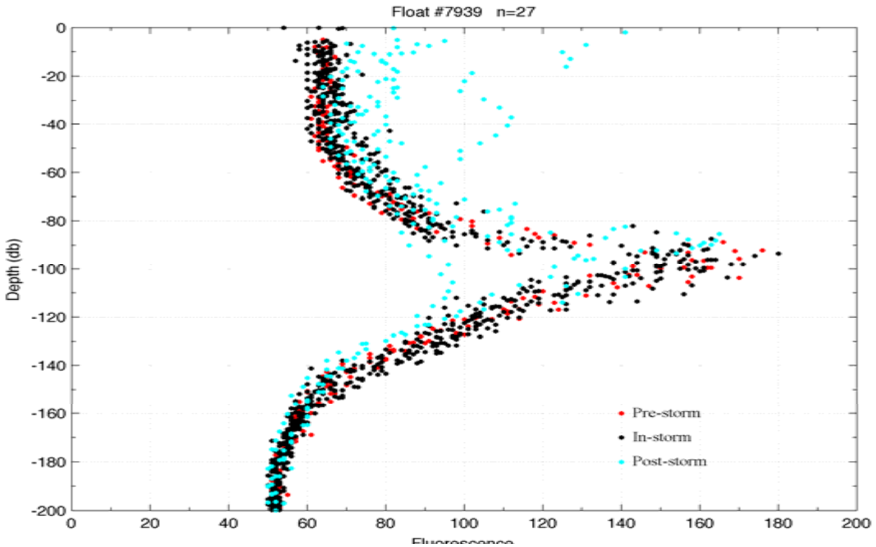
SST (**color**) prior to Nate in the GoM relative to track and intensity of Nate. Note Nate moved over the Gulf at speeds of more than 10 m/s (20 knts). Roughly 83% of the storms over the GoM move at speeds less than 5.8 m/s (~11 knts).

OHC (**color**) relative to pre-storm ocean grid (dots) of expendables deployed from NOAA WP-3D and Nate's track. Light **green** represents data from *state-of-the-art* profiling floats with physical and biochemical sensors deployed as part of GoMRI project that uses the APEX-EM platform (Sanford et al., GRL, 2007).

APEX-EM Float With ECOpuck Sensor Package: Response to Frontal Passage Early May







Measures

- T, S, u,v (continuous, park and profile, near-inertial pairs)
- Dissolved Oxygen
- Chlorophyll fluorescence, Backscatter as proxy of particle concentration, and CDOM
- Communicates via Iridium Remote Sensing

Summary: 19yr Evaluated Data Set

Evaluated altimetry-derived product based on ~ **1M thermal profiles** in North Atlantic/Pacific Ocean show consistent agreement (Meyers et al., JAOT, 2014; McCaskill et al., JAOT, 2016)

Operational OHC Product at NESDIS and at RSMAS (for research purposes) for North Atlantic and Pacific Ocean basins used in forecast models (Where is the heat?).

*During strong winds, SSTs mix with underlying ocean mixed layer and thermocline. OHC **of >17 kJ/cm^2** is a better barometer for intensity change (Leipper, JPO, 1972).*

In deep warm regimes, OHC often exceeds 80 kJ/cm-2 providing fuel for hurricanes especially during RI such as in Harvey, Irma, and Maria. (Mixing is arrested!).

*Over high OHC regimes **enthalpy fluxes of ~1 kW/m^2** **(moisture disequilibrium)** during RI cycles (Shay and Uhlhorn, MWR, 2008; Jaimes et al., MWR, 2014; Jaimes and Shay, 2017).*

In situ measurements (e.g., floats, moorings, etc) critical in approach in resolving the ocean mixed layer balance (advection, mixing and upwelling).