Applying TMI retrievals of sea surface temperature and surface winds to understanding tropical cyclone-induced climate feedbacks

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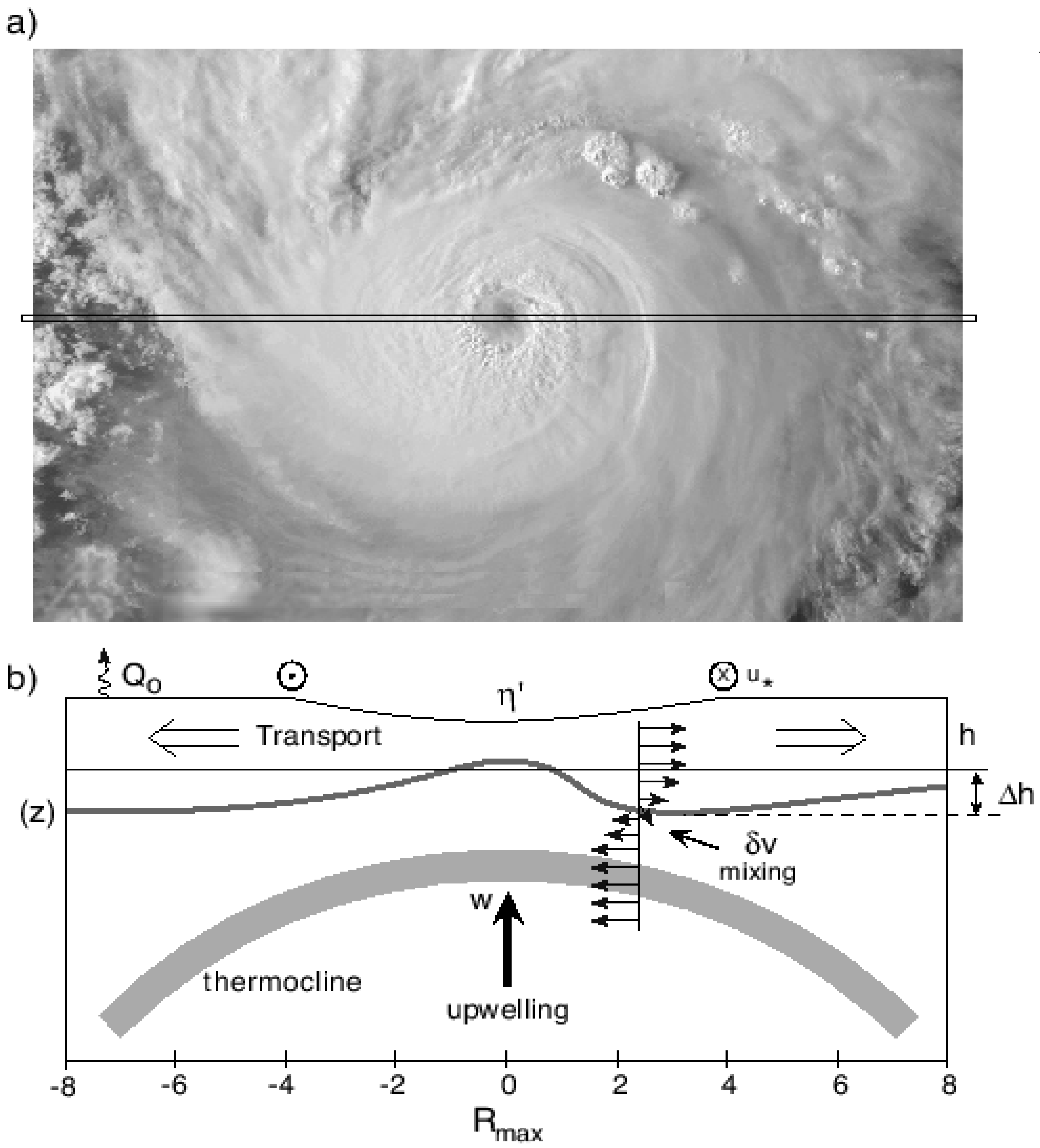
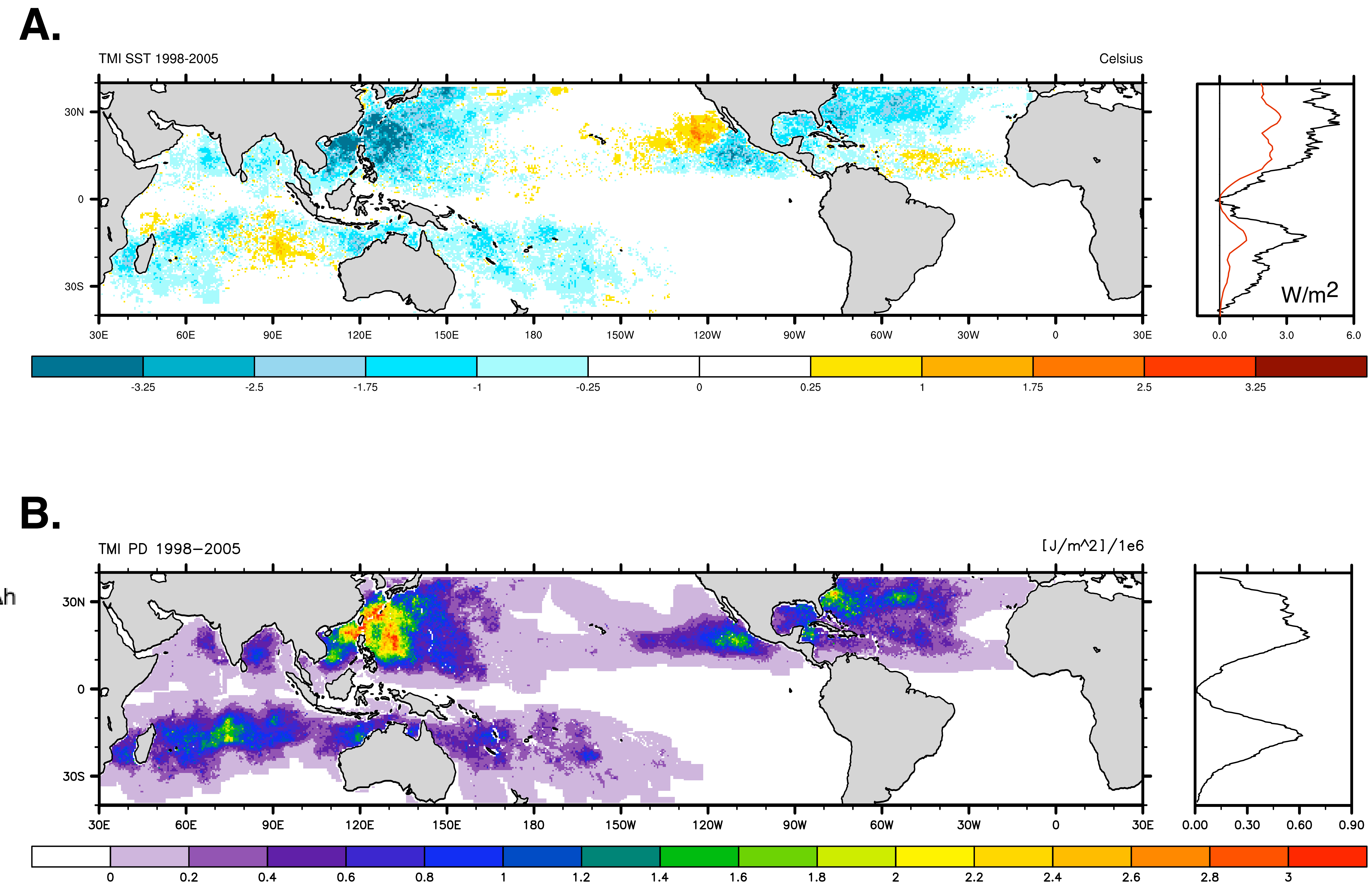


- Figure from Shay, 2006



Entrainment fluxes at the base of the mixed layer account for 60-85% of upper ocean cyclone-induced cooling. (Jacob et al., 2000; Shay, 2006)

Effects of Tropical Cyclones (TC)s on the Upper Ocean

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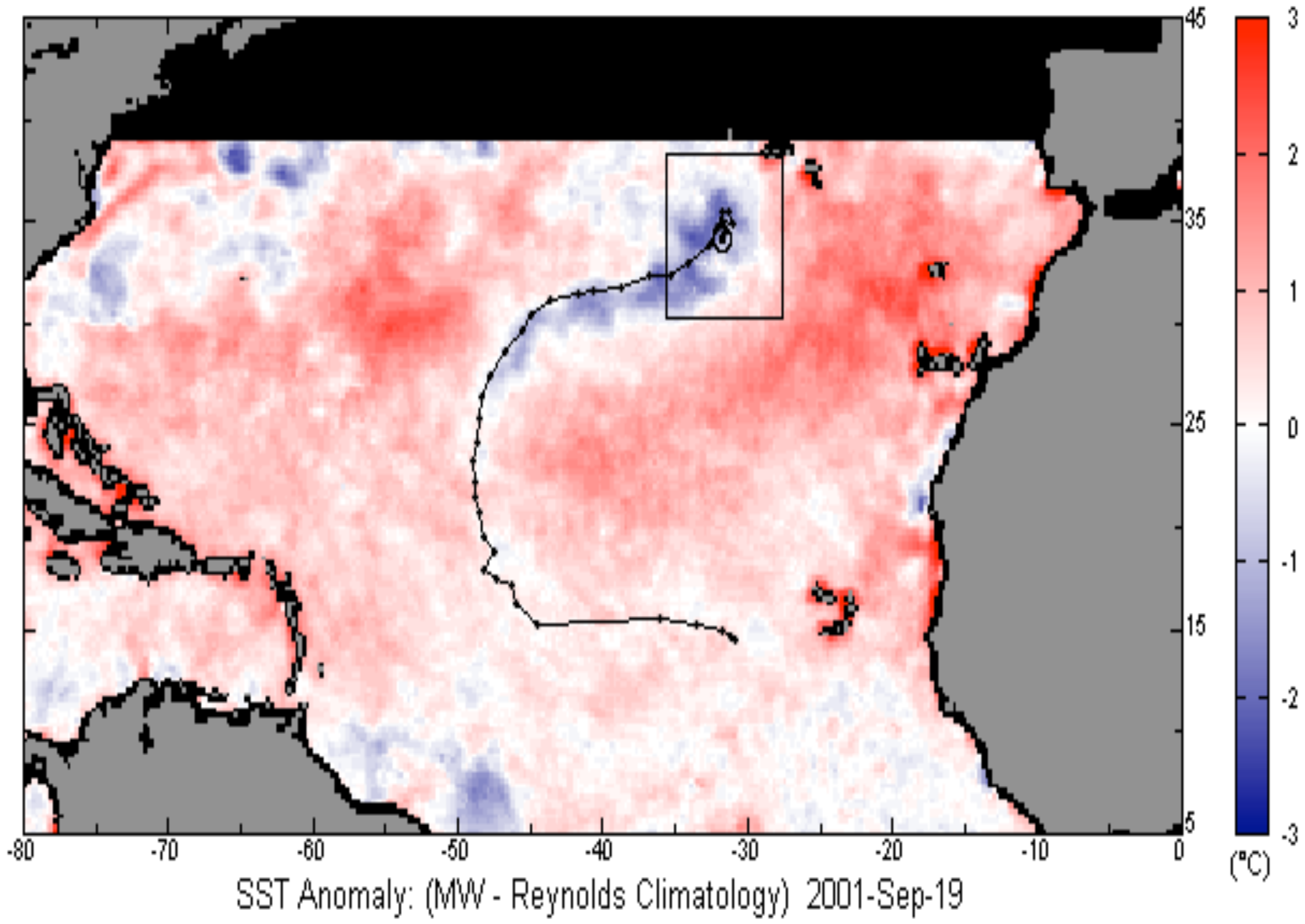
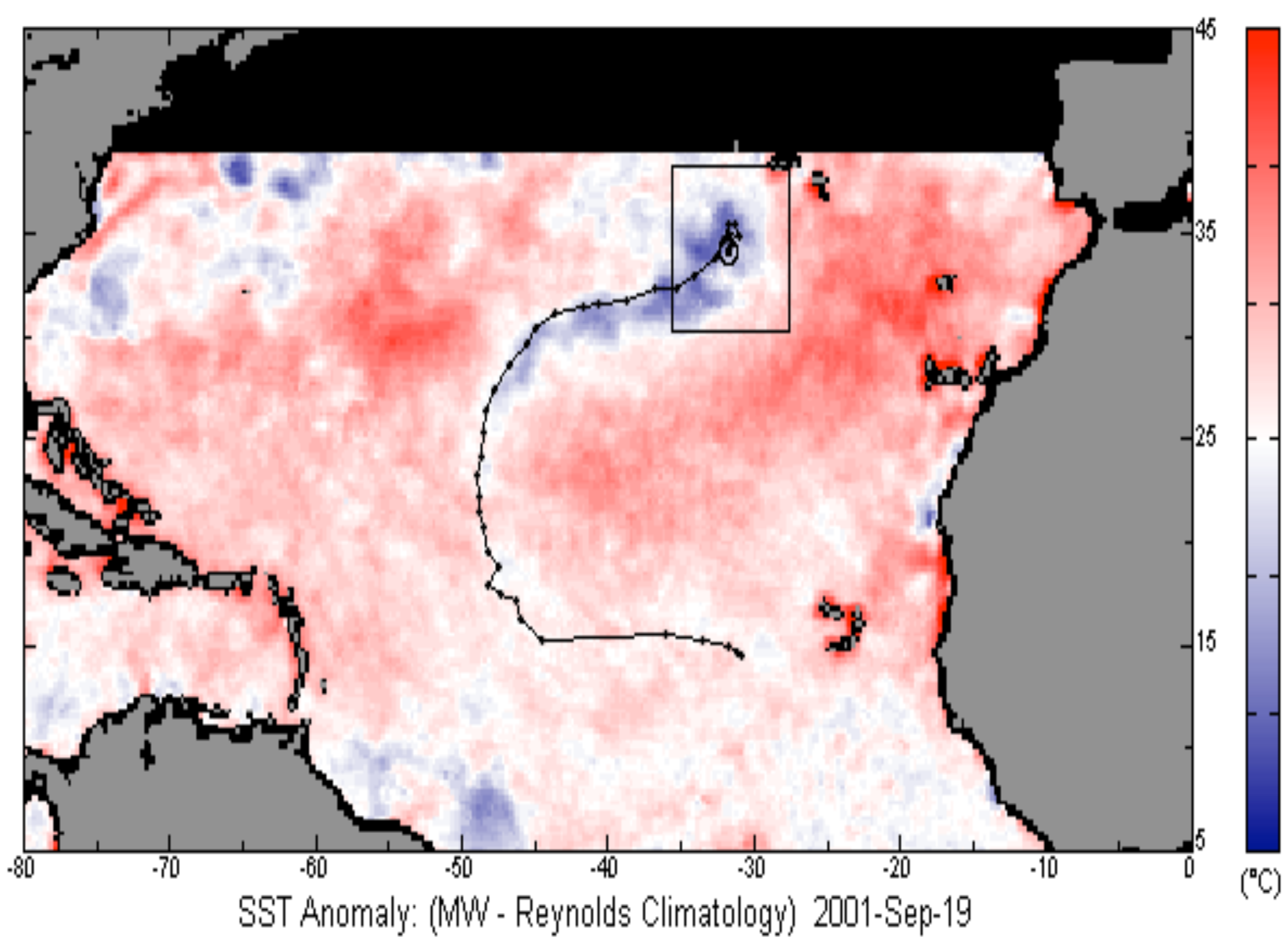
- Leave pronounced cold wakes behind storms (60-85% of cooling due to entrainment through base of mixed layer)



From www.ssmi.com

Effects of Tropical Cyclones (TC)s on the Upper Ocean

- Leave pronounced cold wakes behind storms (60-85% of cooling due to entrainment through base of mixed layer)
- Mix warm surface water down into the thermocline



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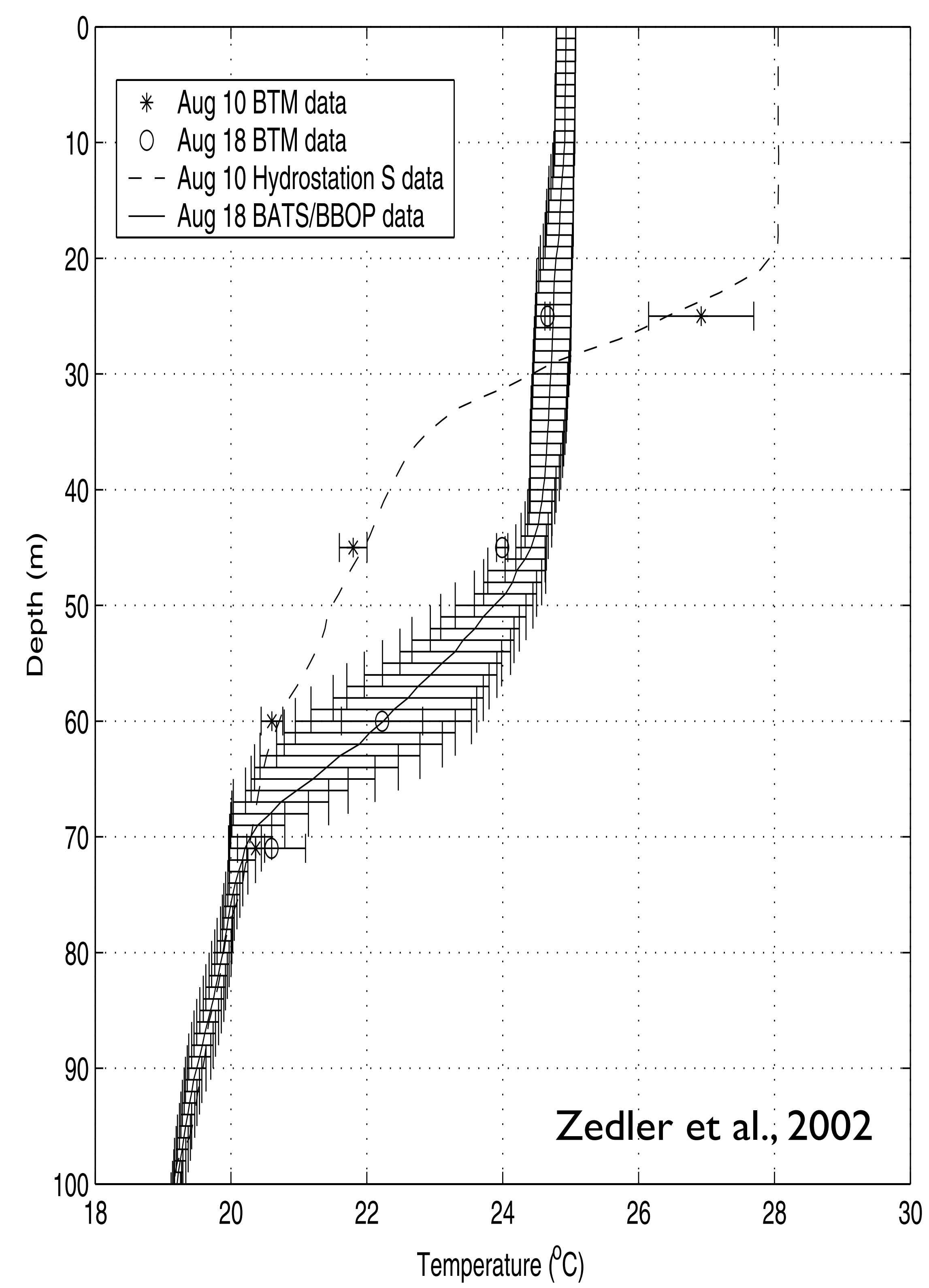

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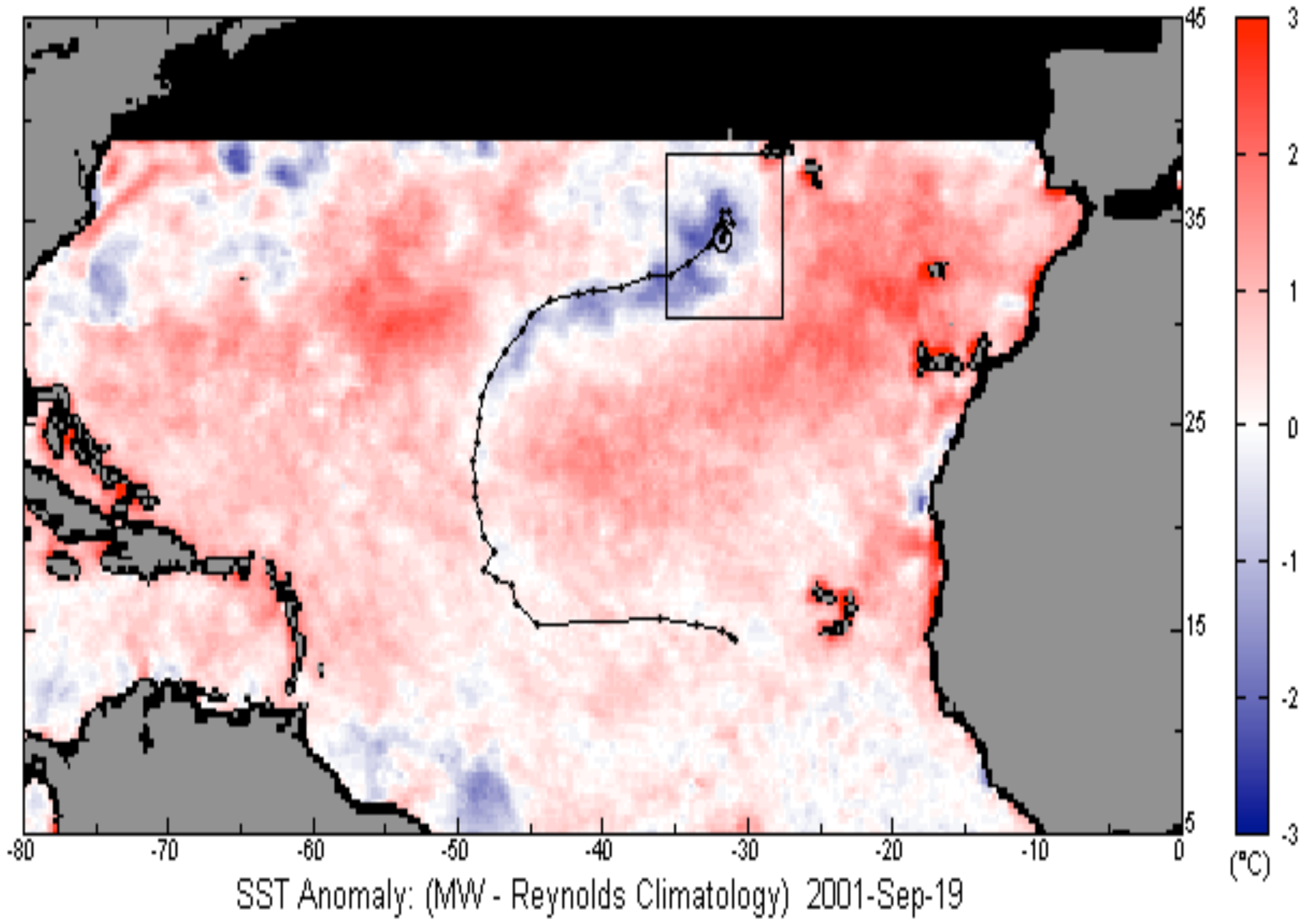

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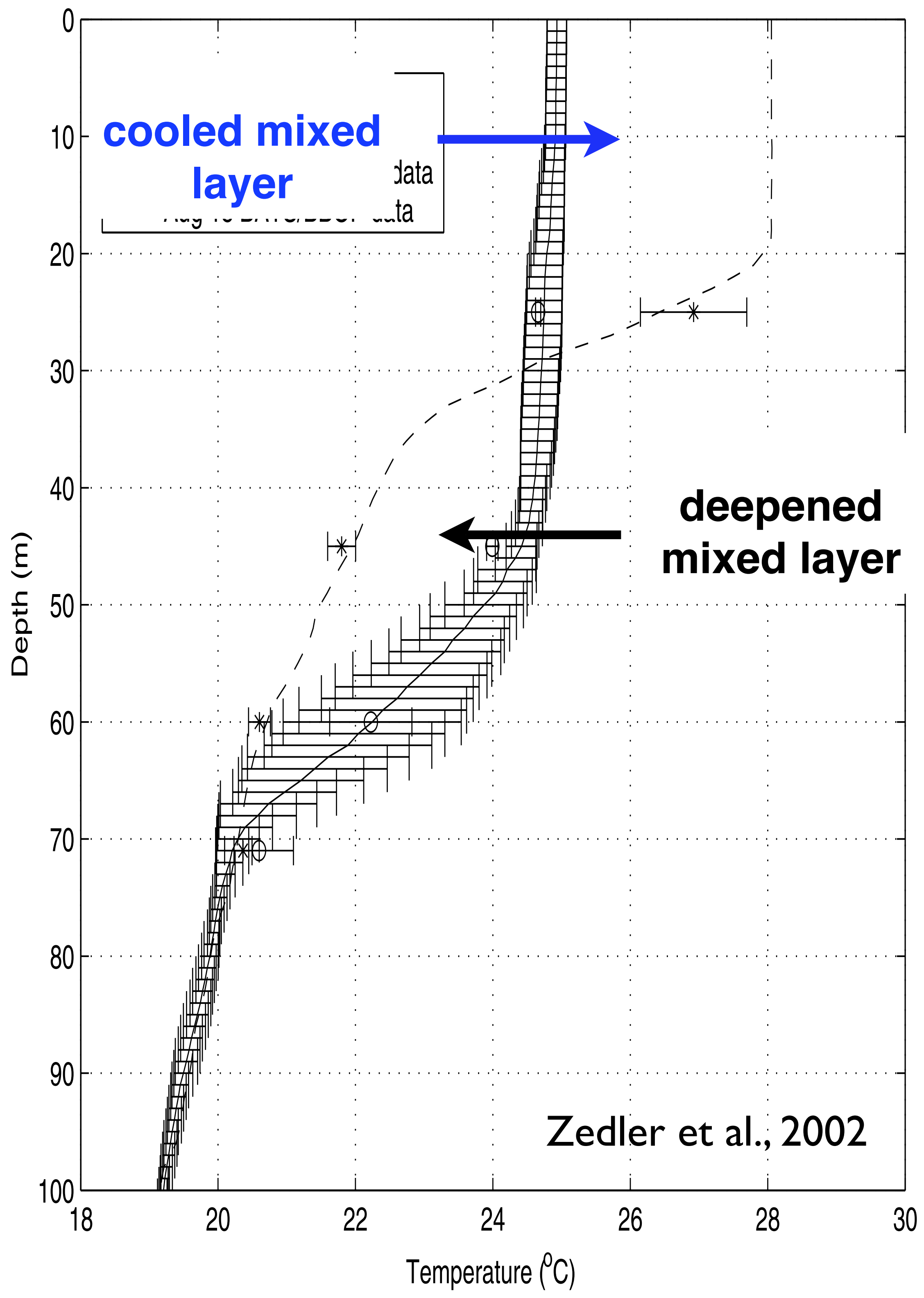

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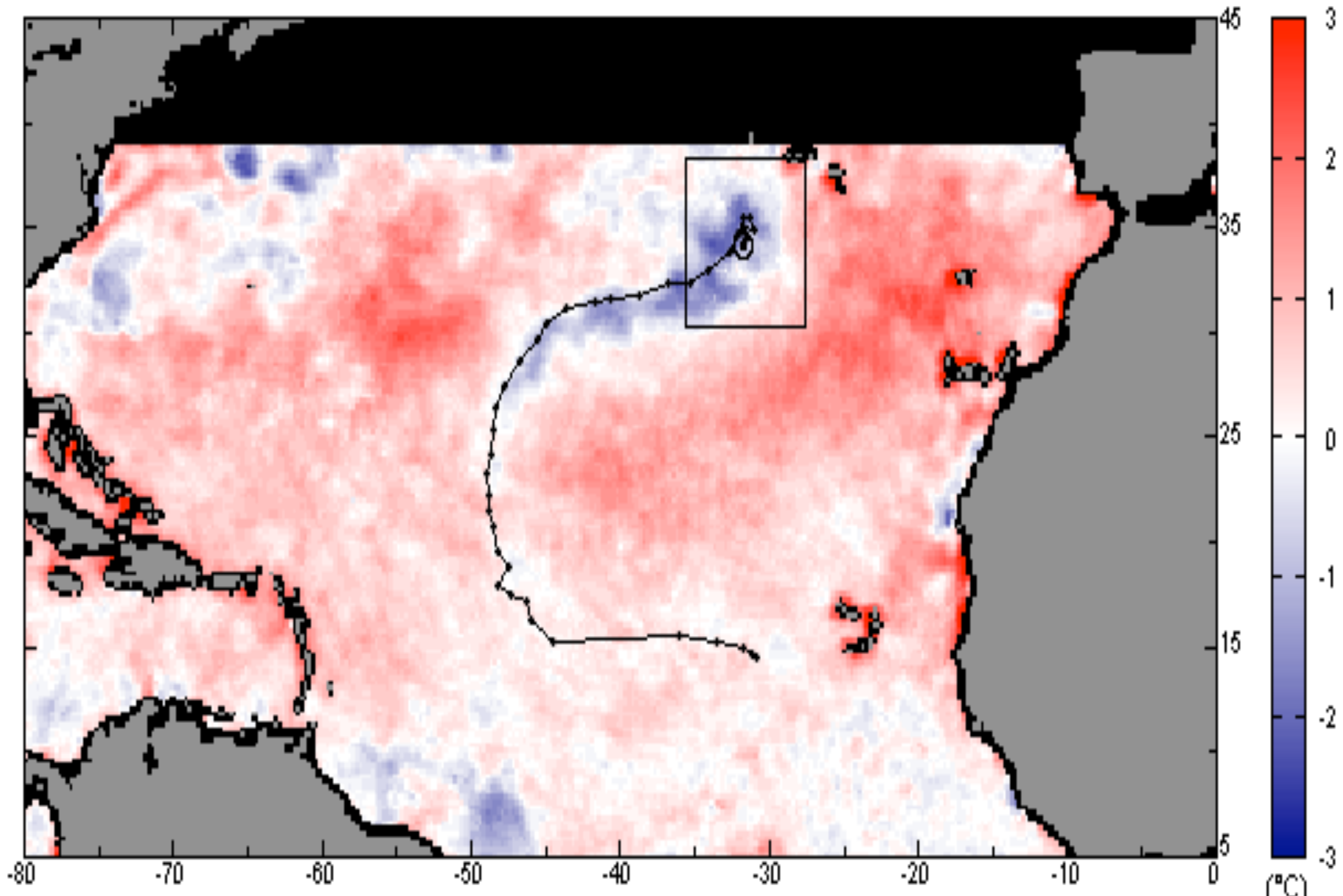

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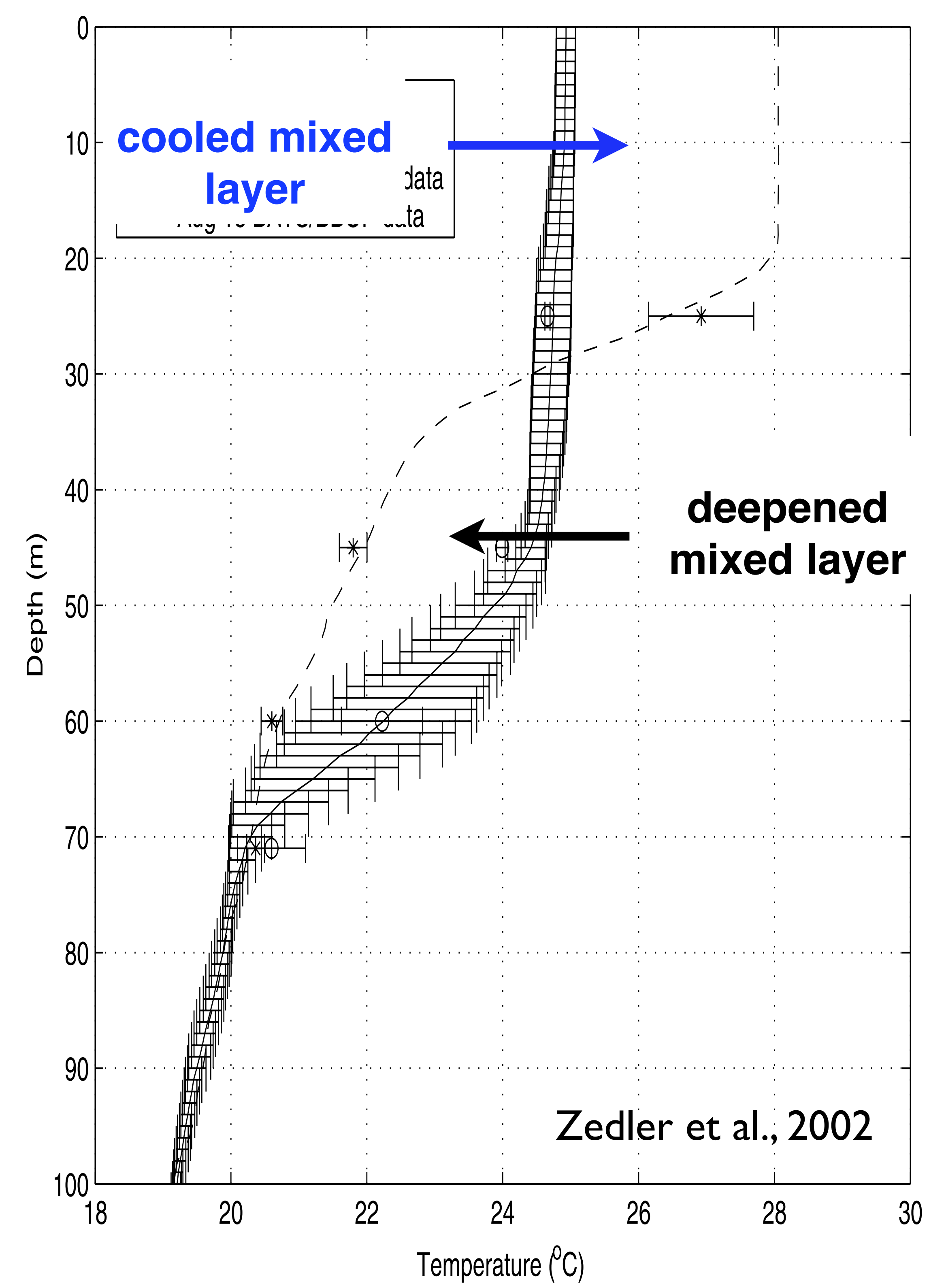

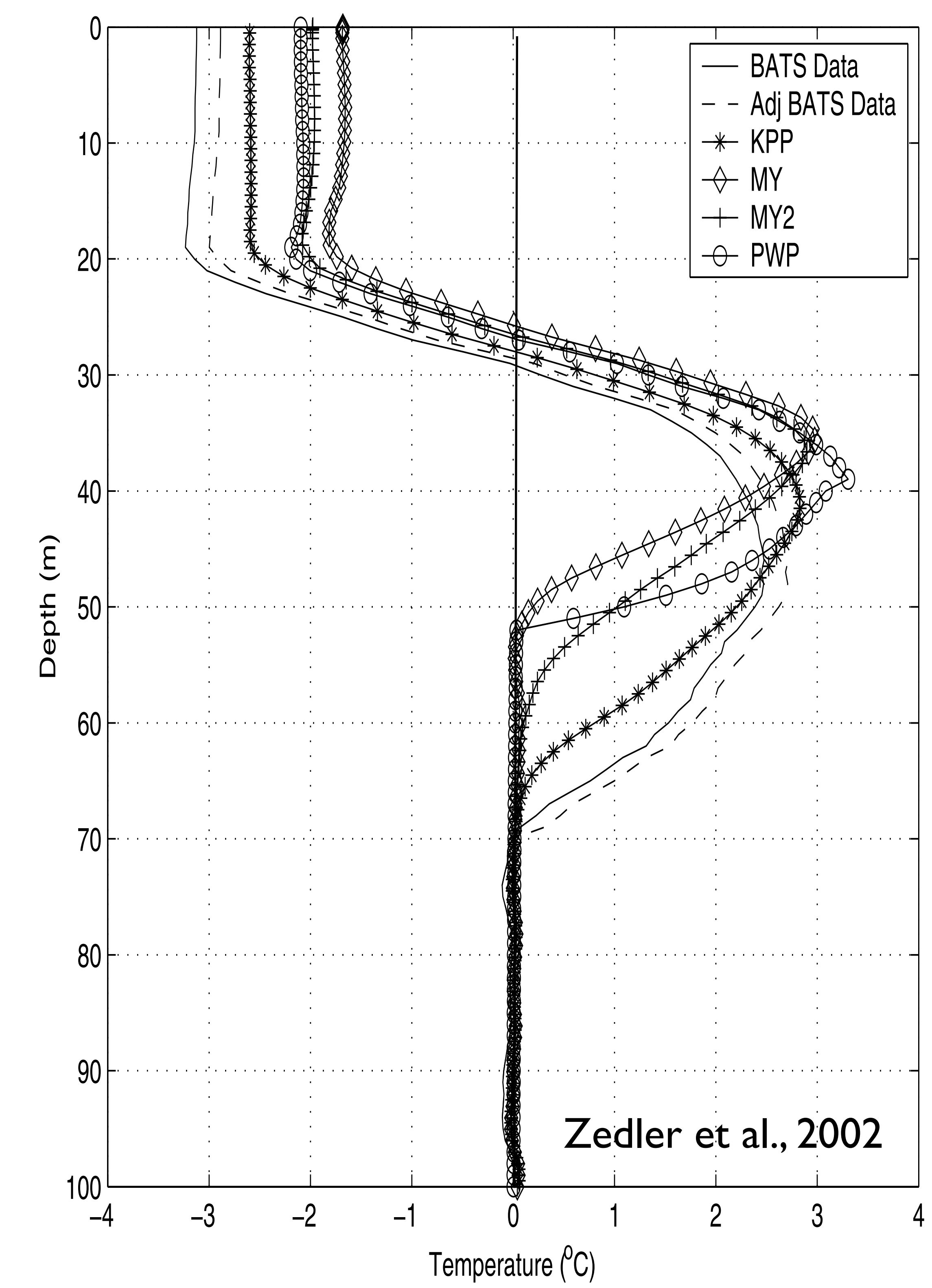

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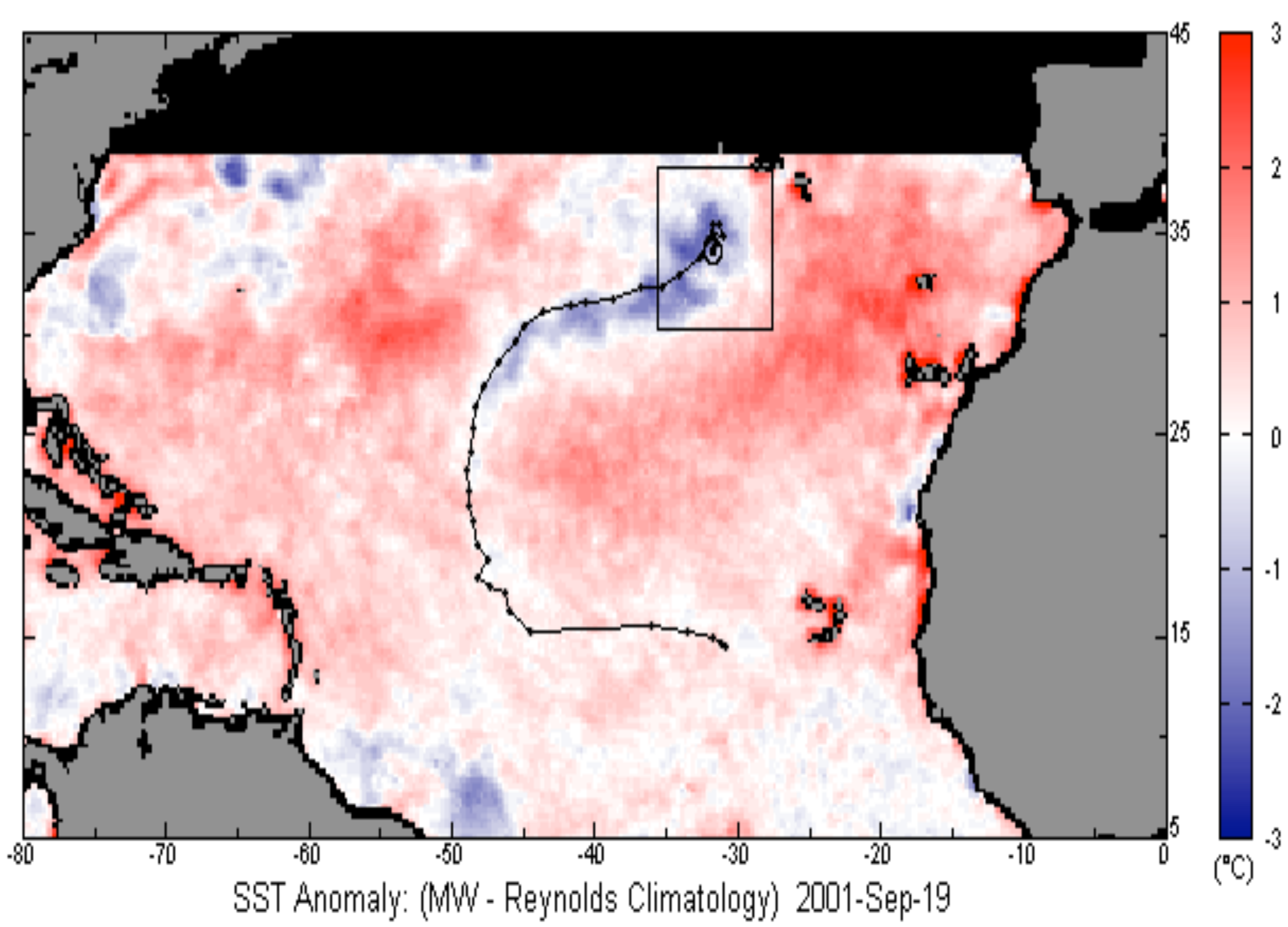

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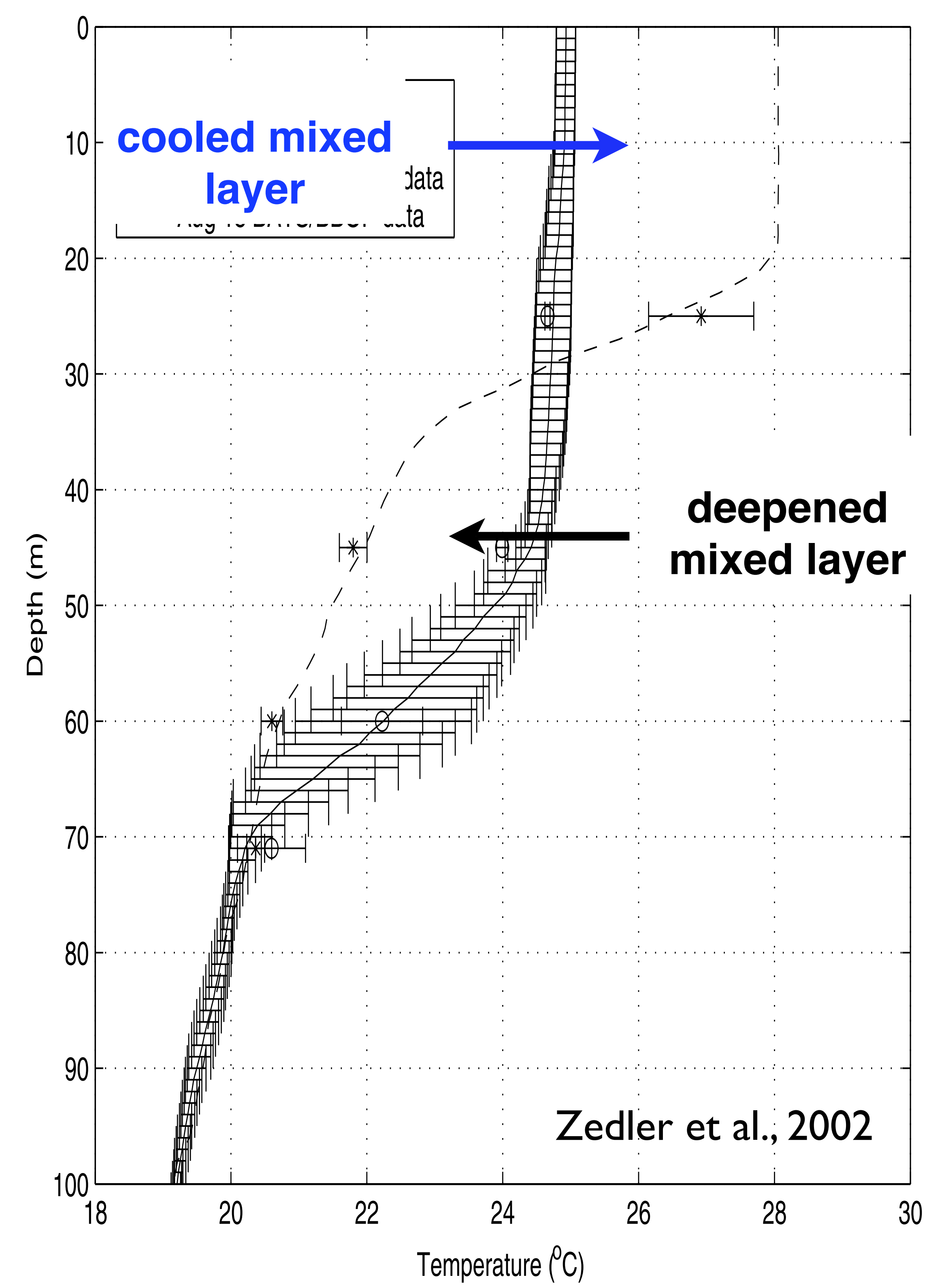

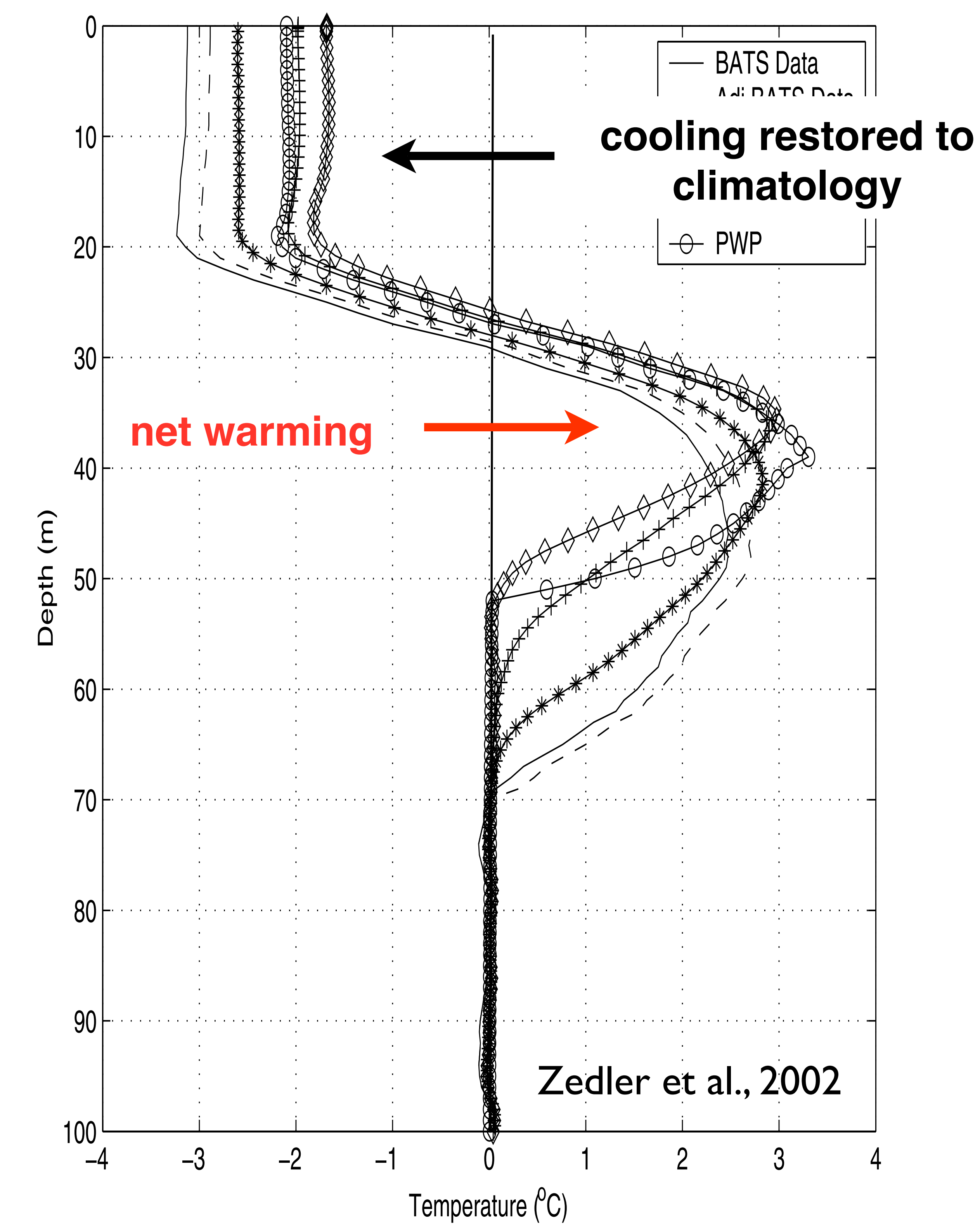

K. Emanuel's 2001 hypothesis:

- TCs lead to strong vertical mixing that pumps heat down into the ocean.
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In order for Emanuel's 2001 hypothesis to be true, the following should be observable:

- TCs mix warm water up and cold water down.
- Positive correlations between:
  - Integrated TC intensity (Power Dissipation (PD)) $$PD = 2\pi \int_0^{\tau} \int_0^{r_0} C_d \rho |V^3| r \, dr \, dt$$
  - Vertical Diffusivity
  - Sea surface temperature (SST) e.g. $V^2 \sim SST \implies PD \sim SST^{\frac{3}{2}}$
  - Changes in ocean heat content (ΔOHC) e.g. $PD \sim \Delta OHC^{\frac{3}{2}} \implies SST \sim \Delta OHC$

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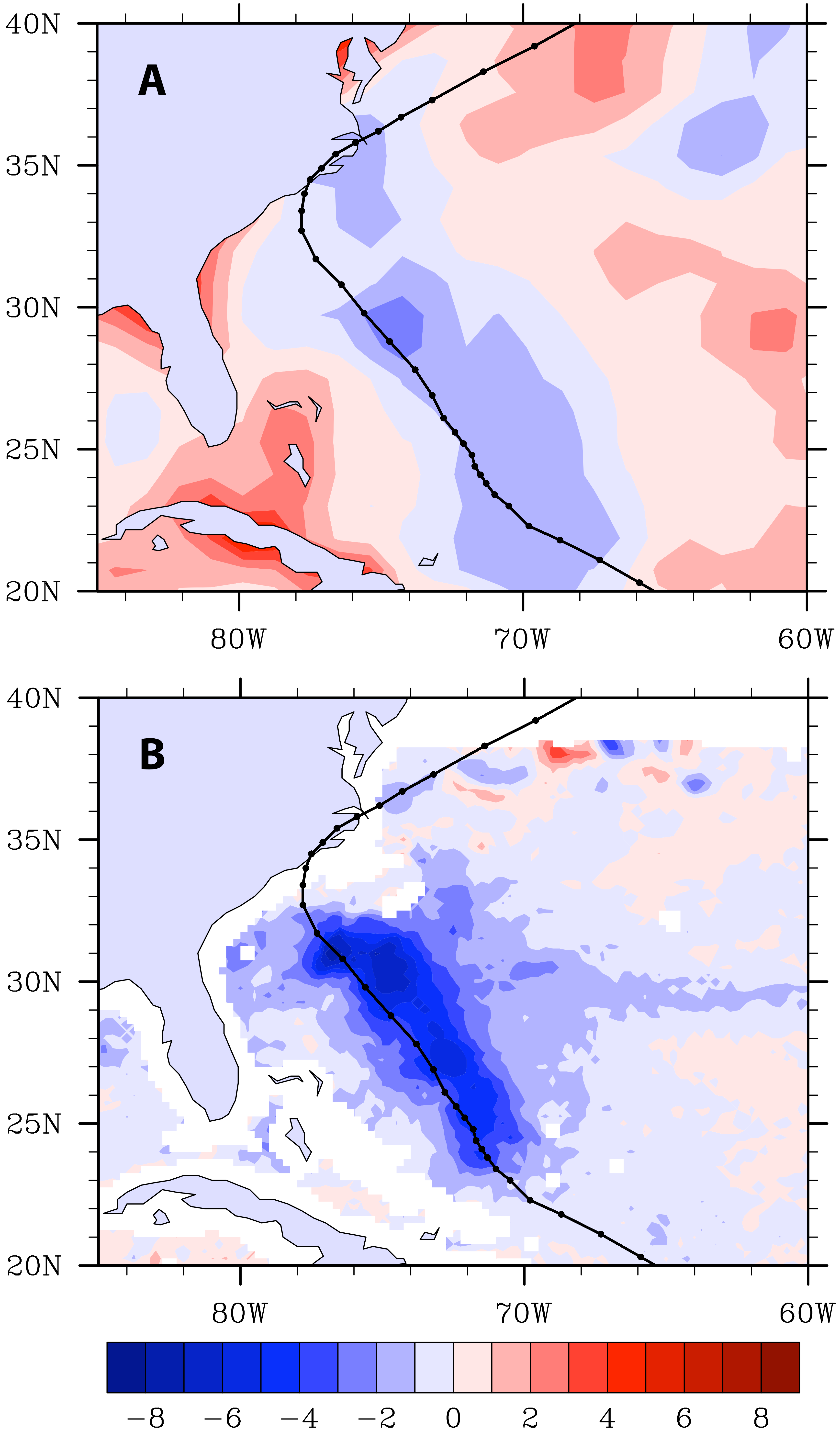
We test Emanuel's 2001 hypothesis by examining these criteria using TMI winds and surface temperature data.

- offers opportunity to represent both quantities with same instrument

Hurricane Bonnie, 1998

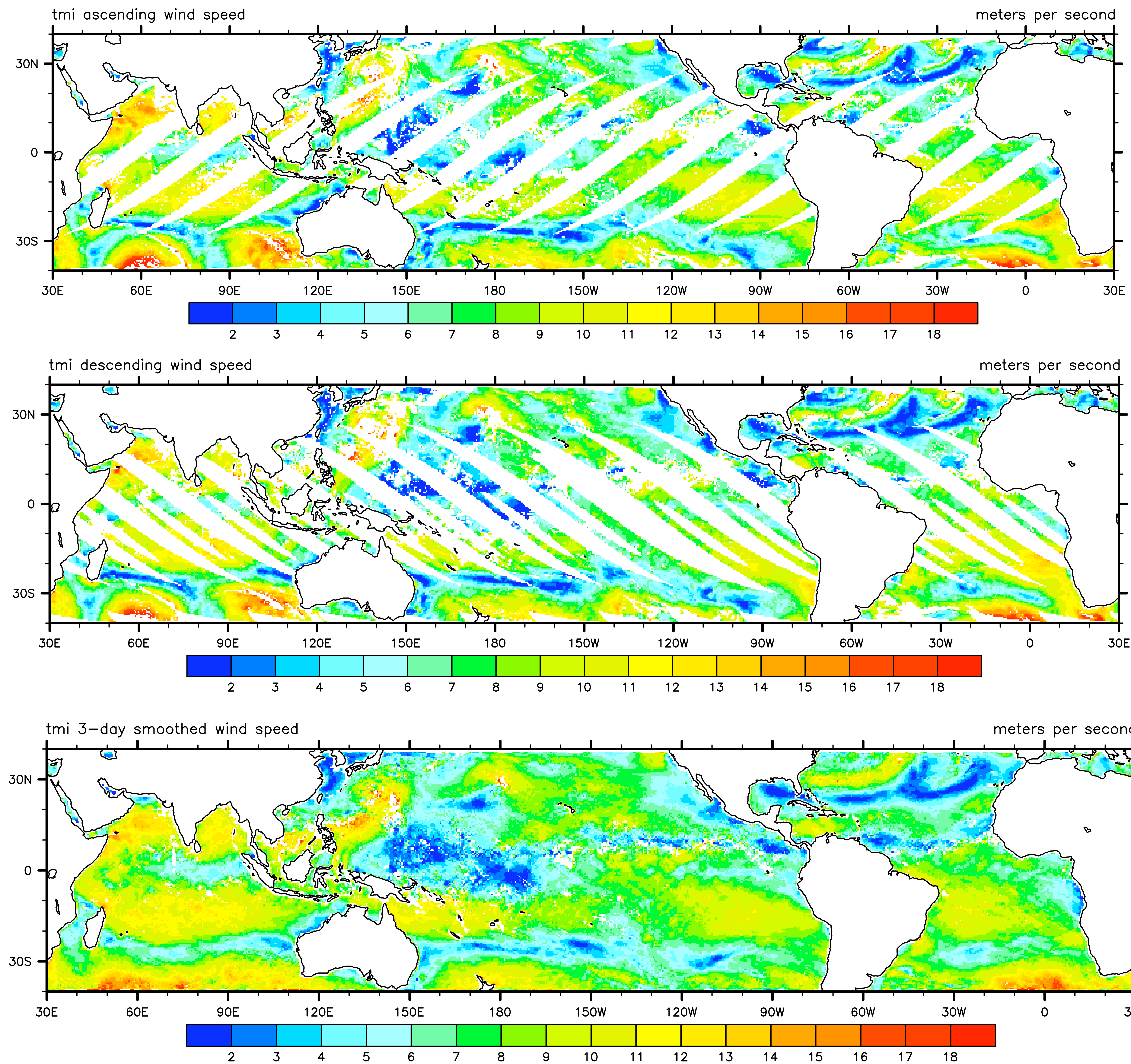
Temperature differences (degrees C) between 08/10/1998 and 08/27/1998.



A. 2 meter air temperature (2MT) anomaly from ERA-40

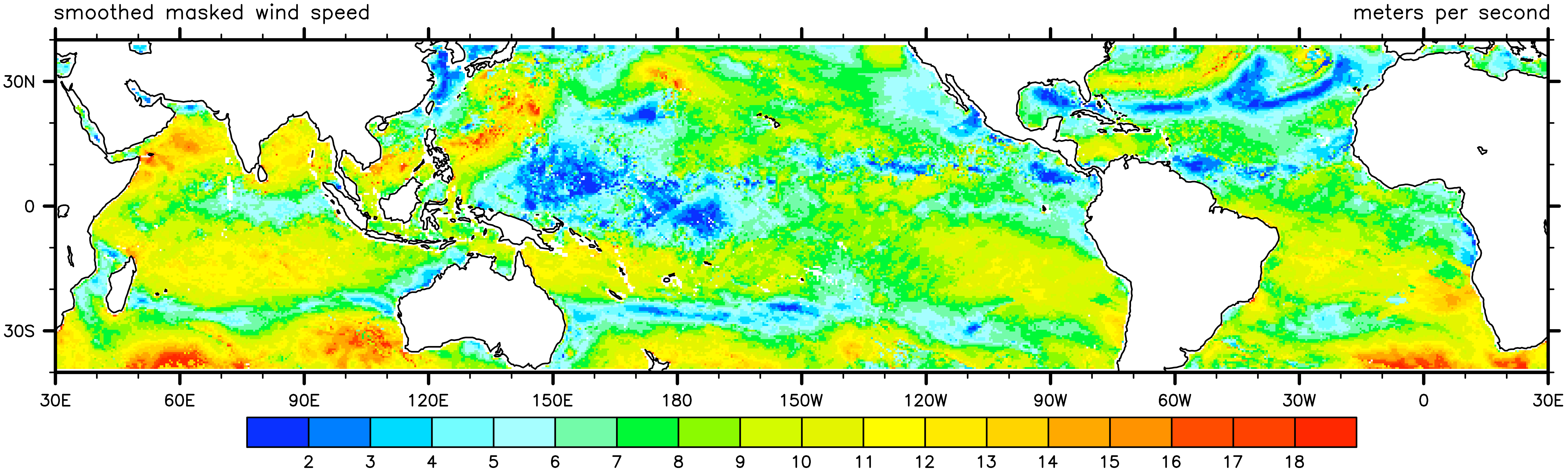
B. Sea surface temperature (SST) anomaly from NASA's TRMM Microwave Imager (TMI)

Processing TMI winds and sst (from remss.com)



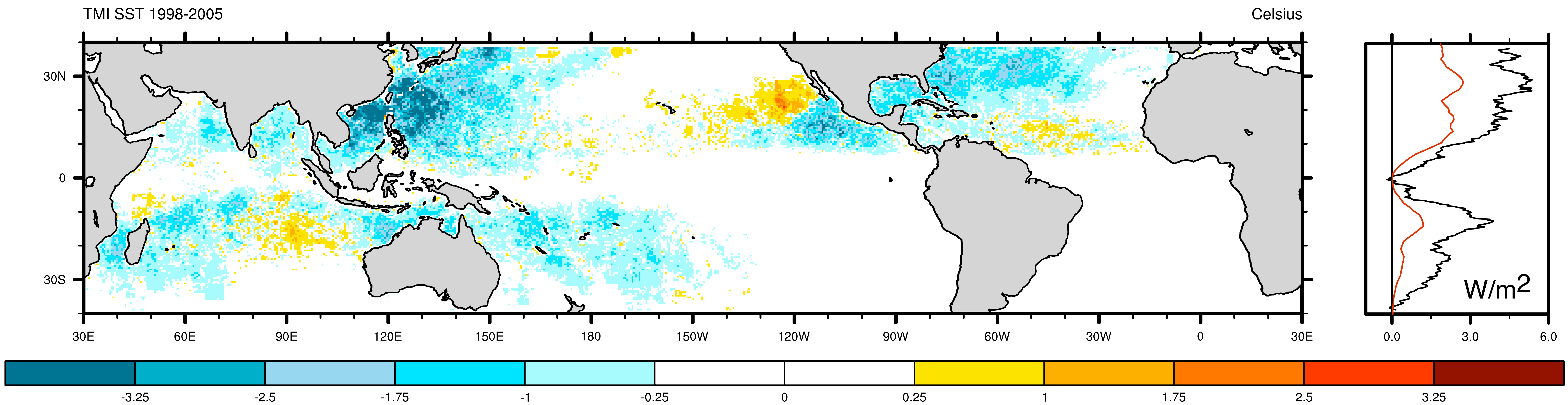
Apply Poisson relaxation to fill in missing values

Example of blended daily maximum wind field



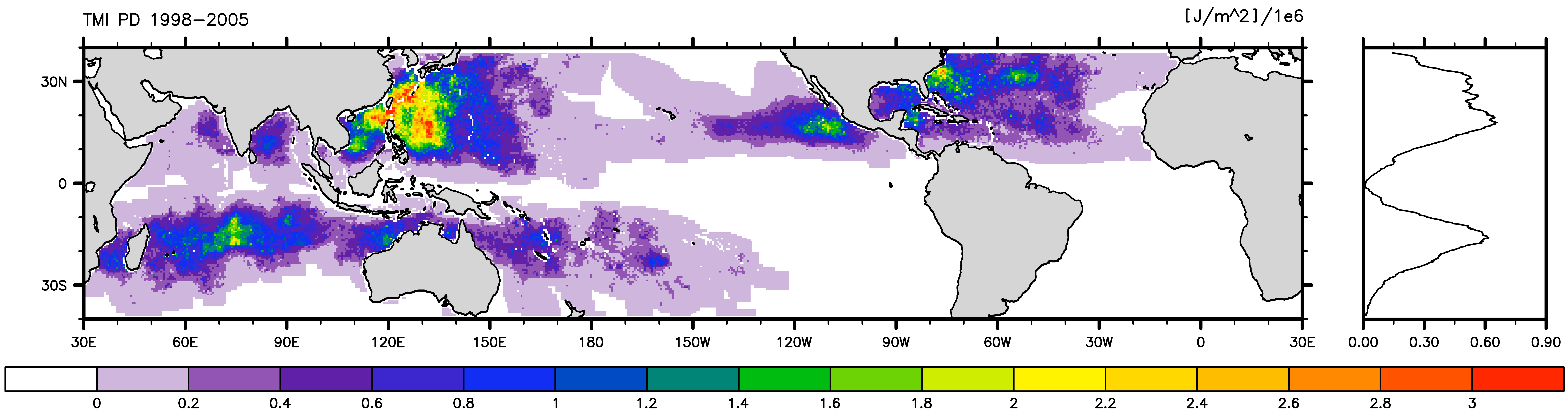
A.

Annualized Accumulated Tropical Cyclone-Induced SST Anomalies



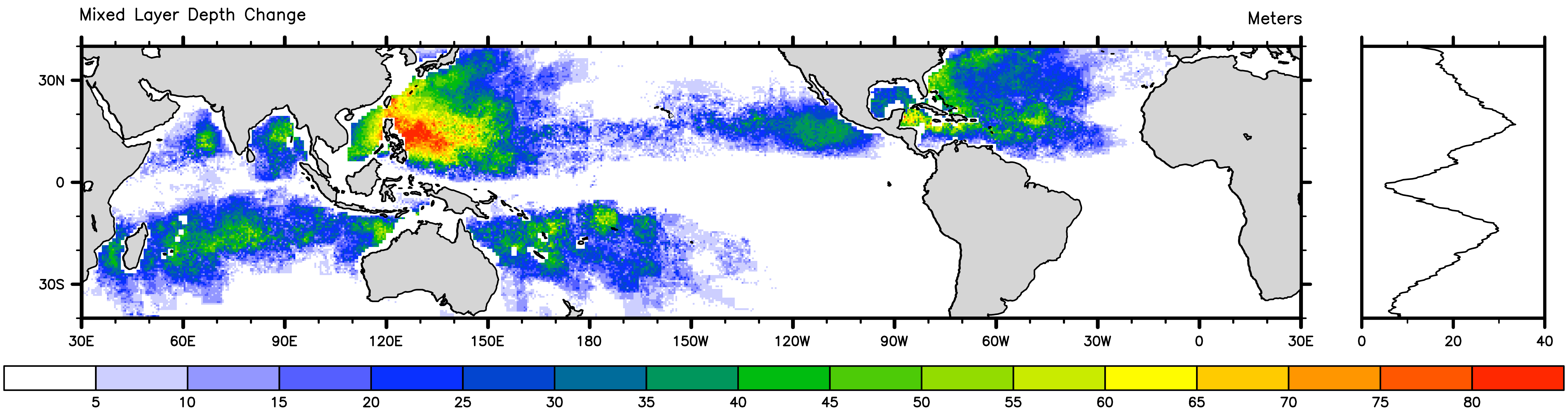
B.

Annualy-averaged Tropical Cyclone Power Dissipation



Tropical cyclone-induced mixed layer depth change

We combine SST anomalies with vertical temperature profiles from the World Ocean Atlas (1998) to determine the depth of mixing (mixed layer depth change)



This calculation assumes the strongest cooling event is only event to affect region annually.

- TCs strongly cool the upper ocean and pump heat downwards through the base of the mixed layer.

Quantifying OHC anomalies:

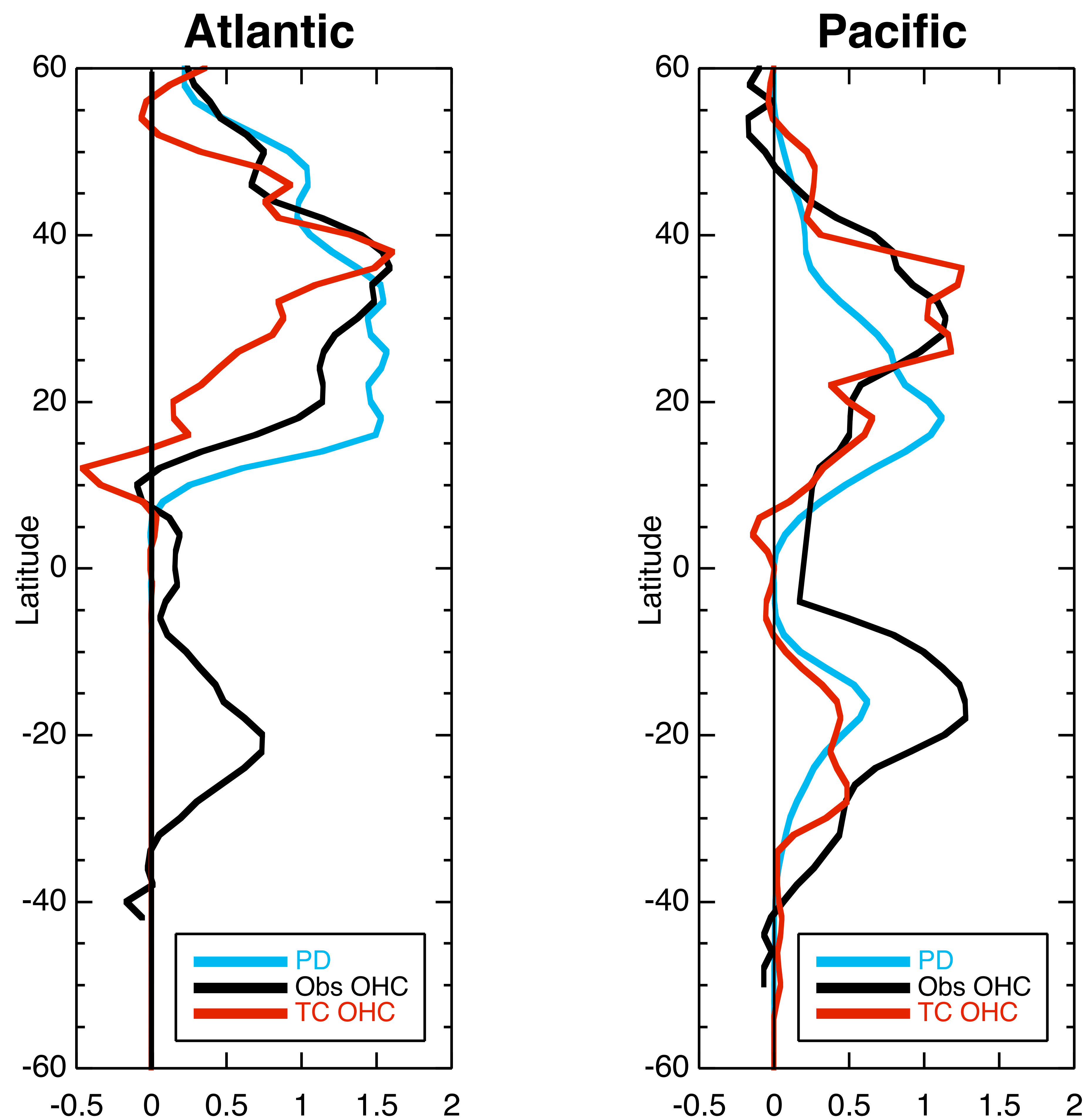
$$Q = \int \int \rho_0 C_l \Delta T dA\, dz$$

ρ_0 - density of sea water
C_l - heat capacity of sea water
ΔT - SST anomaly
dA - surface area
- depth of temperature anomaly
dz - mixed layer depth change

- TC-induced anomalous ocean heat content: ~ 10^22 Joules
- May account for 1/3 of peak poleward ocean heat flux

  ~ nearly twice as much as previous estimates using reanalysis

Observed Upper Ocean Heat Content Anomalies



Sriver and Huber, 2007

Zonally averaged, normalized OHC anomalies and PD averaged from 1994-2001

Blue Line - Globally integrated TC Power Dissipation (PD)
Red Line - TC-induced ocean heat anomalies from SST anomalies
Black Line - Observed OHC anomalies within upper 400 meters (from Scripps)

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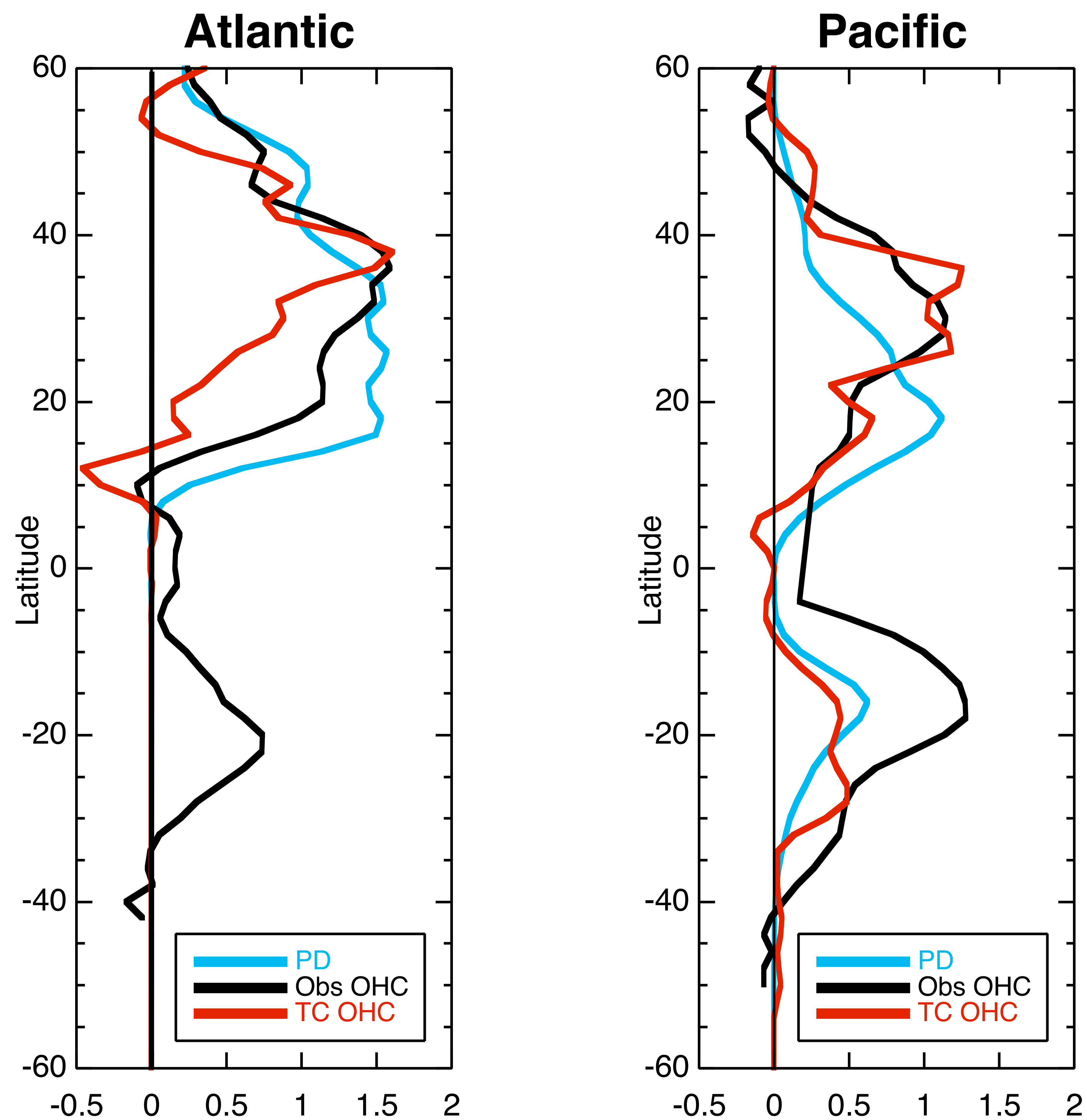

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OHC anomalies associated with global warming occur at the same latitudes as TC events.

- causally related?

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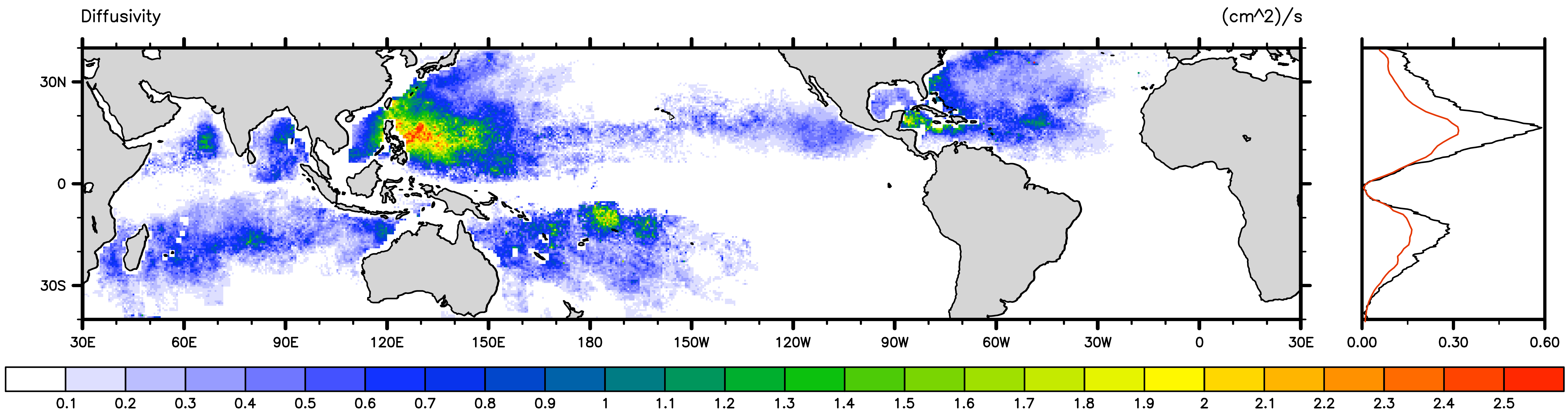
Representation of TC-mixing as vertical diffusivity

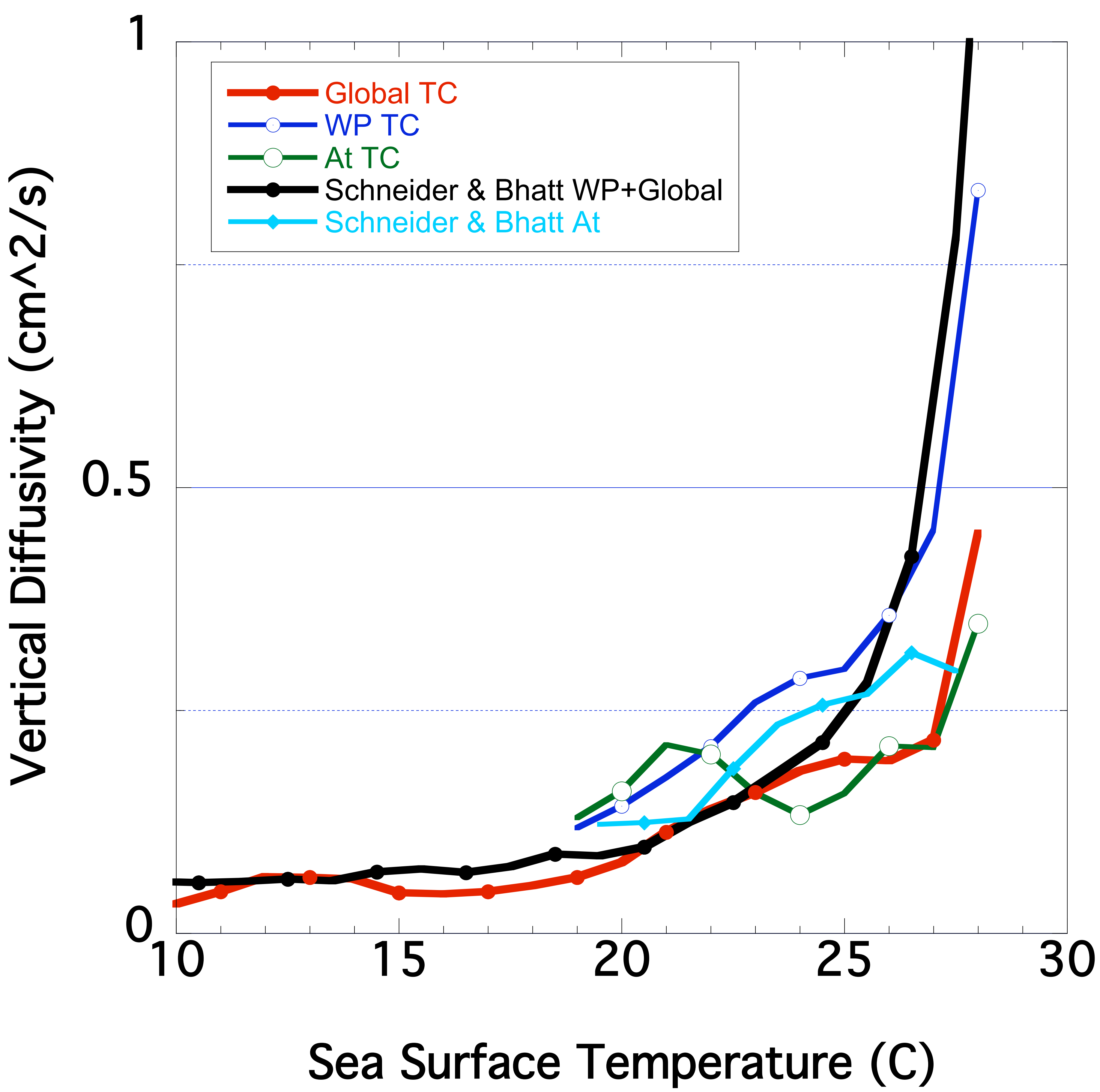
Combine anomalous SST with mixed layer depth change to estimate tropical cyclone ocean mixing



Diffusivity from TC-mixing is spatially variable and comparable to background values used in climate simulations.

- TCs may be responsible for majority of tropical mixing currently missing in ocean models.

Vertical Diffusivity and SST



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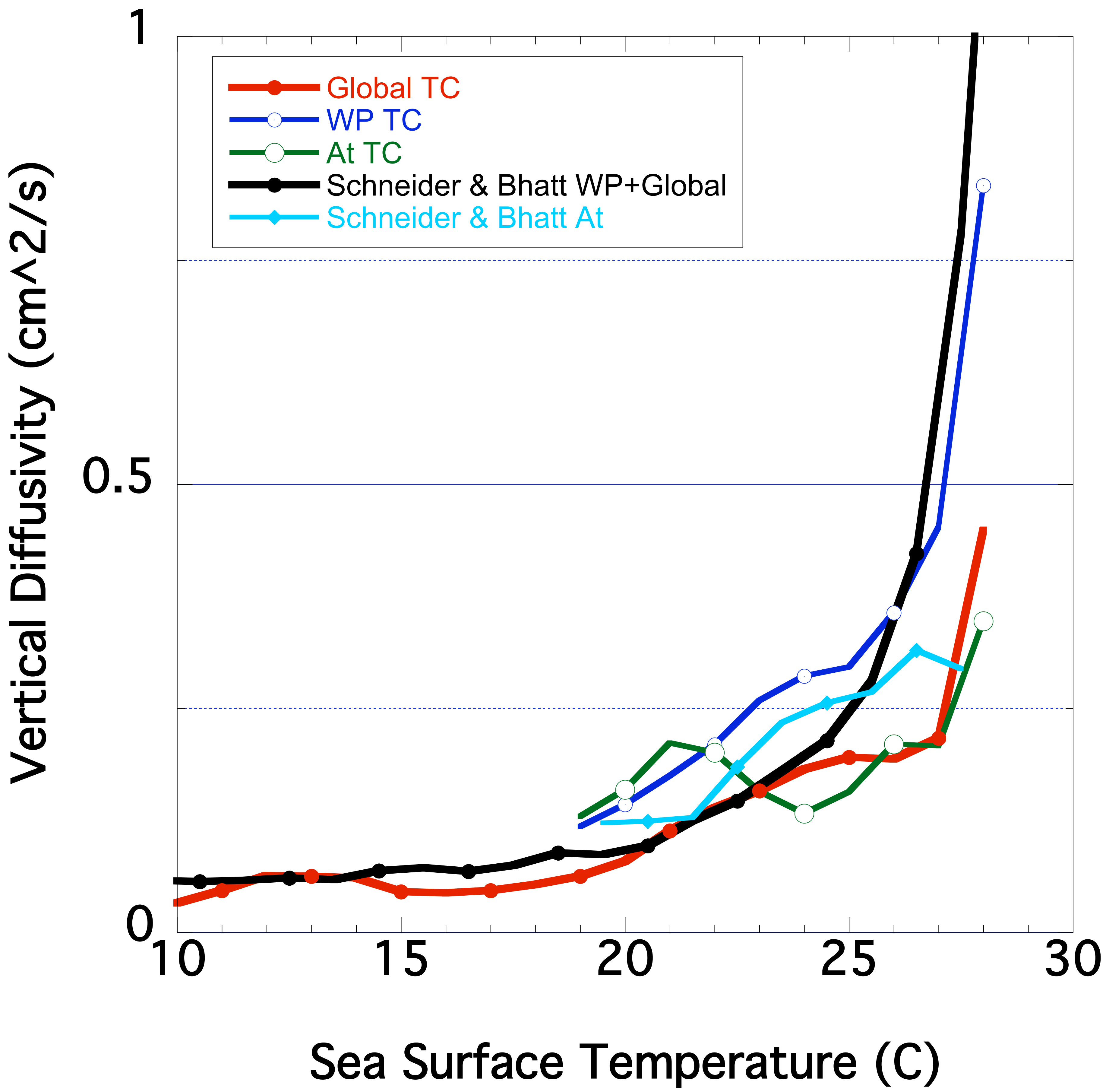


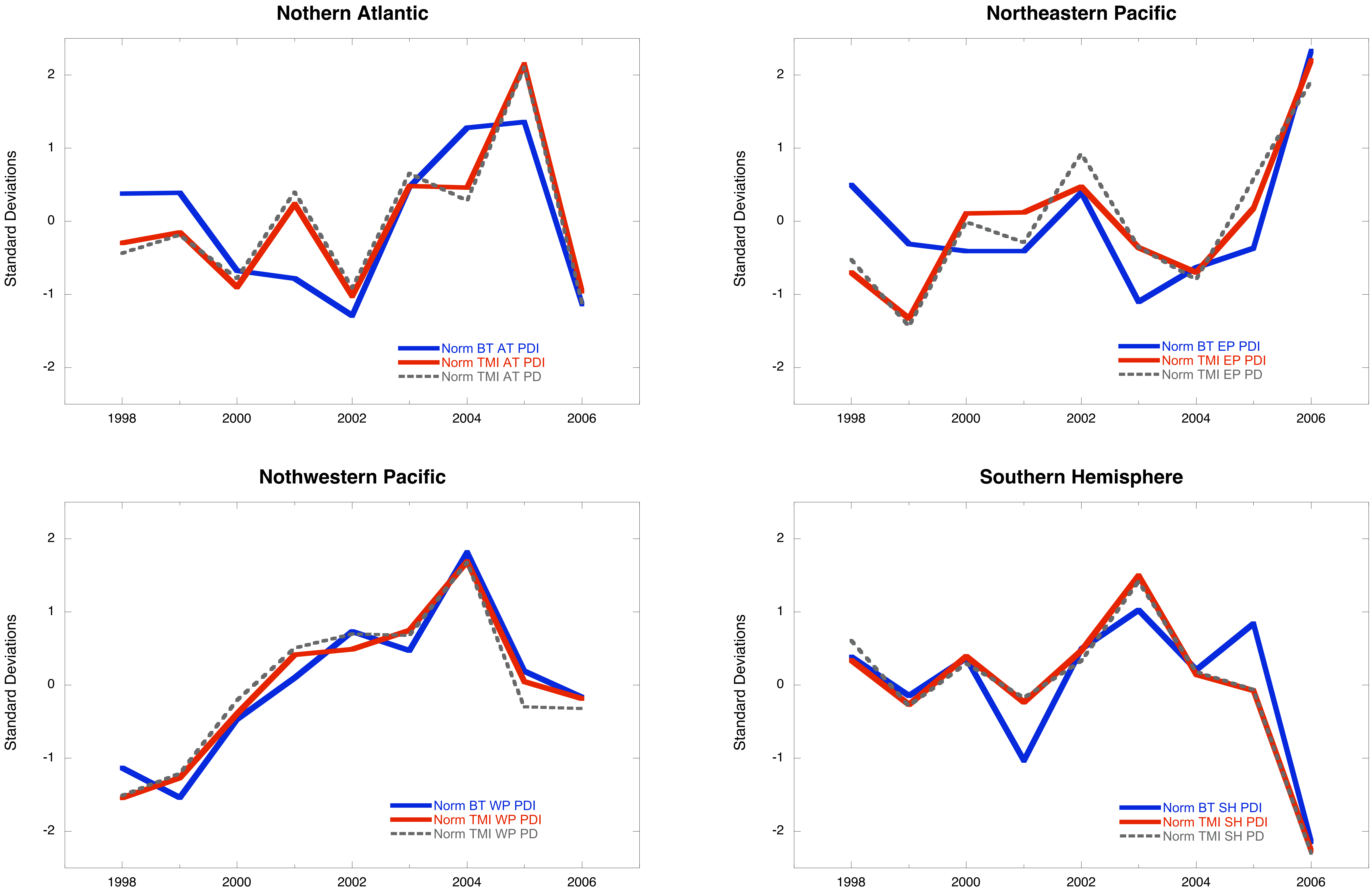
Sriver and Huber, 2007

- Agreement suggests all upper ocean vertical mixing in the tropics is due to TCs.
- In each location, all annual mixing in upper tropical oceans occurs during 1-2 TC events.

- Vertical diffusivity is enhanced under regions with strong TCs.
  - areas of warmest SST

- TC activity provides a physical mechanism for strong positive relationship between vertical diffusivity and SST.

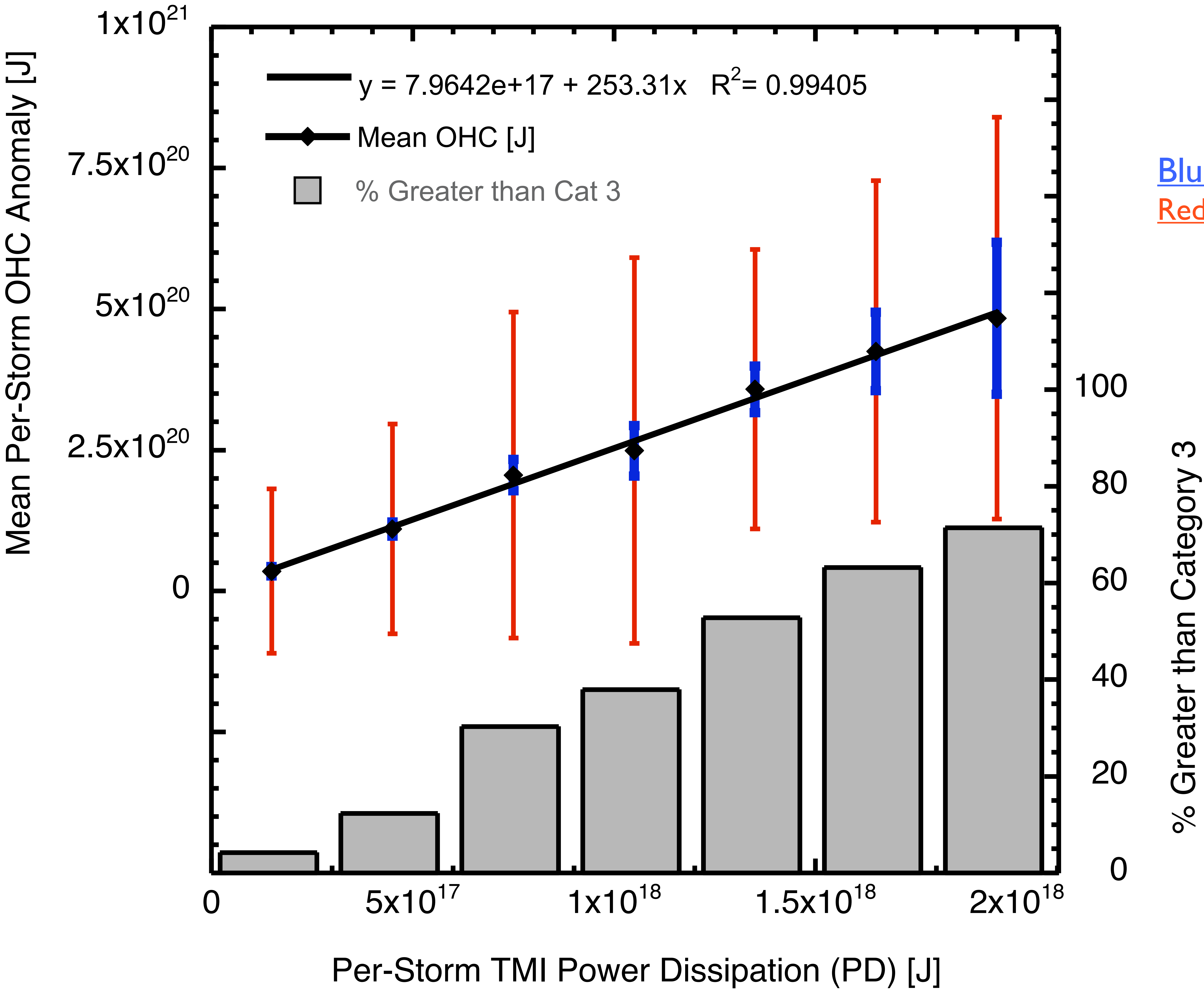
TMI estimation of integrated cyclone intensity



TMI closely reproduces observed trends in integrated cyclone intensity

- Provides high resolution wind field rather than maximum sustained wind

Per-storm anomalous ocean heat content versus power dissipation



Blue Line - Standard error
Red Line - Standard deviation

Conclusions

Our results show positive correlation between the quantities: SST, vertical diffusivity, PD and anomalous OHC,

- supporting Emanuel's 2001 hypothesis that TCs contribute to driving ocean dynamics and regulating the climate system.

TMI provides high-resolution SST and surface winds useful for understanding the effects of tropical cyclones on the upper ocean

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Future Direction

Ultra-high resolution climate modeling is becoming capable of simulating tropical cyclone events.

- Coupling of atmosphere-ocean models: Correct representation of cyclone effects on ocean is critical for exposing possible feedbacks.

- Creation of TMI-derived model diagnostics for tropical cyclones
  - anomalous SST, mixed layer depth change, diffusivity, etc.

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