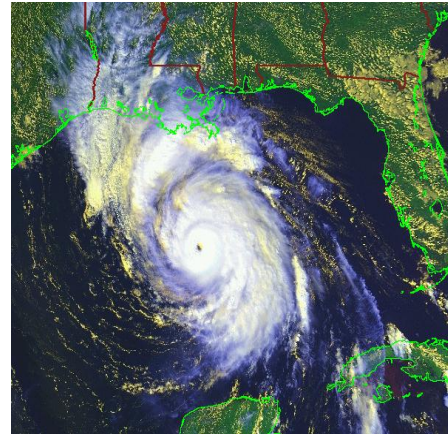


# Upper Ocean Impacts and Air-Sea Fluxes During Hurricane Earl

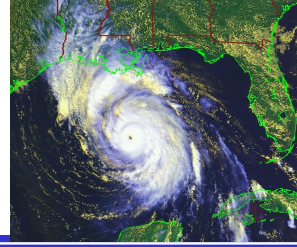


**L.K. Shay, B. Jaimes, P. Meyers, E. Uhlhorn and J. Brewster**

*Goal: Using satellite, in situ data, work towards improving an ocean model to couple to HWRF by **assessing** the oceanic role in intensity changes (rapid deepening and weakening).*



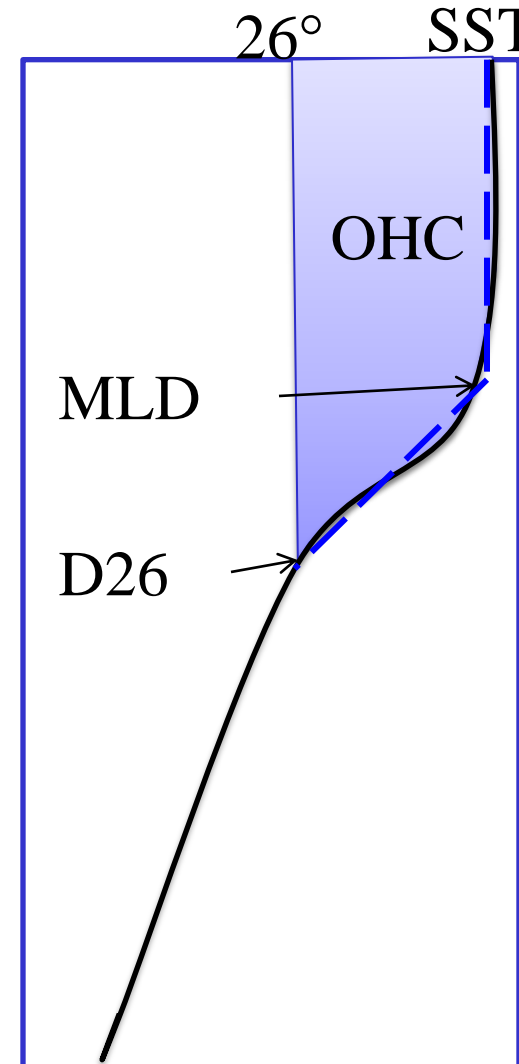
# Motivation and Background



- Minimum sea surface temperature threshold for hurricane formation:  $SST > 26^{\circ}\text{C}$  (Palmen, 1948)
- Leipper (1972) introduced Ocean Heat Content
  - Integrated thermal energy from surface to  $26^{\circ}$  isotherm

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

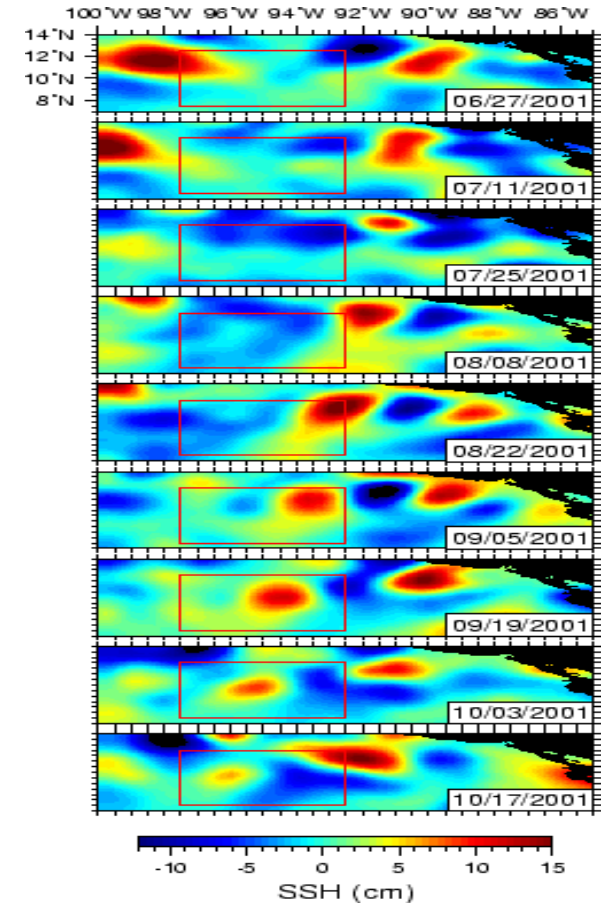
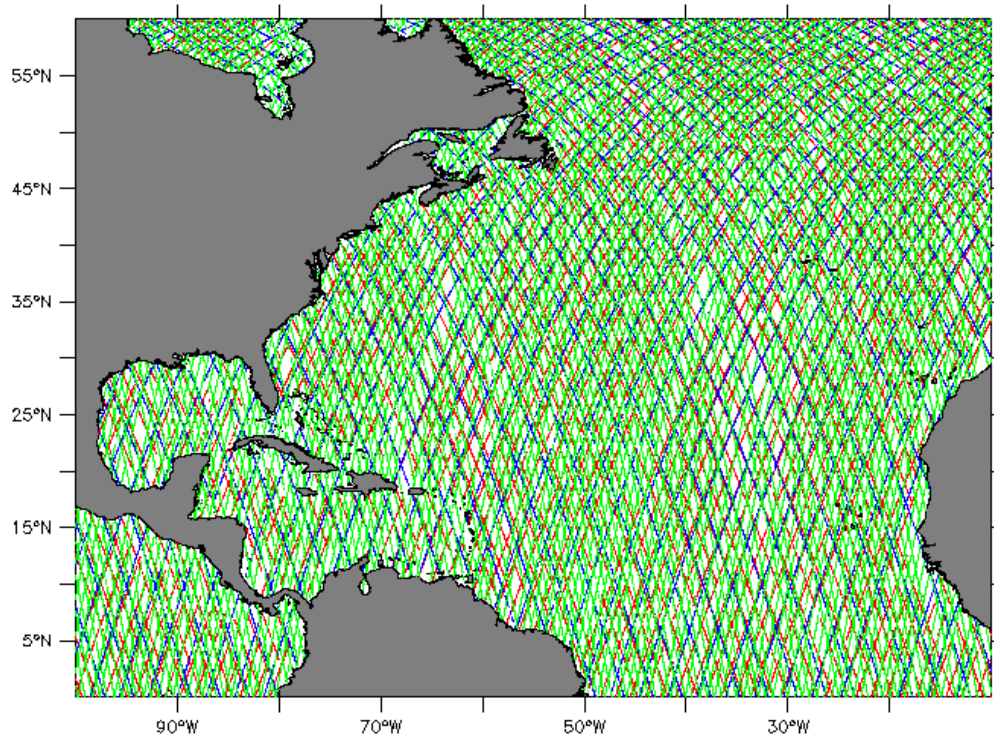
- Empirical approach to estimate OHC from satellite altimetry (Shay and Brewster, 2010)
- Ocean thermal structure is important feedback mechanism (Chang and Anthes, 1978)
- Warm core eddies inhibit mixing and provide deep energy source for hurricanes (Shay et al., 2000; Jaimes and Shay, 2009)



# Satellite Altimetry Availability Since 1998

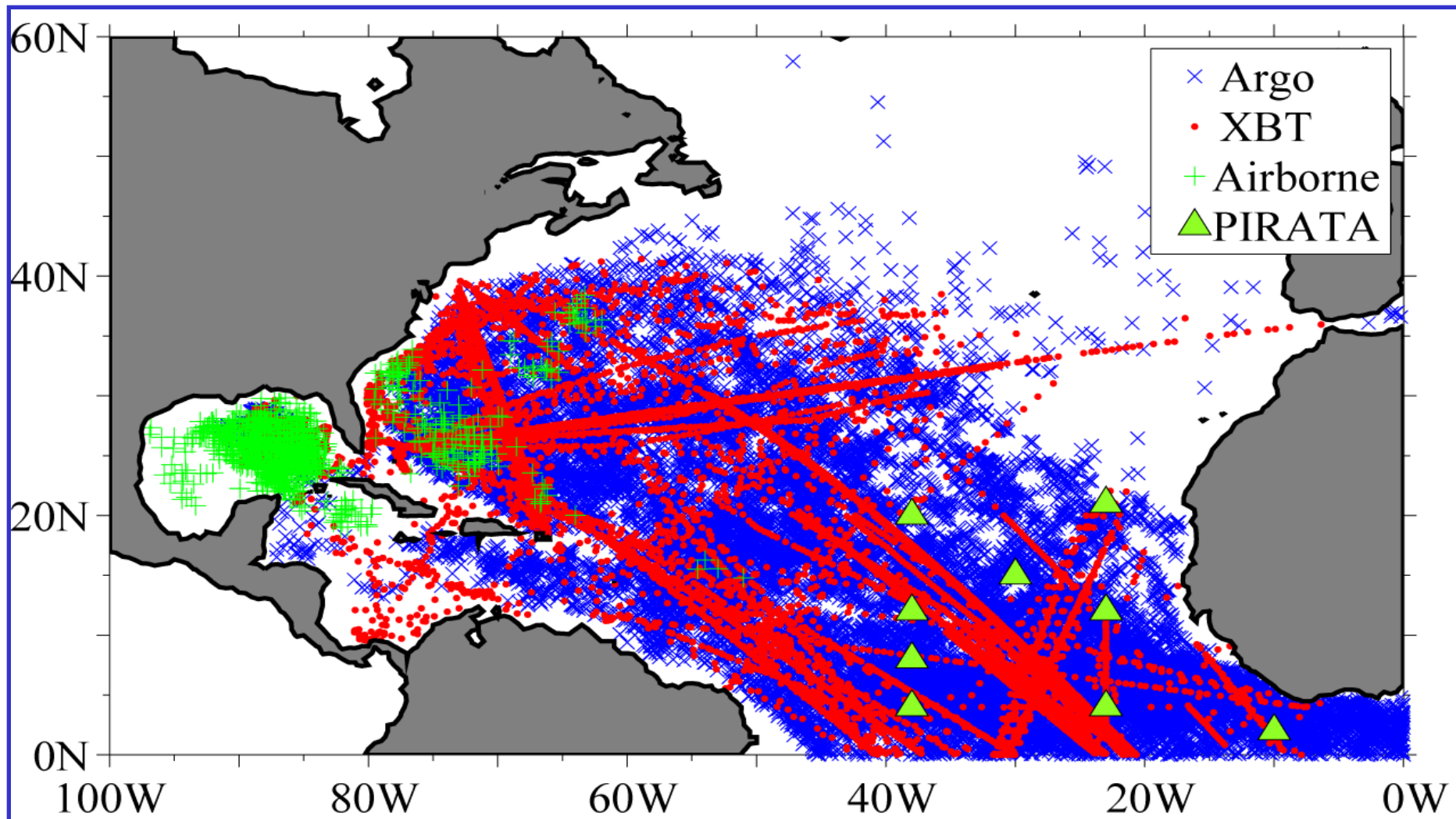


Altimeter (period)	'98	'99	'00	'01	'02	'03	'04	'05	'06	'07	'08	'09	'10	'11	'12
TOPEX (10d)					Sep										
ERS (35d)						Jun									
GFO (17d)			Aug								Sep				
Jason-1 (10d)					Jul										
Envisat (35d)						Oct									
Jason-2 (10d)												Jan			

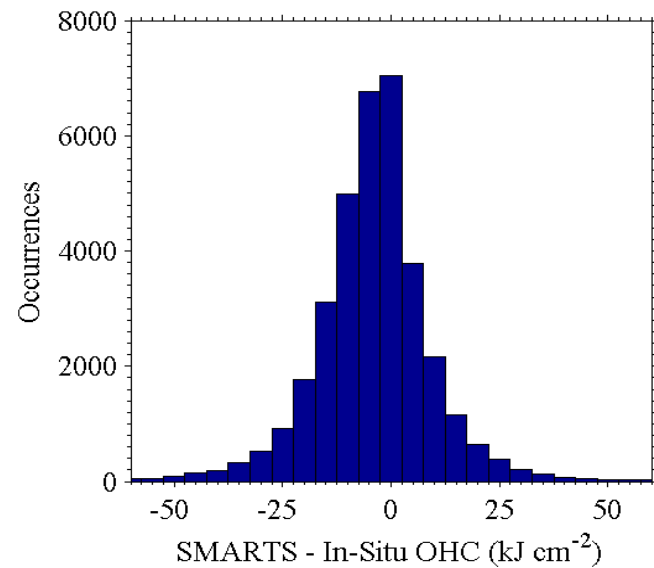
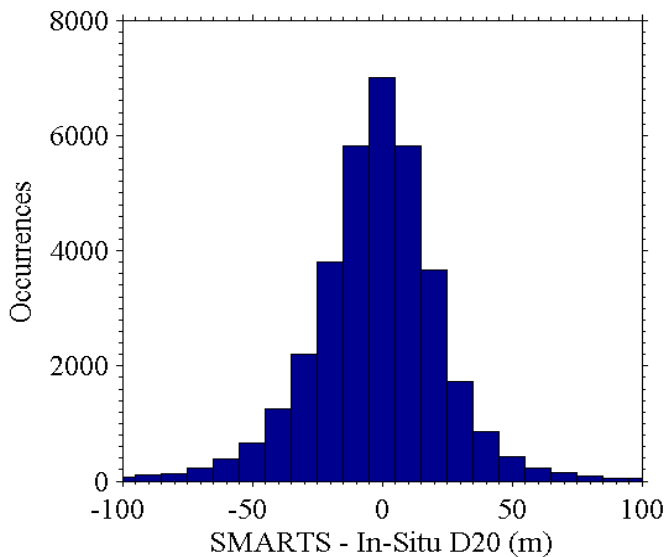
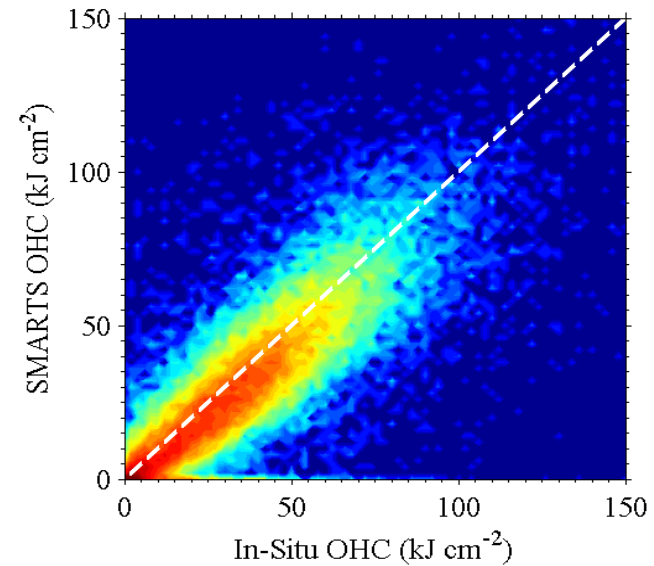
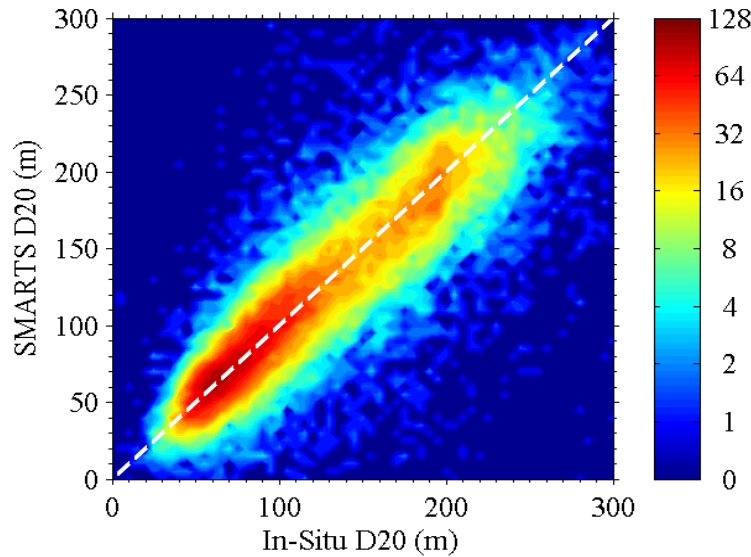
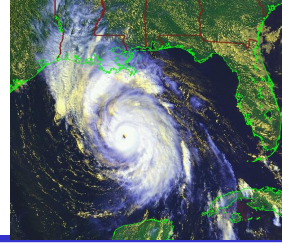


- LAT[D=gr02005\_250\_266\_30.trk]
- LAT[D=js12005\_253\_283\_30.trk]
- LAT[D=env2005\_241\_276\_30.trk]

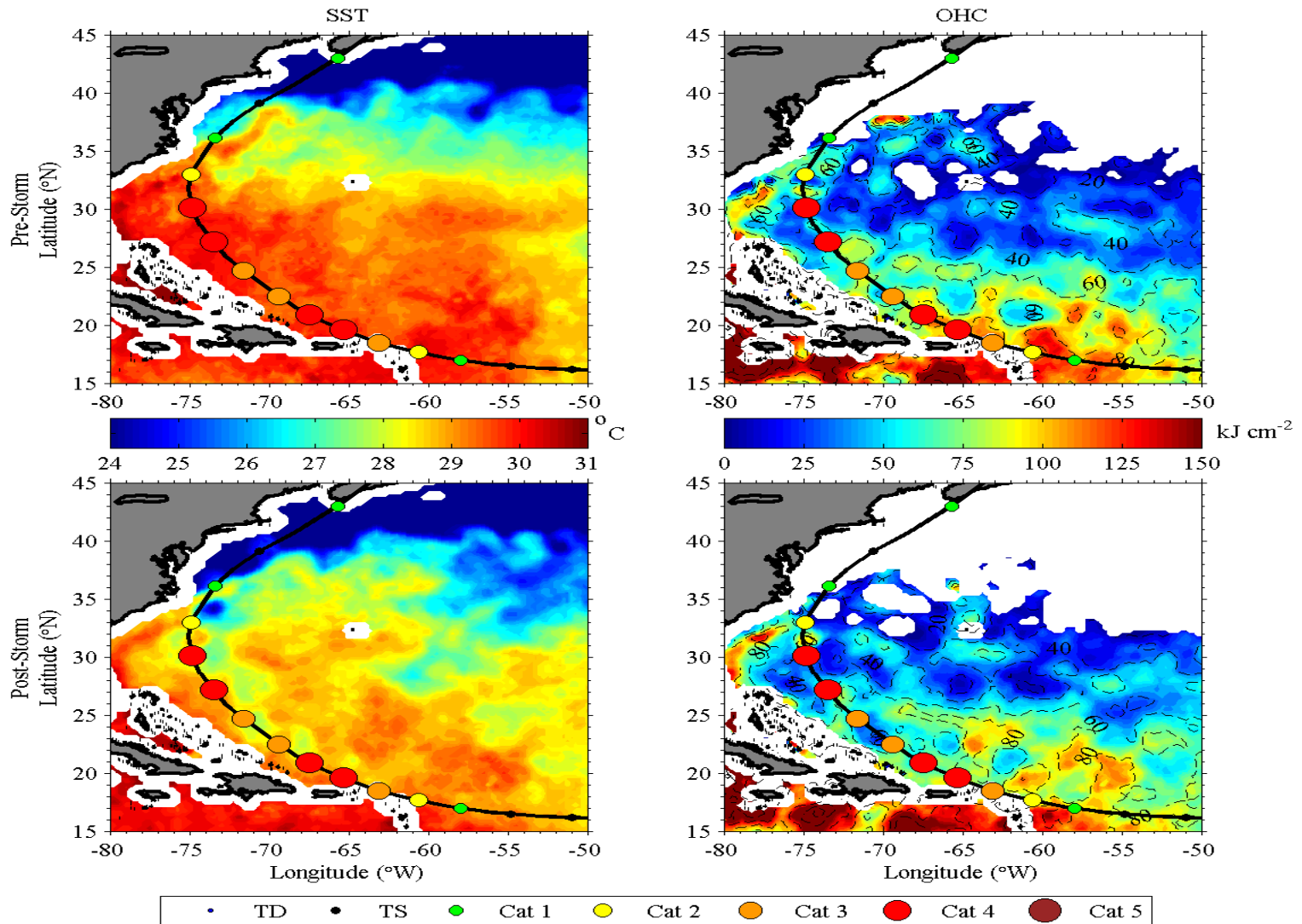
# Over 50,000 Thermal Profiles From Multiple Platforms Used In SMARTS Evaluation (Meyers et al., 2012)



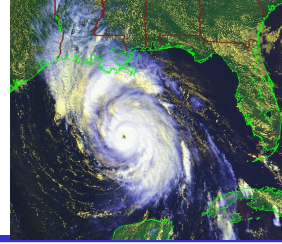
# SMARTS Performance (Meyers, 2011)



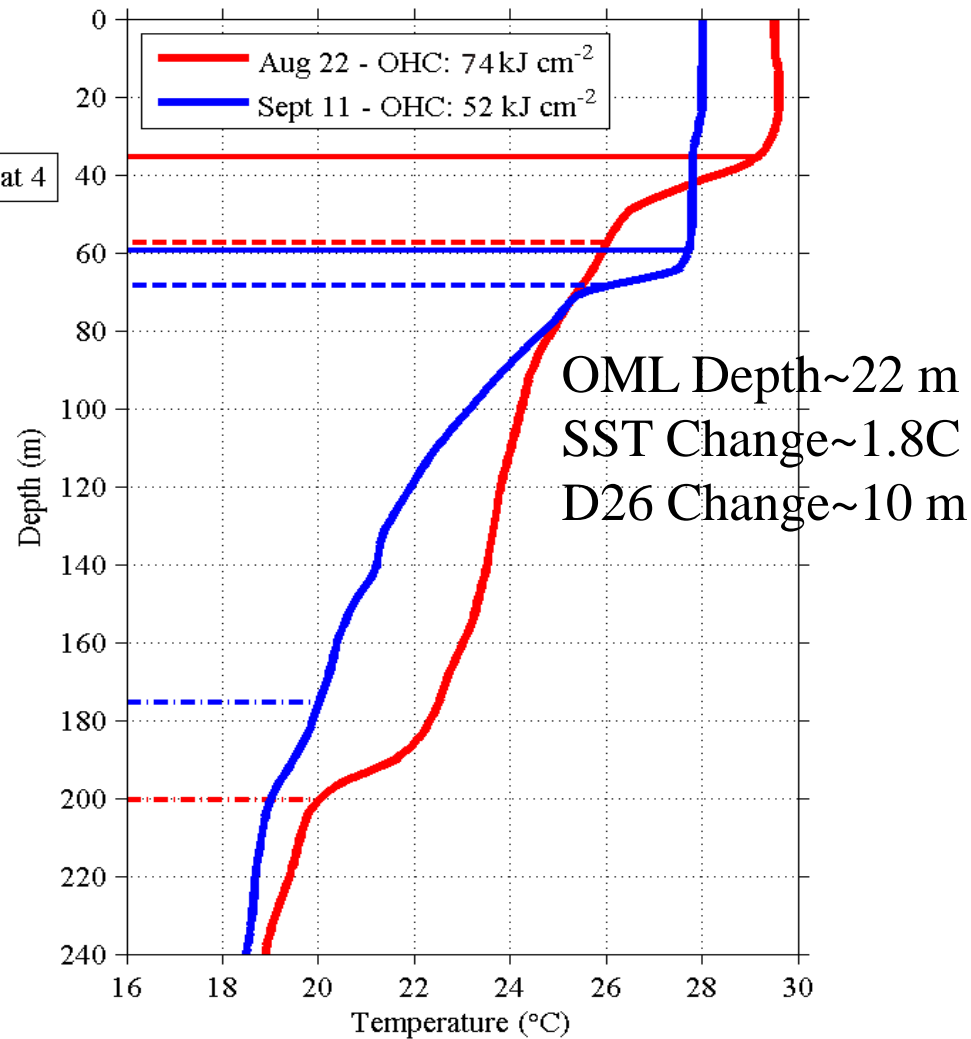
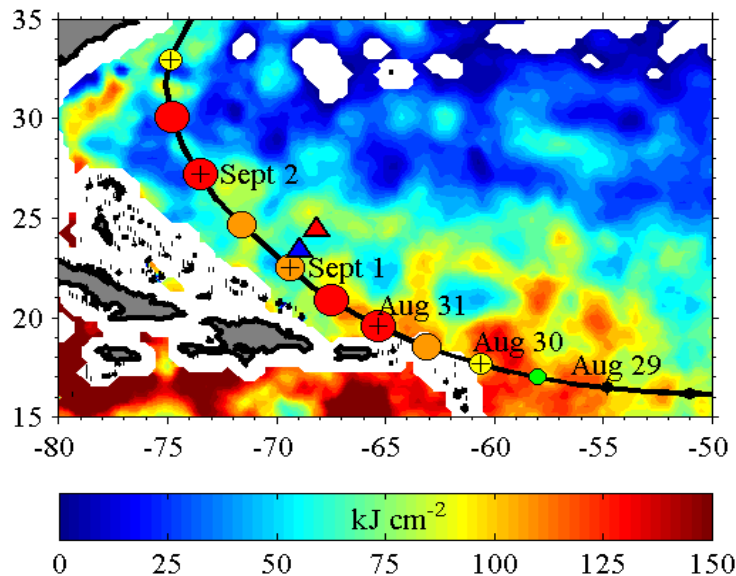
# SST (TMI Courtesy of RSS) and OHC (Jason, Envisat Altimeters)

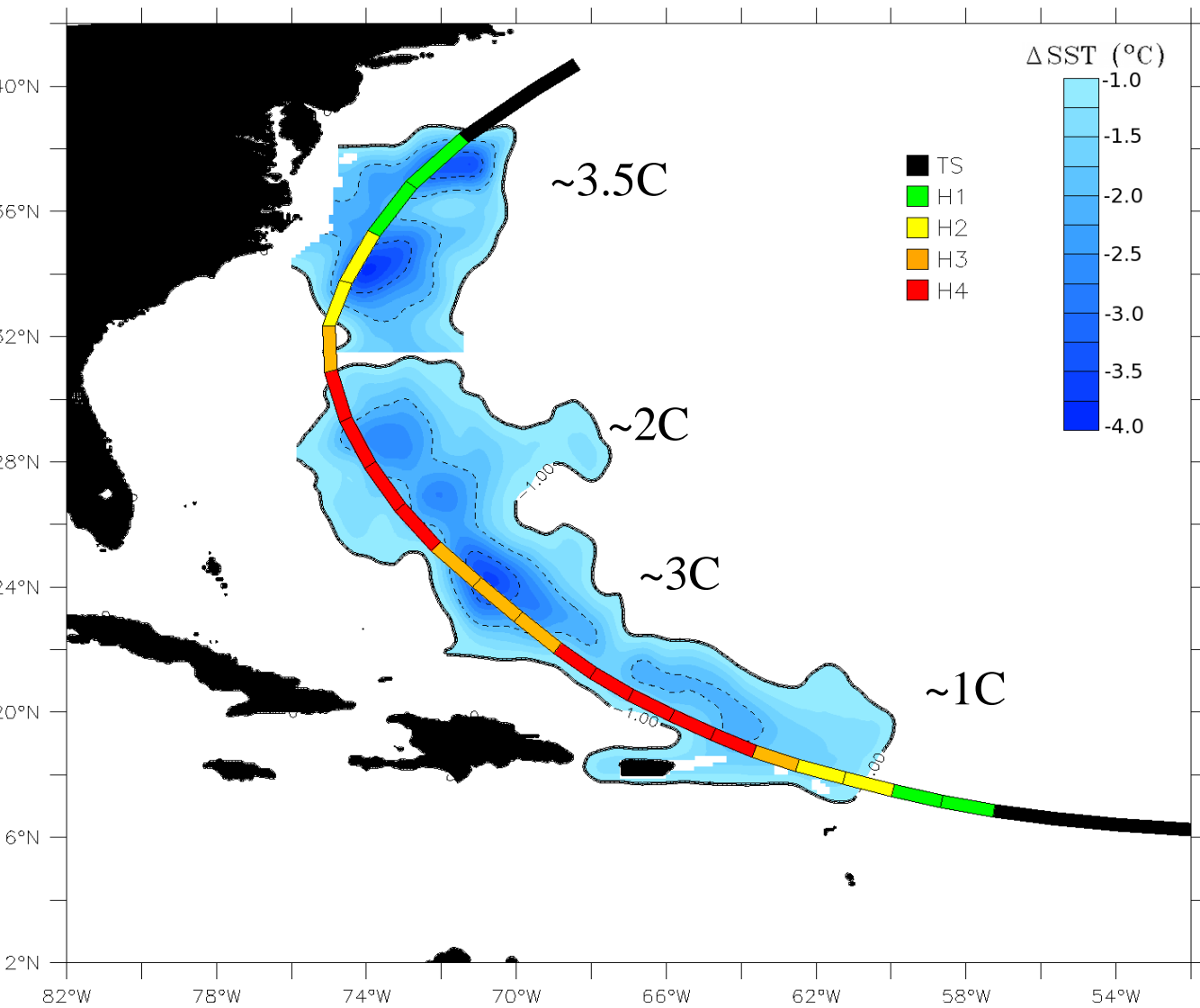


# Hurricane Earl (2010): satellite and ARGO Float Measurements (Pre/Post)



• TS    ● Cat 1    ● Cat 2    ● Cat 3    ● Cat 4



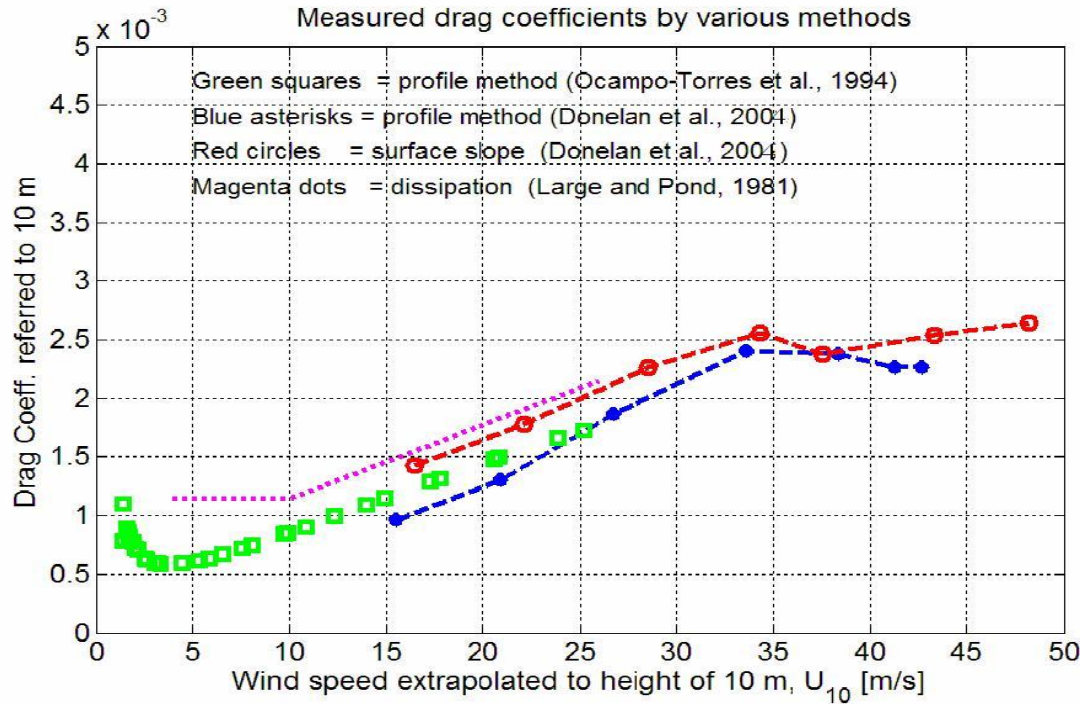


**SST Cooling (C)  
induced by  
Hurricane Earl  
from TMI  
relative to Track  
and Intensity.**



# Momentum and Enthalpy fluxes

Emanuel (1995):  $c_k/c_d \geq 1$  (50 m/s); Black et al. (2007):  $c_k/c_d \sim 0.7$



Stress measurements from hot-film anemometer, particle velocimetry and laser line scan cameras at the surface (From Donelan et al. GRL (2004)).

$$\boldsymbol{\tau}(x, y) = \rho_a c_d |\mathbf{U}_{10}| \mathbf{U}_{10}$$

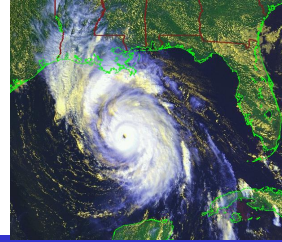
$$c_d = 10^{-3} \times \max(0.49 + 0.065|\mathbf{U}_{10}|, 2.5)$$

$$Q_s(x, y) = \rho_a C_p c_h |\mathbf{U}_{10}| \Delta T$$

$$Q_l(x, y) = \rho_a L_v c_q |\mathbf{U}_{10}| \Delta q$$

$$c_h = c_q = c_d$$

$$Q_k = Q_s + Q_l$$

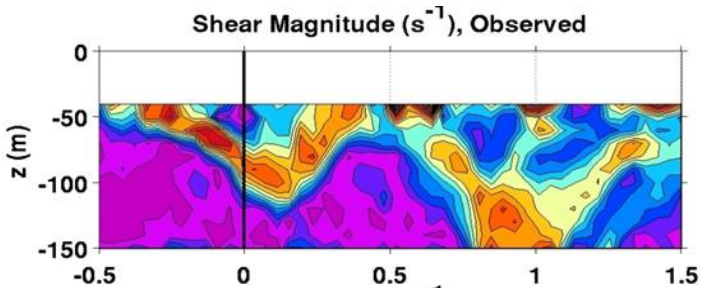


# Testing Drag Coefficient Using Ocean Momentum Response (Halliwell et al., MWR, 2011)

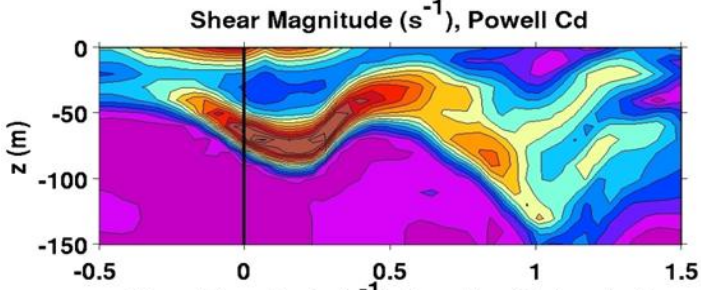
Parameterizations that yield coefficients between  $2.2 \times 10^{-3}$  and  $2.6 \times 10^{-3}$  at high wind speeds produce the most realistic shear response. Larger (smaller) coefficient values increase (decrease) mixed layer deepening and SST Cooling.

*Use ocean current measurements as a tracer of momentum flux (Shay and Jacob, 2006)!*

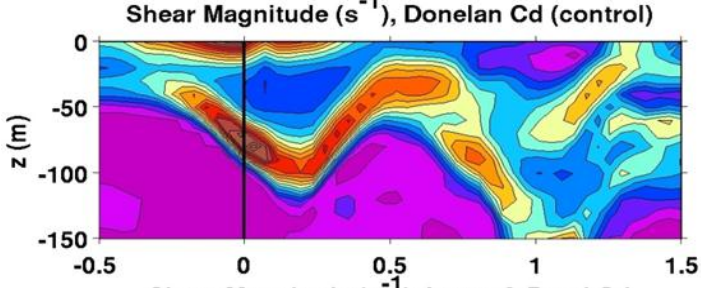
Observed



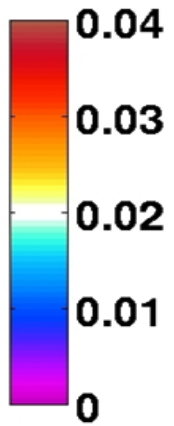
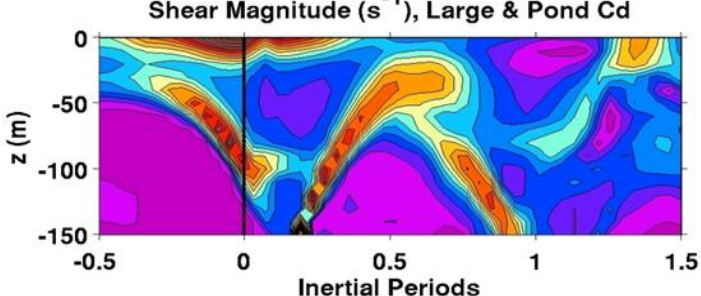
Powell et al.



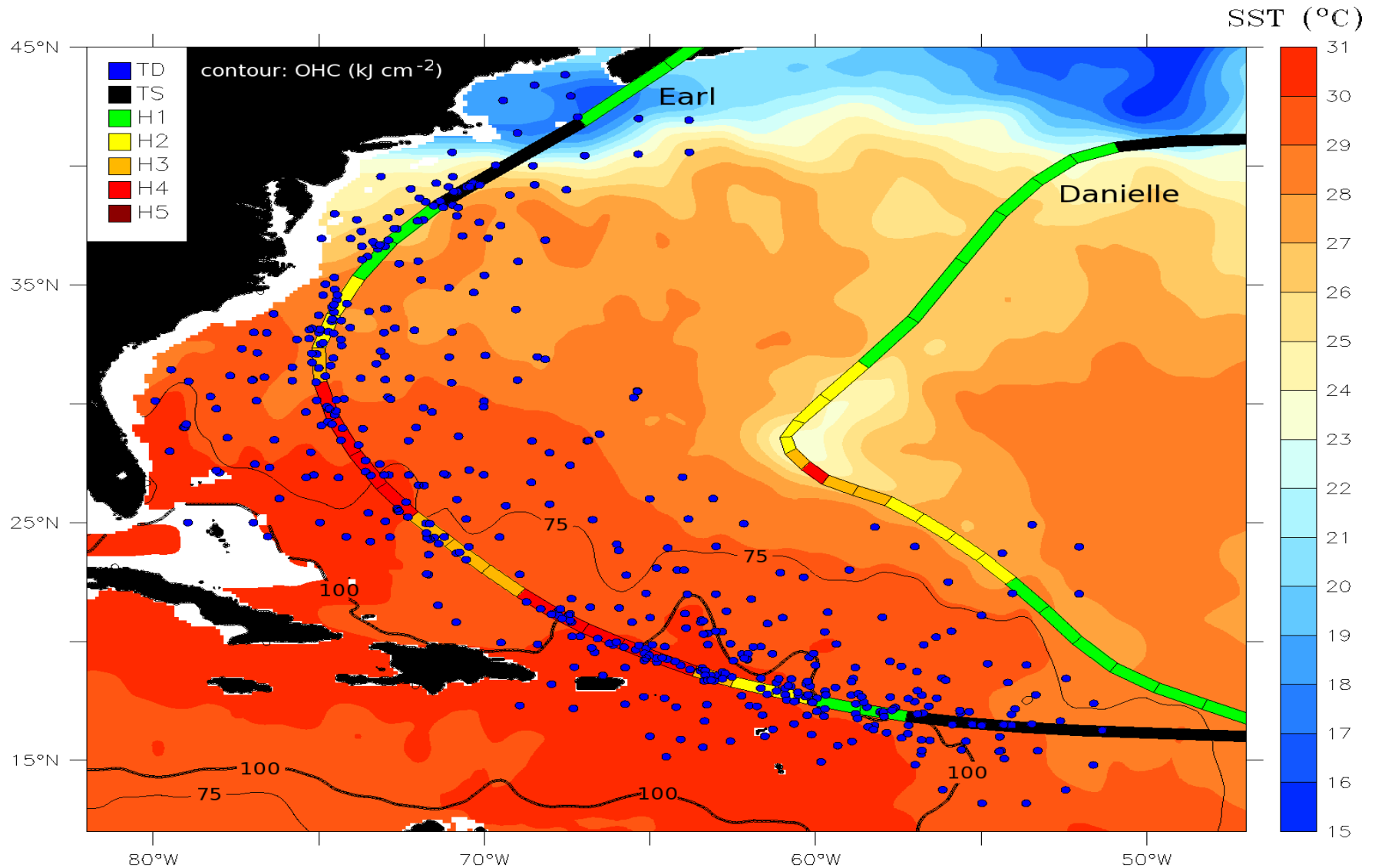
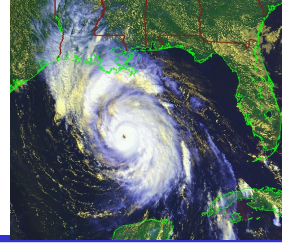
Donelan et al. (control)



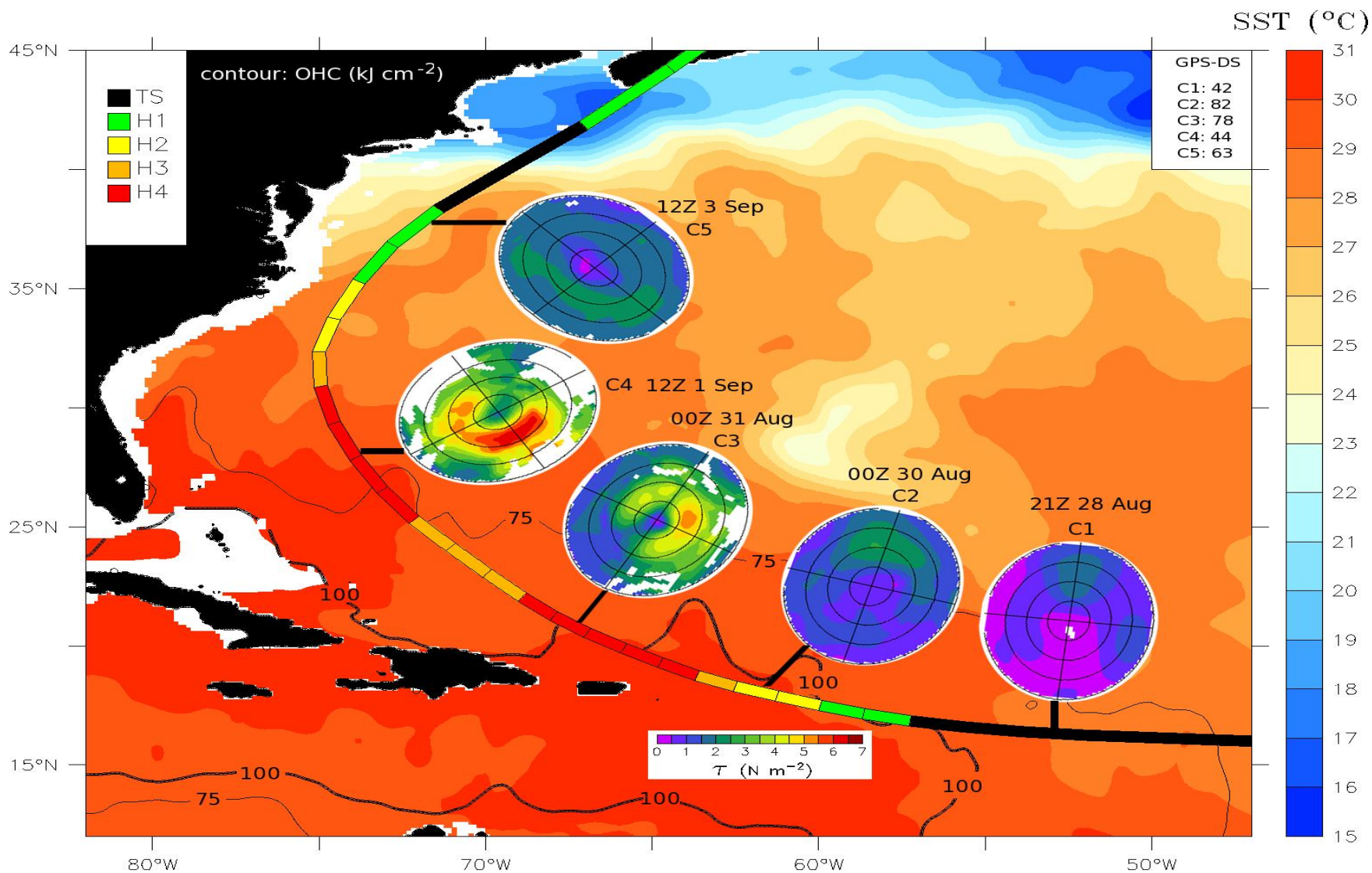
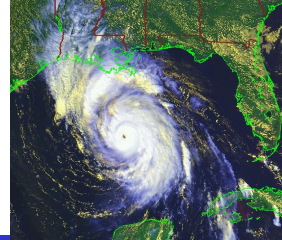
Large and Pond



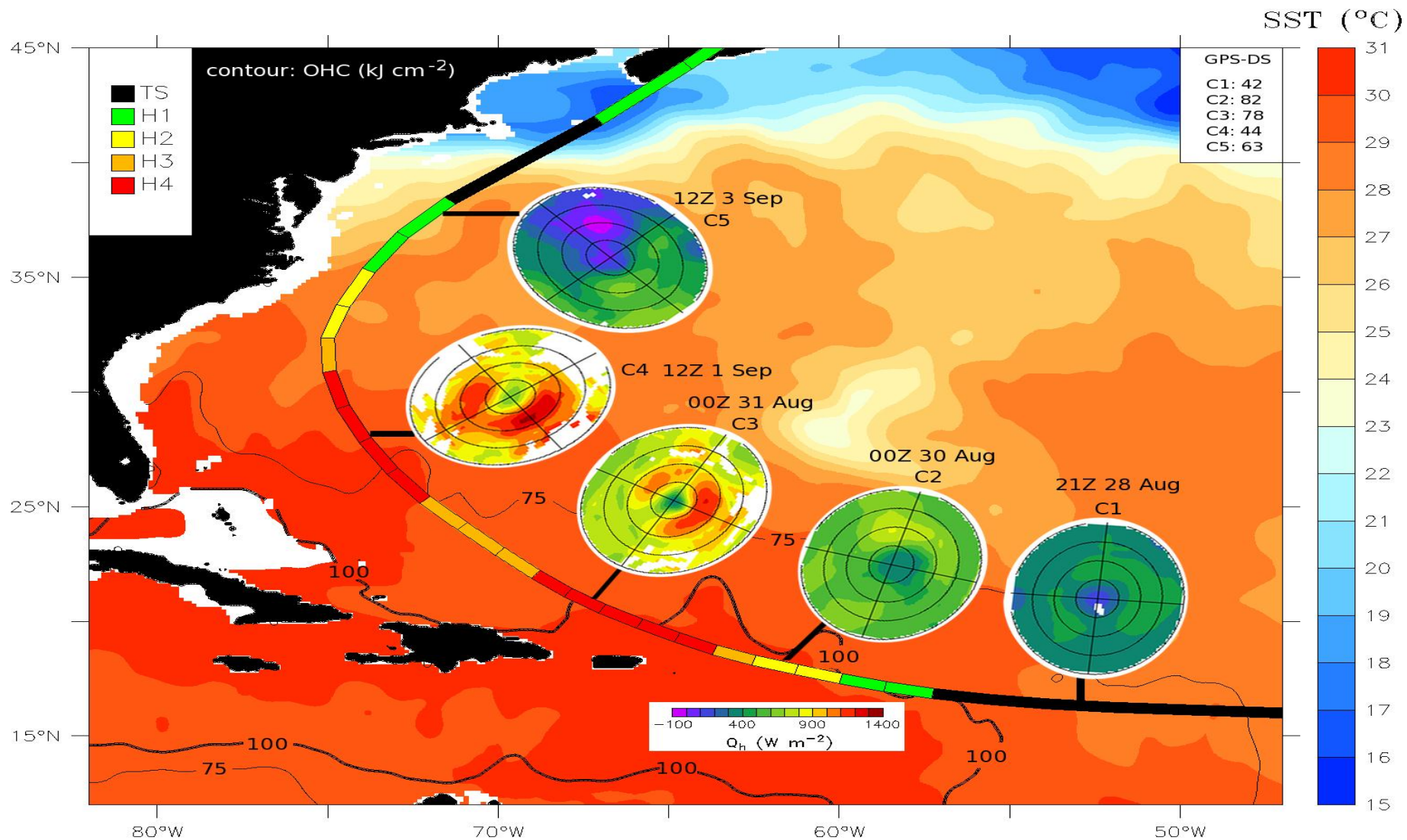
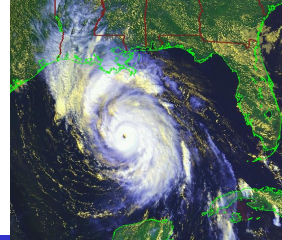
# Earl's Track (and Intensity), SST (C: color), OHC (contours), and GPS Sondes

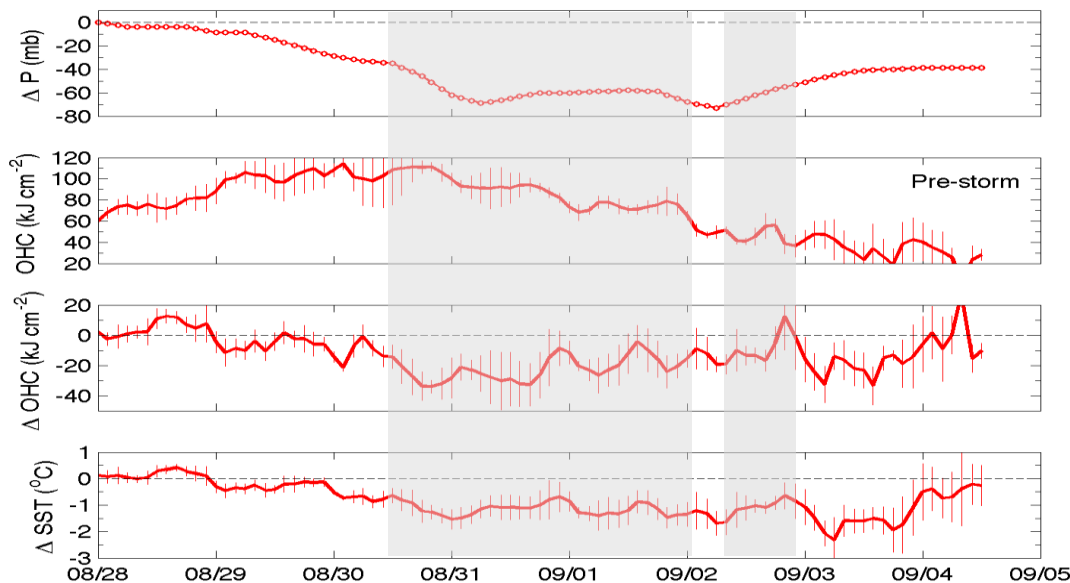
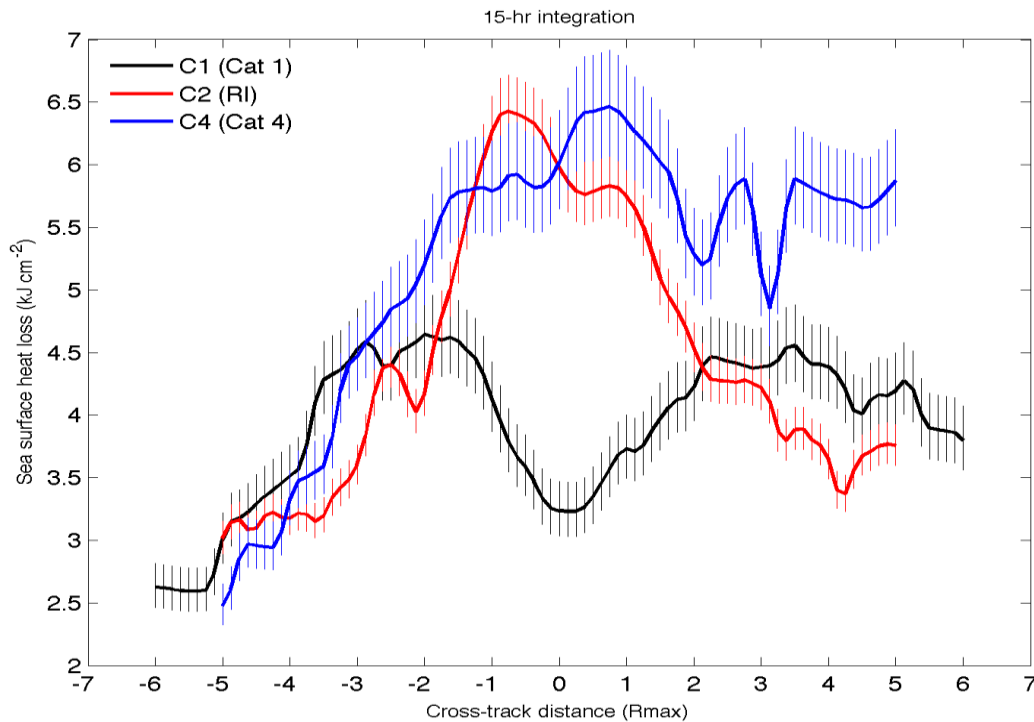


# Momentum Flux Estimates From SSTs, GPS and SFMR Data During GRIP



# Enthalpy Flux Estimates From SST, GPS and SFMR Data During GRIP

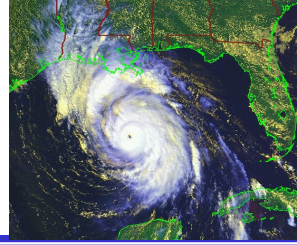




**15-hr along-track integration of estimated enthalpy fluxes at stages C1 (Cat 1), C2 (RI), and C4 (Cat 4).**

**Cross-track integration from  $\pm 6R_{\text{max}}$  of surface pressure, pre-storm OHC, Post-Pre OHC and SST. Average OHC loss is  $\sim 20 \text{ kJ/cm}^2$  per day.**

# Work In Progress



- Extensive in-situ temperature profile data (~50,000 profiles) used to evaluate SMARTS regionally and seasonally in Atlantic Ocean basin. (14 year continuous data set 98-2012).

From Earl's Extensive GPS Sonde Coverage:

- *High OHC values ( $>100$  kJ/cm<sup>2</sup>)-juxtaposed with high cross-OHC gradient **enthalpy fluxes of 1.2 to 1.4 kW/m<sup>2</sup>** during Earl's RI cycles based on SST, GPS sondes and SFMR data.*
- *Low OHC values ( $<40$  kJ/cm<sup>2</sup>) with negative enthalpy fluxes during Earl's rapid weakening where SST cooling approached 4C.*
- Assess impact of SST and OHC gradients on fluxes.
- *Conduct sensitivity testing with the ratio of  $C_k/C_d$  following Bryan (MWR, 2012) from these data sets.*
- *Applied research is needed to understand these effects for coupled models*