With major contributions from

Bernard Bourlès, IRD/LEGOS/CRHOB, Cotonou, Benin

Bill Johns, RSMAS, Miami, USA

Marcus Dengler, IFM-GEOMAR, Kiel, Germany

Tropical Atlantic Climate Experiment

Peter Brandt, IFM-GEOMAR, Kiel, Germany

Tropical Atlantic Climate Experiment in 2006

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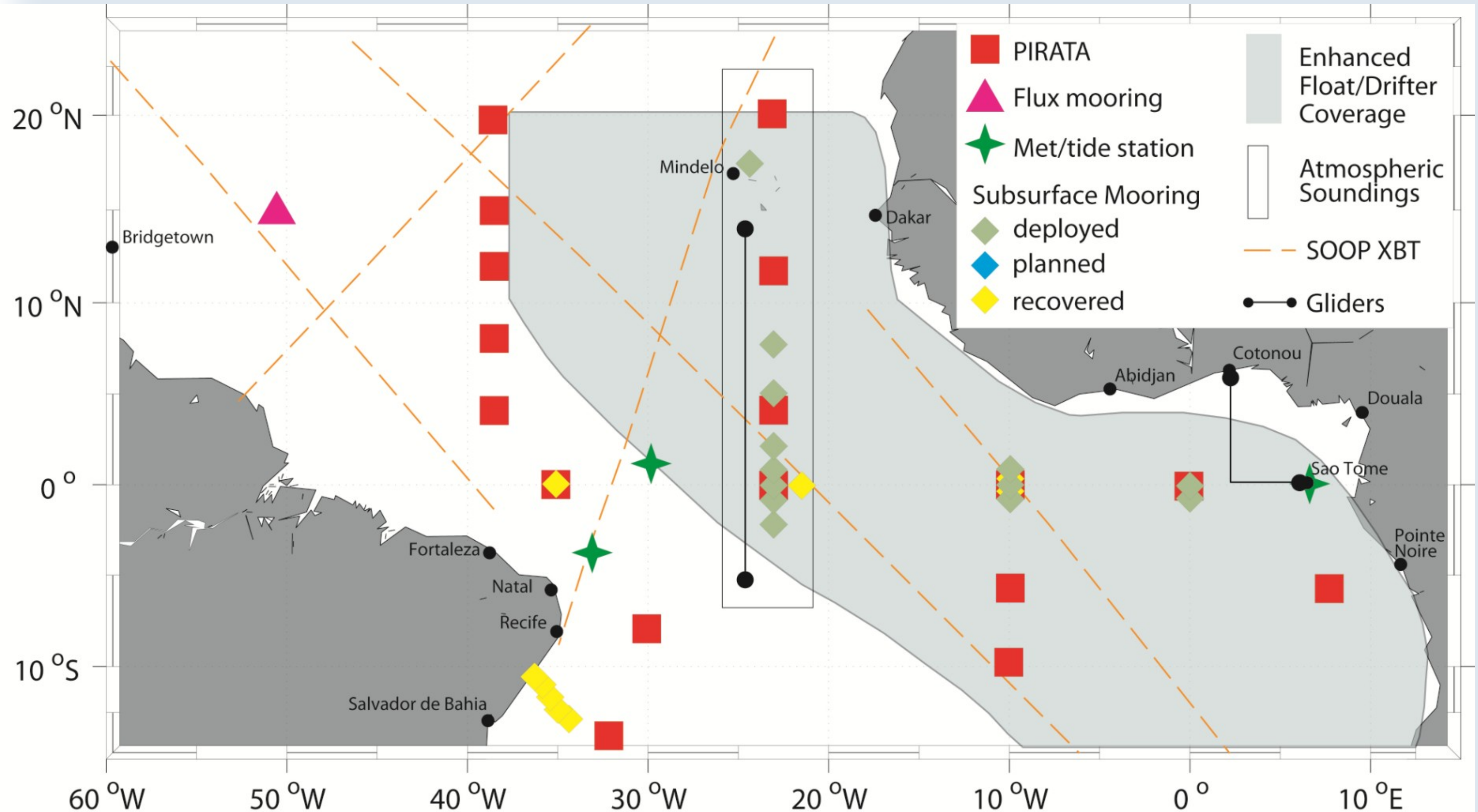
- A focused observational and modeling effort in the tropical Atlantic to advance the predictability of climate variability in the surrounding region and to provide a basis for assessment and improvement of coupled models.
- TACE was envisioned as a program of enhanced observations and modeling studies 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.

TACE observational network



The PIRATA buoy network is the backbone of the tropical Atlantic observing system that foster research in the region.

Process Studies

- AMMA/EGEE
  - Bourlès et al.: Two cruises per year (2005-2007) during onset and mature phase of Atlantic Cold Tongue
- DFG Emmy Noether
  - Dengler et al.: Diapycnal Mixing Study
- BMBF Nordatlantik/SOPRAN
  - Brandt et al.: Moored observations at 23°W
  - Rhein et al.: Upwelling fluxes using tracer measurements
- US-TACE
  - Johns et al.: Moored observation, termination of the EUC

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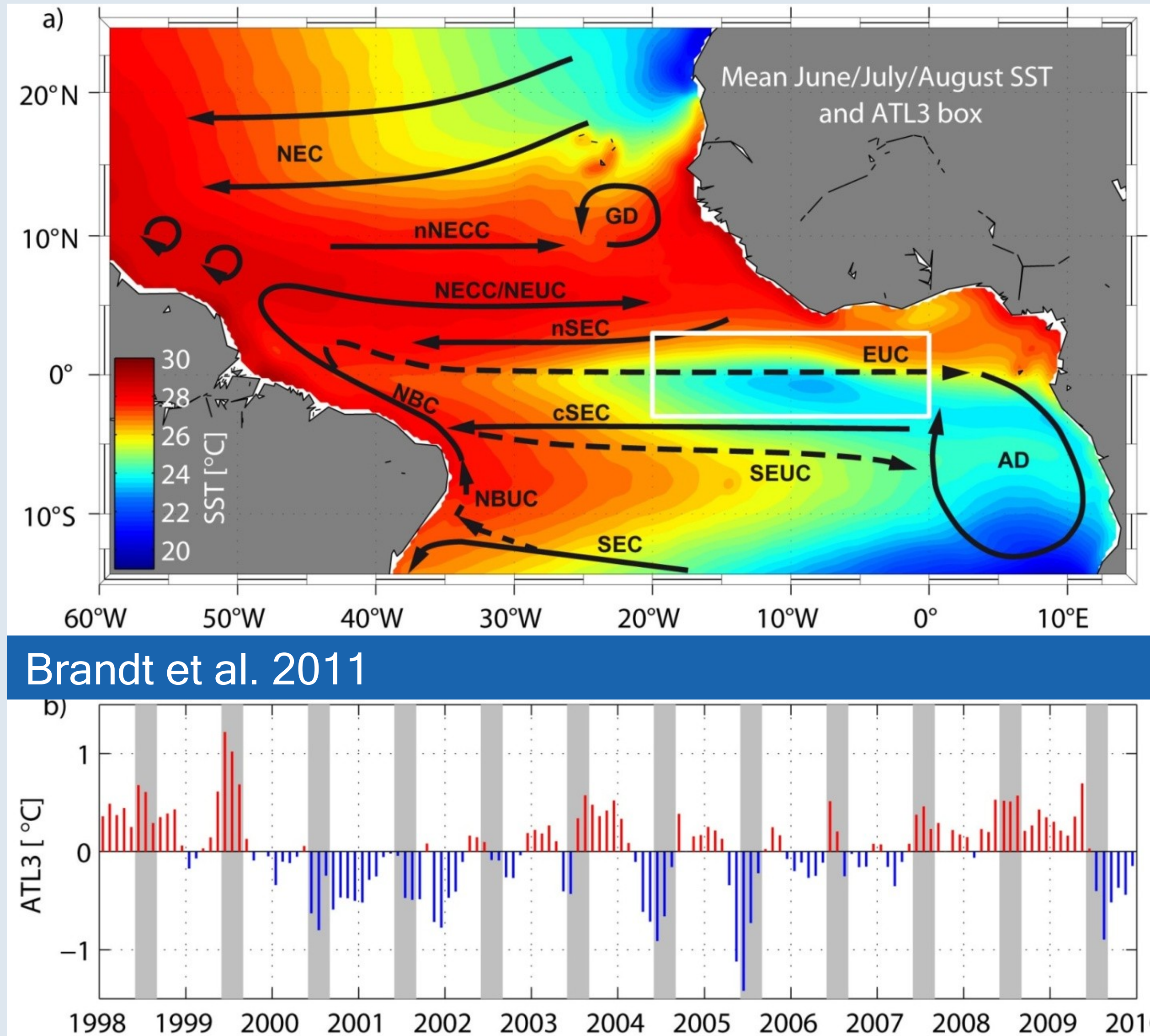
Equatorial Atlantic Cold Tongue

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



Brandt et al. 2011

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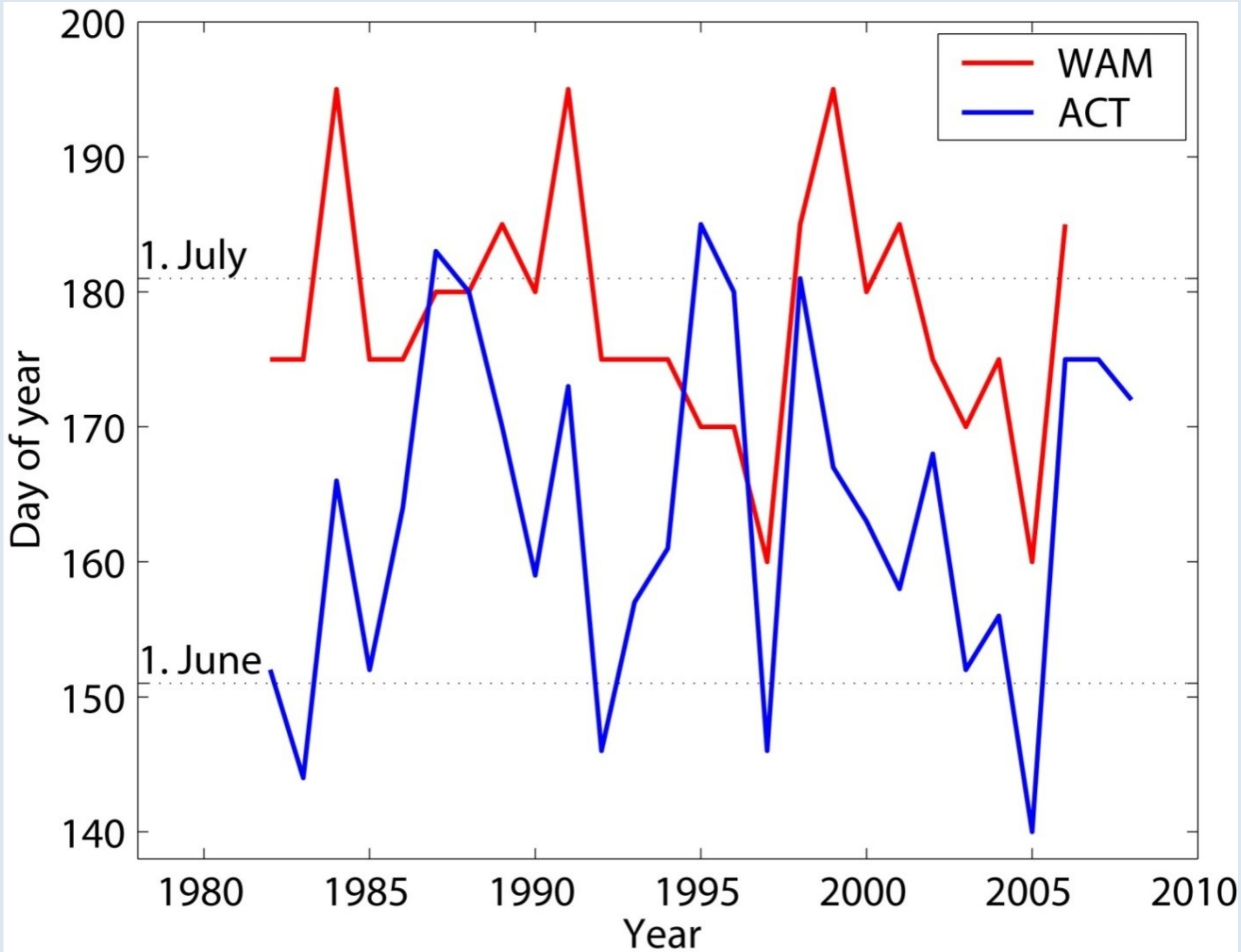
Onset of Atlantic Cold Tongue and West African Monsoon

- 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

Brandt et al. 2011, Caniaux et al. 2011

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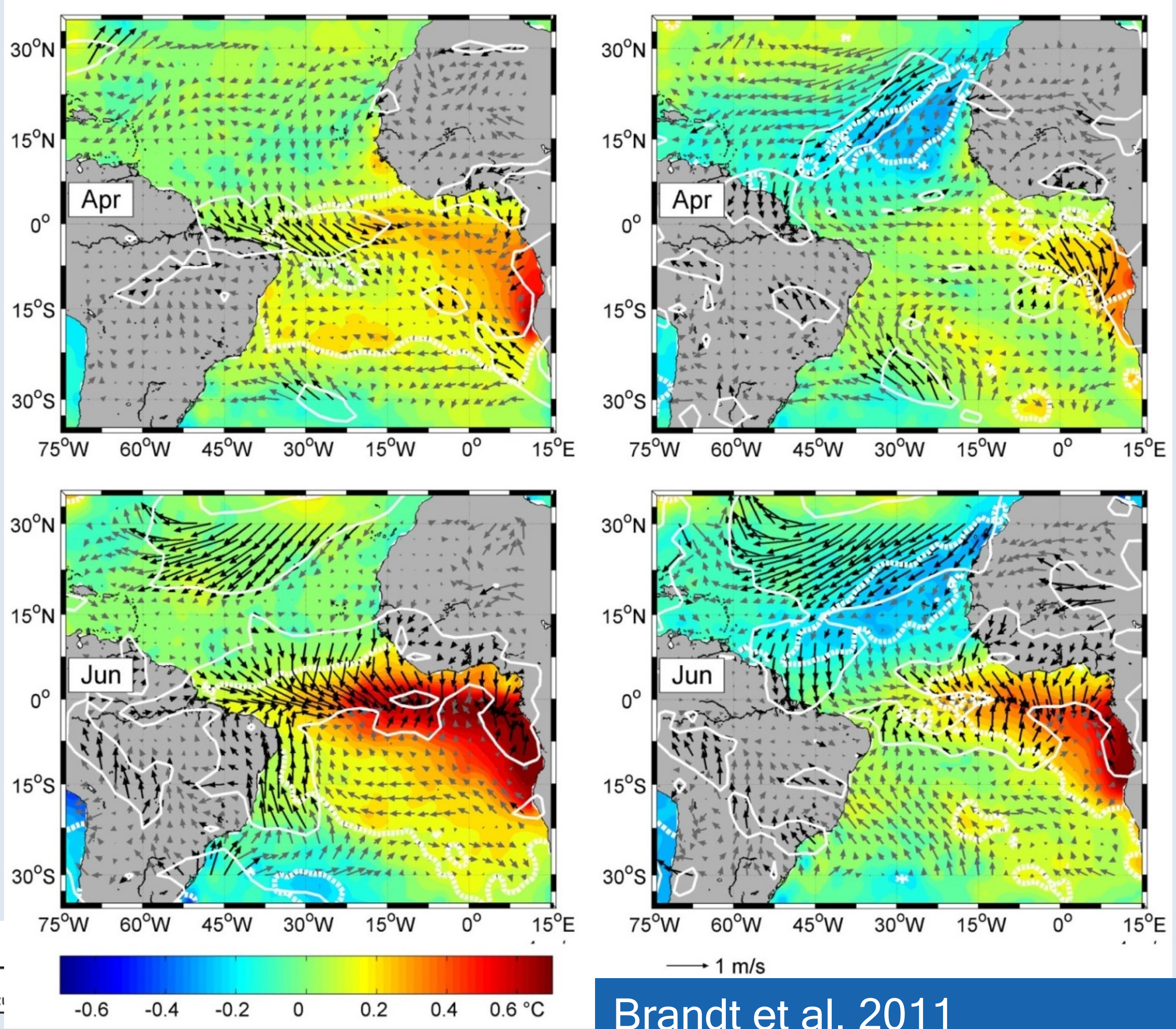
Regression of SST and Wind onto

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

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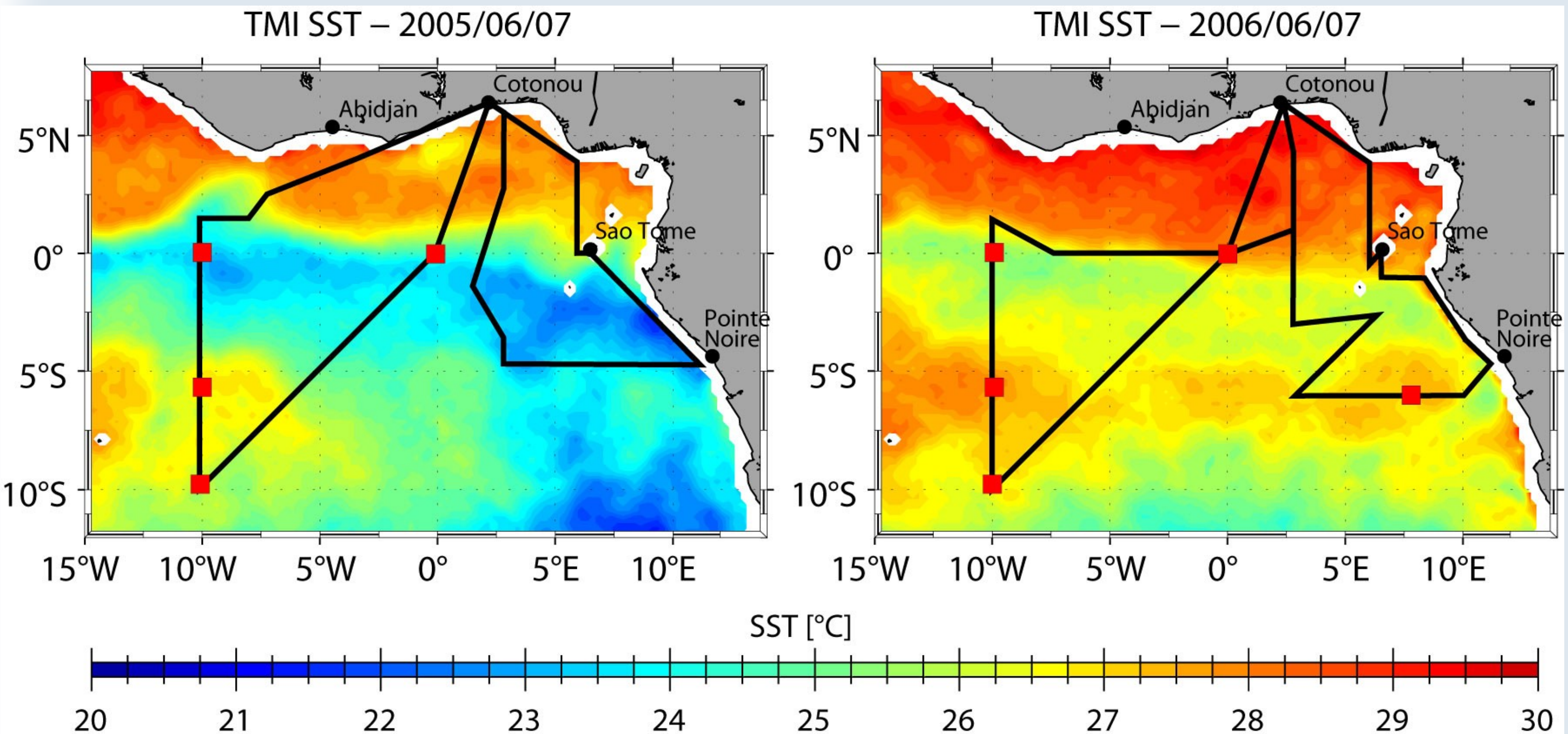
AMMA/EGEE Program 2005-2007

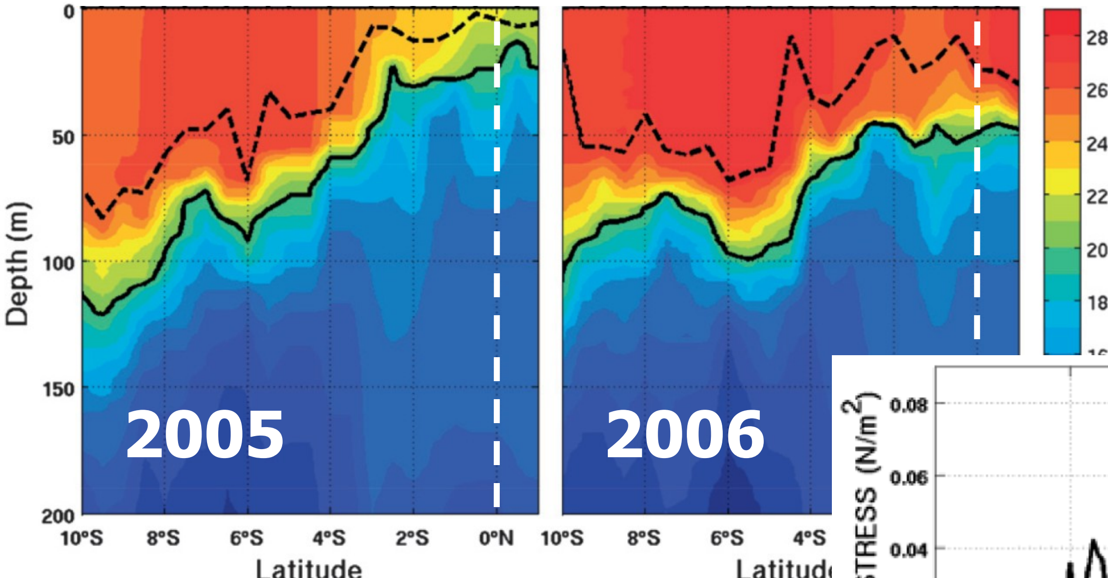
- Six research cruises into the Gulf of Guinea (Jun. and Sep. each year)
- Measurements of radiative fluxes, atmospheric parameters for the calculation of turbulent fluxes, profiles of temperature, salinity and currents in the mixed layer, microstructure, upwelling tracers.



Bourlès et al. (2007)

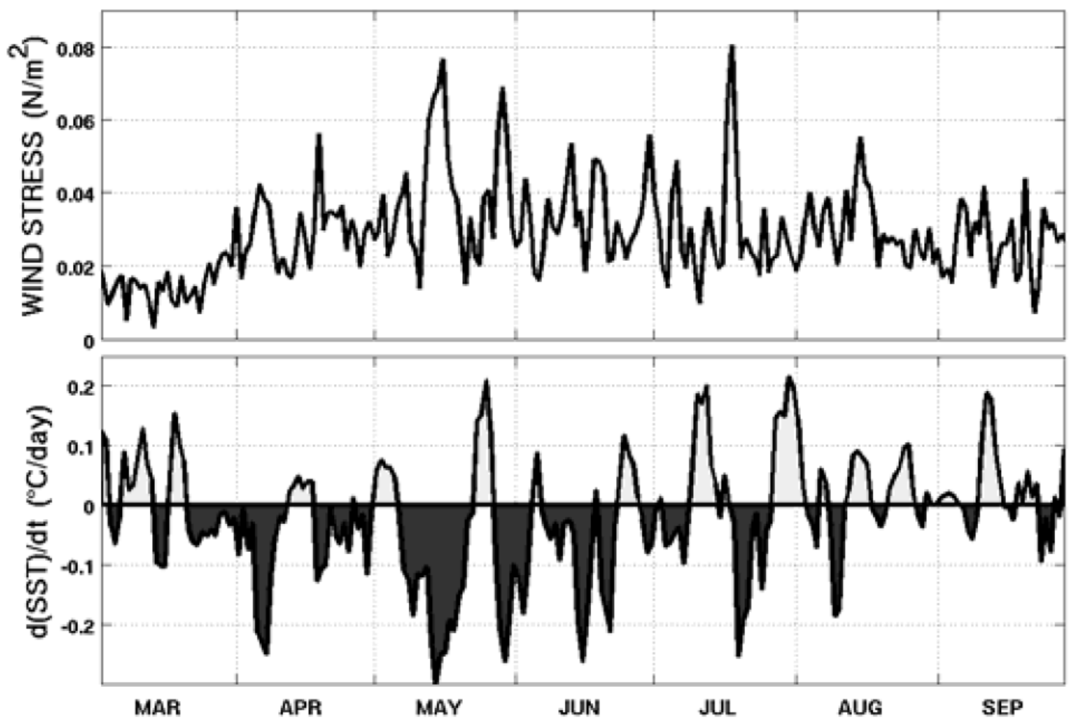
Cold (warm) event during boreal summer 2005 (2006)

Temperature at 10°W



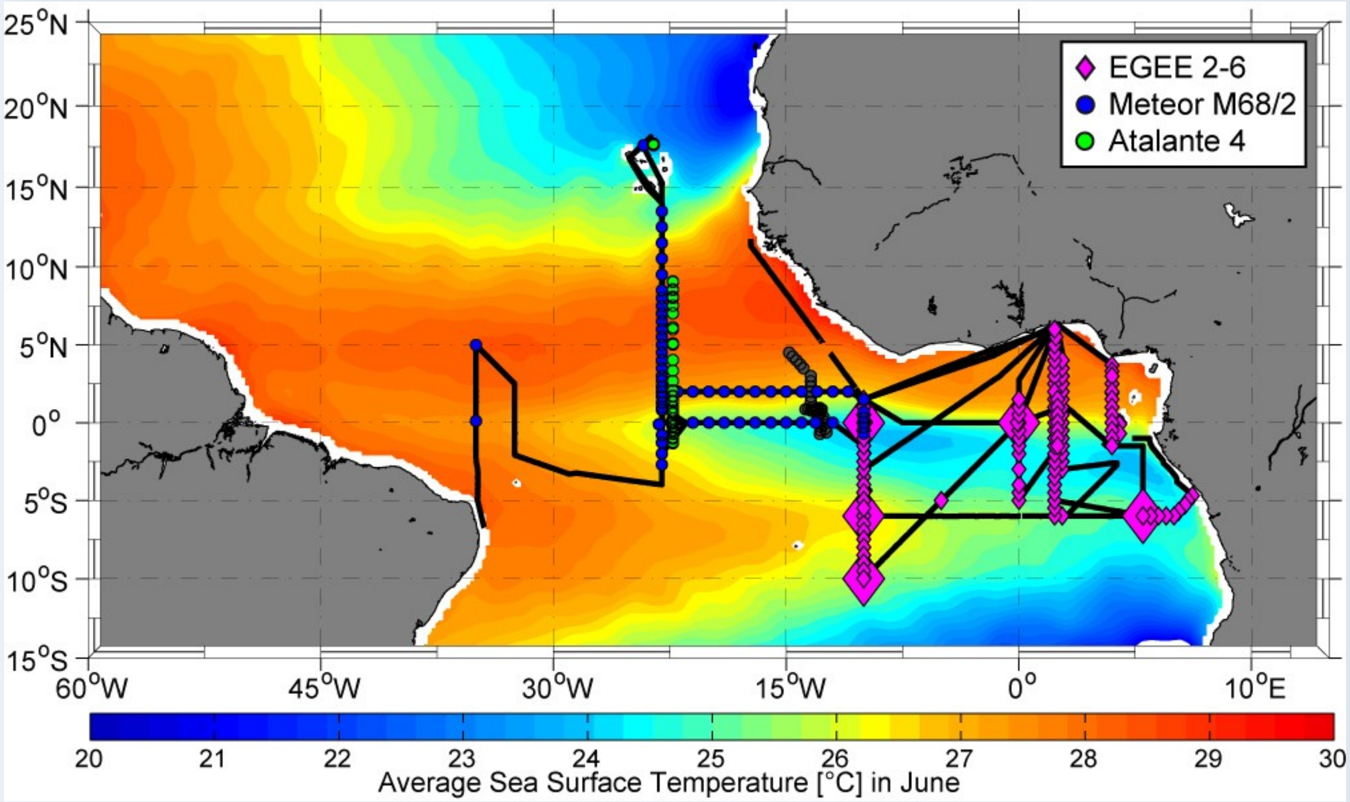
Shallow (deep) equatorial thermocline in June 2005 (2006)
⇒ preconditioning due to wind anomalies prior to the cold tongue season.

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)

Diapycnal Mixing and Heat Fluxes Below the Mixed Layer

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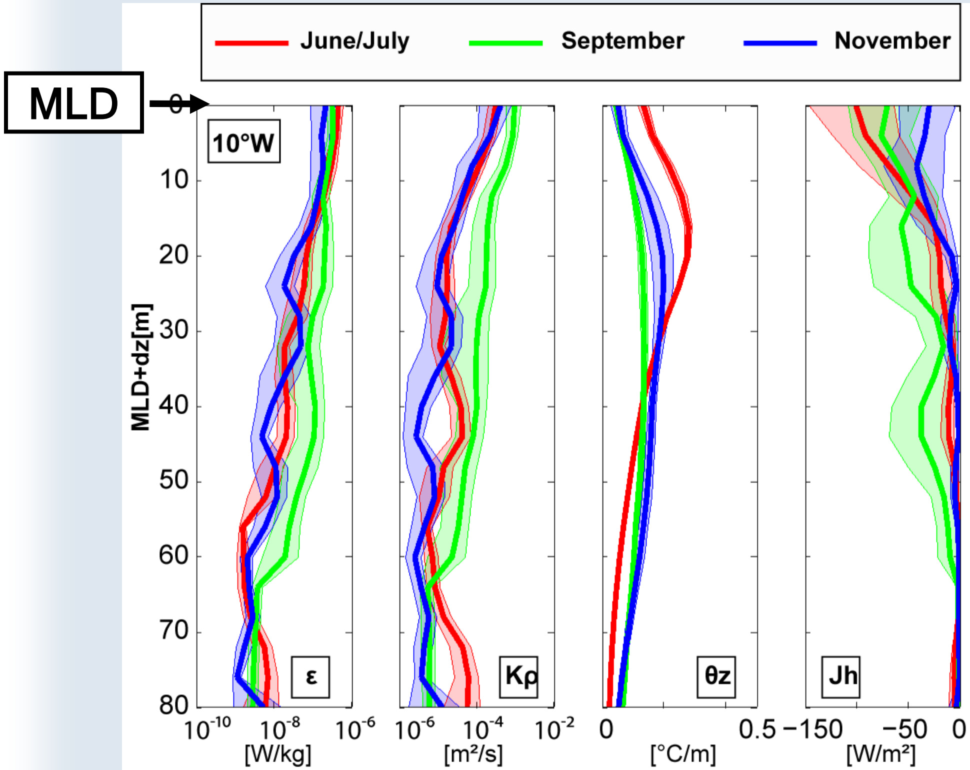
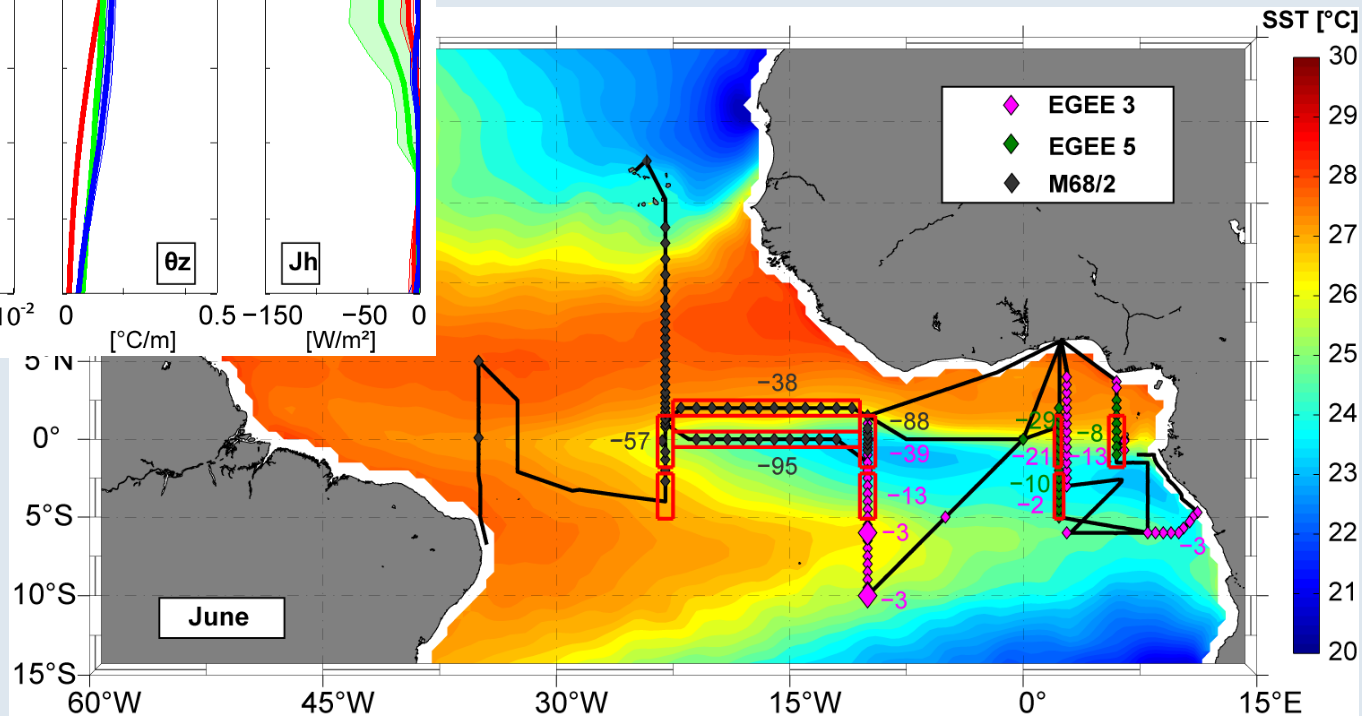
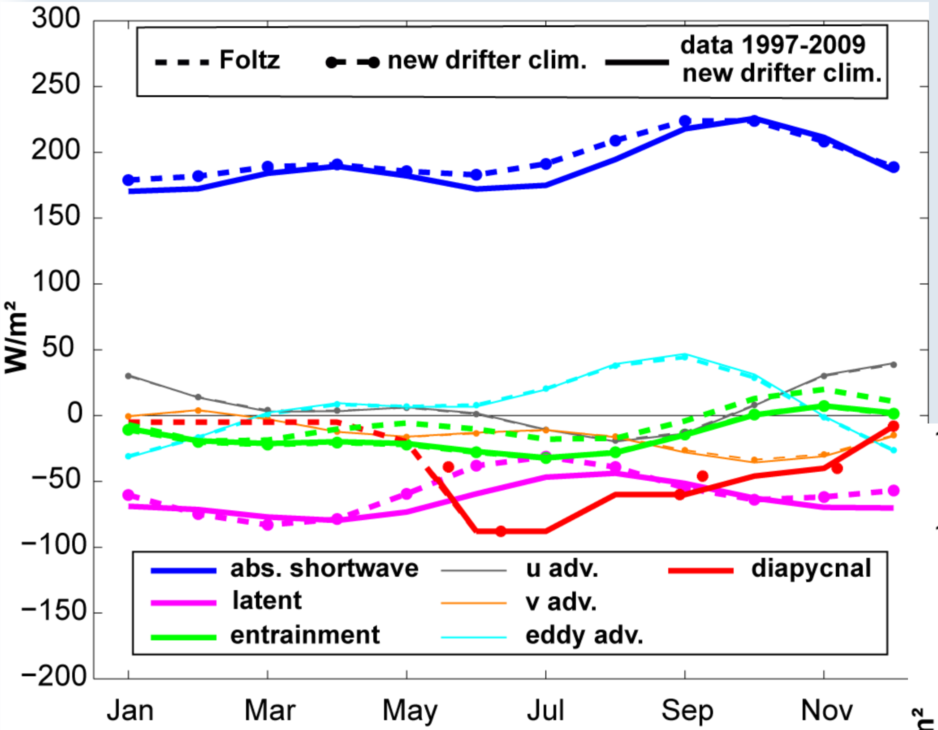


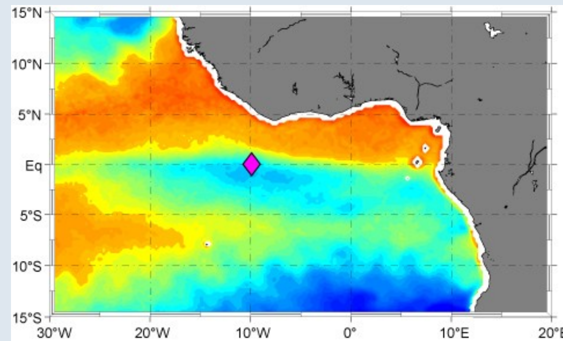
Elevated mixing below the mixed layer was found from May throughout November at 10°W. Diapycnal heat flux peaks during early summer due to the presents of strong temperature gradients below the mixed layer.

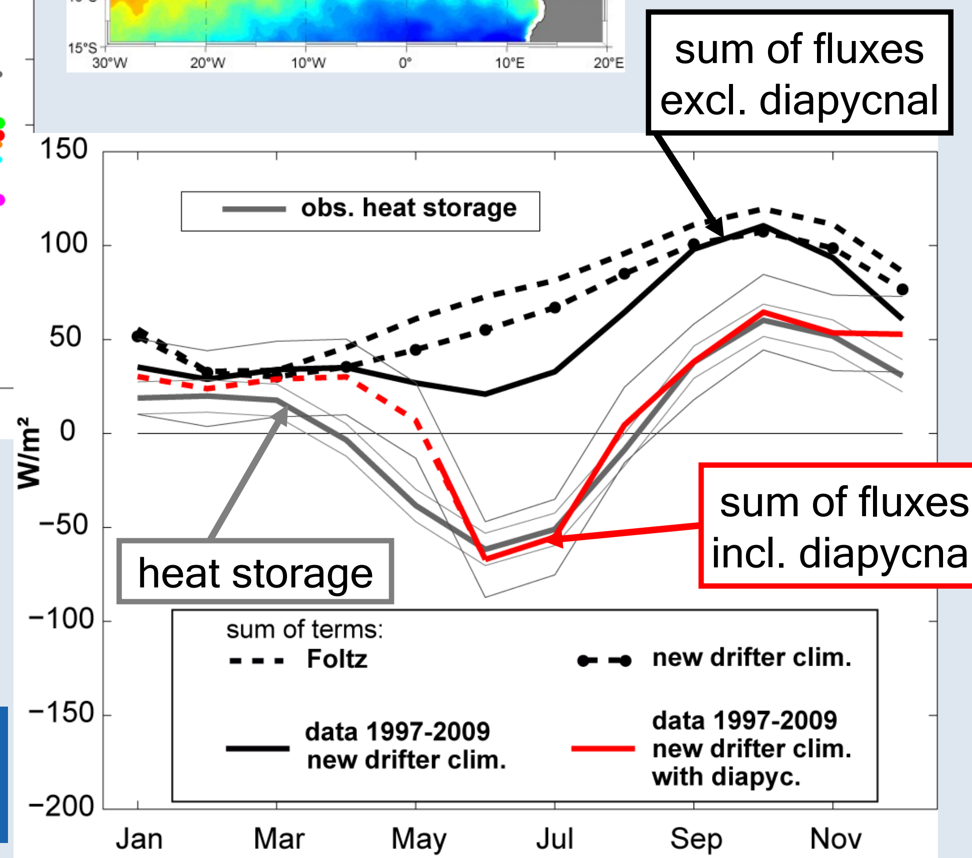


Diapycnal heat fluxes are particularly pronounced in the center and western part of the cold tongue.

Annual Cycle of Mixed Layer Heat Budget at 10°W





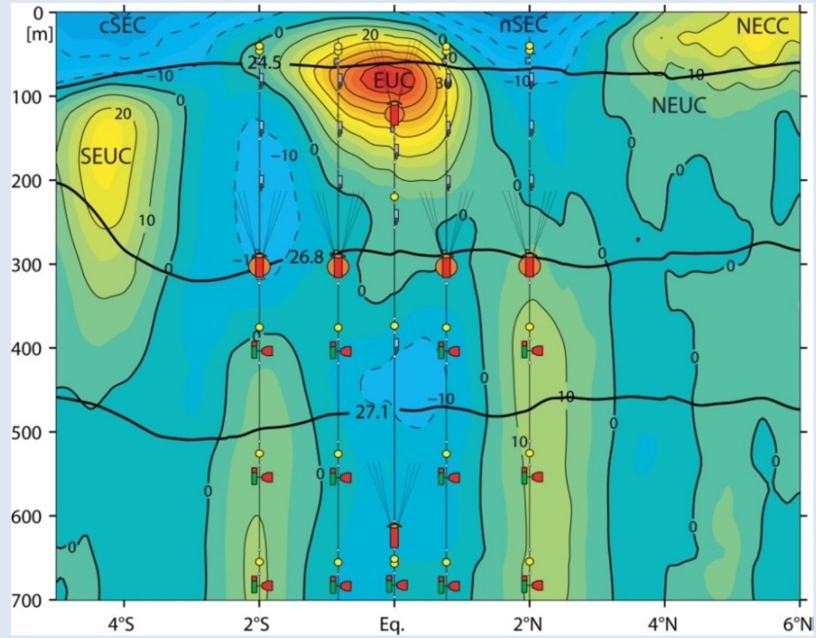


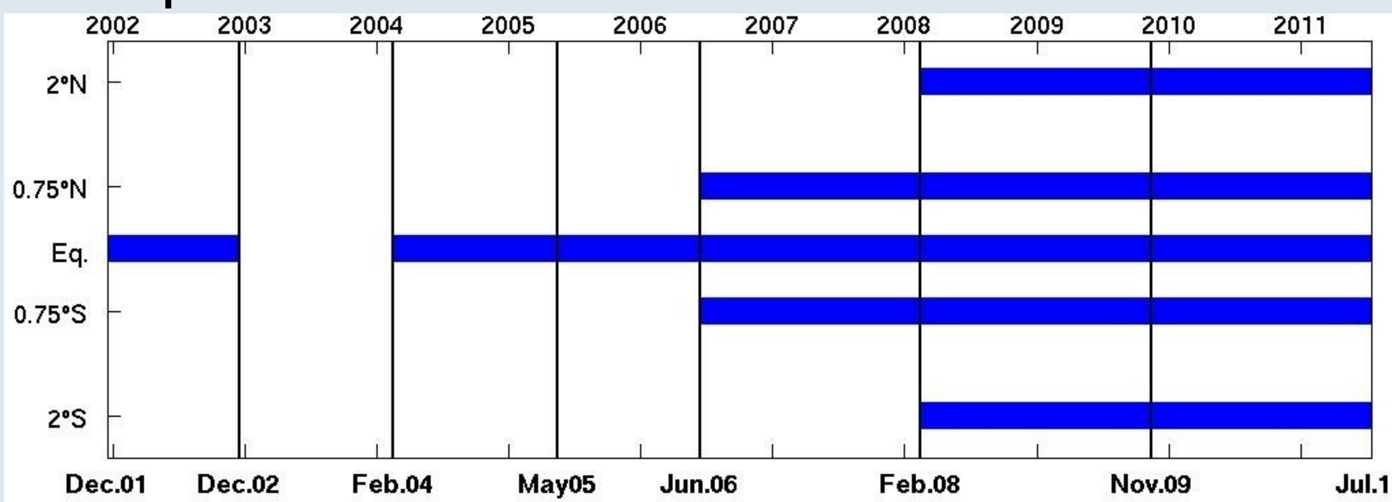
Diapycnal heat fluxes dominantly contribute to heat loss of the mixed layer from boreal summer throughout late autumn.

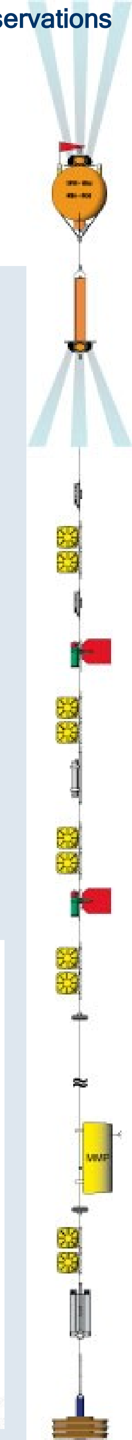
Foltz et al. 2003 (without diapycnal flux)
Hummels et al. 2011

Interannual Current Variability at the Equator, 23°W

- Current meter mooring array in the frame of BMBF Nordatlantik.
- Cooperation with PIRATA (Bernard Bourlès) provide shallow ADCP
- From Jun 06 - Feb 08 deep ocean moored profiler provided by John Toole (WHOI)







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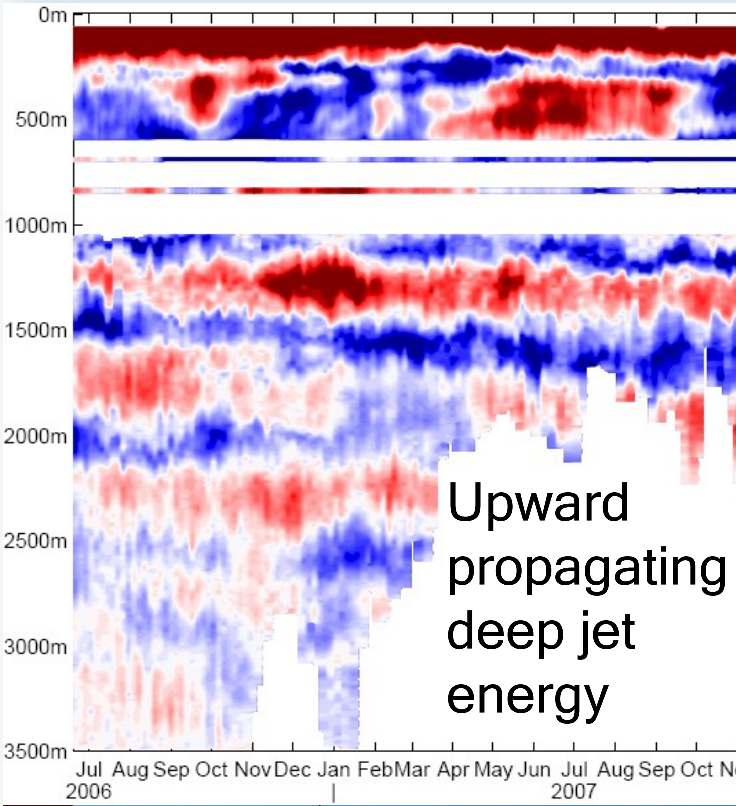
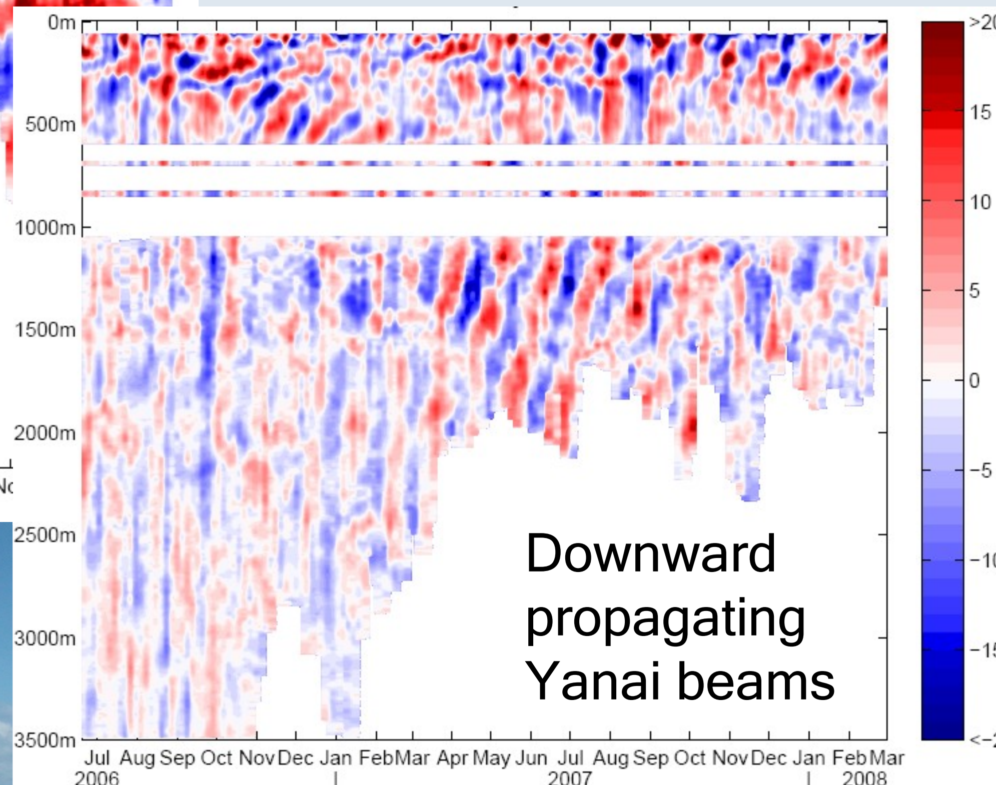
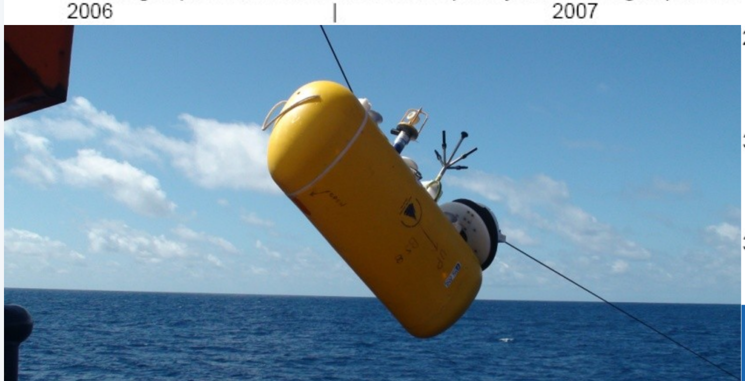
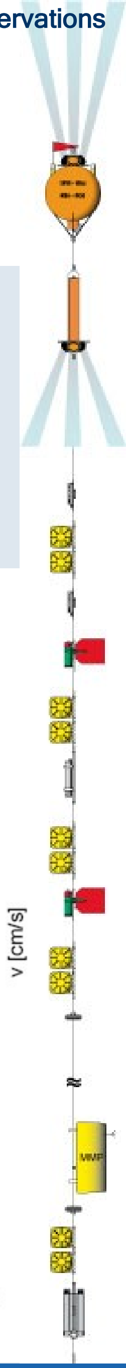
Deep Equatorial Dynamics

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









Brandt et al. 2011, accepted

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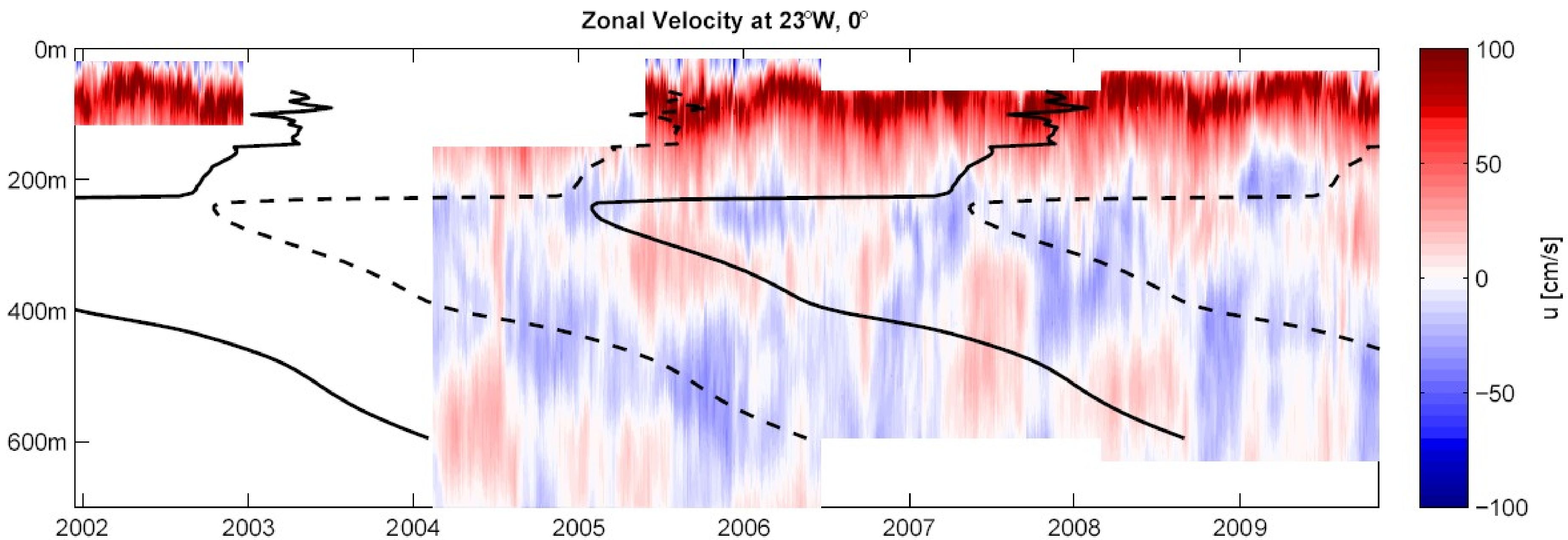
Equatorial Deep Jets (EDJ) in the Upper Ocean

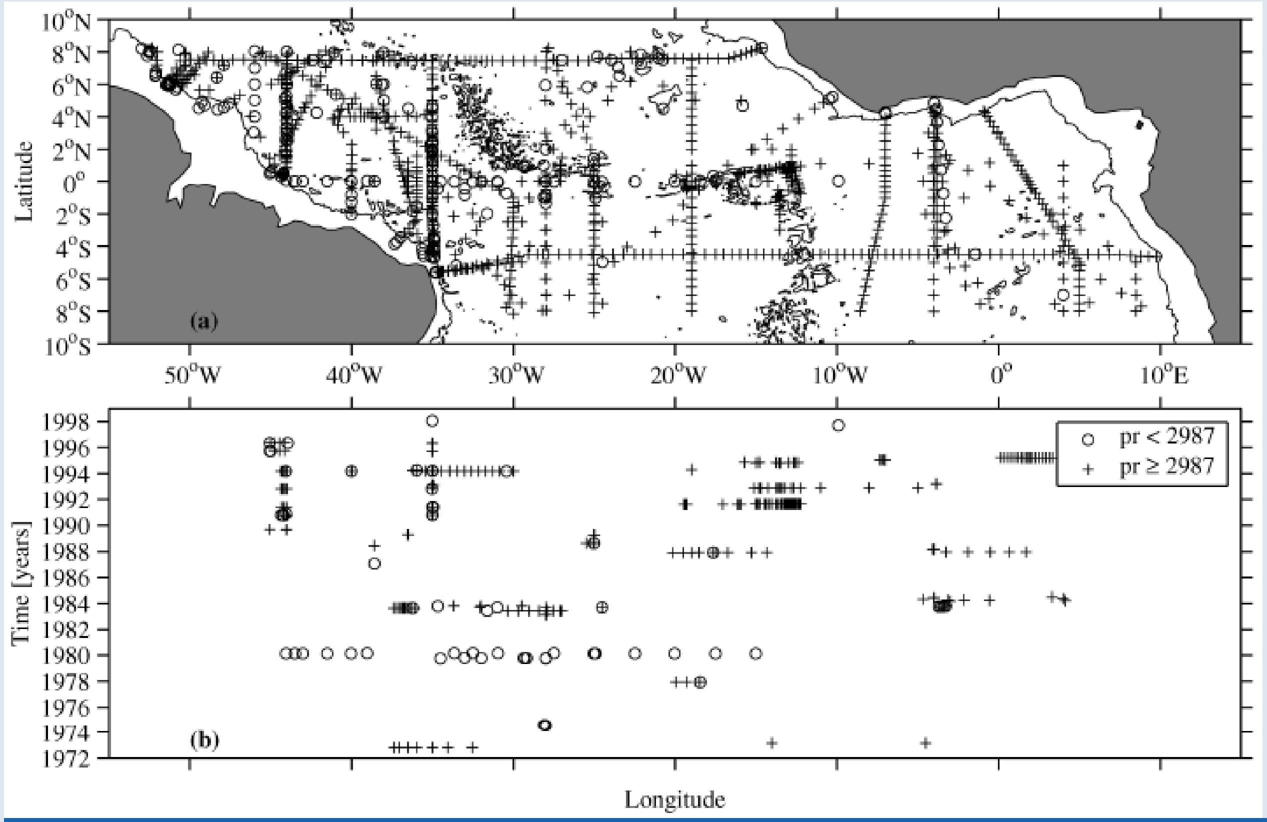
- Consistent downward phase propagation below the EUC ⇒ upward energy propagation from the deep ocean toward the EUC
- 4.5-year cycle also within the EUC



Brandt et al. 2011, accepted

Atlantic Equatorial Deep Jets

- Analysis of vertical strain from deep CTD data within ±2.75° off the equator.
- 5±1 years period
- 660 sdbar vertical wavelength (ref. ~1700dbar)
- 70°±60° zonal wavelength
- Downward and westward phase propagation

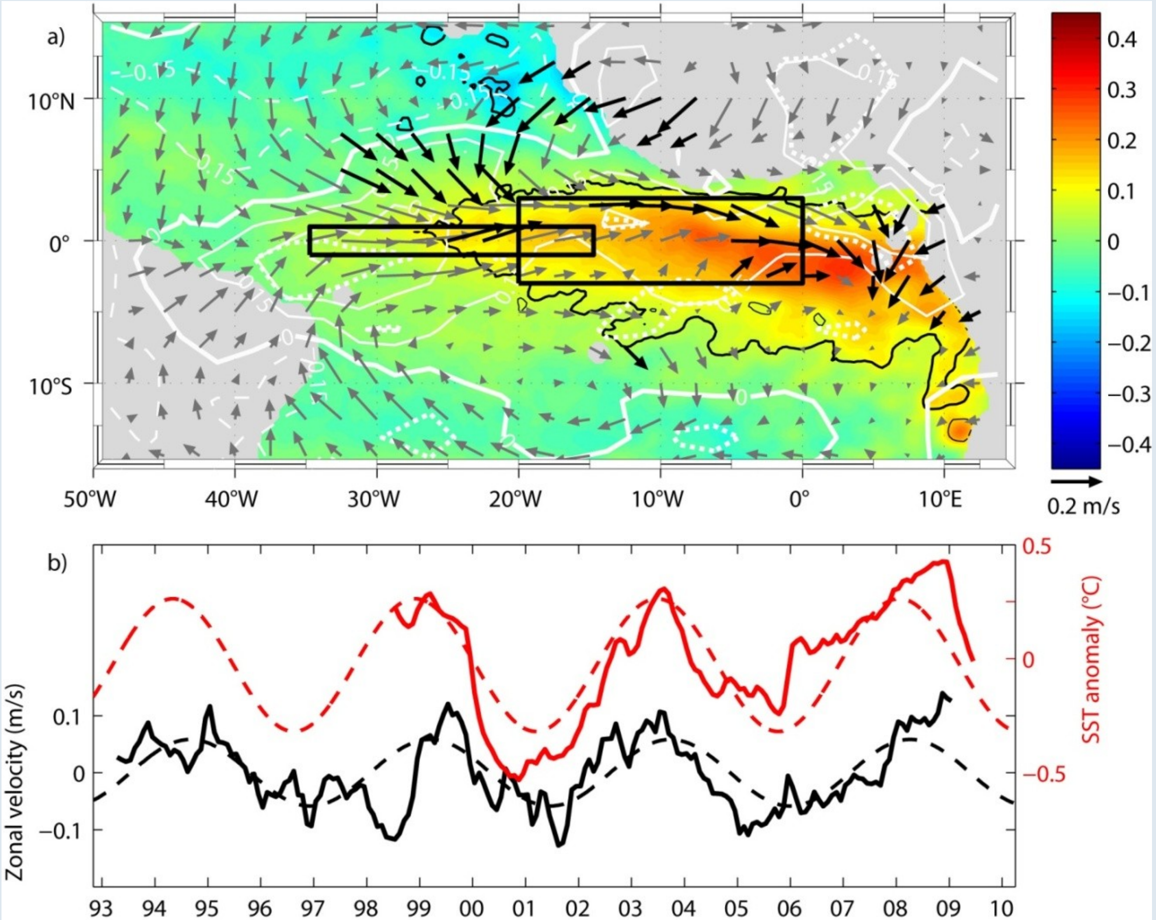


Johnson & Zhang 2003

The 4.5-year cycle in the deep equatorial Atlantic is now well established likely being the result of an equatorial basin mode.

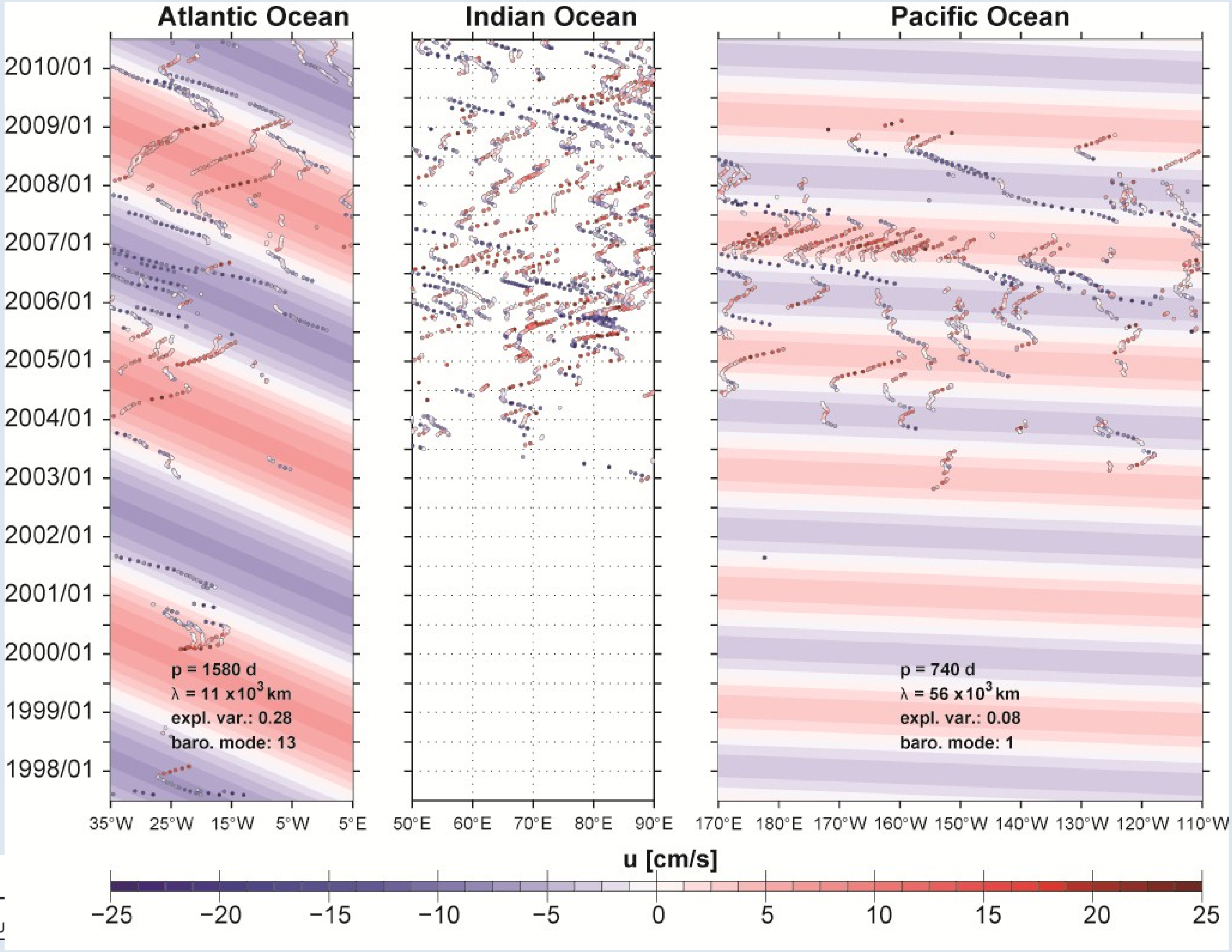
4.5-year Climate Cycle

- Geostrophic equatorial zonal surface velocity (from sea level anomalies 15°W-35°W) and ATL3 SST show a similar 4.5-year cycle
- Regression of SST, wind, and rainfall onto the harmonic cycle



The 4.5-year cycle was found to be associated with distinct wind and rainfall pattern, which is suggested to be exploited to improve Atlantic climate forecasting.

Variability in the Global Equatorial Ocean (1000m) from Argo



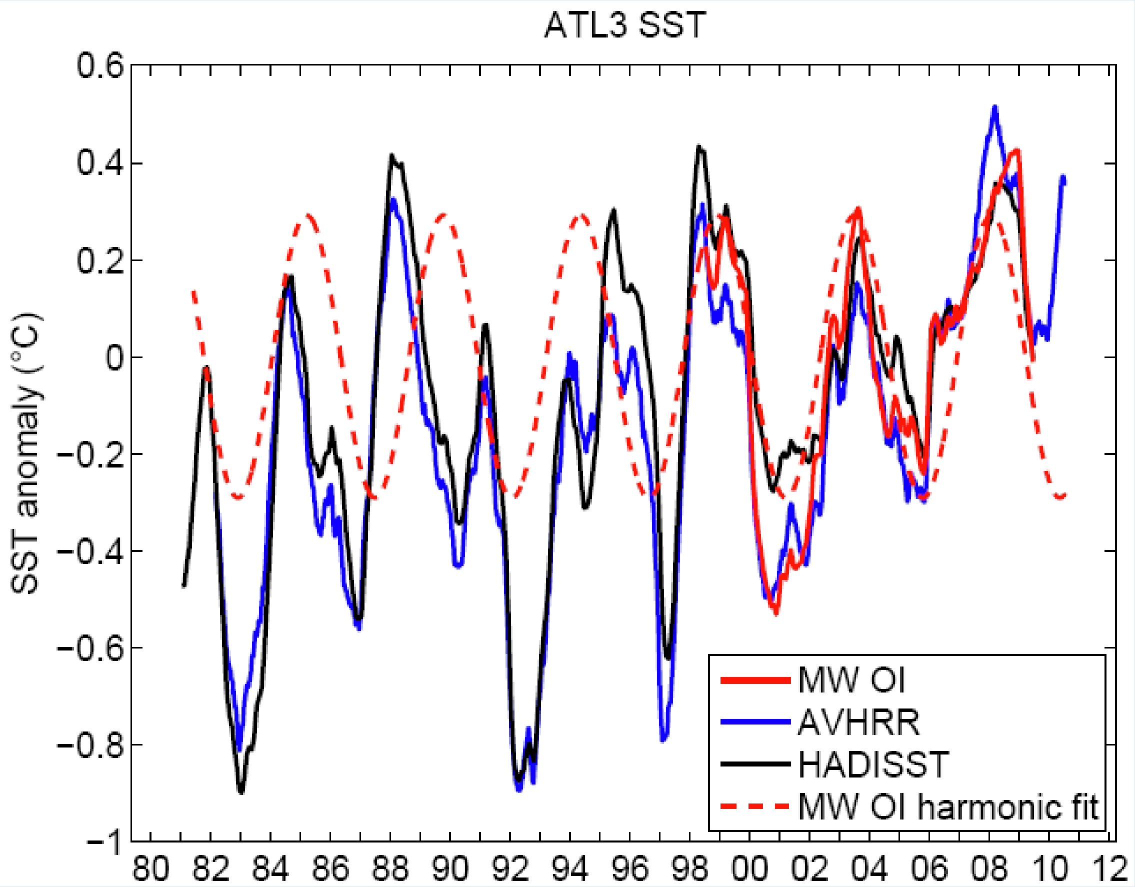
Variability in the Global Equatorial Ocean (1000m) from Argo

- Argo data show that 4.5-year Atlantic cycle associated with slowly propagating high-baroclinic mode waves is the dominant variability at depth
- Besides similar geometry, there are mostly incoherent signals at 1000m in the Indian Ocean
- Pacific variability is dominated by fast propagating (probably wind generated) waves
  - EDJ period about 30 yr (Johnson et al. 2002)

The Atlantic Ocean is very special with regard to interannual variability and we expect no influence of Equatorial Deep Jets on Indian and Pacific SST on interannual time scales.

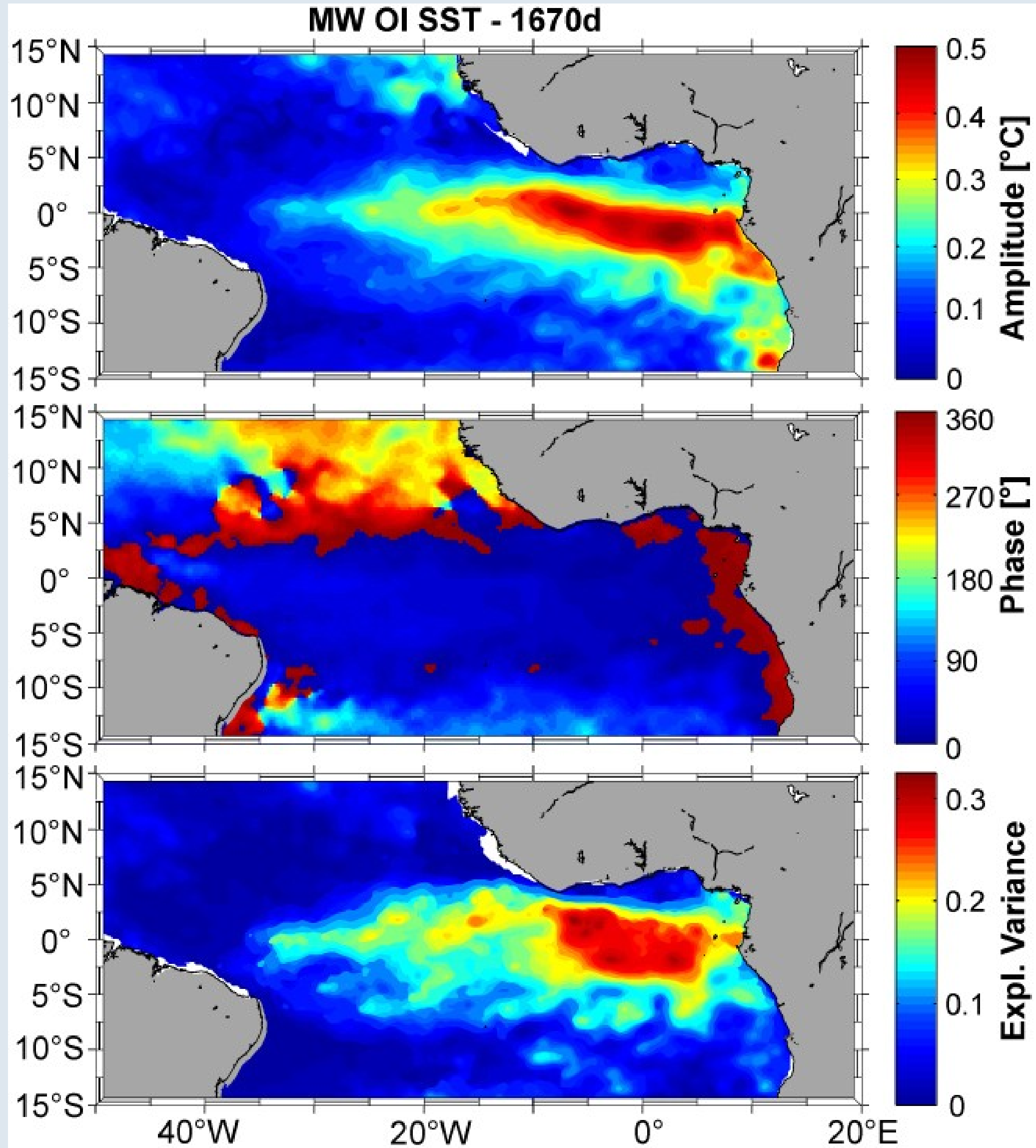
Longer ATL3 SST time series

- More irregular behavior on longer time scales ⇒ possible influence of other modes of variability
- Other data sets does not as well capture the 4.5-year cycle.



Pattern of the 4.5-year Cycle in Microwave OI SST

- Amplitude, phase, and explained variance of the 1670d harmonic of SST (Microwave OI SST from Jan 98 - Dec 2009)
  - 4.5-year signal is closely confined to the equatorial region
  - phase in the equatorial region varies only slightly
  - explains up to 25% of the variance of monthly SST data after subtracting seasonal cycle



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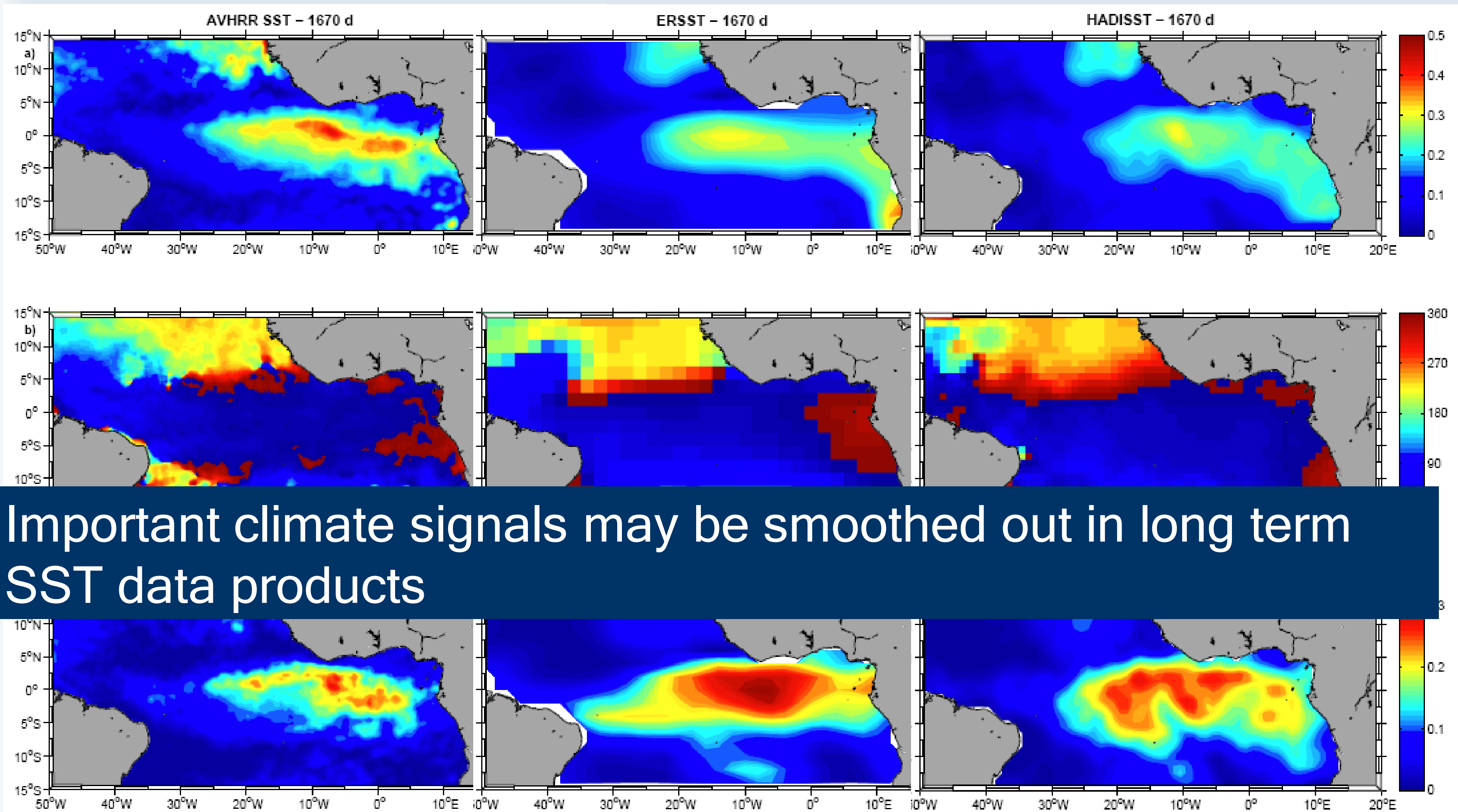
Different SST Data Sets - Same Period of Analysis

AVHRR-only ERSST HADISST



Important climate signals may be smoothed out in long term SST data products

Equatorial Undercurrent (EUC) Termination

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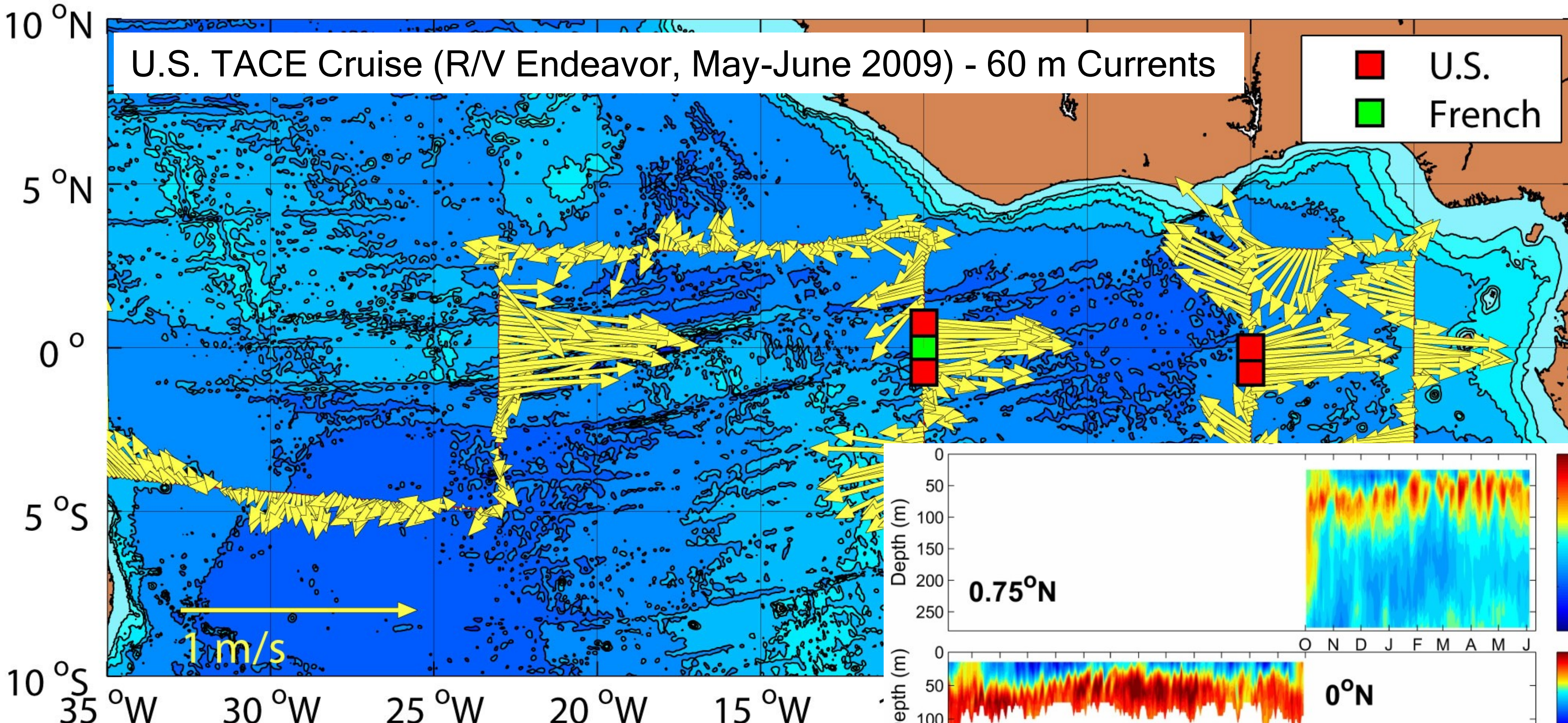

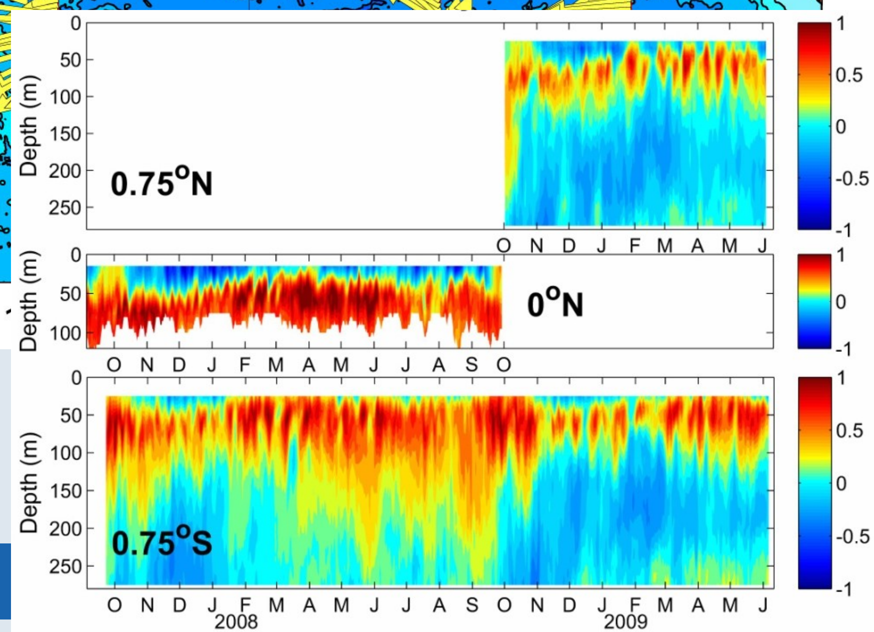

The French/U.S. subsurface moored ADCP array along 10°W and 0° was deployed in Sep 07 and will be finally recovered in Jun 11

Johns, Bourlès et al.

Mean Ship Sections and Transport Timeseries

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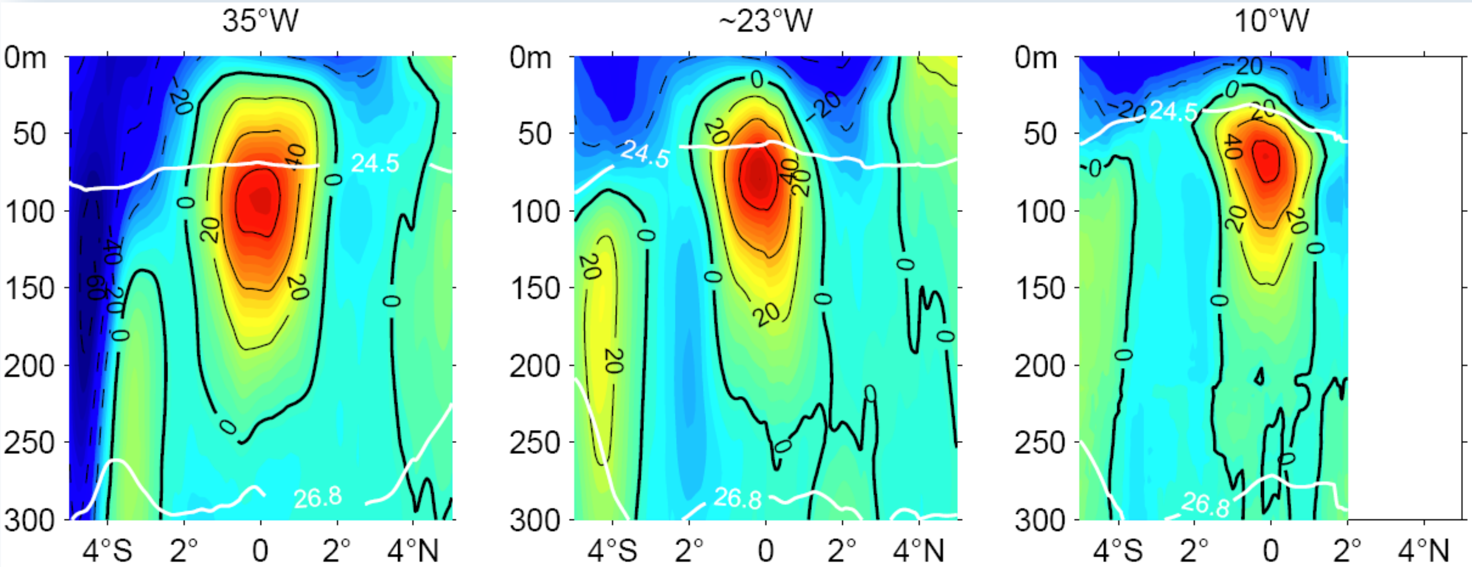
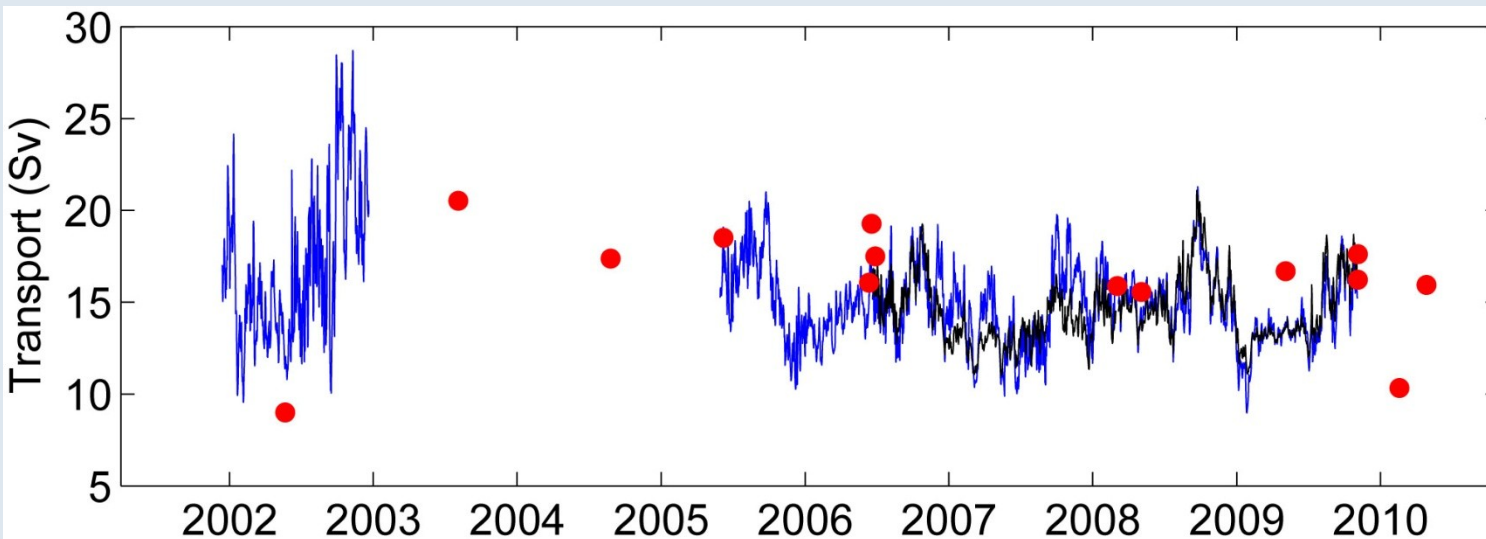


Mean zonal velocity sections along different meridians.

EUC transport time series calculated from ship section variability pattern and moored observations.



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Summary/Conclusion

- The data base available for tropical Atlantic climate studies largely increased during TACE (2006-2011)
  - Mean currents and hydrography from ship sections
  - Moored observations showing intraseasonal to interannual variability of velocity and hydrographic fields
  - Surface drifter, Argo floats, glider transects, XBT lines
- From these observations, we have now a better understanding of SST evolution and mixed layer heat budget on seasonal time scale, interannual variations of the heat budget still difficult to address
- PIRATA network with cruises will foster continuing research in the tropical Atlantic region $\Rightarrow$ need for SE extension
- Full exploitation of available data for model assessment and improvement not done yet

Outlook

- Data synthesis/recommendation for sustained observations
- Predictable and non-predictable elements of the climate system on (intra)-seasonal time scales
  - Interaction of SST and wind on frontal and meso-scales
  - Role of water cycle and salinity variations in shaping tropical Atlantic variability
  - Variability of diapycnal mixing processes on interannual time scales and its parameterization
- Better understanding of observed variability requires simulations with high horizontal and vertical resolution