# Role of equatorial ocean dynamics for sea surface temperature variability in the eastern equatorial Atlantic and its relation to the West African monsoon

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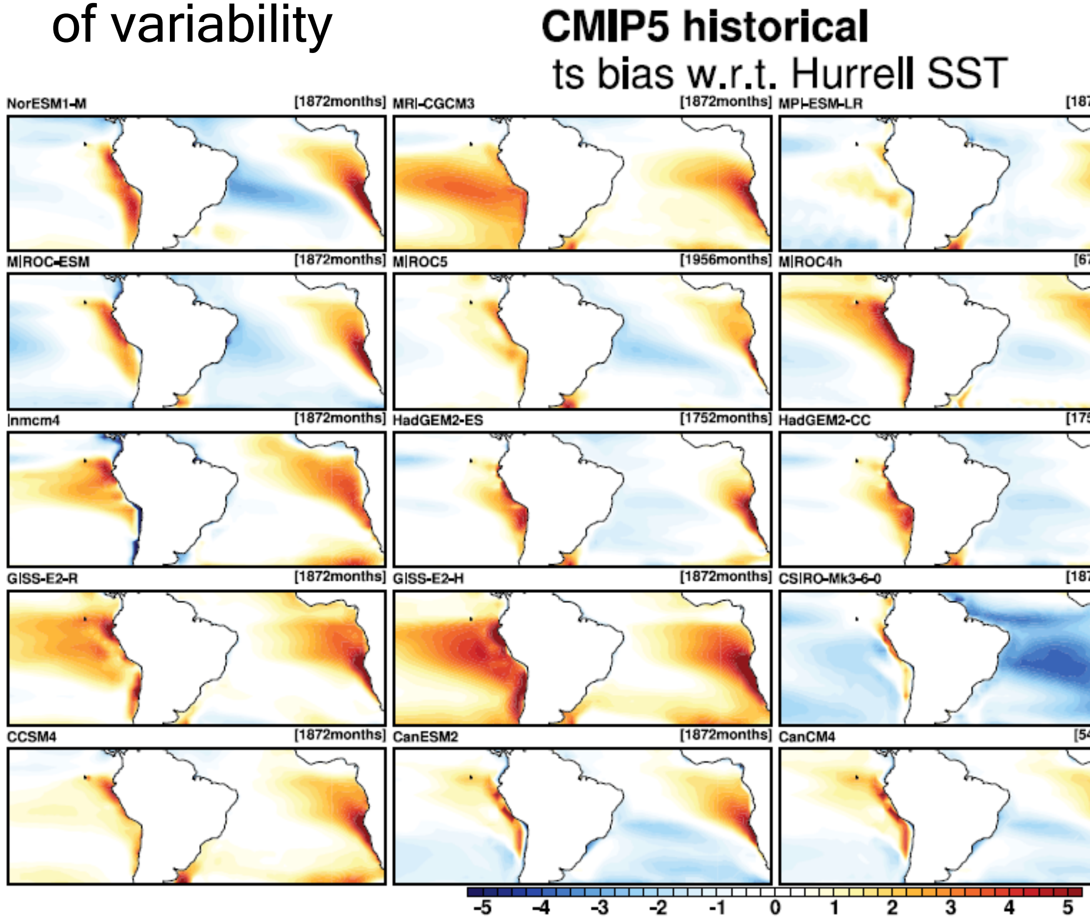
# Tropical Atlantic Bias

- Strong SST bias still present in recent CMIP5 simulations (no improvement in the eastern tropical Atlantic)
- Bias significantly alter climate feedbacks and inhibit realistic simulation of variability



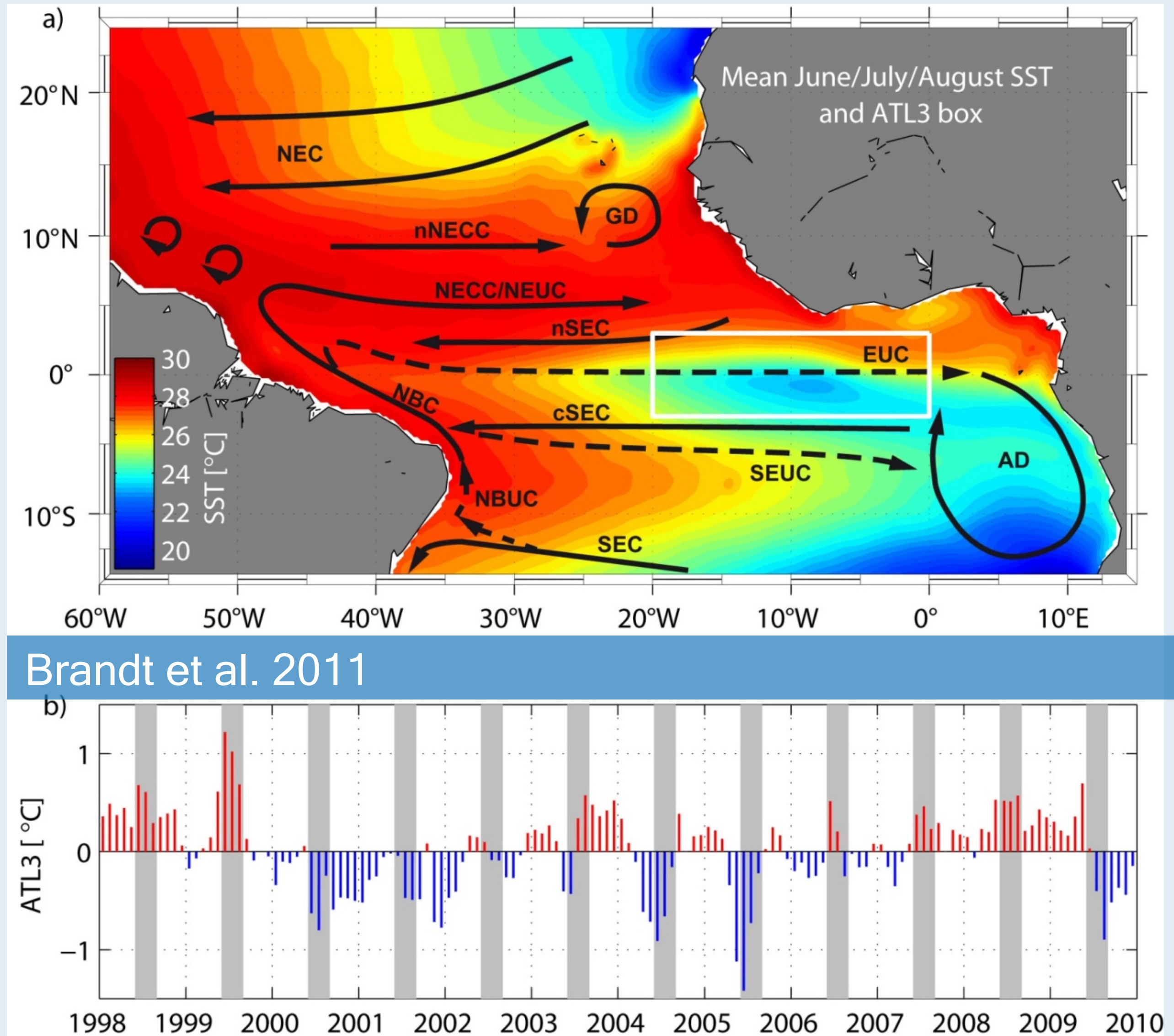

Medeiros, UCAR (pers. com.)

# Tropical Atlantic Climate Experiment in 2006

- A focused observational and modeling effort in the tropical Atlantic to advance the predictability of climate variability in the surrounding region and to provide a basis for assessment and improvement of coupled models.
- TACE was envisioned as a program of enhanced observations and modeling studies spanning a period of approximately 6 years (2006-2011). The results of TACE were expected to contribute to the design of a sustained observing system for the tropical Atlantic.
- TACE focuses on the eastern equatorial Atlantic as it is badly represented in coupled and uncoupled climate models and is a source of low prediction skill on seasonal to interannual time scales. Presently, it is also a region of very limited sustained observations.

# Equatorial Atlantic Cold Tongue

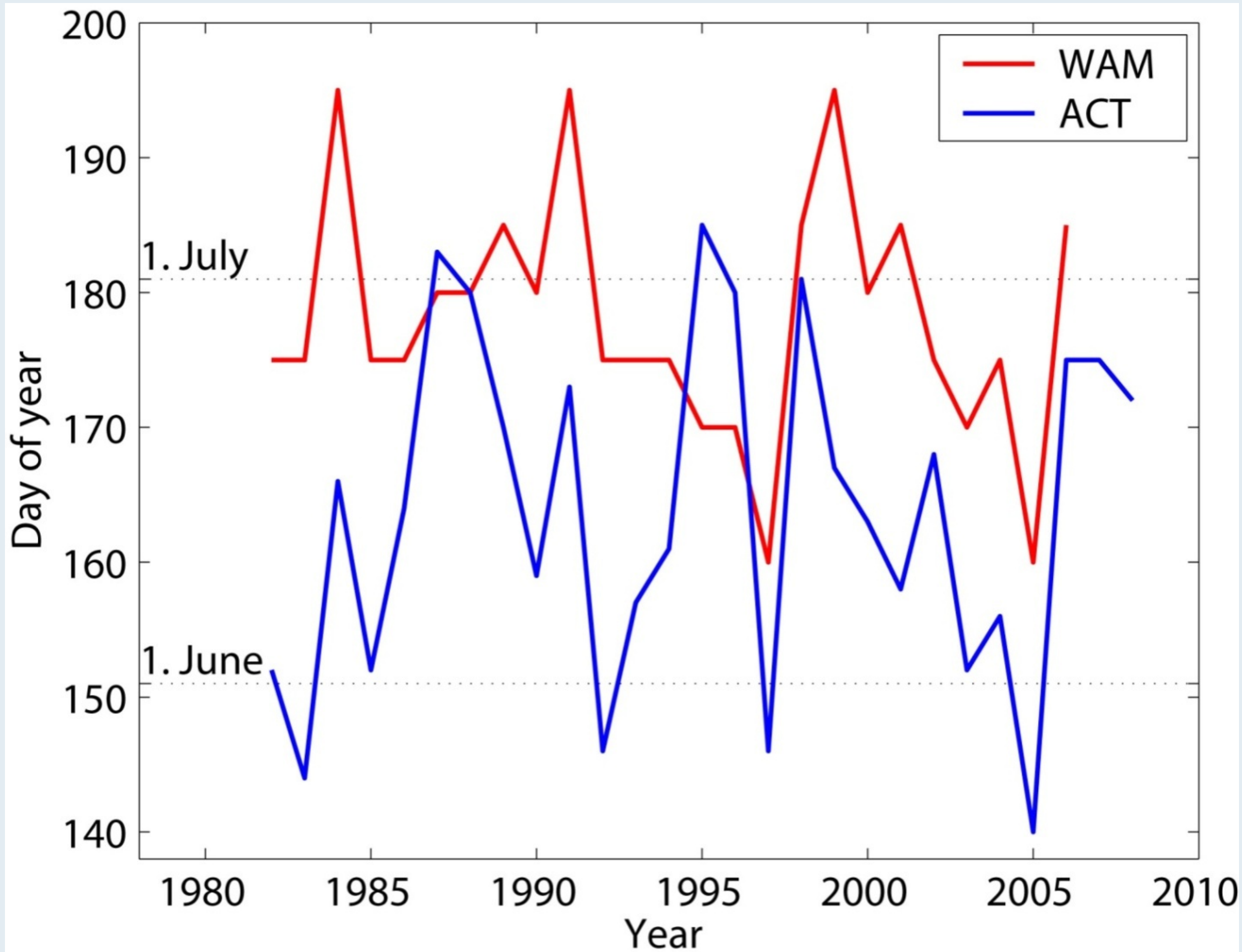
- Cold tongue develops during boreal summer
- Strong interannual variability of ATL3 SST index (3°S-3°N, 20°W-0°)




Brandt et al. 2011

# Onset of Atlantic Cold Tongue and West African Monsoon

- WAM onset follows the ACT onset by some weeks.
- Significant correlation of ACT and WAM onsets




WAM onset – northward migration of rainfall (10°W-10°E.) (*Fontaine and Louvet, 2006*)
ACT onset – surface area (with T<25°C) threshold

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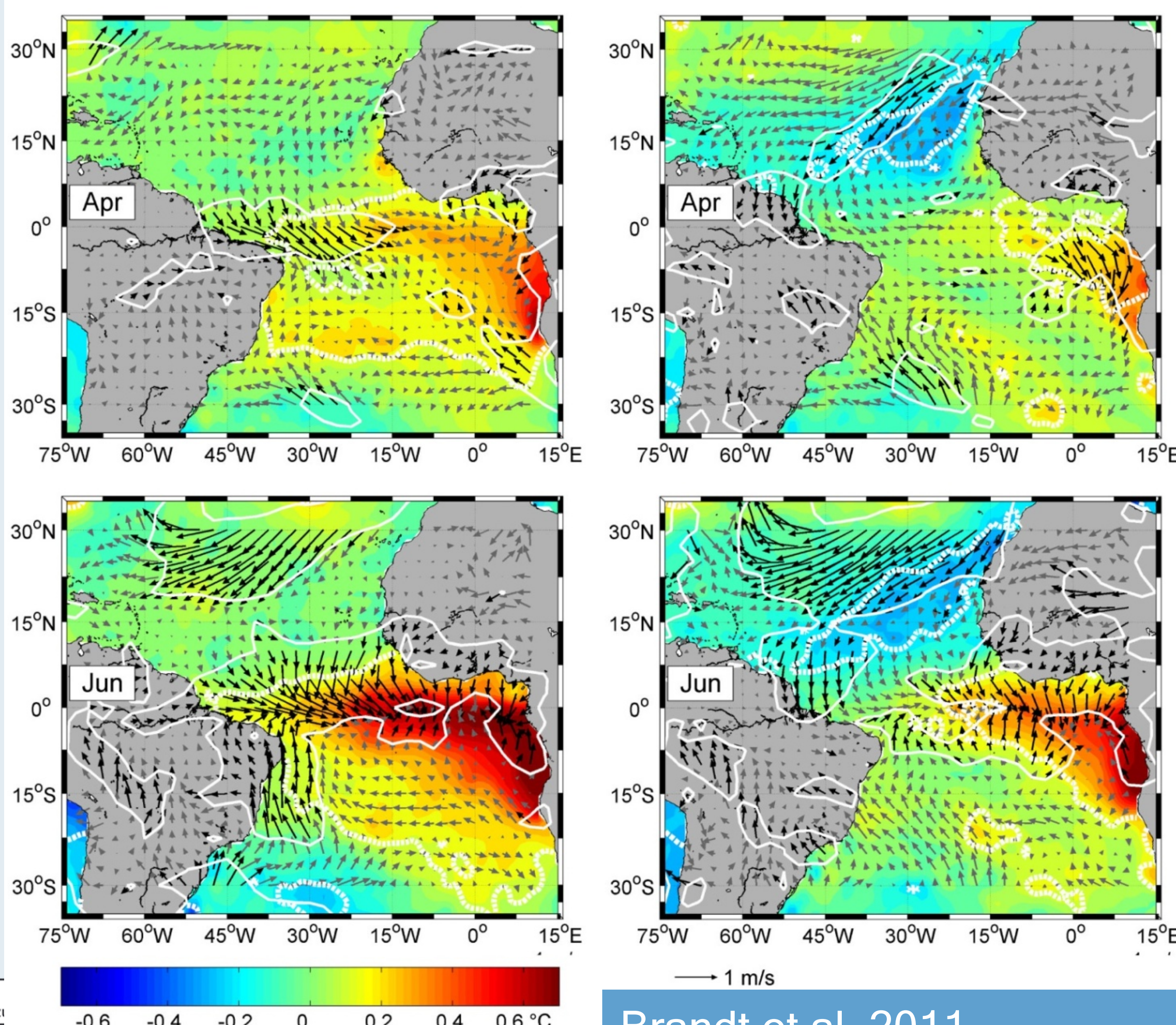
Caniaux et al. 2011, Brandt et al. 2011

# Regression of SST and Wind onto

## ACT Onset

Cold tongue SST; Wind forcing in the western equatorial Atlantic (zonal mode)



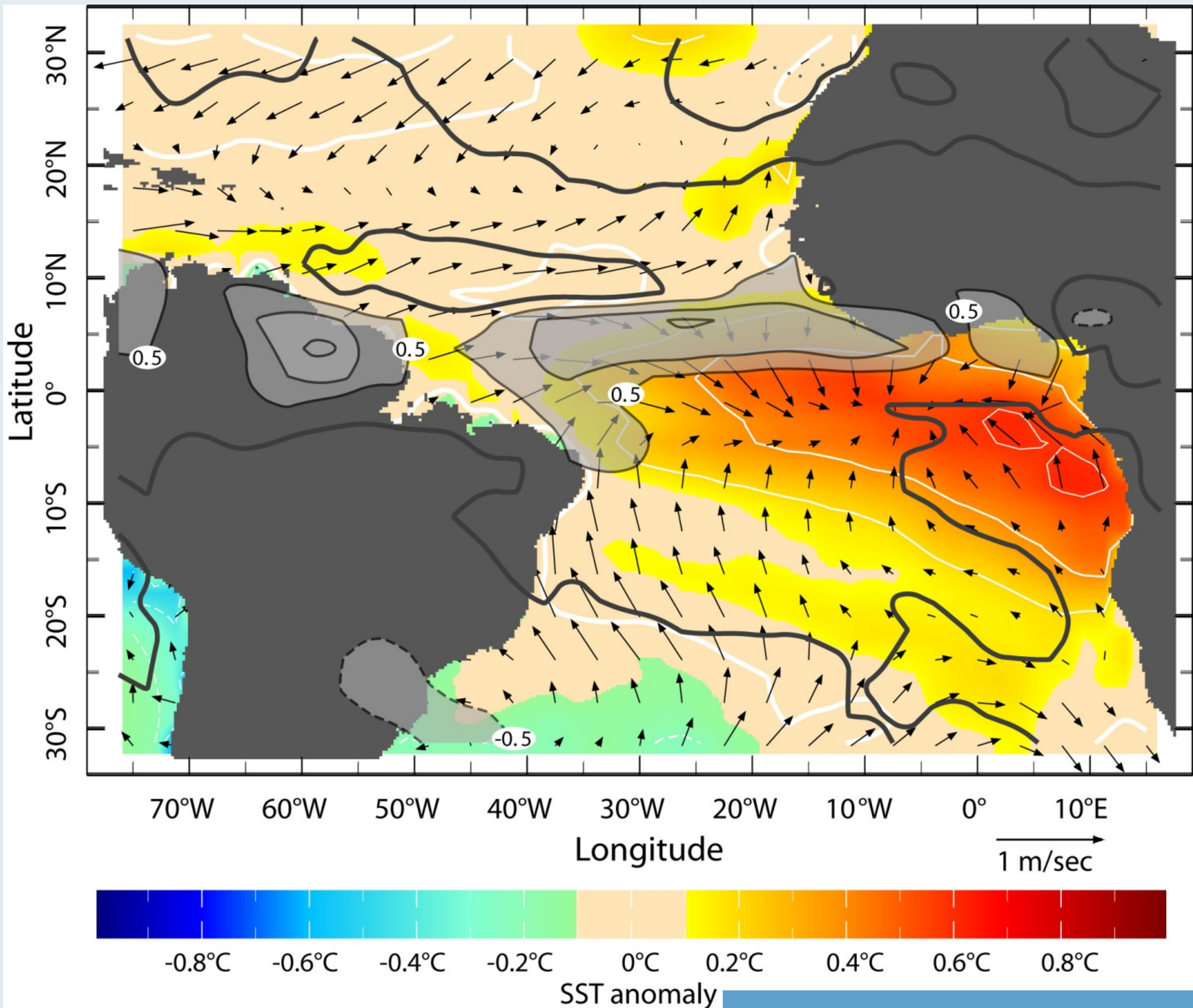

## WAM Onset

Significant correlation with cold tongue SST (zonal mode) and SST in the tropical NE Atlantic (meridional mode)

Brandt et al. 2011

# Zonal Mode (June-August)

- First EOF (33%) of the June-August rainfall from GPCP 1979-2001 (contours in mm/day). June-August SST anomaly (colors, in °C & white contours, every 0.2°) and surface wind anomaly (vector, in m/sec) are determined by regression on the time series of the rainfall EOF




Kushnir et al. 2002

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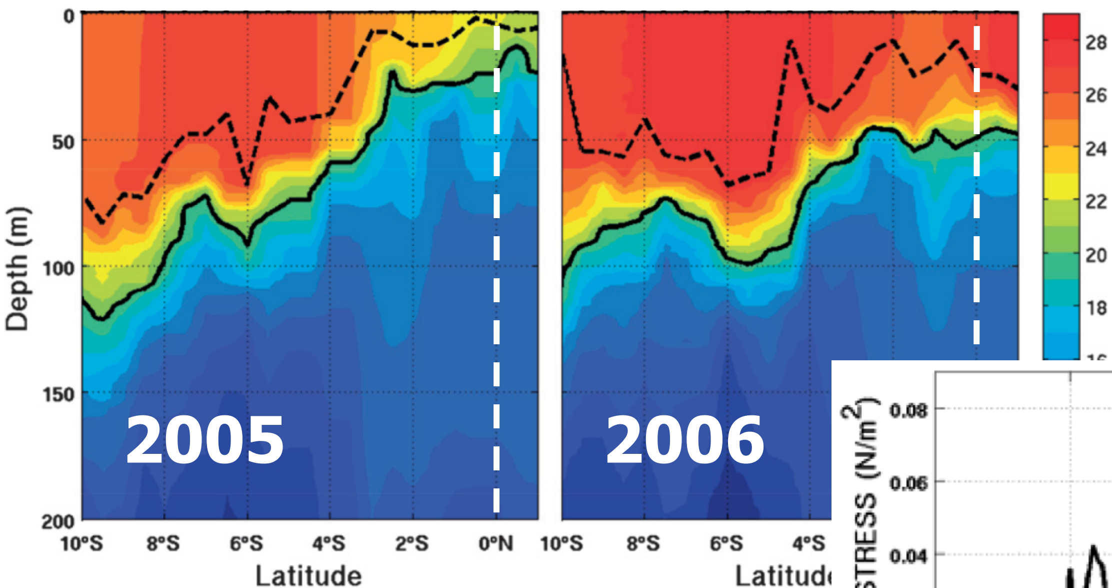
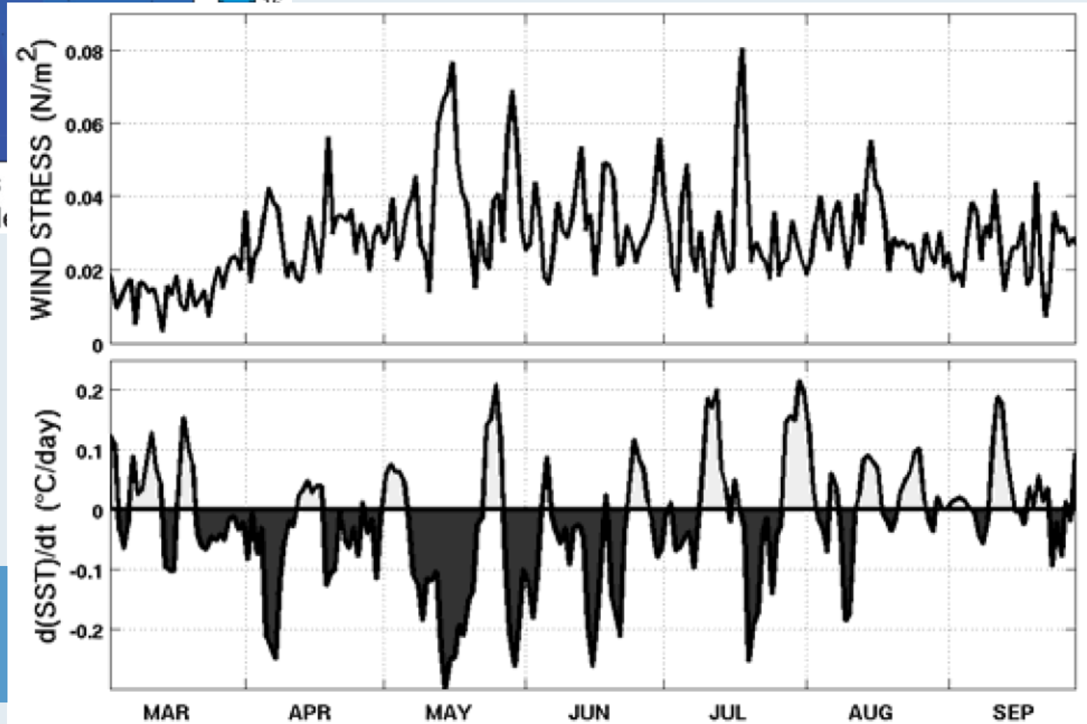
# Cold (warm) event during boreal summer 2005 (2006)

Temperature at 10°W



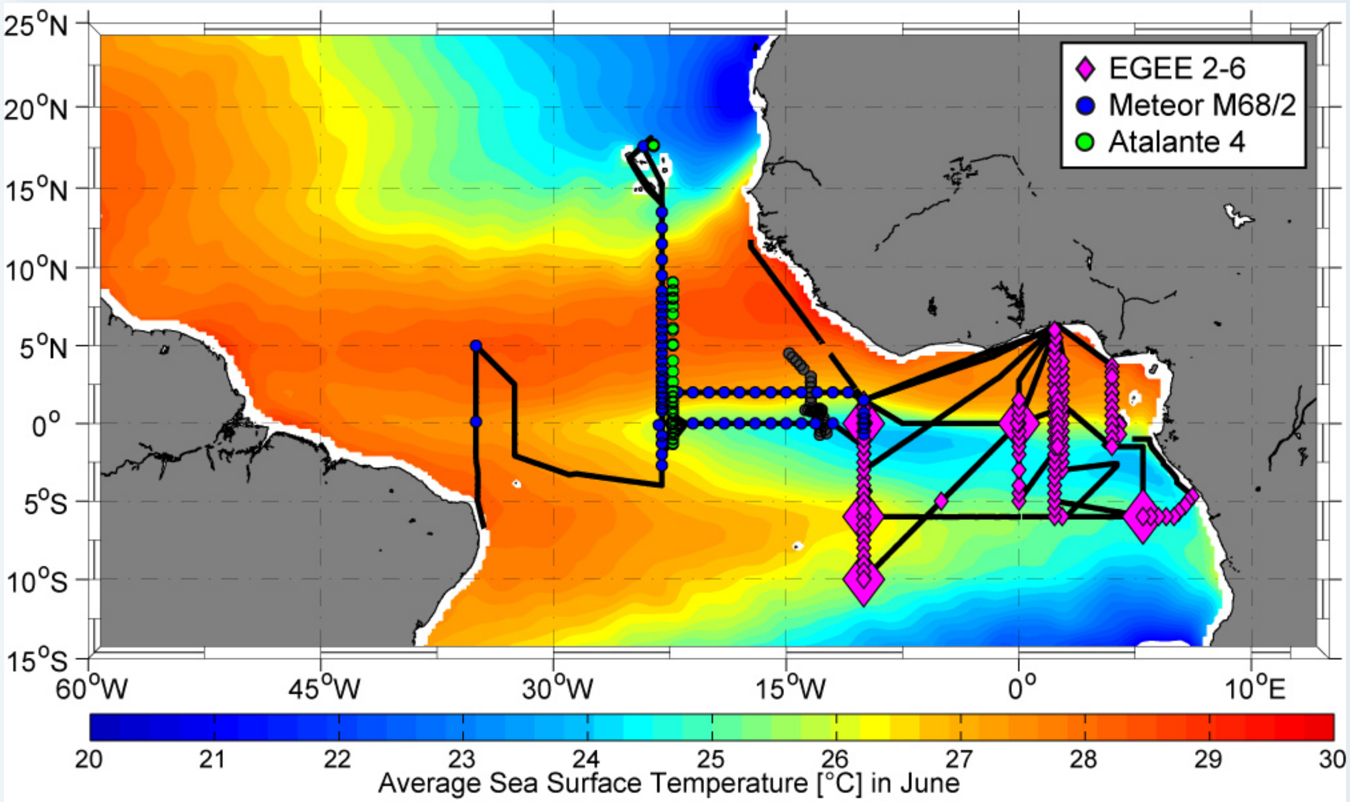

Shallow (deep) equatorial thermocline in June 2005 (2006)
⇒ preconditioning due to wind anomalies prior to the cold tongue season.




Rapid and early intense cooling in 2005 due to intraseasonal intensification of the southeastern trades

Marin et al. 2009
Hormann and Brandt 2009

# Upper Ocean Microstructure Observations




- Station with 3 to 20 repeated casts
- Stations occupied for 24 hours or longer

Microstructure measurements were performed on 8 cruises (2005-2009) to the central and eastern equatorial Atlantic:

3 cruises in early summer (May/June)

2 cruises in early autumn (September)

3 cruises when the cold tongue is absent (2 in November, WHOI cruise in December)

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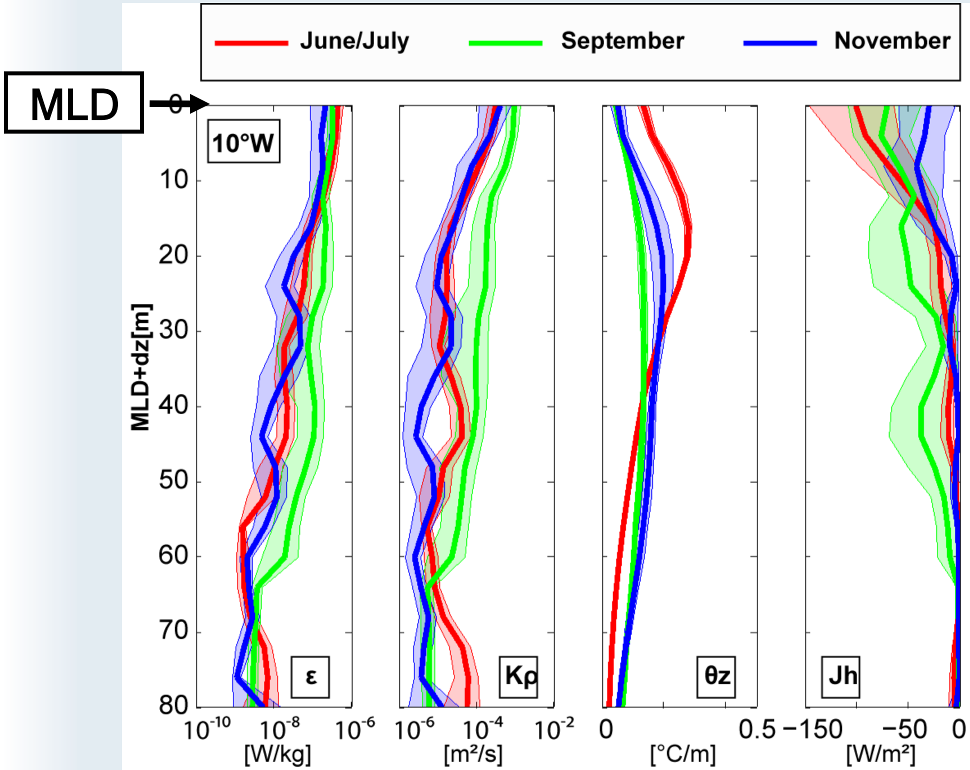
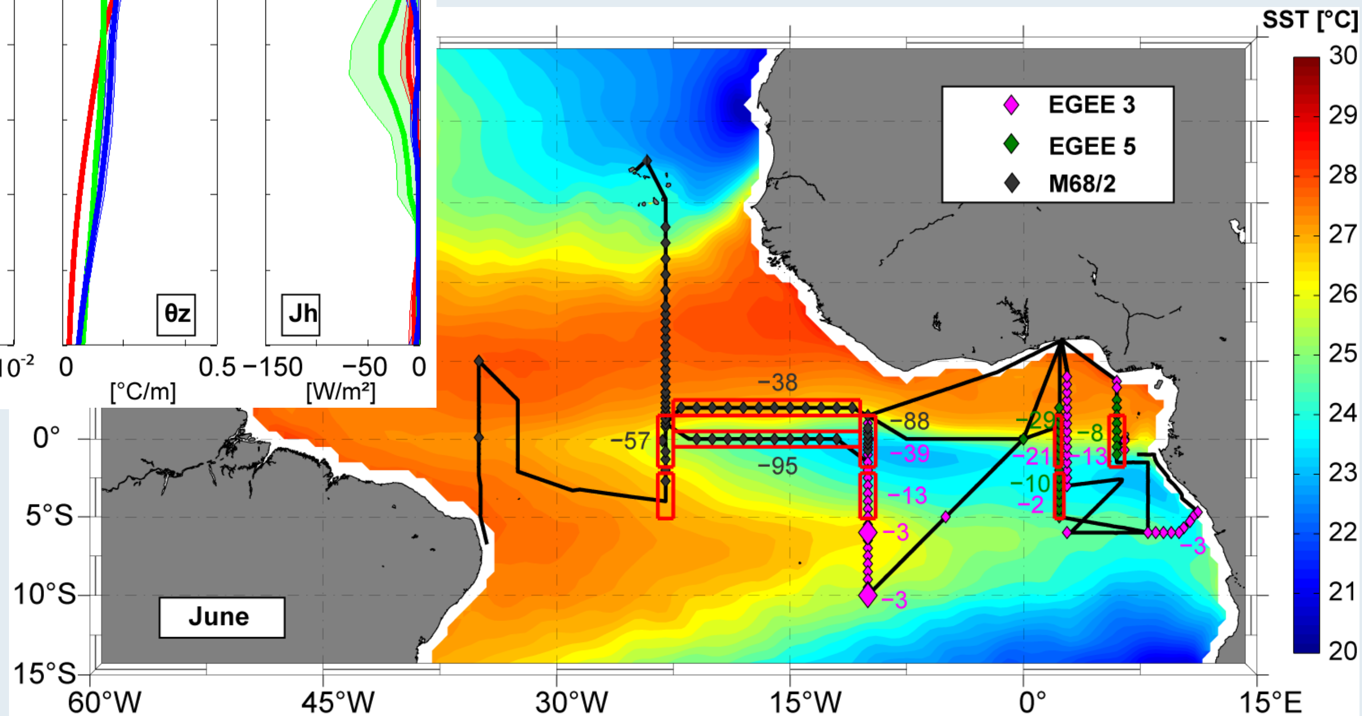
# Diapycnal Mixing and Heat Fluxes Below the Mixed Layer



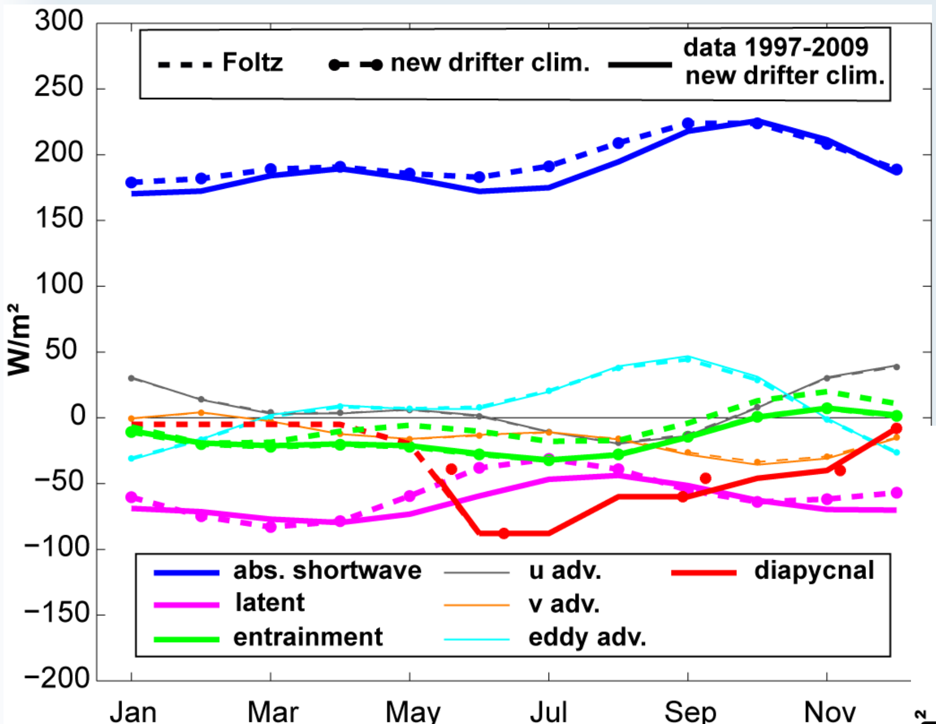

Elevated mixing below the mixed layer was found from May throughout November at 10°W. Diapycnal heat flux peaks during early summer due to the presents of strong temperature gradients below the mixed layer.

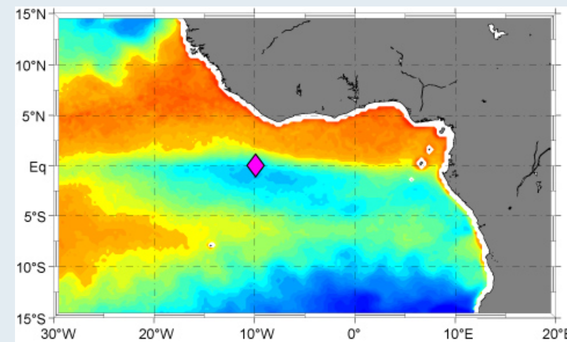


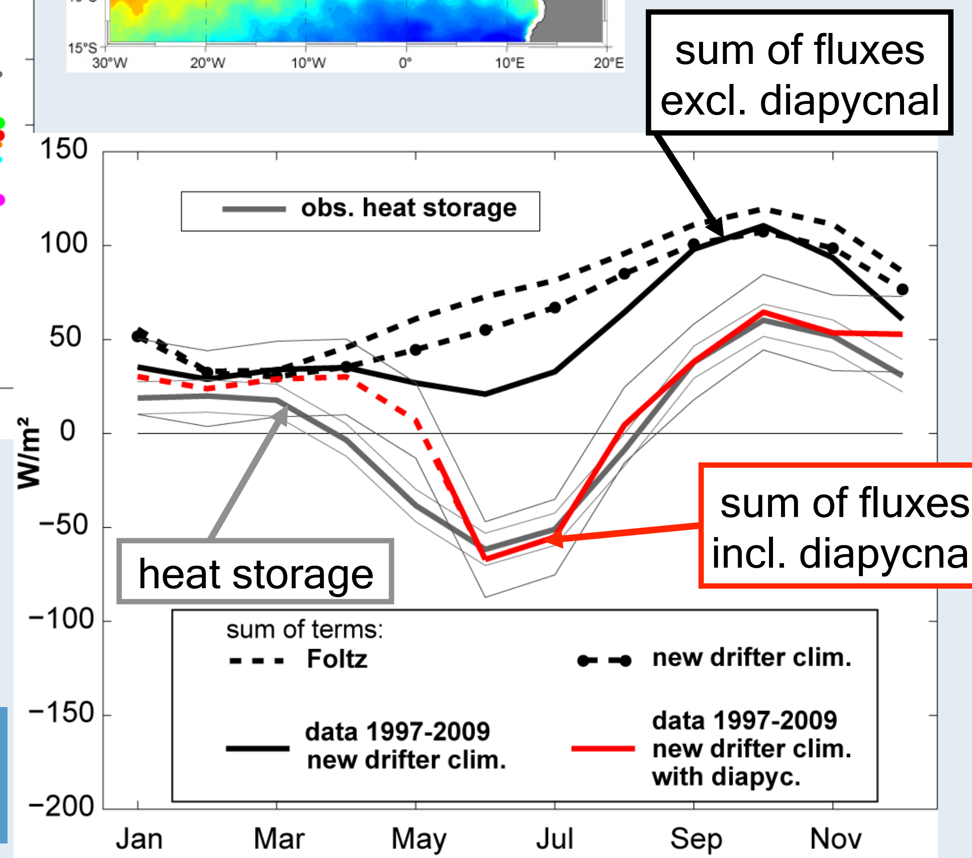

Diapycnal heat fluxes are particularly pronounced in the center and western part of the cold tongue.

Hummels et al. 2012, submitted

# Annual Cycle of Mixed Layer Heat Budget at 10°W



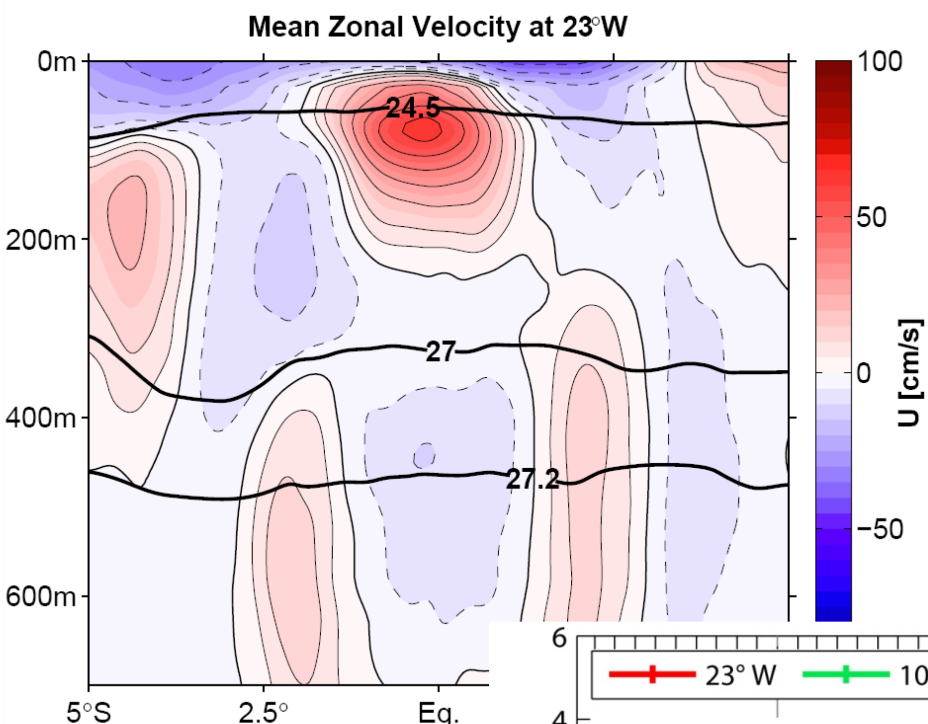



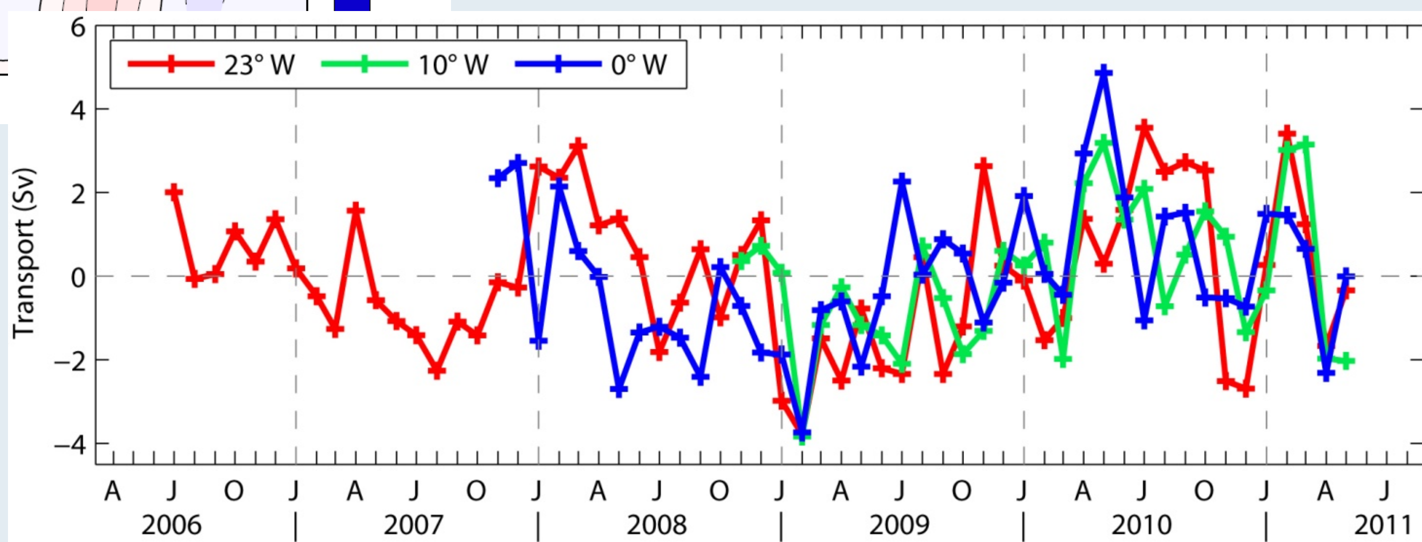

Diapycnal heat fluxes dominantly contribute to heat loss of the mixed layer from boreal summer throughout late autumn.

Foltz et al. 2003 (without diapycnal flux)
Hummels et al. 2012, submitted

# Mean Zonal Velocity along 23°W and Equatorial Time Series




- EUC supplies the equatorial upwelling
- EUC Transport time series at different longitudes during TACE (in cooperation with Bill Johns, RSMAS, Miami, US)



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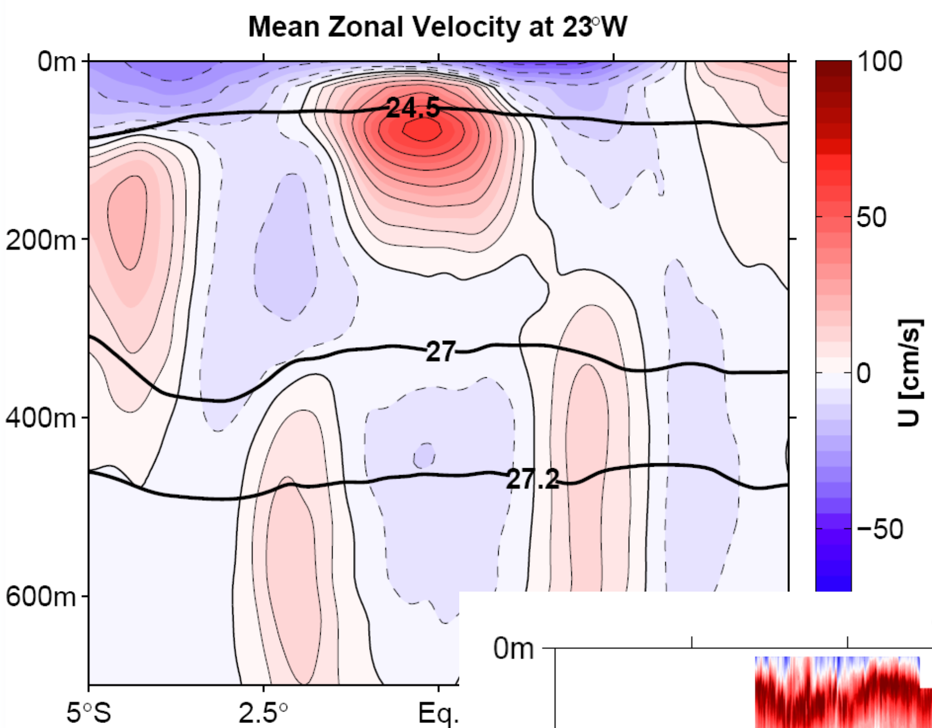
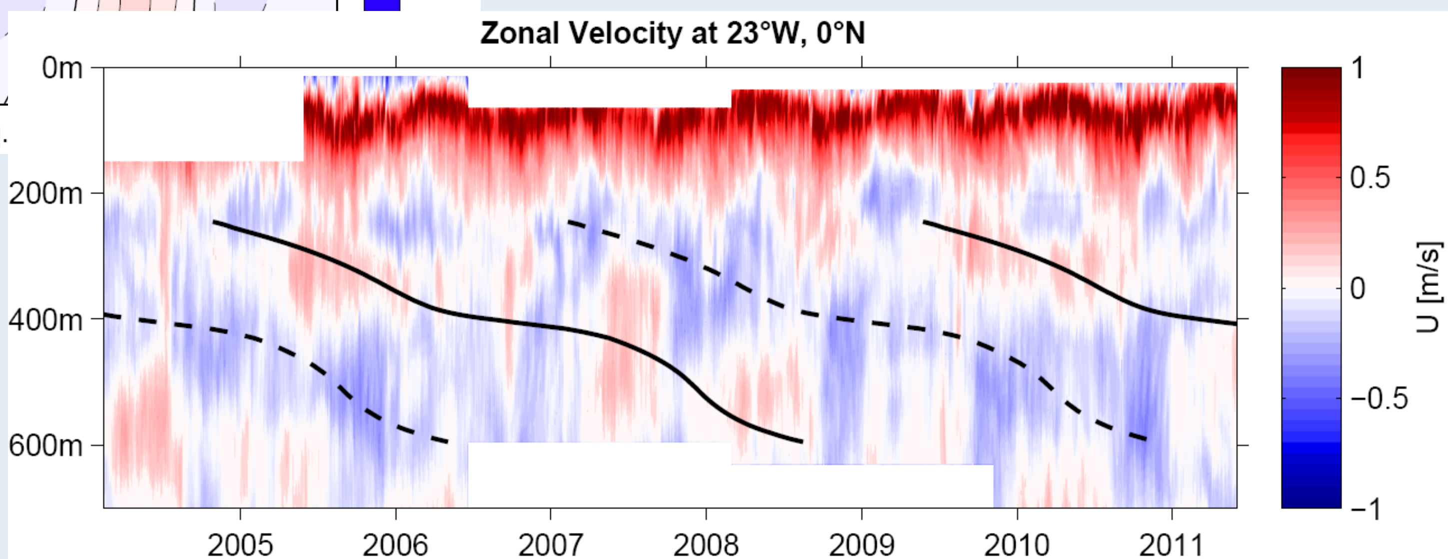



- Equatorial Deep Jets are a dominant flow feature below the Equatorial Undercurrent and oscillate with a period of about 4.5 years
- Downward phase and upward energy propagation





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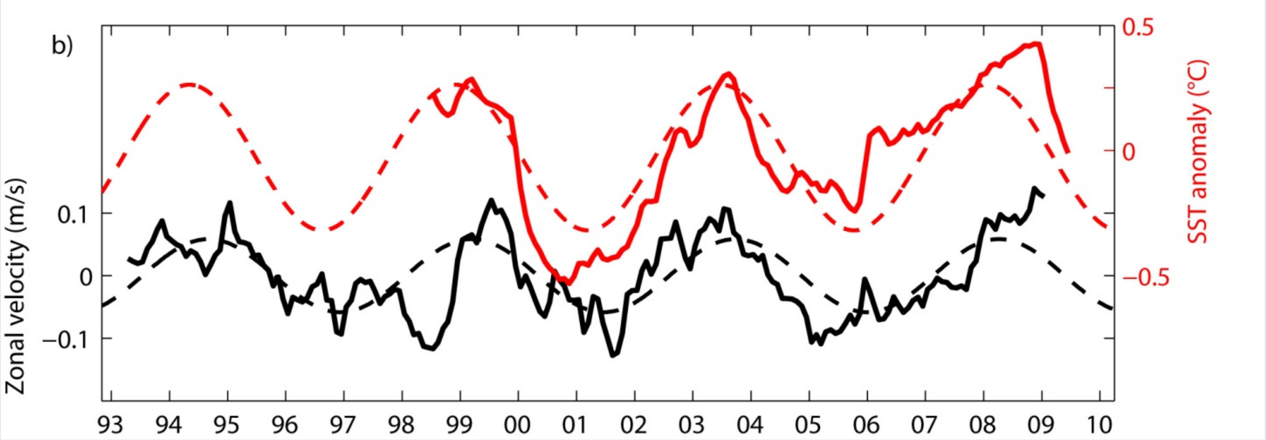
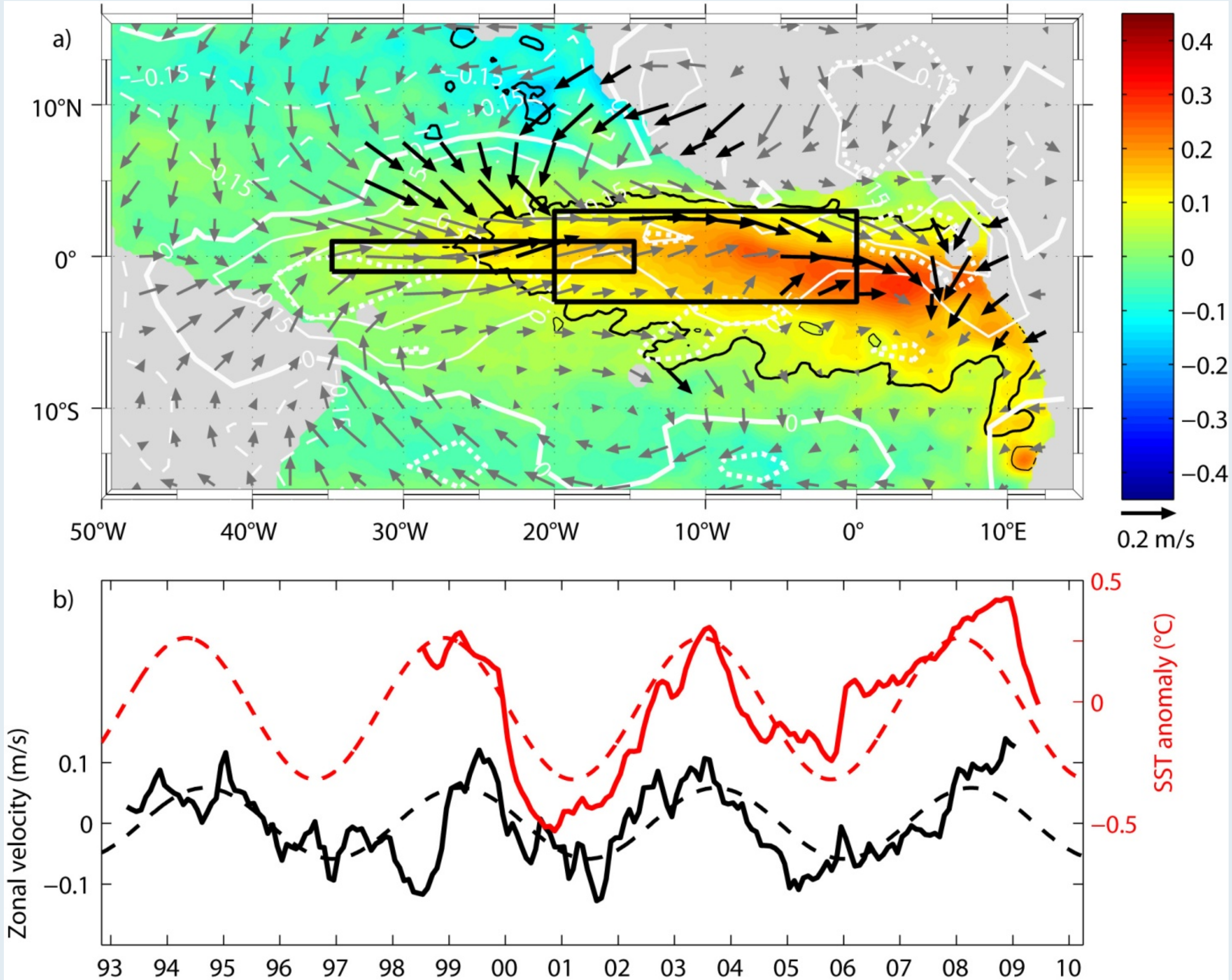
# Surface Geostrophic Velocity

- 4.5-year cycle of the geostrophic equatorial zonal surface velocity (from sea level anomalies 15°W-35°W)
- Corresponding signal of the ATL3 SST index (3°S-3°N, 20°W-0°)
- Eastward surface flow anomaly corresponds to warm eastern equatorial Atlantic.



# Surface Geostrophic Velocity

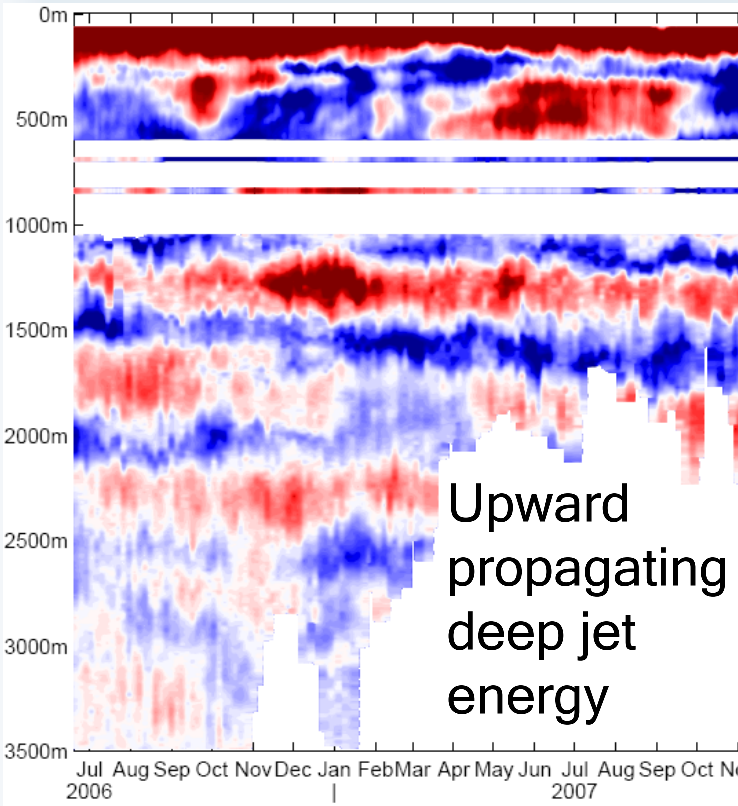
- Regression of SST (color), wind (arrows), and rainfall (contours) onto 4.5-year harmonic fit: convergent wind field and enhanced rainfall.



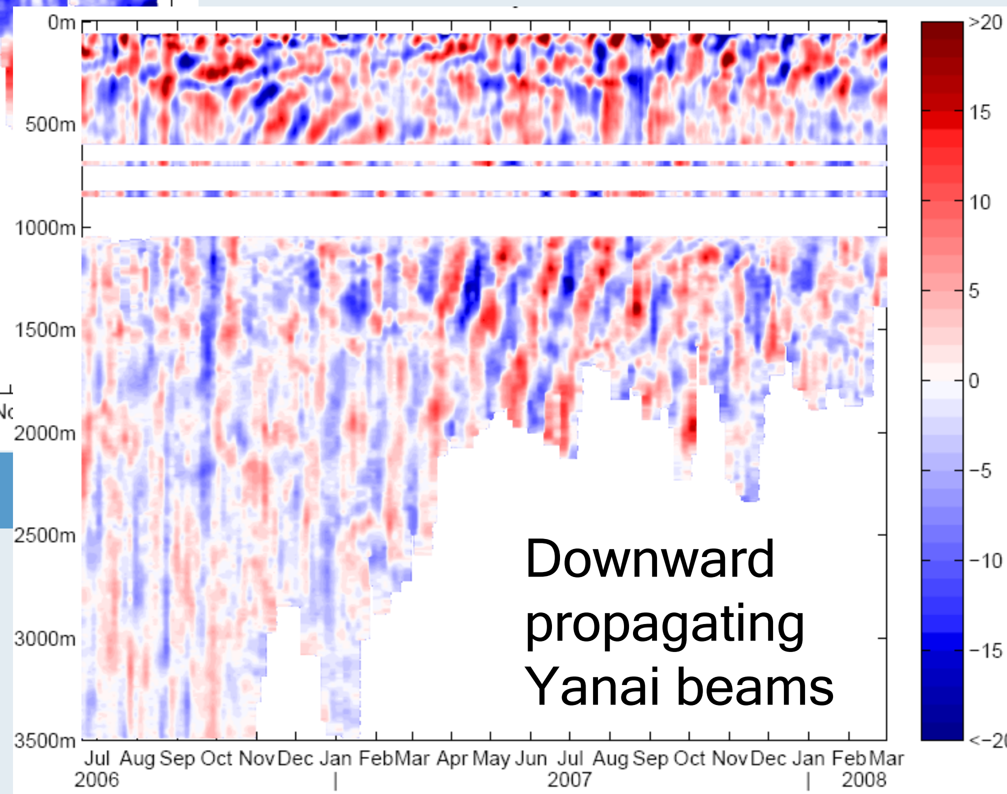

Brandt et al. 2011

# Moored Velocity Observations at the Equator, 23°W

Zonal (left) and meridional (right) velocity measured at 23°W, 0°N with ADCP and moored profiler




Brandt et al. 2011

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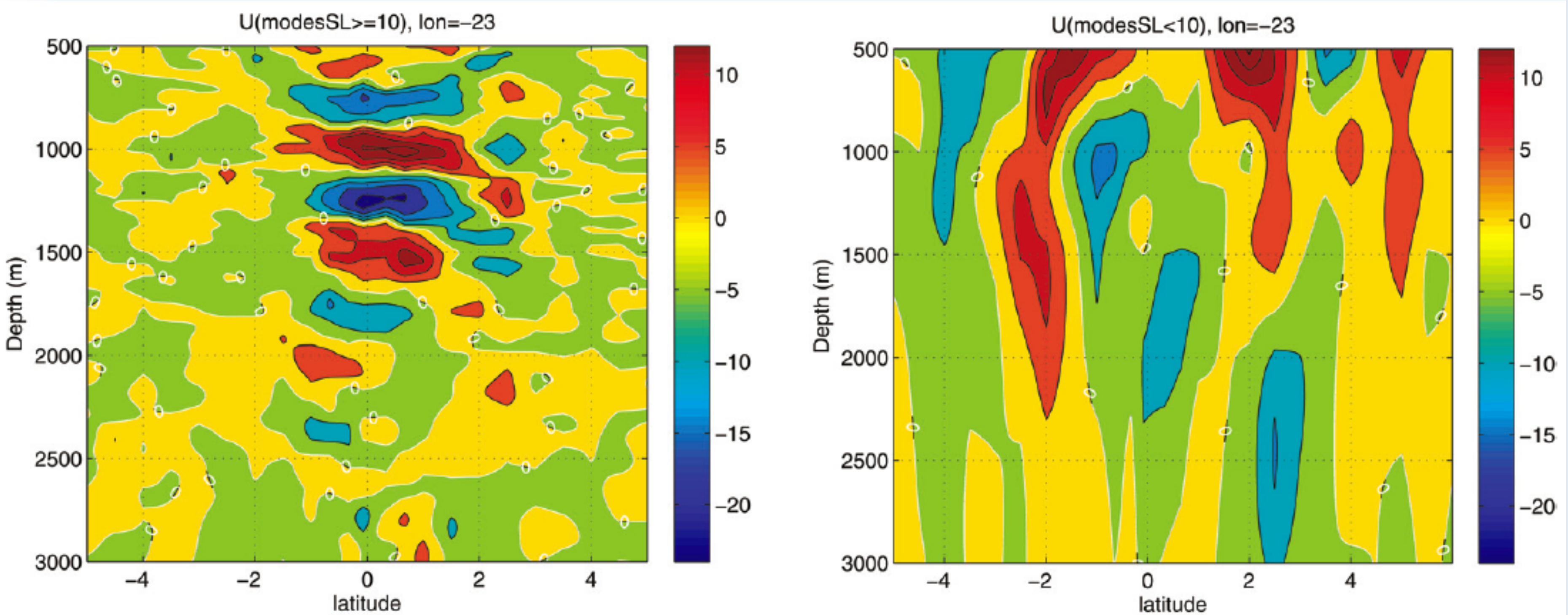
# Idealized Simulations of EDJs

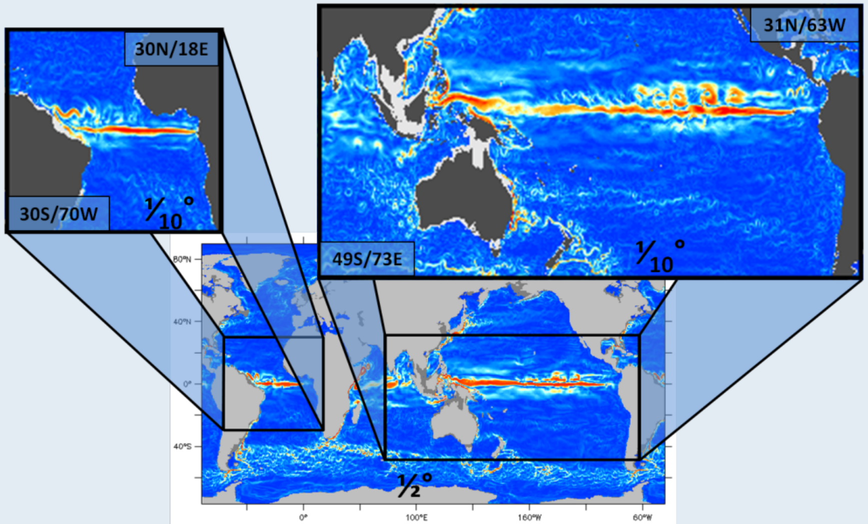
- Idealized model (1/4°, 100 levels) forced by oscillations at the western boundary producing Rossby-gravity waves
- Both, EDJ and extra-equatorial jets (EEJ) are generated in this simulation; EDJ perform basin mode oscillations

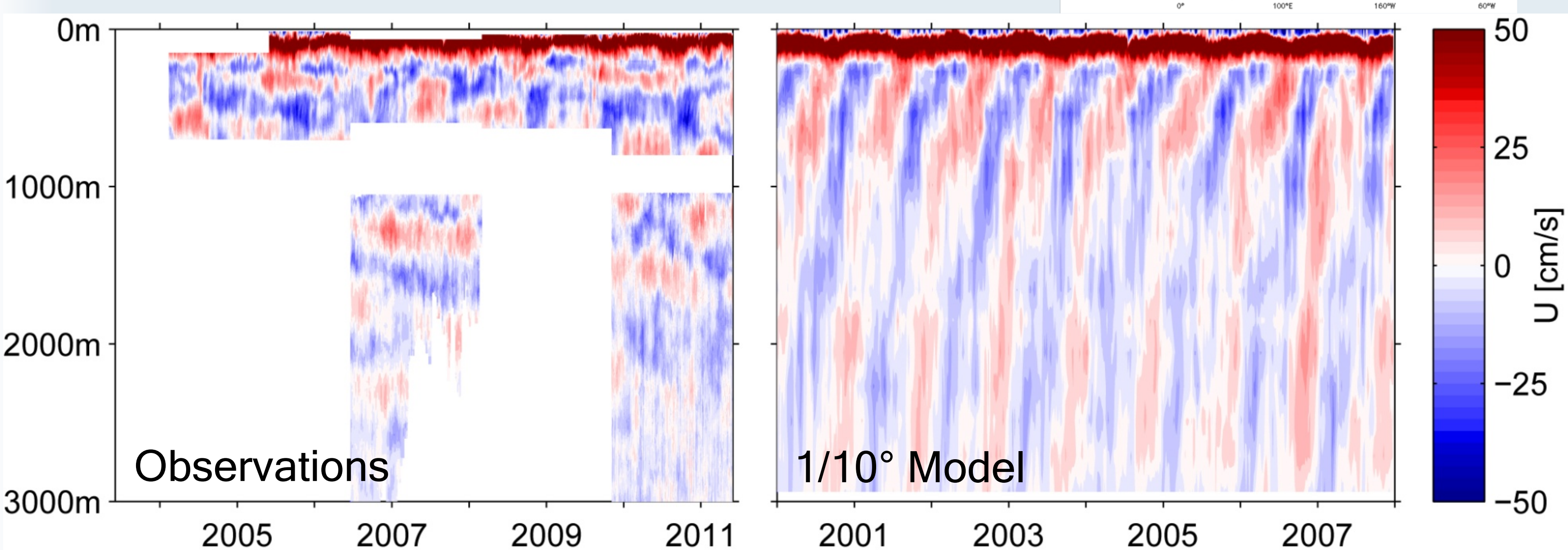



Ménesguen et al. 2009

# Observations versus Model

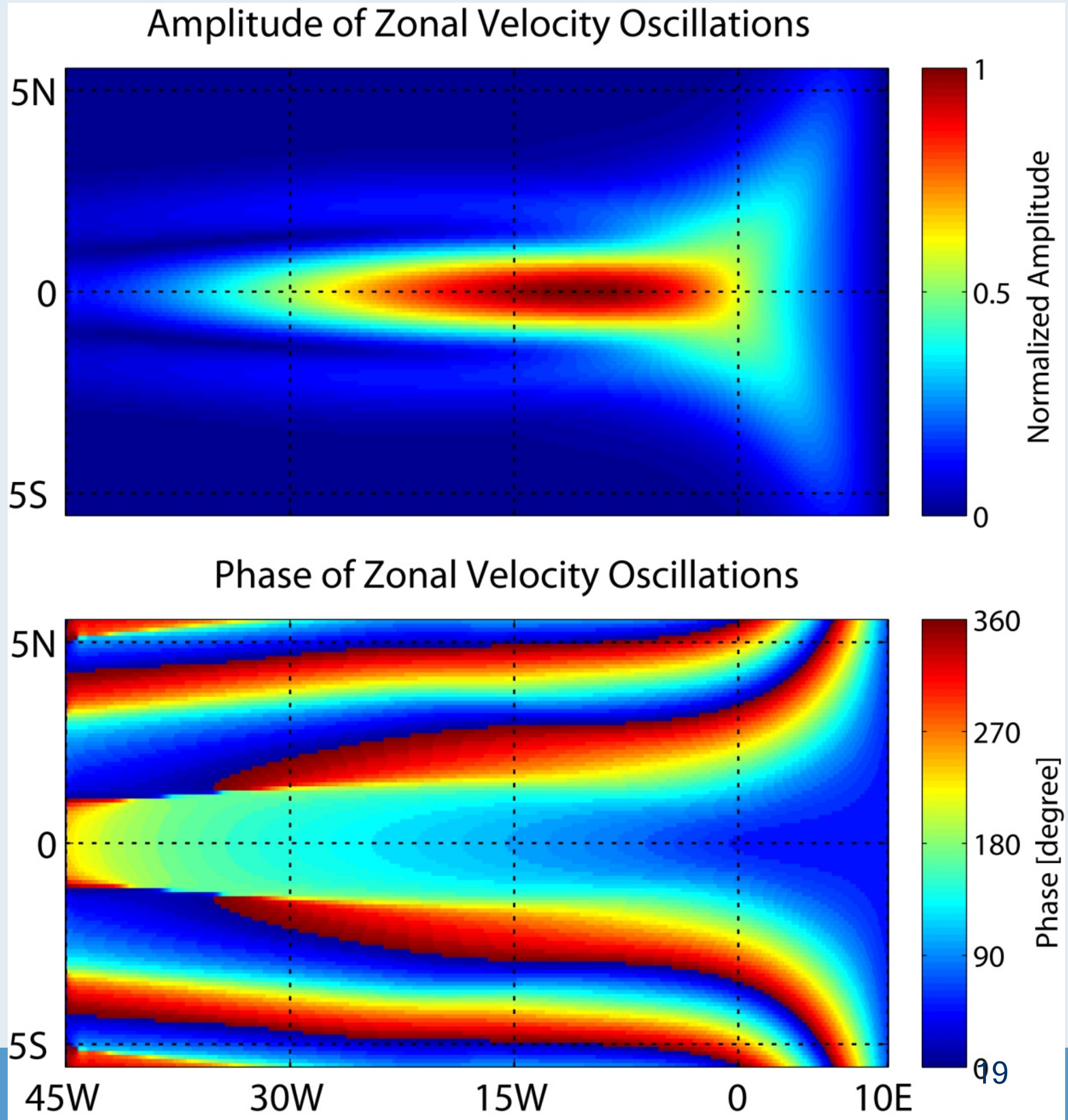
- State-of-the-art, high-resolution model (ORCA, 45 vertical levels) does not represent EDJ (pers. comm. C. Böning)
- Simulation is dominated by low-baroclinic mode variability



# Equatorial Basin Mode

- Reduced-gravity model used to simulate regular high-baroclinic-mode oscillations (Kelvin and Rossby wave propagation) with a period of 4.5 years
- Width of the EDJs could be correctly simulated by including lateral eddy viscosity of about 200-300 $m^2/s$




Greatbatch et al. 2012

# Summary

- Major modes of tropical Atlantic variability:
  - meridional and zonal coupled modes
  - internal ocean (equatorial deep jets, TIWs) and atmosphere (intraseasonal wind) variability
  - external forcing from ENSO and NAO
- TACE (2006-2011) major achievements:
  - improved ocean mixed layer heat budget: its seasonal to interannual variability
  - identification of interannual flow variability including variability of the EUC and equatorial deep jets
  - realistic high-resolution simulations of the Gulf of Guinea
  - better understanding of coupled ocean-atmosphere interaction in the tropical Atlantic

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But no improvement of the eastern tropical Atlantic SST bias!