Application of Near-Real Time Satellite Altimetry for Initializing the Ocean Component of Coupled Tropical Cyclone-Ocean Forecast Models

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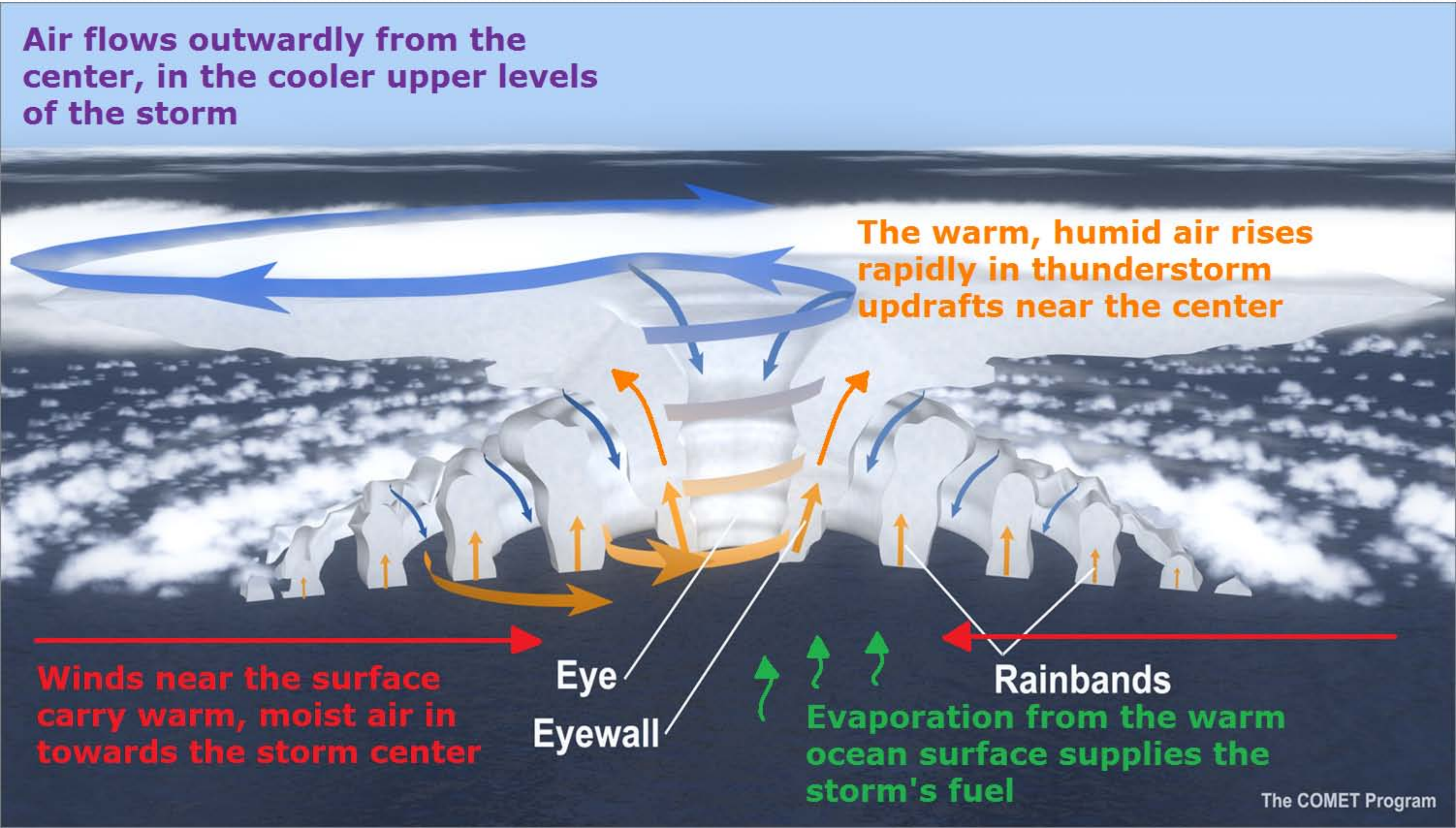
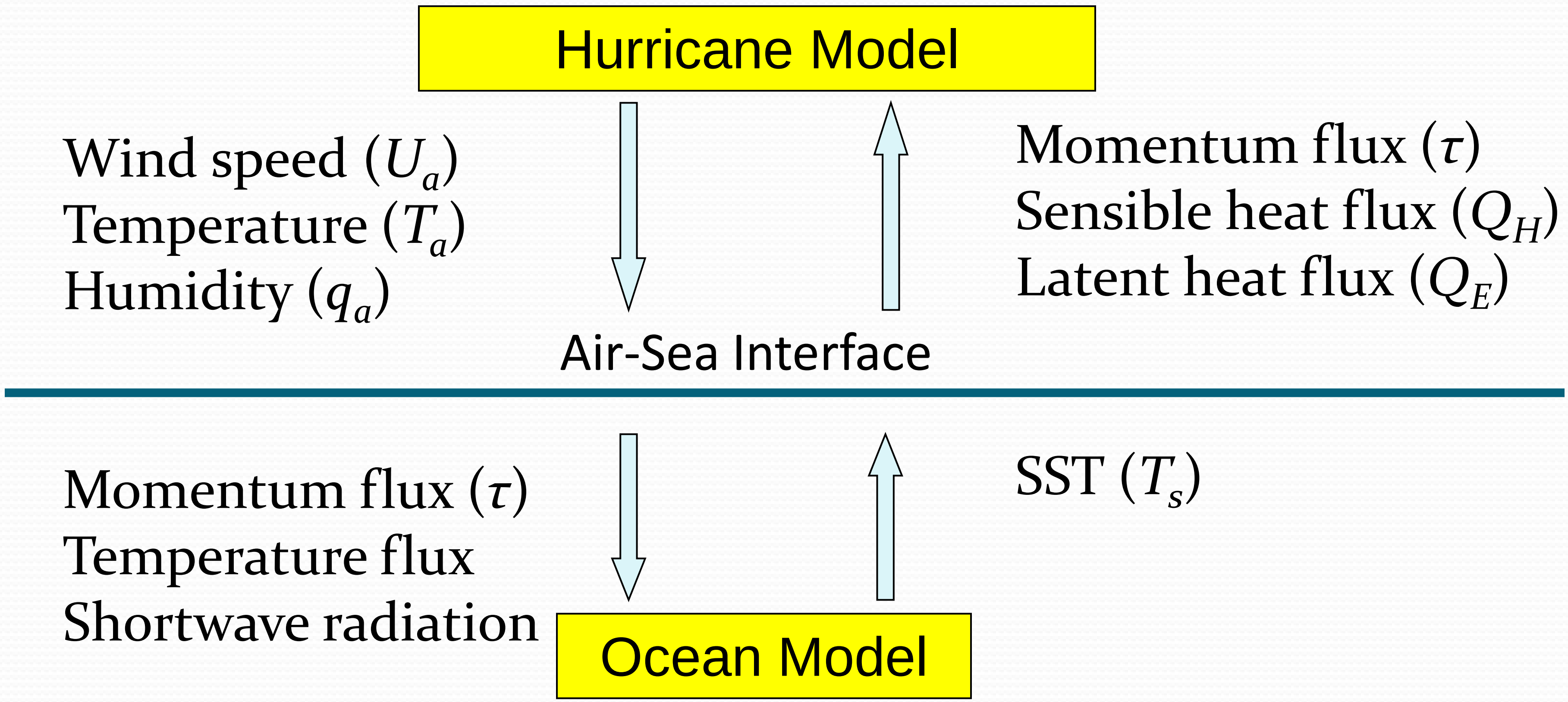
Tropical cyclone secondary circulation



Why couple a 3-D ocean model to a tropical cyclone (TC) forecast model?

- To create accurate SST field for input into TC model
- Evaporation (moisture flux) from sea surface provides heat energy to drive a TC, especially in storm's core
- Available energy decreases if storm-core SST decreases
- Uncoupled TC models with static SST neglect SST cooling during model integration → high intensity bias
- One-dimensional (vertical-only) ocean models neglect upwelling, which can impact SST cooling during model integration (e.g. Yablonsky and Ginis 2009, MWR)

Typical TC-ocean model coupling



$$\tau = \rho_a C_D U_a U_a \qquad Q_H = C_H U_a (T_a - T_s) \qquad Q_E = \frac{L_V}{C_P} C_E U_a (q_a - q_s)$$

Coupled TC-ocean forecast models operational at U.S. NOAA and Navy

- Hurricane Weather Research and Forecast model (HWRF)
- Geophysical Fluid Dynamics Laboratory model (GFDL)
- GFDL model with Navy's NOGAPS initialization (GFDN)
- All 3 are coupled to Princeton Ocean Model (POM-TC)

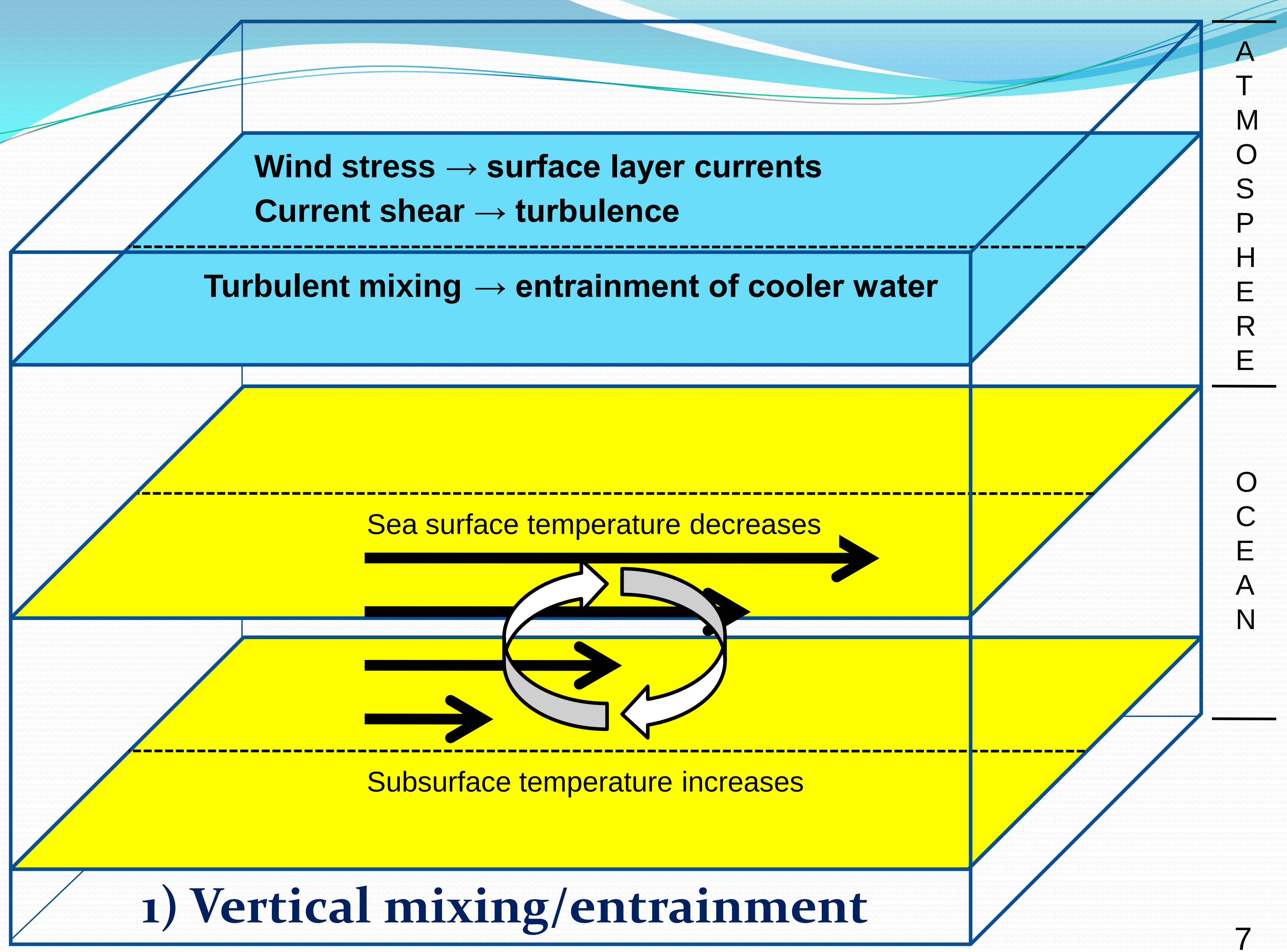
Physics of storm-core SST change

1) Vertical mixing/entrainment (Slide 7)

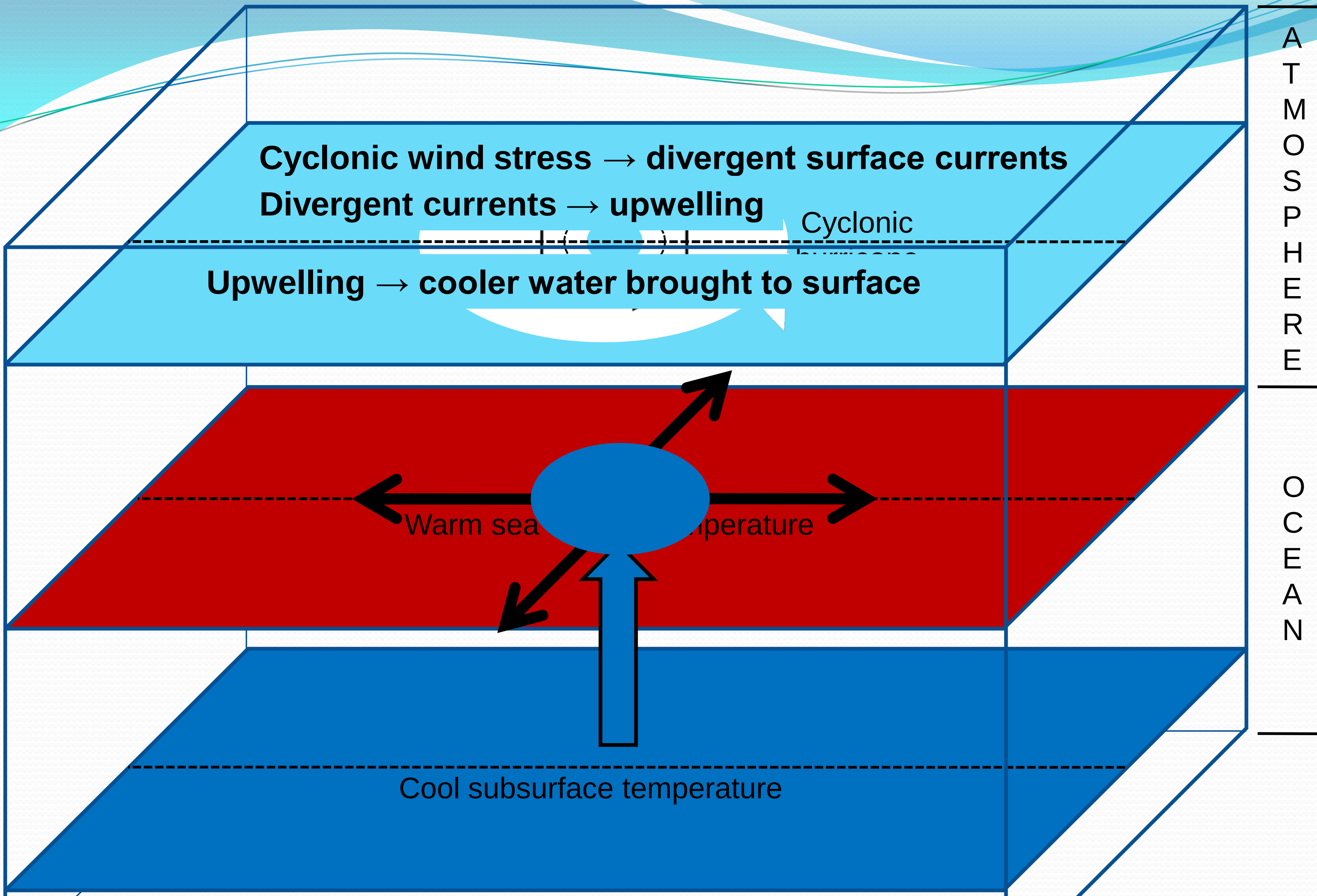
2) Upwelling (Slide 8)

3) Horizontal advection (Slide 9)

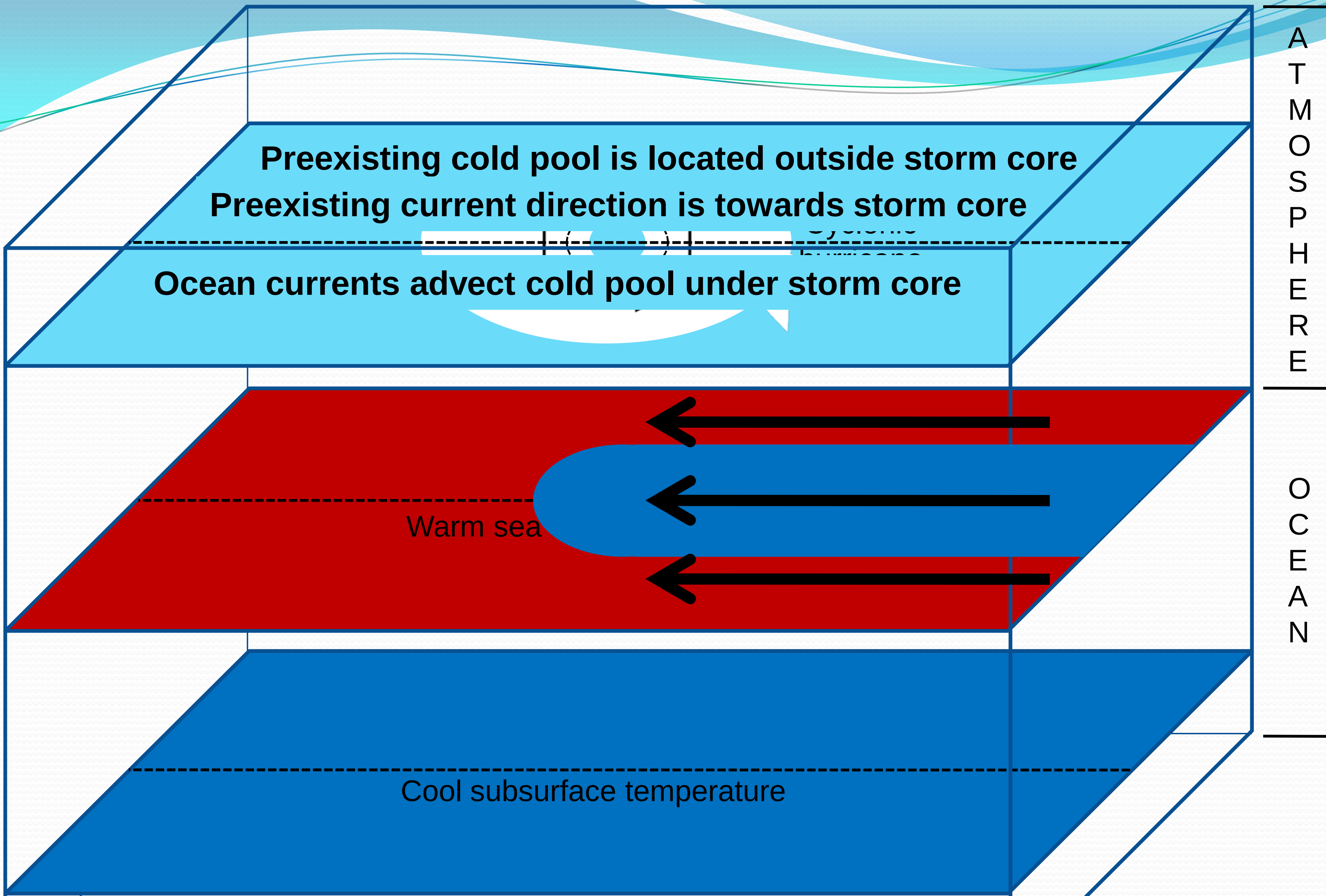
4) Heat flux to the atmosphere (not shown): smaller than 1, 2, and 3 except in shallow coastal areas



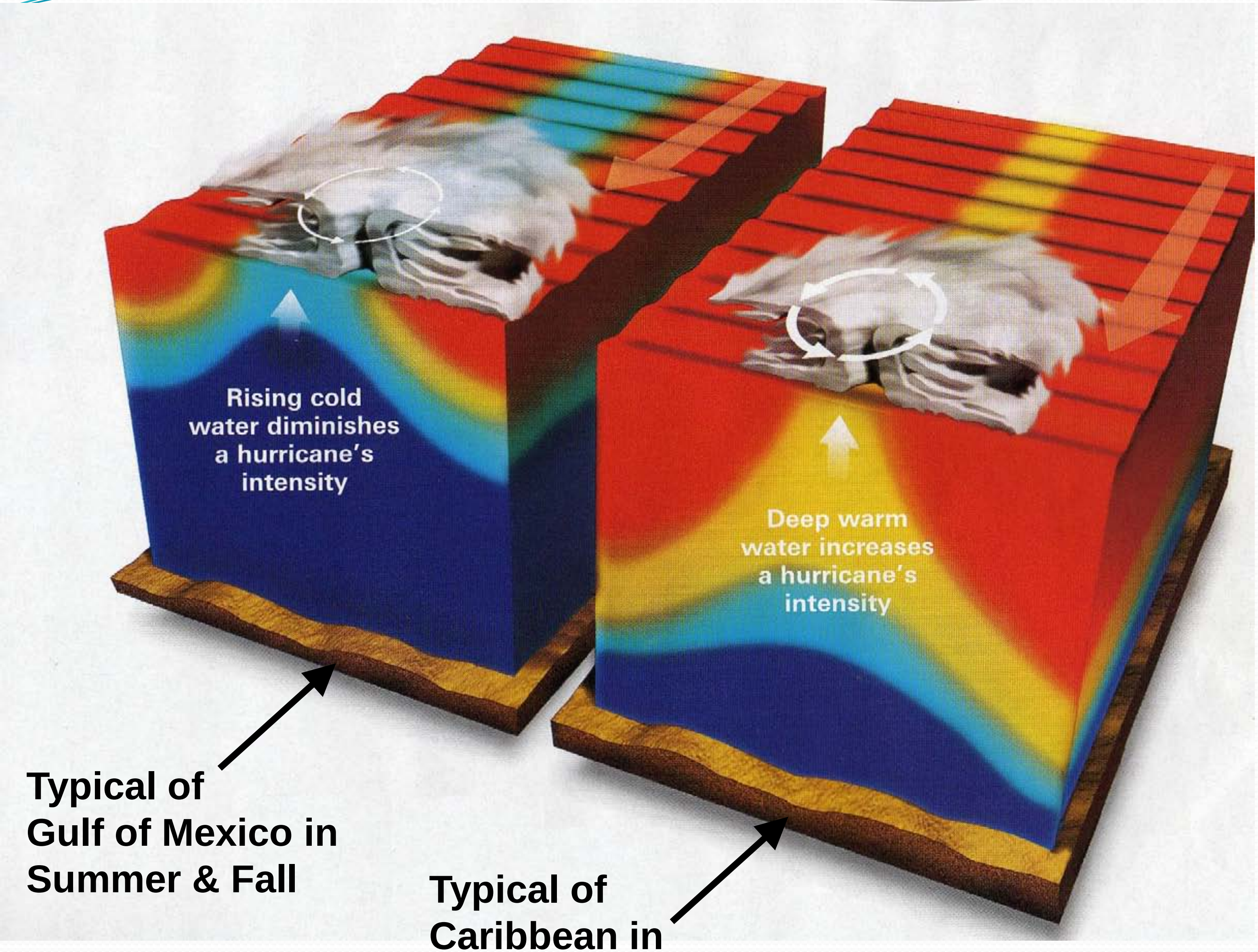
1) Vertical mixing/entrainment


Cyclonic wind stress → divergent surface currents
Divergent currents → upwelling
Cyclonic
Upwelling → cooler water brought to surface
Warm sea
Cool subsurface temperature
ATMOSPHERE
OCEAN

2) Upwelling

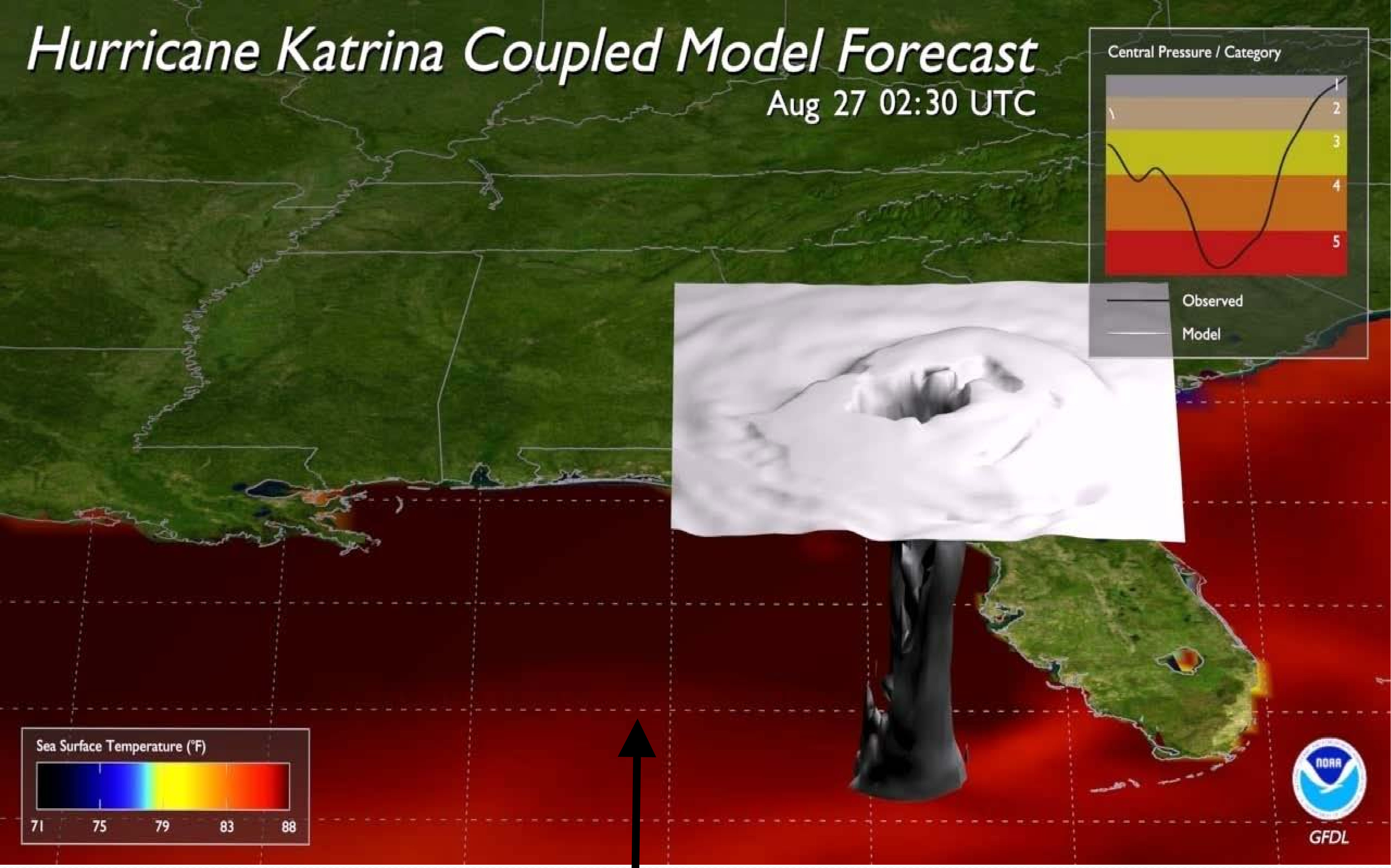


3) Horizontal advection



Typical of Gulf of Mexico in Summer & Fall

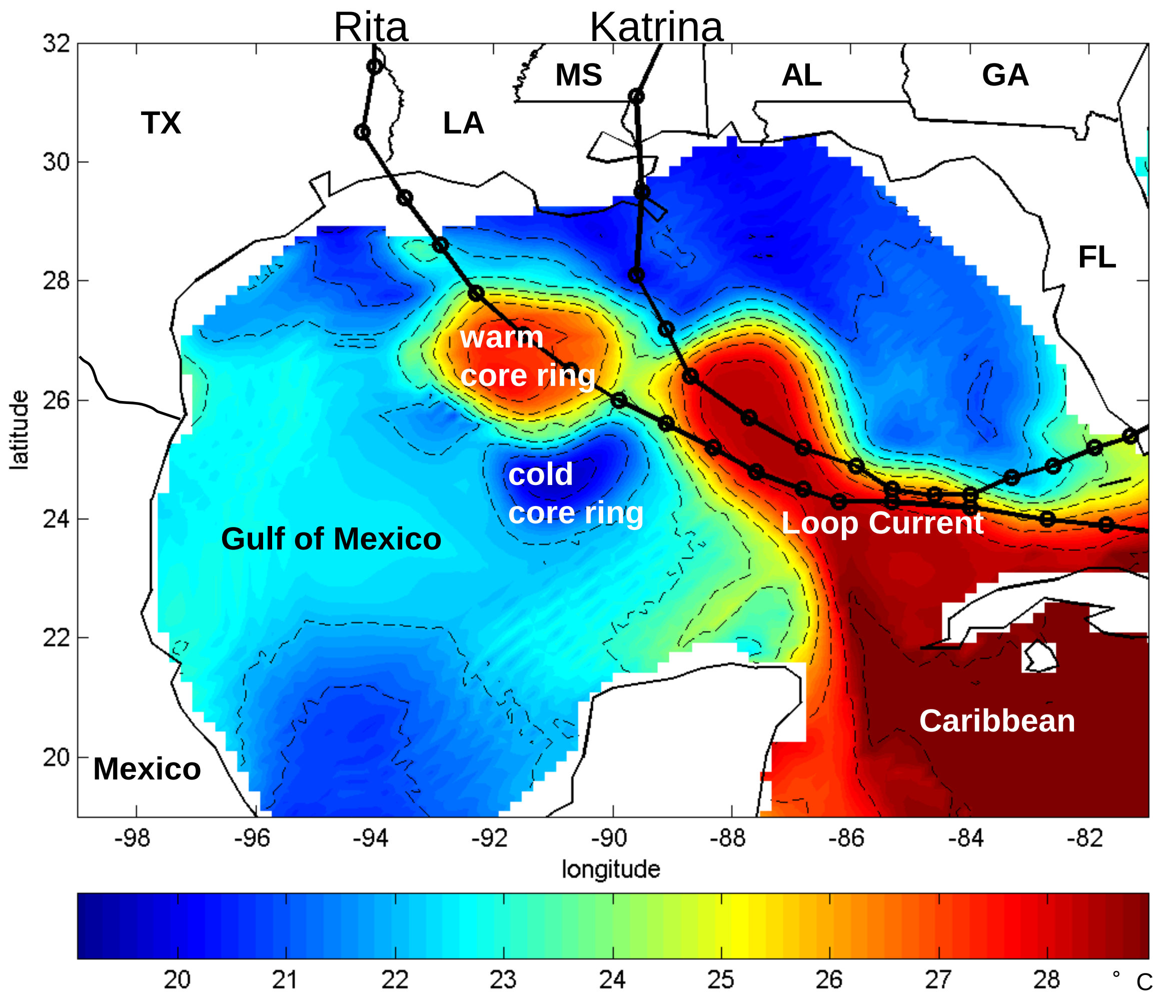
Typical of Caribbean in Summer & Fall



Why is the cold wake "not as cold" here?

Answer: We must look **under** the ocean surface!

Approximate Locations of Oceanic Features During Hurricanes Katrina and Rita (2005)



Subsurface (75-m) ocean temperature during Katrina & Rita

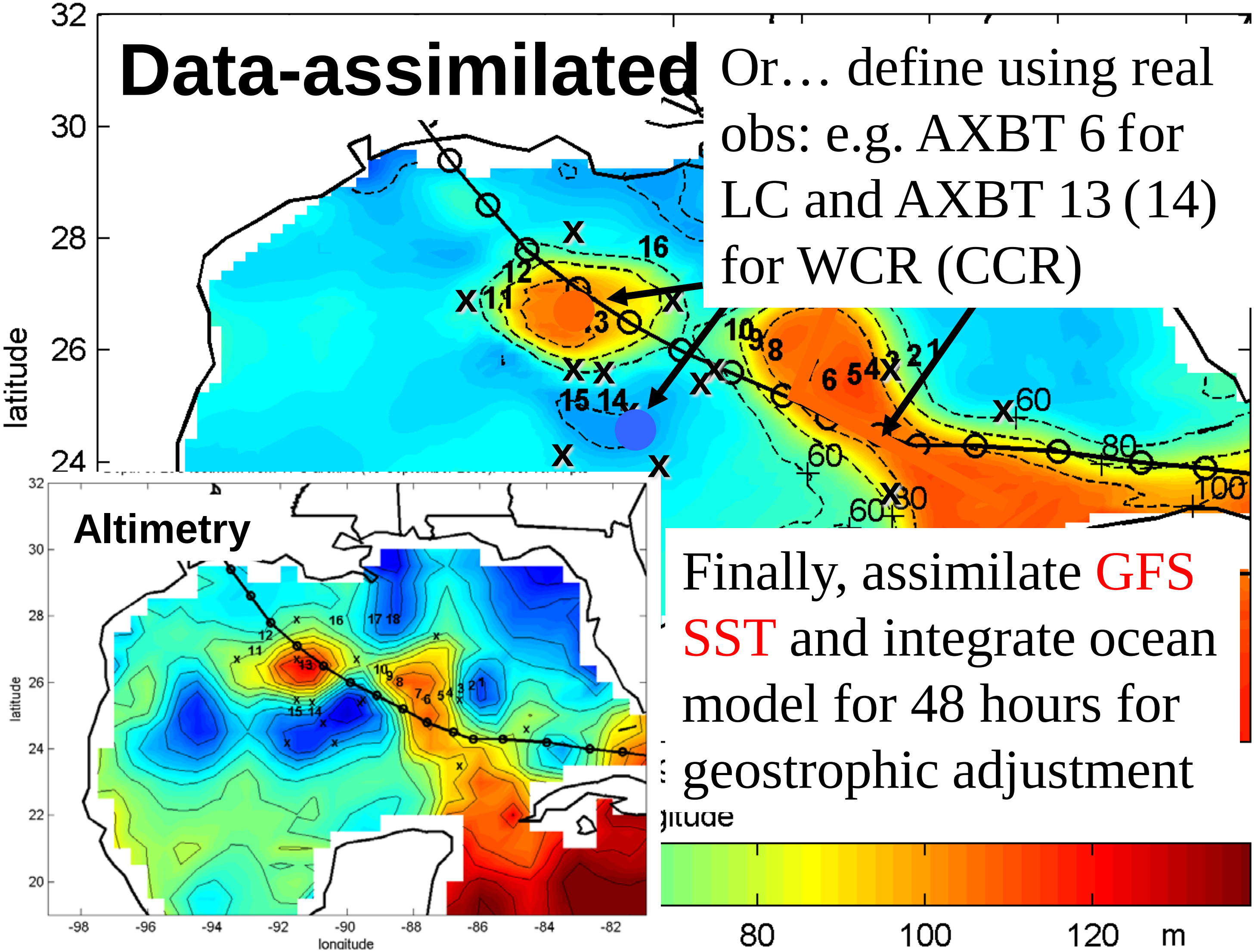
Warm Loop Current water and a warm core ring extend far into the Gulf of Mexico from the Caribbean…

Directly under Rita's & Katrina's track…

But… how do we know the locations of (& how do we assimilate) these features in real-time?

How we modify GDEM T/S Climatology:

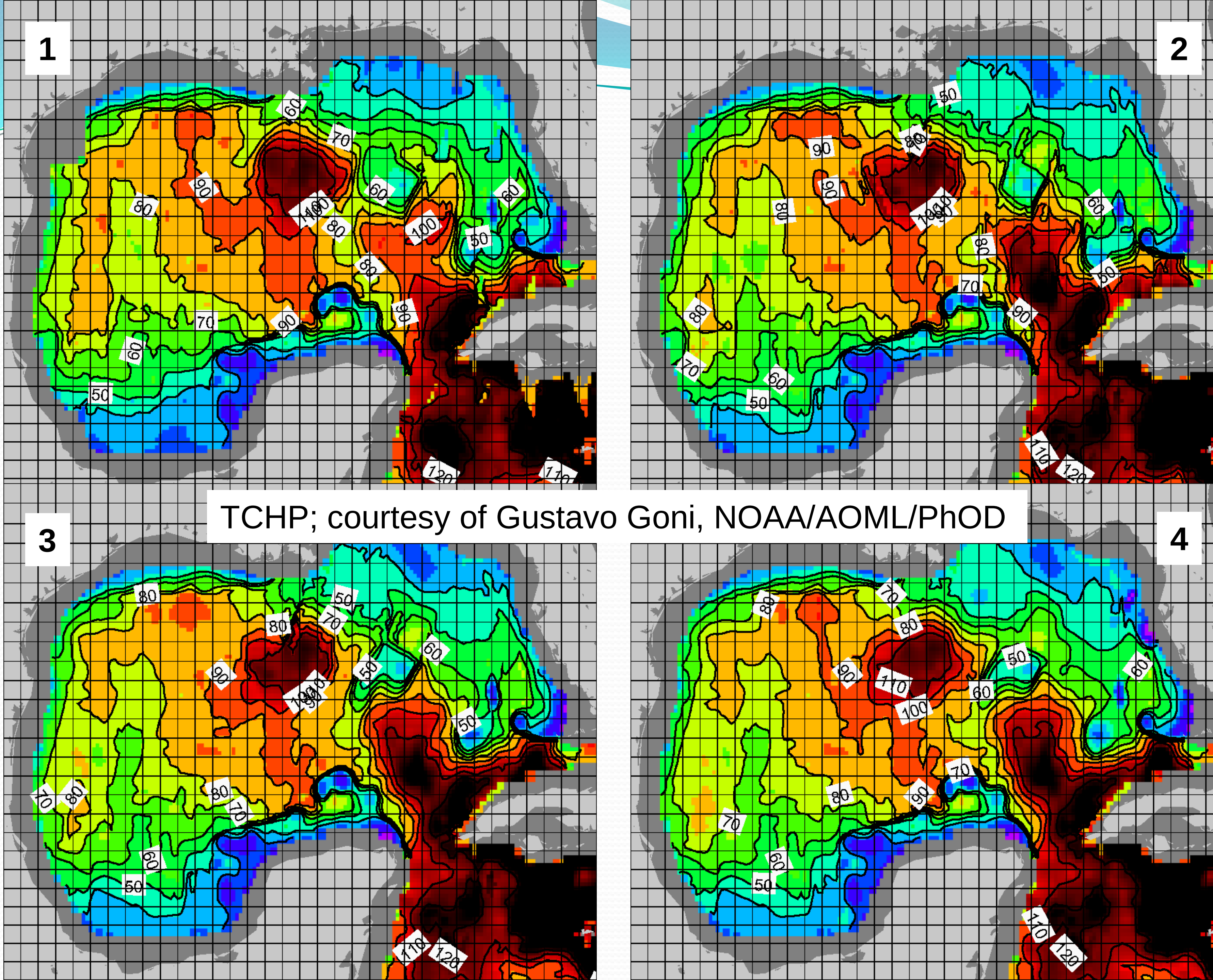
Feature-based (F-B) modeling!



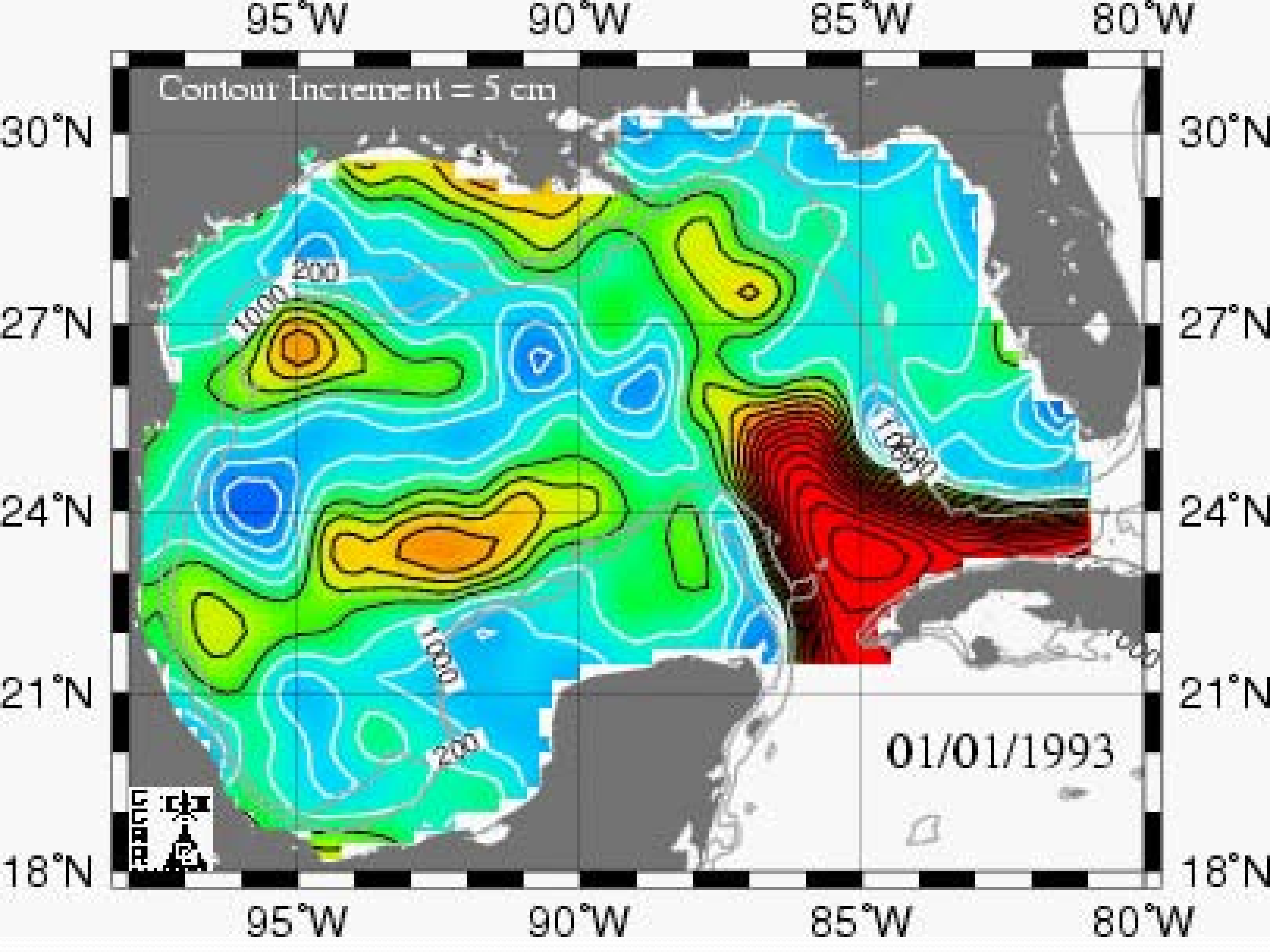
Or… define using real obs: e.g. AXBT 6 for LC and AXBT 13 (14) for WCR (CCR)

Finally, assimilate GFS SST and integrate ocean model for 48 hours for geostrophic adjustment

- Start with GDEM T/S
- Look at altimetry/obs
- Define LC & ring positions
- Use Caribbean water along LC axis & in WCR center
- Make CCR center colder than environ.
- Blend features w/ env. & sharpen fronts



TCHP; courtesy of Gustavo Goni, NOAA/AOML/PhOD



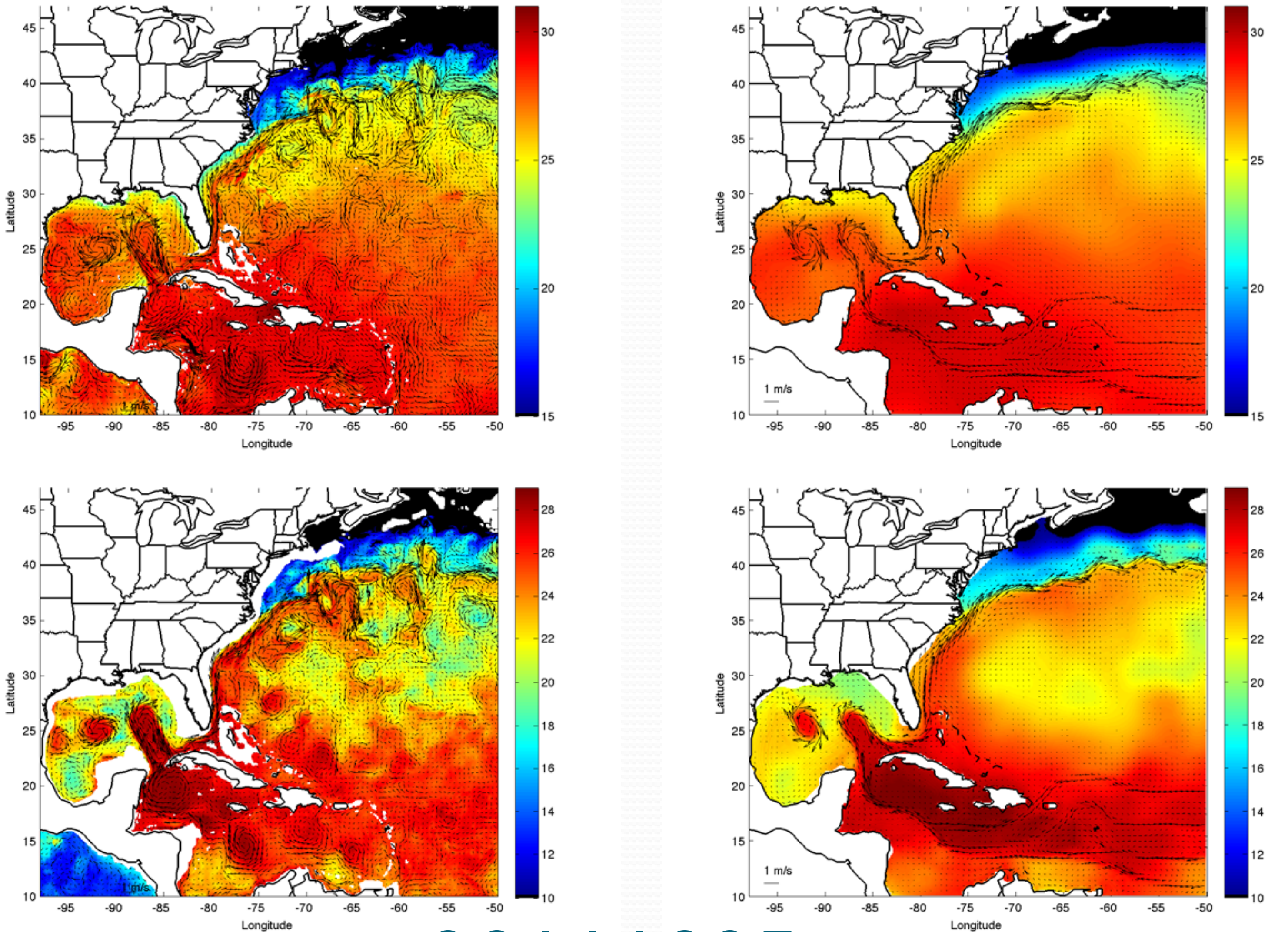
95°W
90°W
85°W
80°W
30°N
27°N
24°N
21°N
18°N
Contour Increment = 5 cm
200
1000
01/01/1993

RTOFS-Global*

- Global 1/12 degree HYCOM model implemented operationally 10/25/2011.
    - Brand new model the size of the GFS implemented within two years, after 2 years of planning and developing partnership with Navy. NCODA initialization provided daily by Navy.
- Application for hurricane modeling (HFIP)
    - Base of unified HWRF-HYCOM regionally coupled model for anywhere in the world.
    - Possible downstream use:
        - Simplified POM initialization (HWRF-POM). ← **URI Effort**
        - Possibly OHC products.

* Slide courtesy of H. Tolman (U.S. NOAA/NCEP/EMC)

RTOFS-Global | Feature-based w/ GFS SST



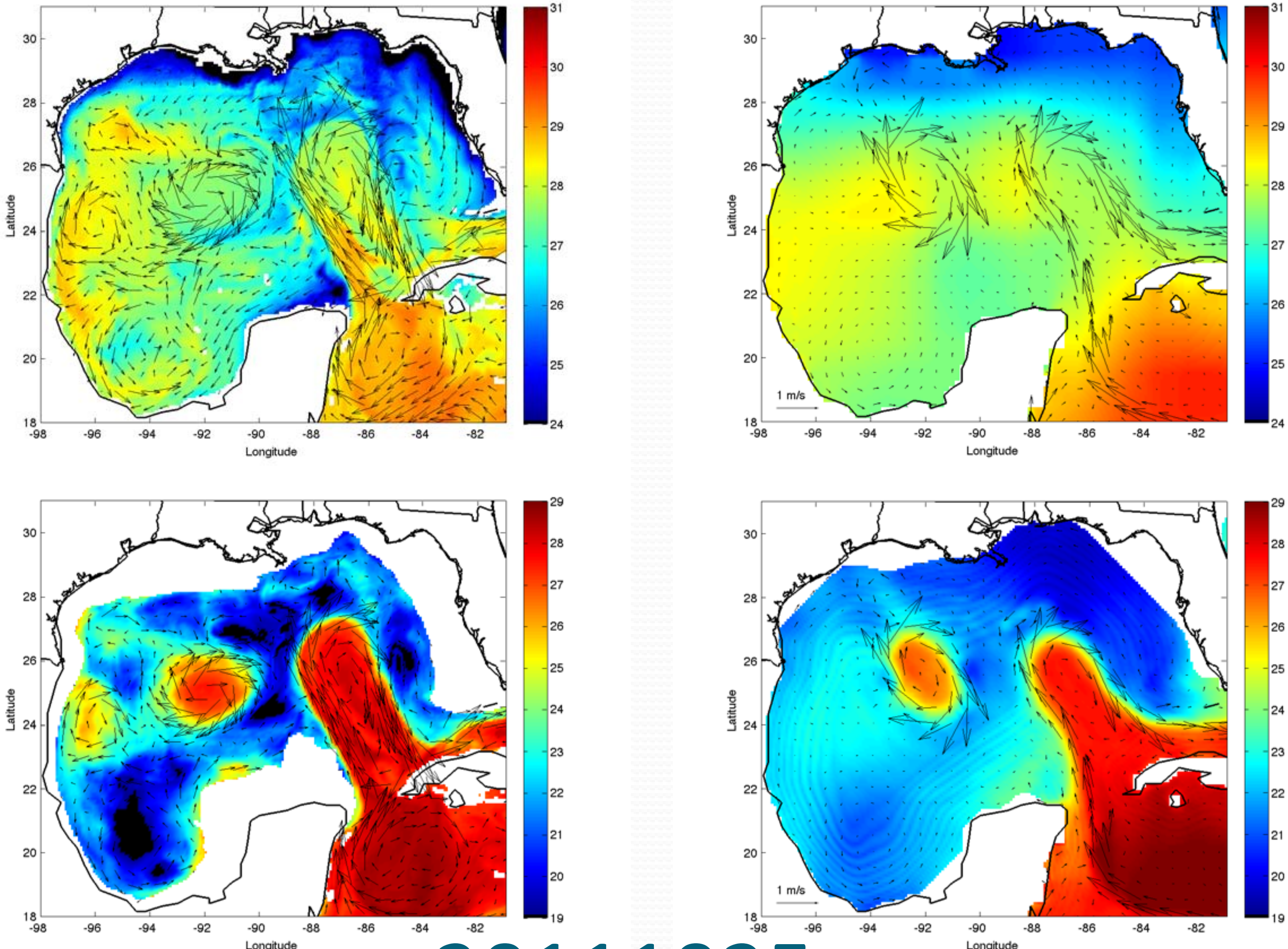
SST

75-m T

20111025

RTOFS-Global

Feature-based w/ GFS SST



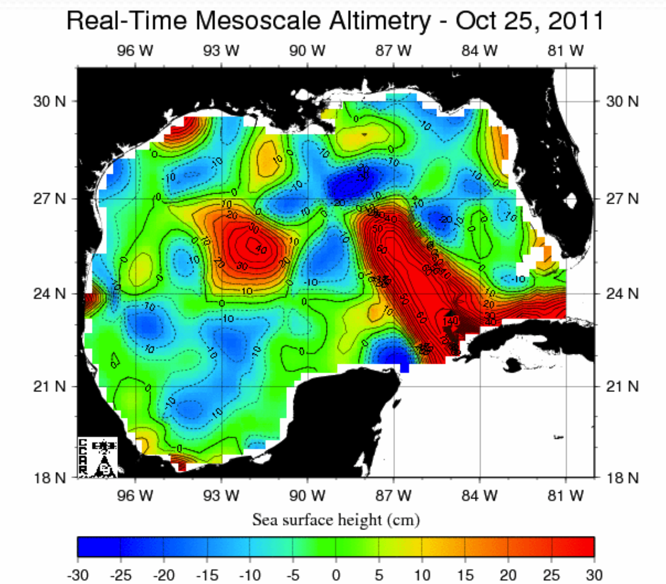
SST

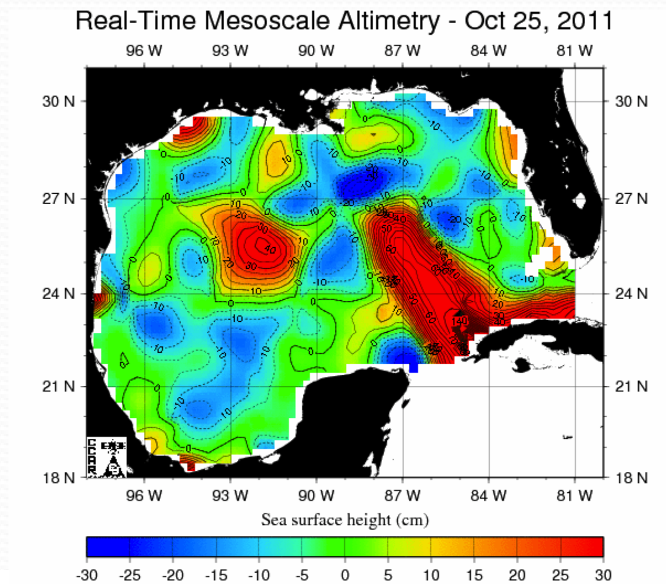
75-m T

20111025

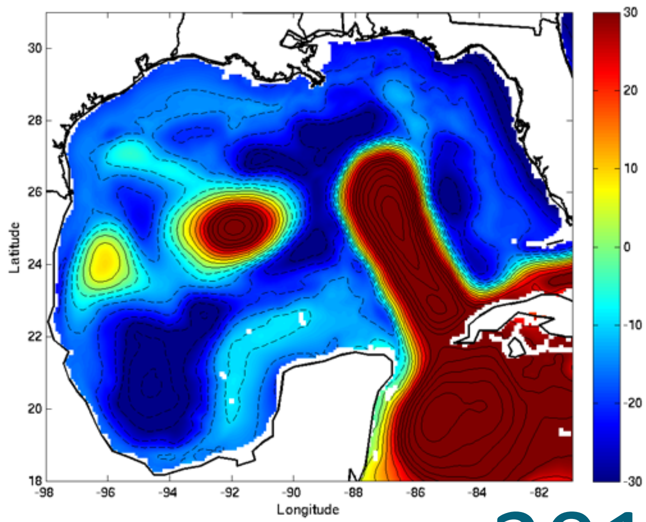
RTOFS-Global | Feature-based w/ GFS SST

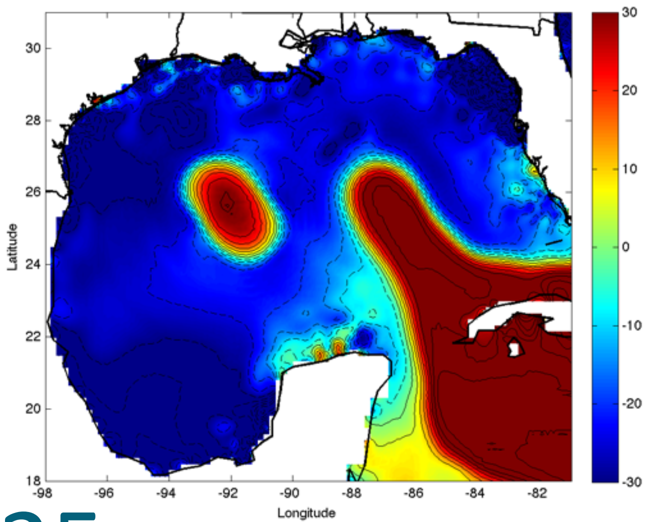
CCAR SSH





Model SSH





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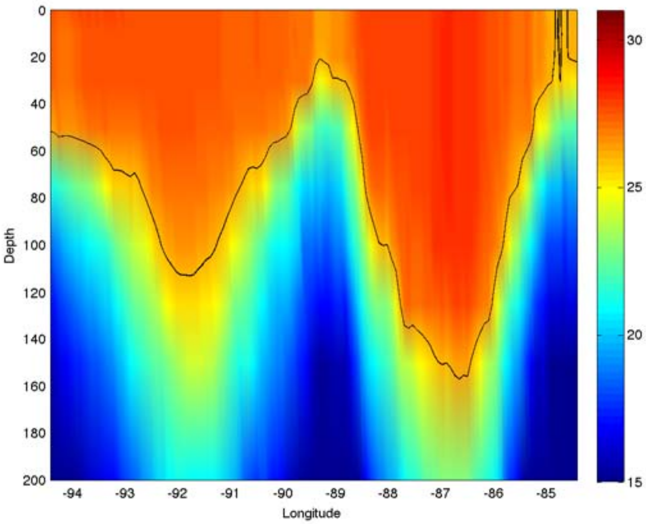
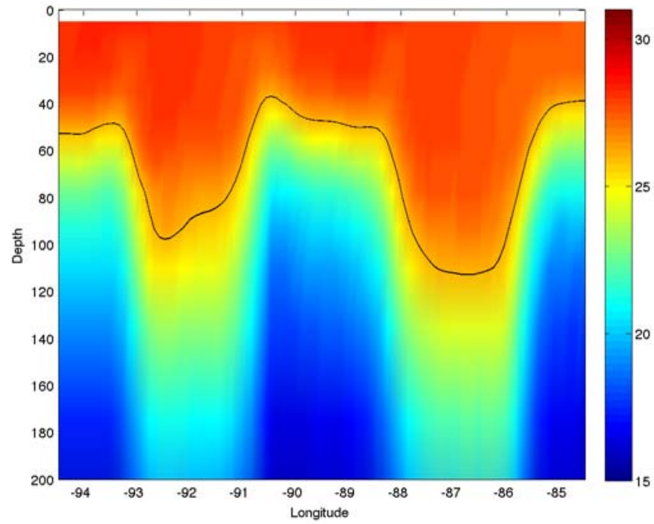
RTOFS-Global

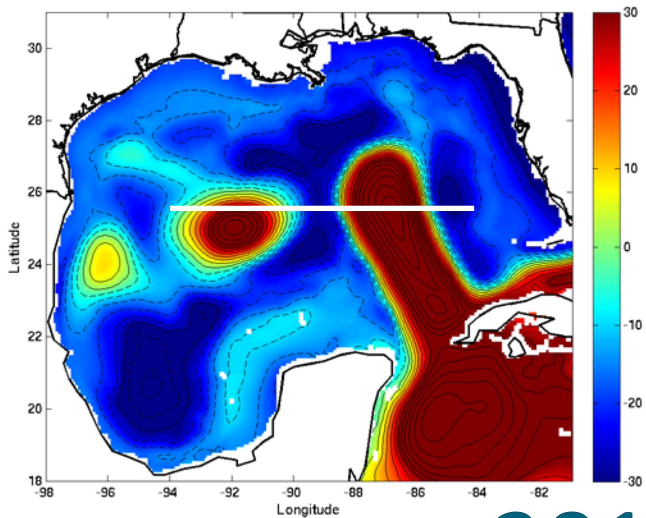
Feature-based w/ GFS SST

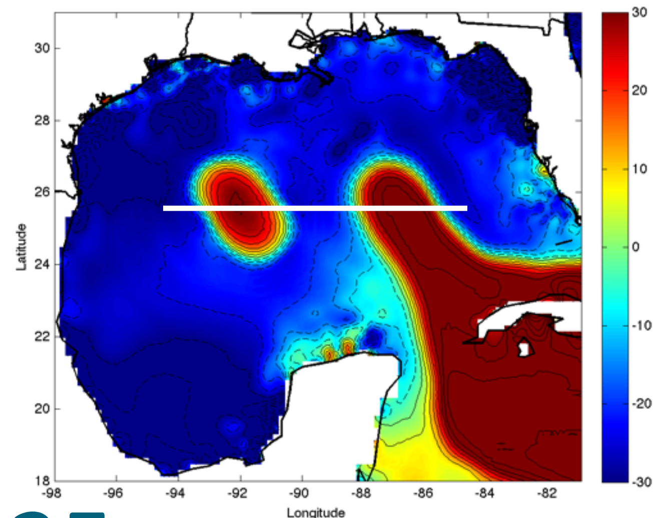
X-section





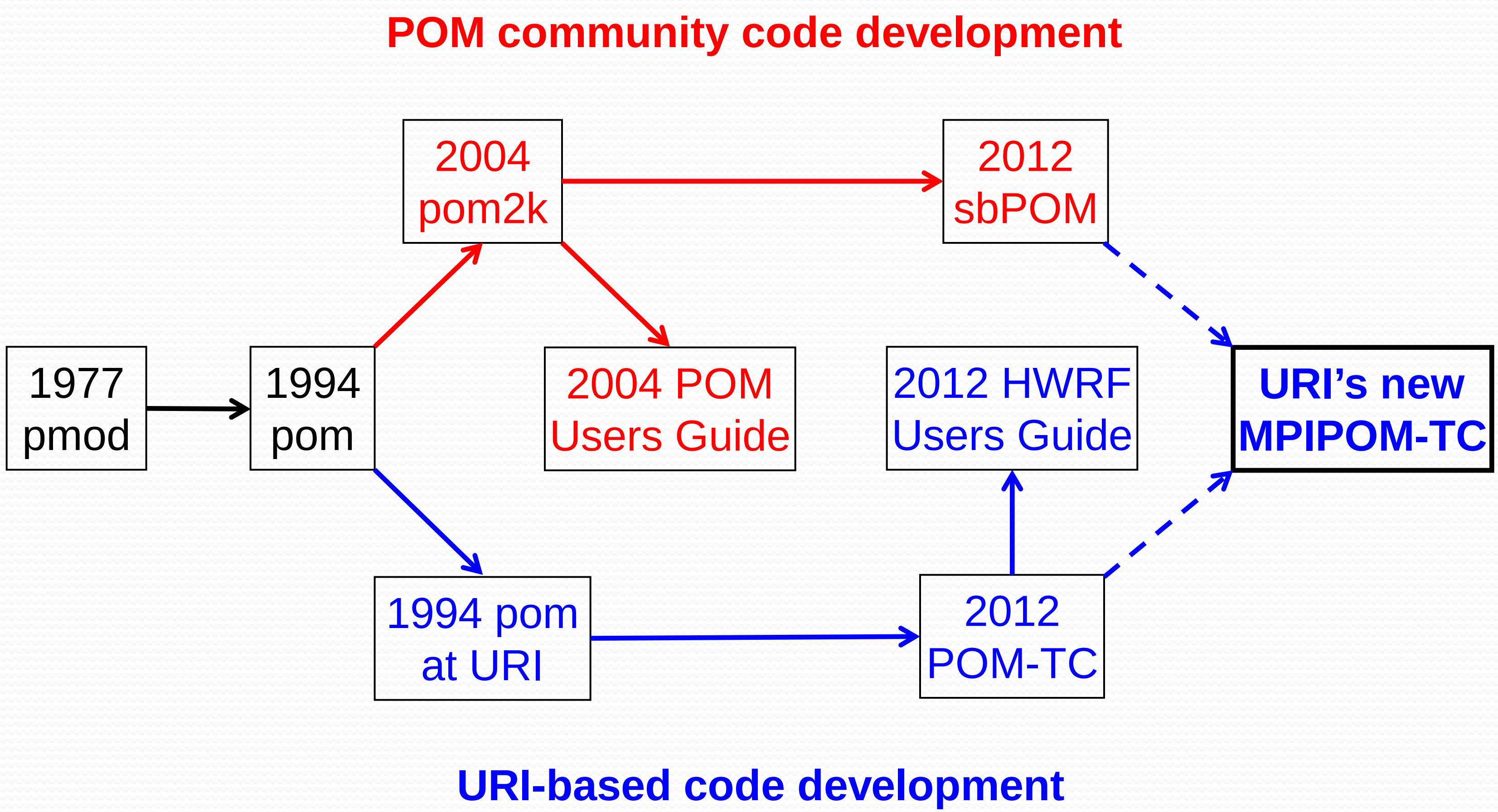
Model SSH



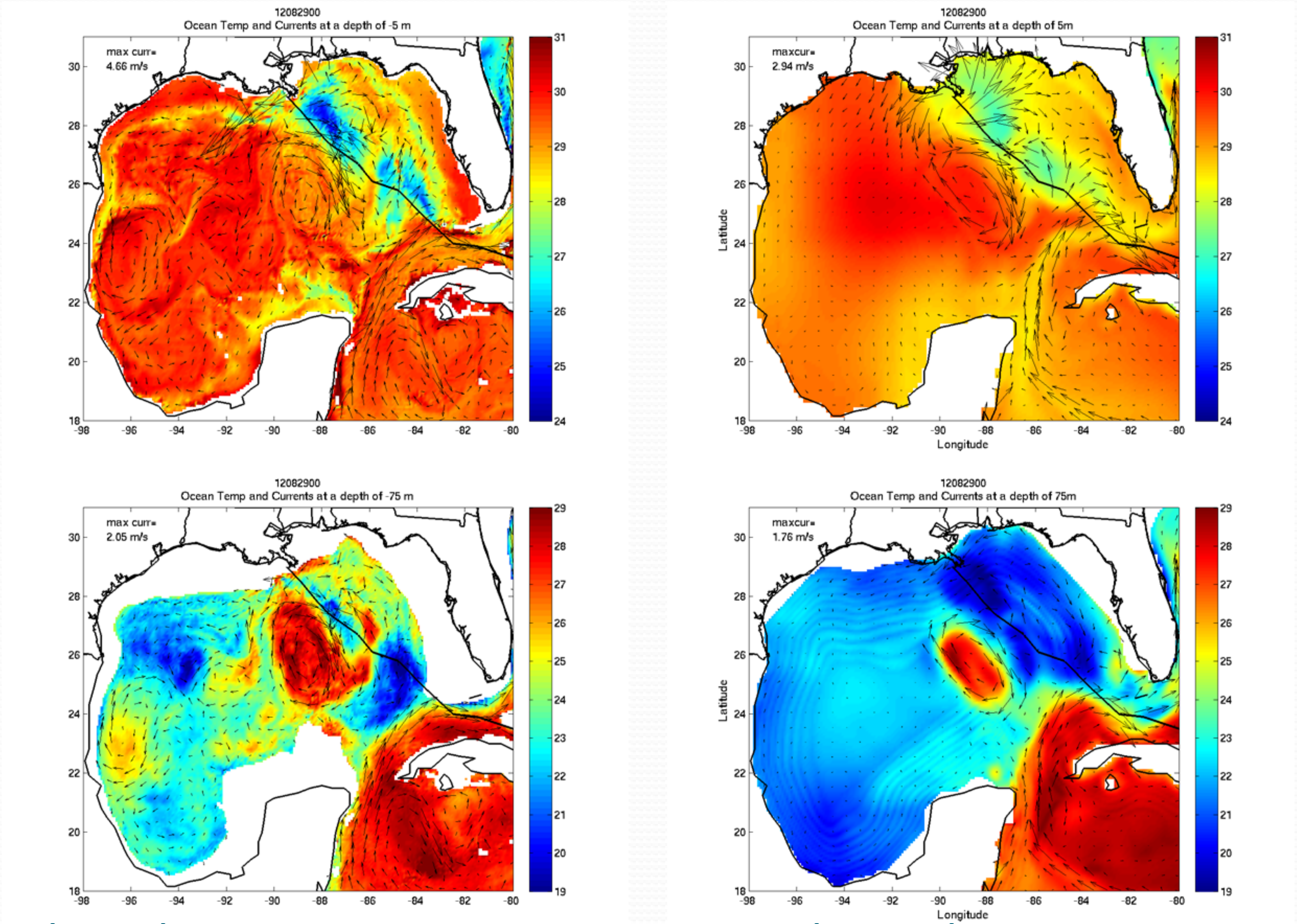


20111025

Developing a new MPIPOM-TC at URI



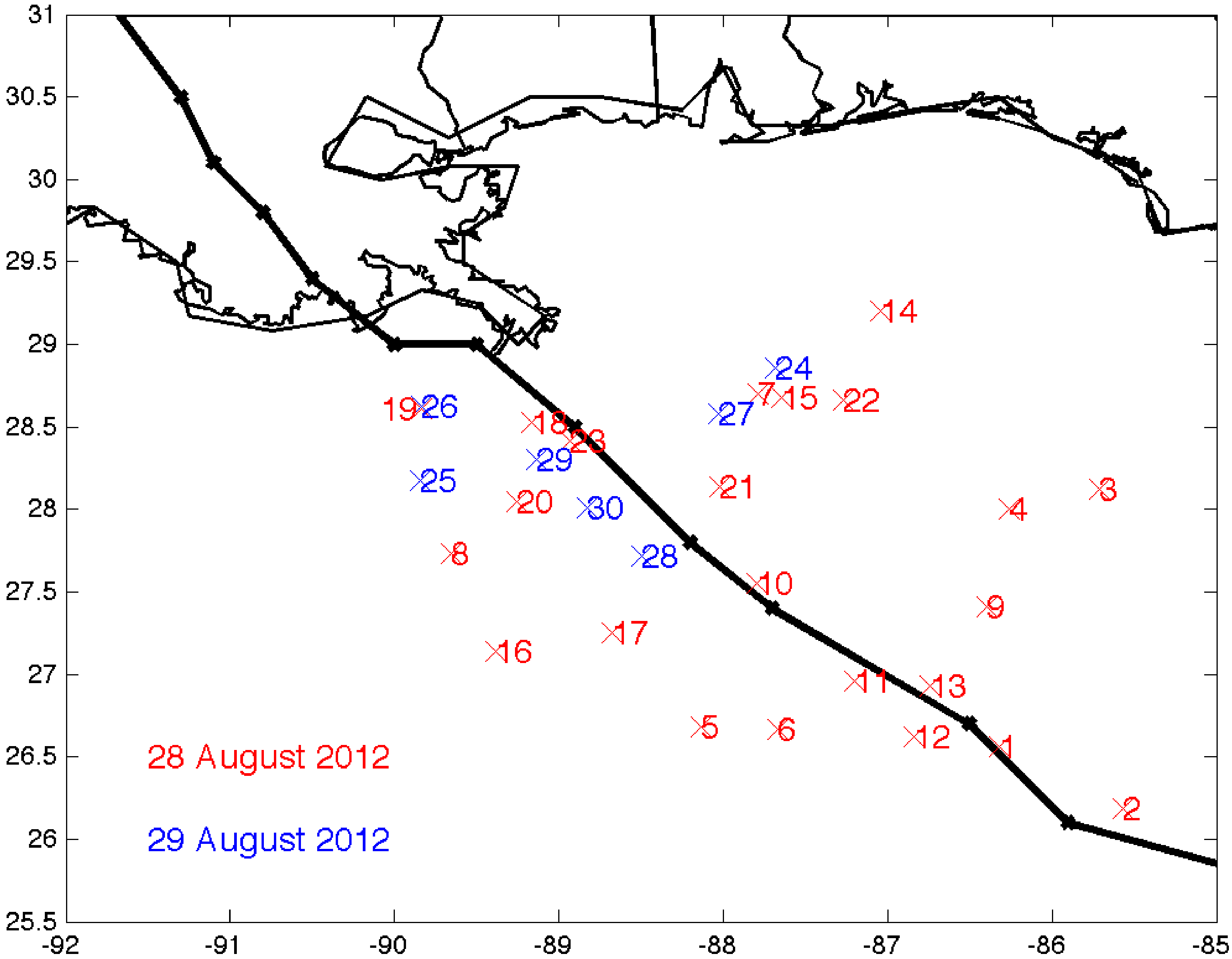
RTOFS-Global | Feature-based w/ GFS SST



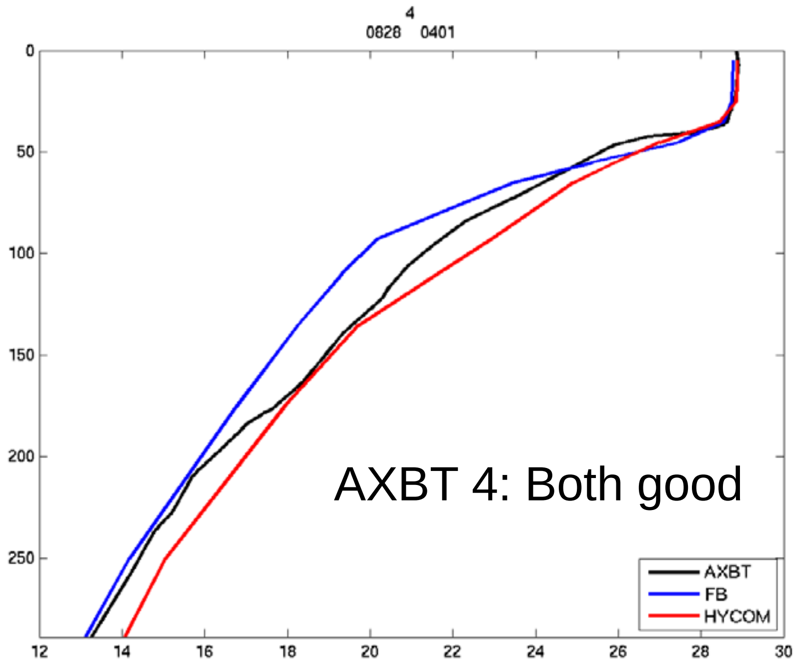
SST

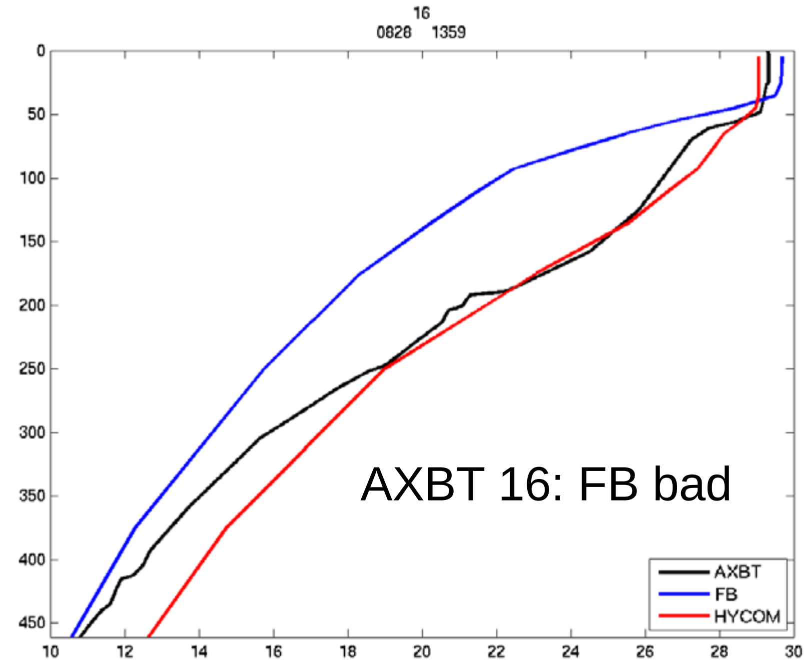
75-m T

(MPI)POM-TC: Hurricane Isaac (2012) wind stress

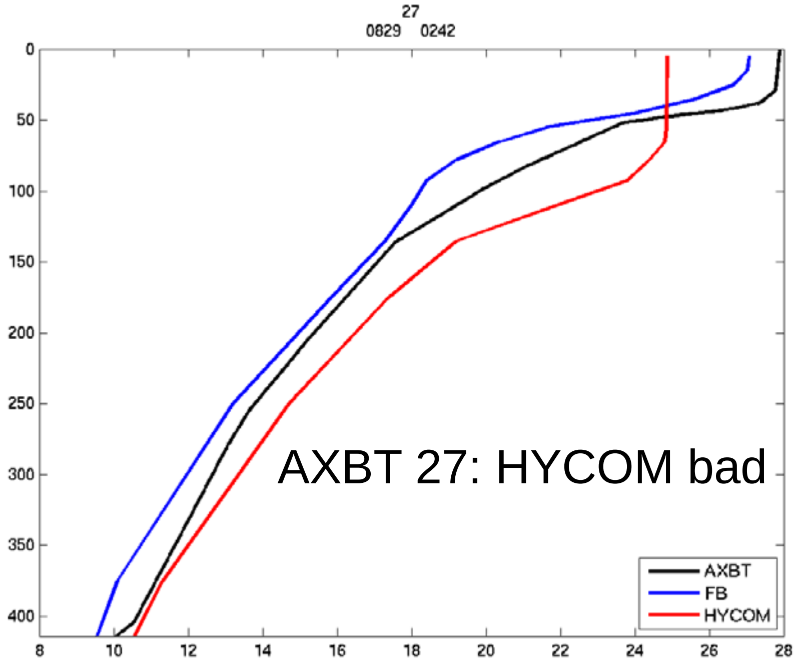


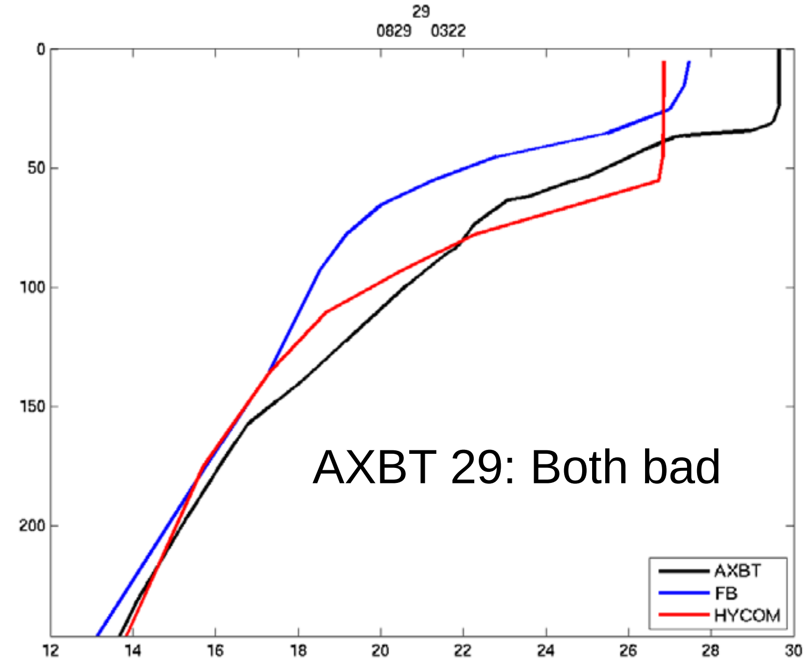
Hurricane Isaac (2012) AXBTs (courtesy Beth Sanabia, USNA)



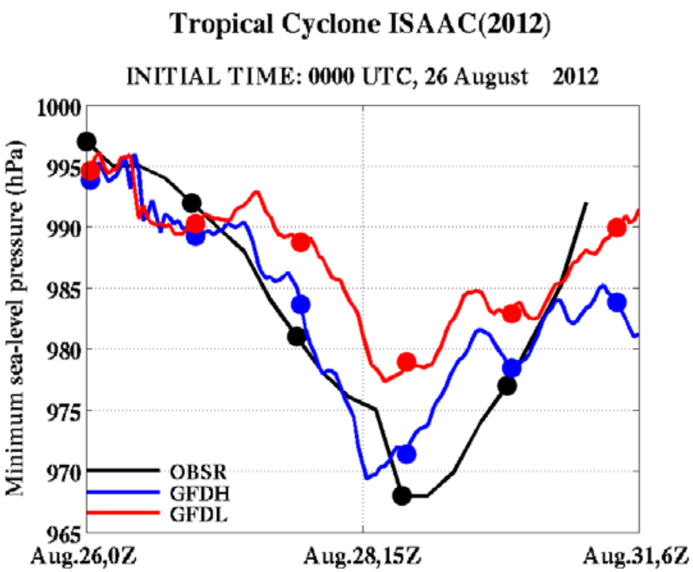


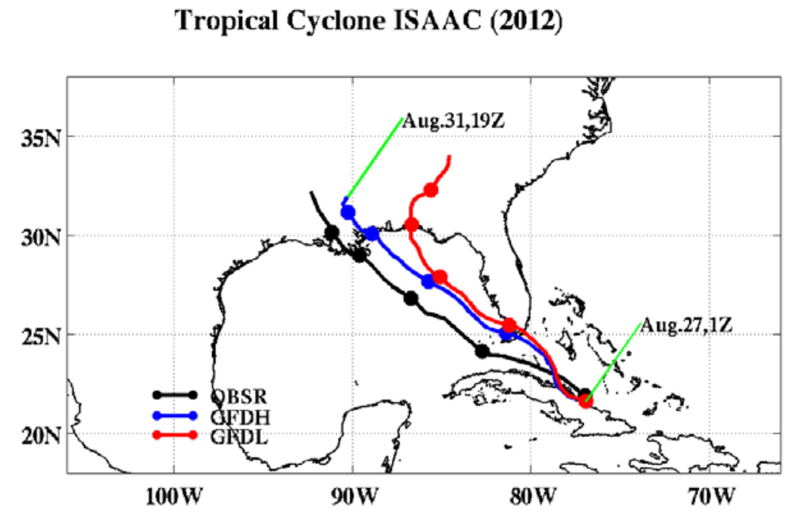
Analysis courtesy of Melissa Kaufman, URI/GSO



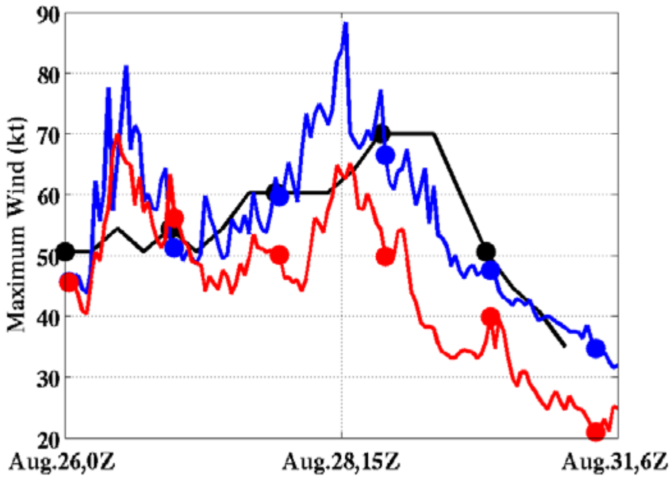


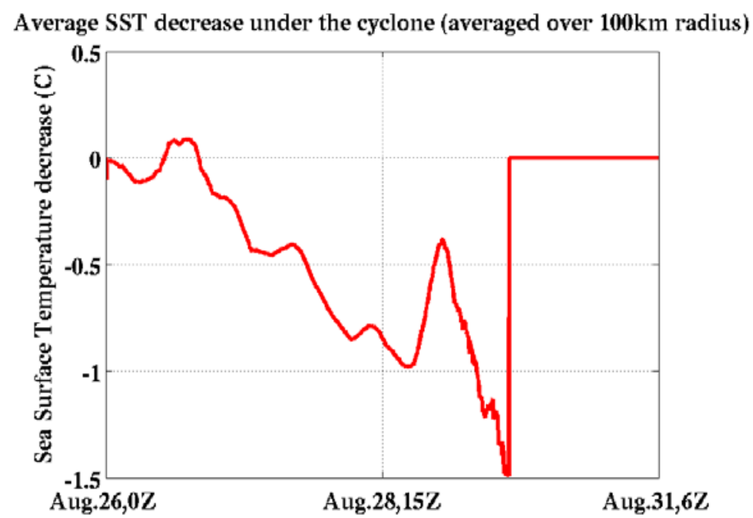
OBSR = observed; GFDH = RTOFS-Global; GFDL = operational





Analysis courtesy of Biju Thomas, URI/GSO





Coupled GFDL/(MPI)POM-TC: Hurricane Isaac (2012)

Summary of initializing MPIPOM-TC with Global HYCOM RTOFS/NCODA

- RTOFS-Global initialization is an alternative to feature-based initialization
- A potential issue is differences between RTOFS-Global SST and GFS SST
- MPIPOM-TC facilitates future developments (e.g. increased resolution, larger ocean domains, plug-and-play initializations, community support)
- GFDN coupled model already uses NCODA T/S operationally for POM-TC initialization outside Atlantic basin where no feature-based model exists
- Quality of initialization technique is largely dependent on quality of altimetry product(s) and method of altimetry assimilation into T/S fields

Some Key References

- Yablonsky, R. M., and I. Ginis, 2008: Improving the ocean initialization of coupled hurricane-ocean models using feature-based data assimilation. *Mon. Wea. Rev.*, **136**, 2592-2607.
- Yablonsky, R. M., and I. Ginis, 2009: Limitation of one-dimensional ocean models for coupled hurricane-ocean model forecasts. *Mon. Wea. Rev.*, **137**, 4410-4419.
- Yablonsky, R., and I. Ginis, 2012: Impact of a warm ocean eddy's circulation on hurricane-induced sea surface cooling with implications for hurricane intensity. *Mon. Wea. Rev.* doi:10.1175/MWR-D-12-00248.1, in press.
- Gopalakrishnan, S., Q. Liu, T. Marchok, D. Sheinin, V. Tallapragada, M. Tong, R. Tuleya, R. Yablonsky, and X. Zhang, 2012: *Hurricane Weather Research and Forecasting (HWRF) Model: 2012 scientific documentation.* L. Bernardet, Ed., 96 pp.