Upper ocean mixing observations during TACE: Mixing processes in the equatorial Atlantic vs. Pacific

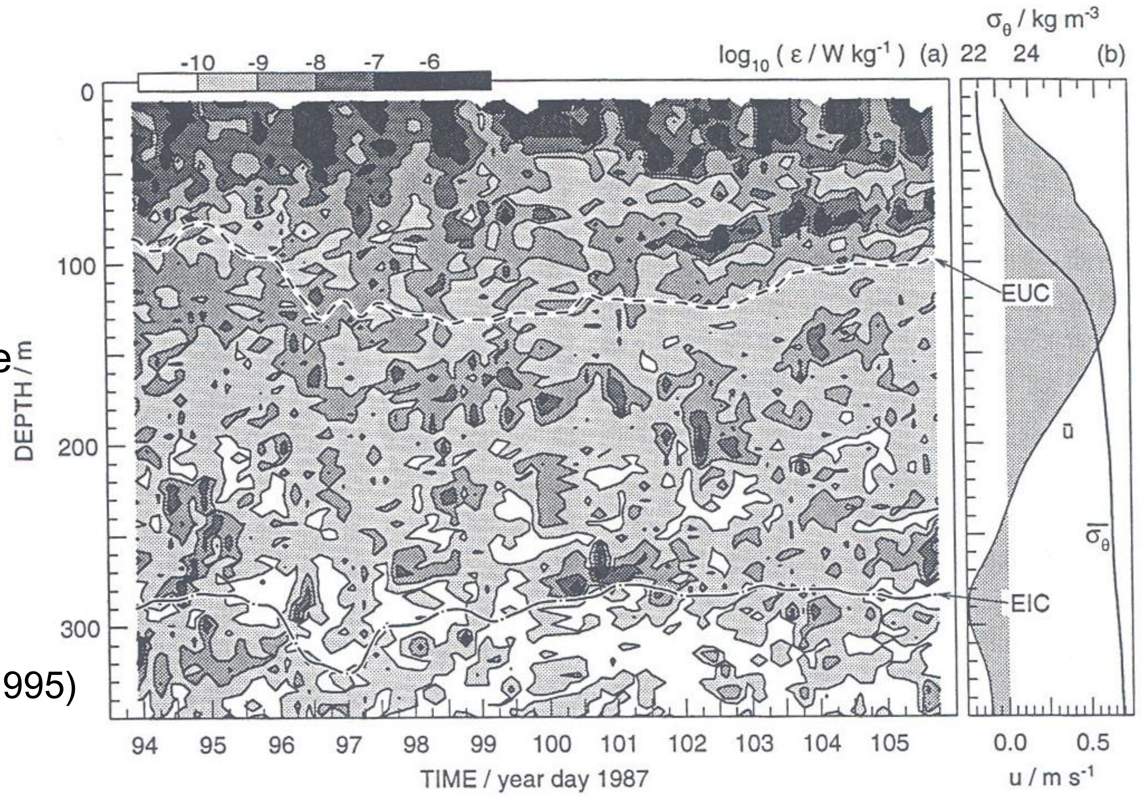
Marcus Dengler

Helmholtz Centre for Ocean Research Kiel

In cooperation with: Rebecca Hummels, Peter Brandt, Tim Fischer and Gerd Krahmann (all GEOMAR)

Motivation: Microstructure observations prior to TACE

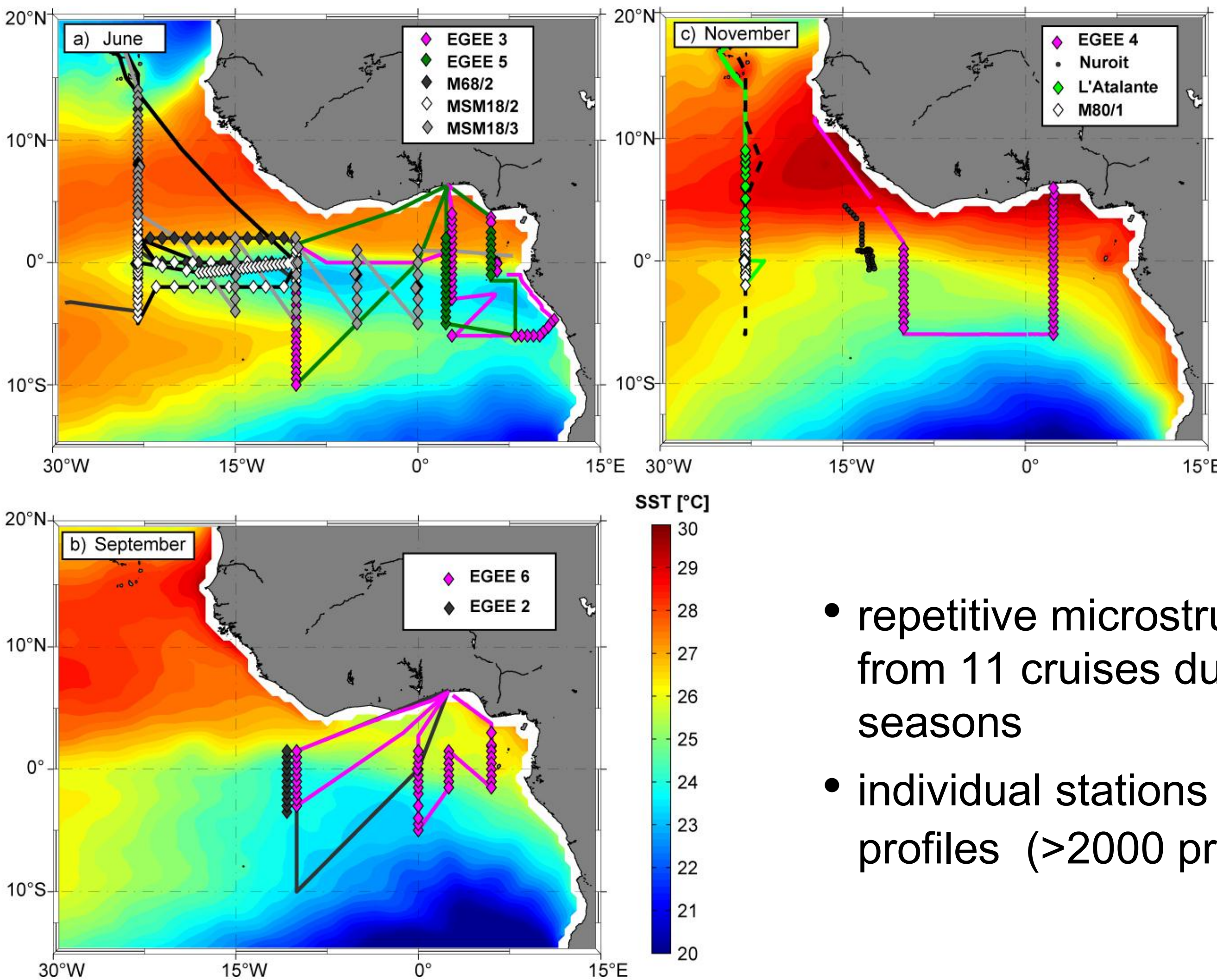
- Equatorial Pacific
  - Microstructure measurements from the upper thermocline in the late 70's and 80's revealed deep-cycle turbulence (Gregg et al., 1985, Moum and Caldwell, 1985)
  - Numerous measurement programs since the late 70's



(Peters et al, 1995)

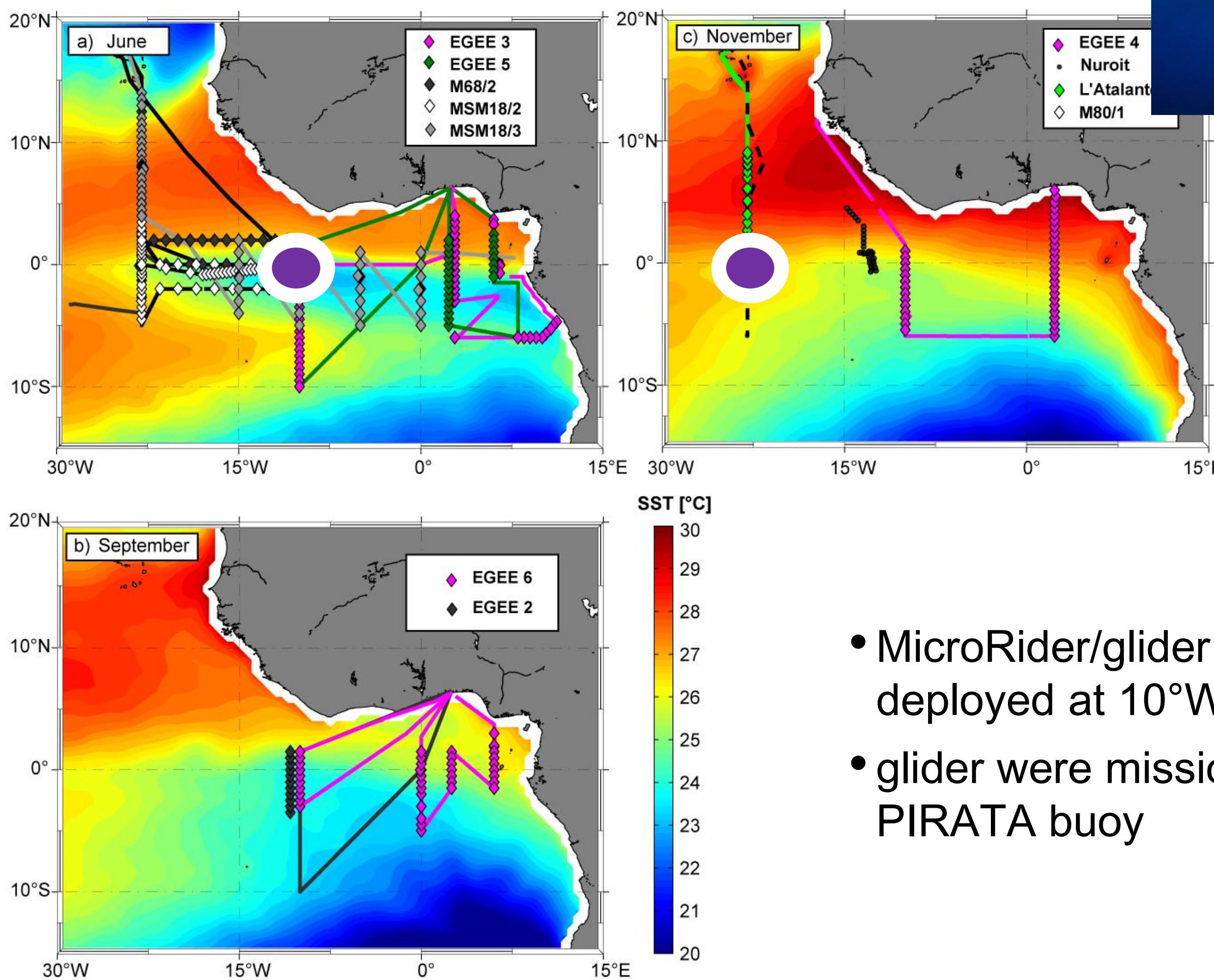
- Equatorial Atlantic
  - 8 microstructure profiles sampled in 1976 indicated enhanced mixing above the EUC core (Crawford and Osborn, 1979)
  - Le Noroit cruise by WHOI in late autumn 1994 to the eastern flank of the Mid-Atlantic Ridge (Romache Fracture Zone)

Ship-board microstructure measurements (2005-2011)



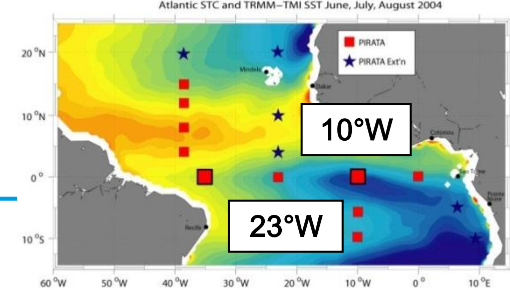
- repetitive microstructure sections from 11 cruises during different seasons
- individual stations with at least 3 profiles (>2000 profiles)

Autonomous microstructure measurements

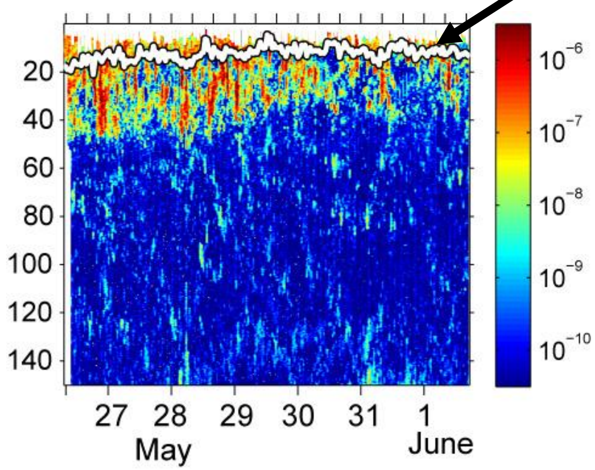


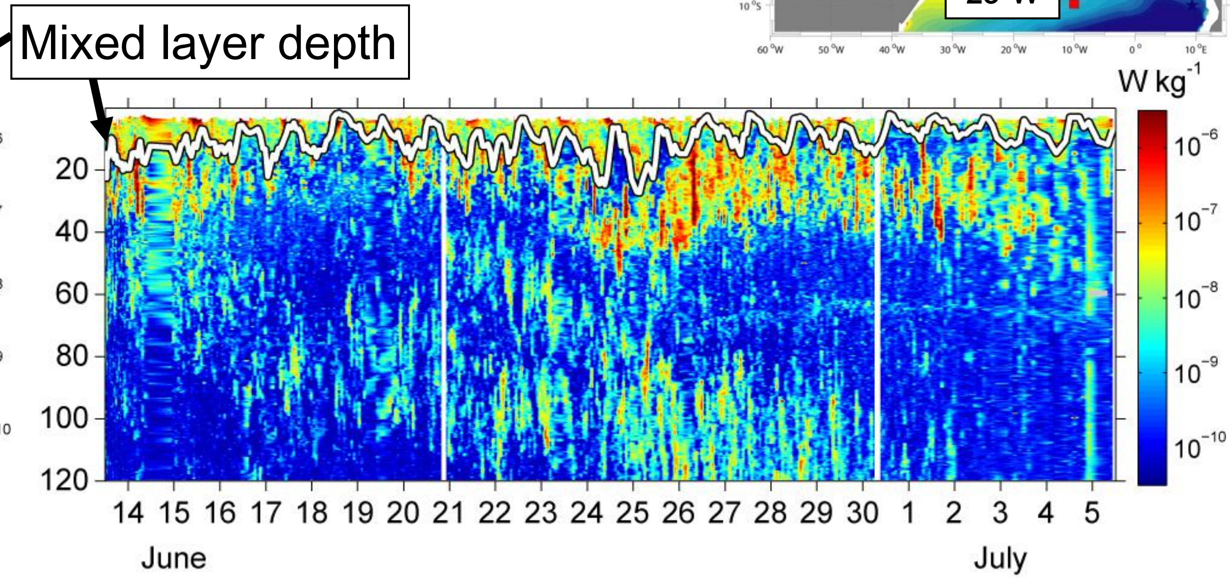
- MicroRider/glider package deployed at 10°W and 23°W
- glider were missioned to circle a PIRATA buoy

Time series of turbulent kinetic energy dissipation from a MicroRider/glider package

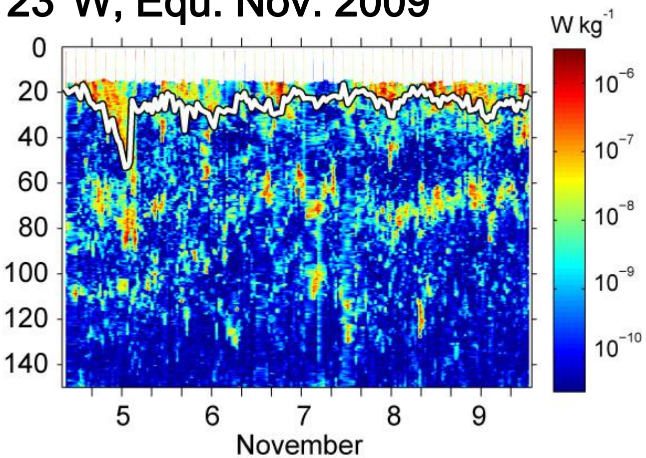


10°W, Equ., May-Jul. 2011

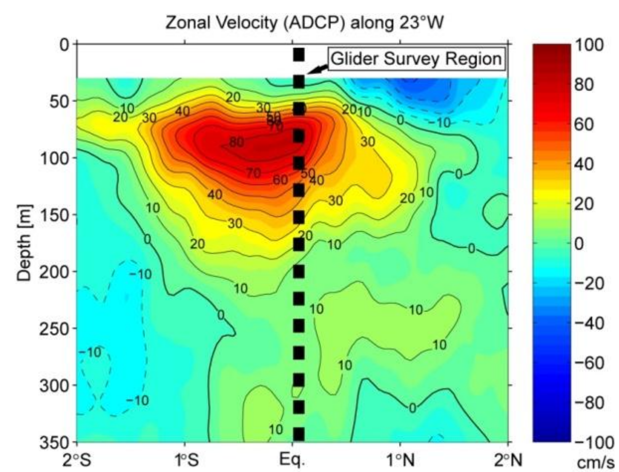




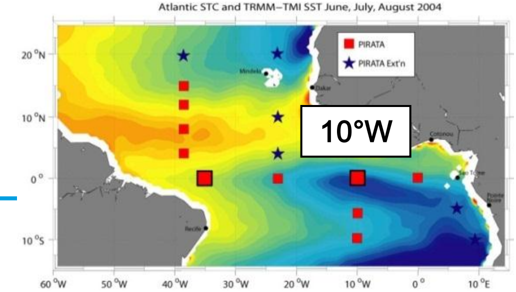
23°W, Equ. Nov. 2009

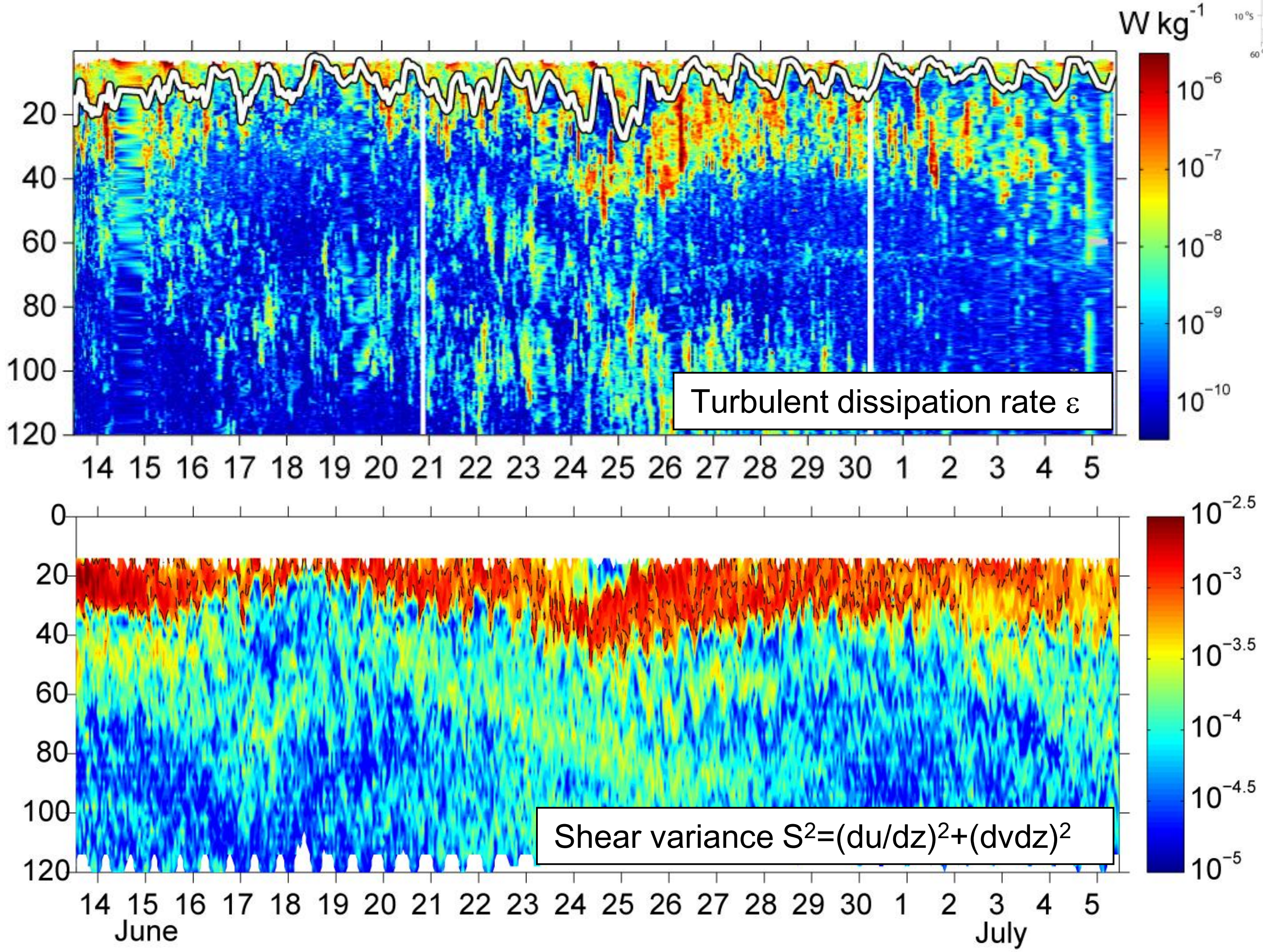


- bursts of elevated turbulence in the upper thermocline occur sporadically and last up to a few hours



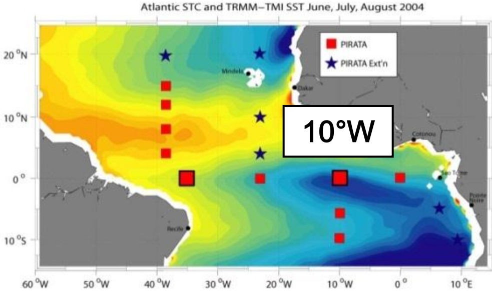
Vertical shear of horizontal current and turbulent kinetic energy dissipation rates

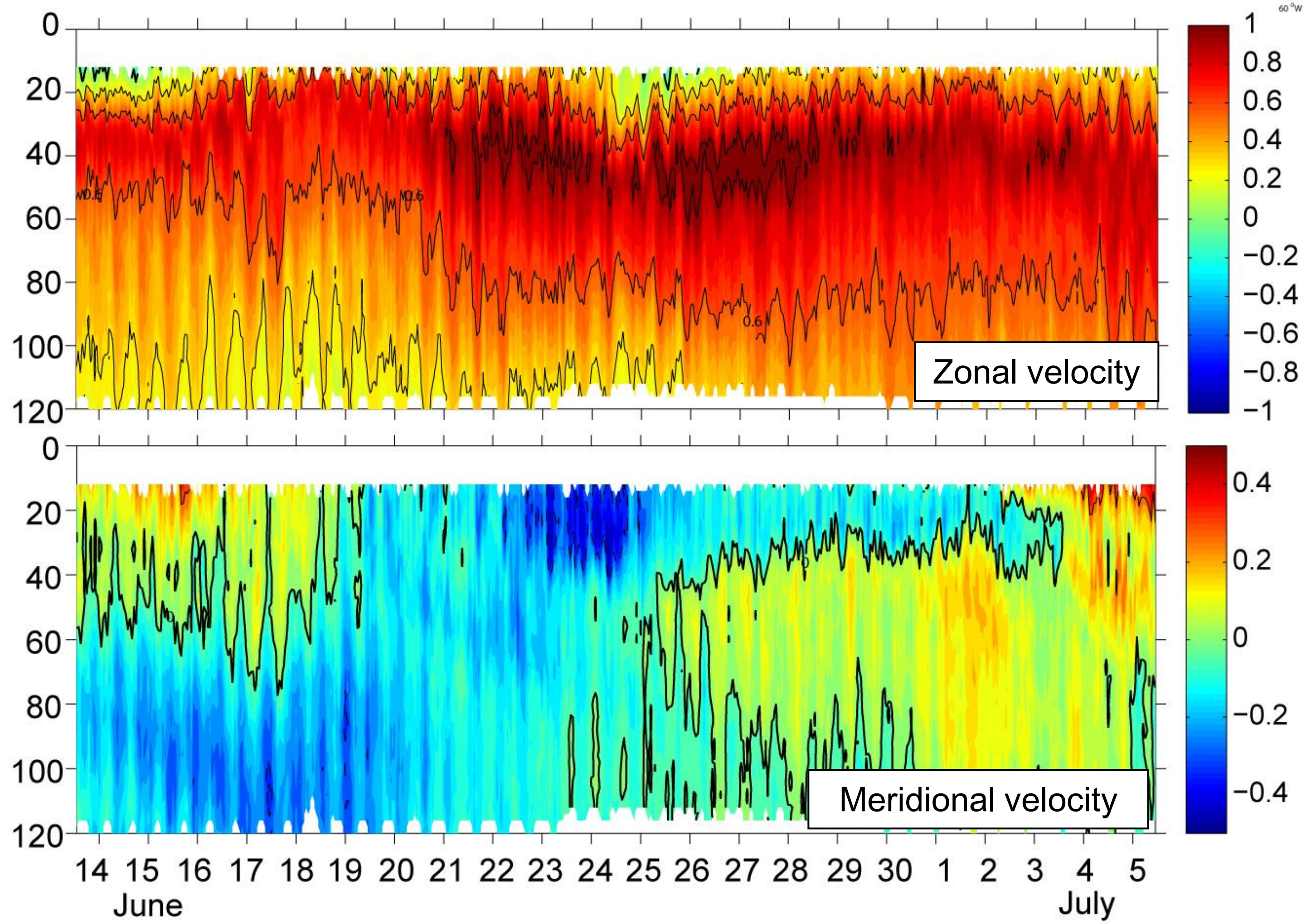




- elevated dissipation rates coincide with elevated shear variance

Horizontal currents observed during the 2011 MicroRider/Glider mission





- EUC core located at 30m-50m depth
- Strong tidal currents (baroclinic) with amplitude of ~8 cm s^{-1}

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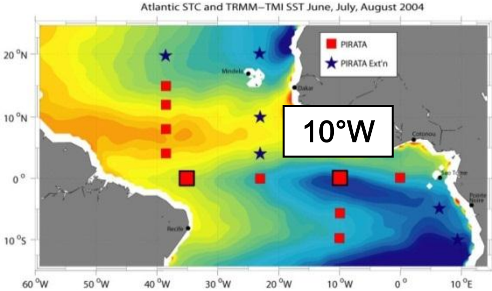
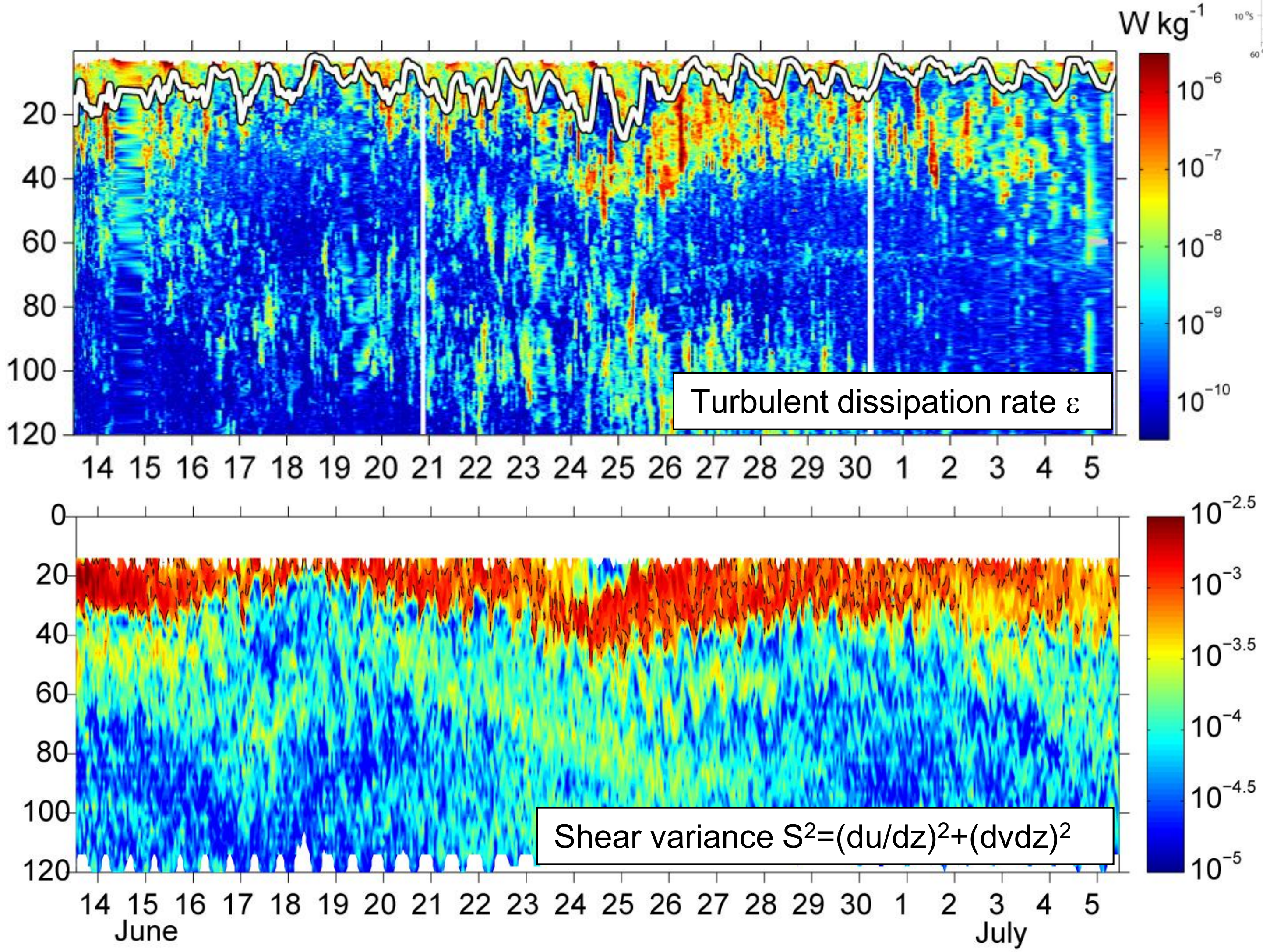
Vertical shear of horizontal current and turbulent kinetic energy dissipation rates





- elevated shear levels restricted to region above the EUC core
- background setting similar to equatorial Pacific

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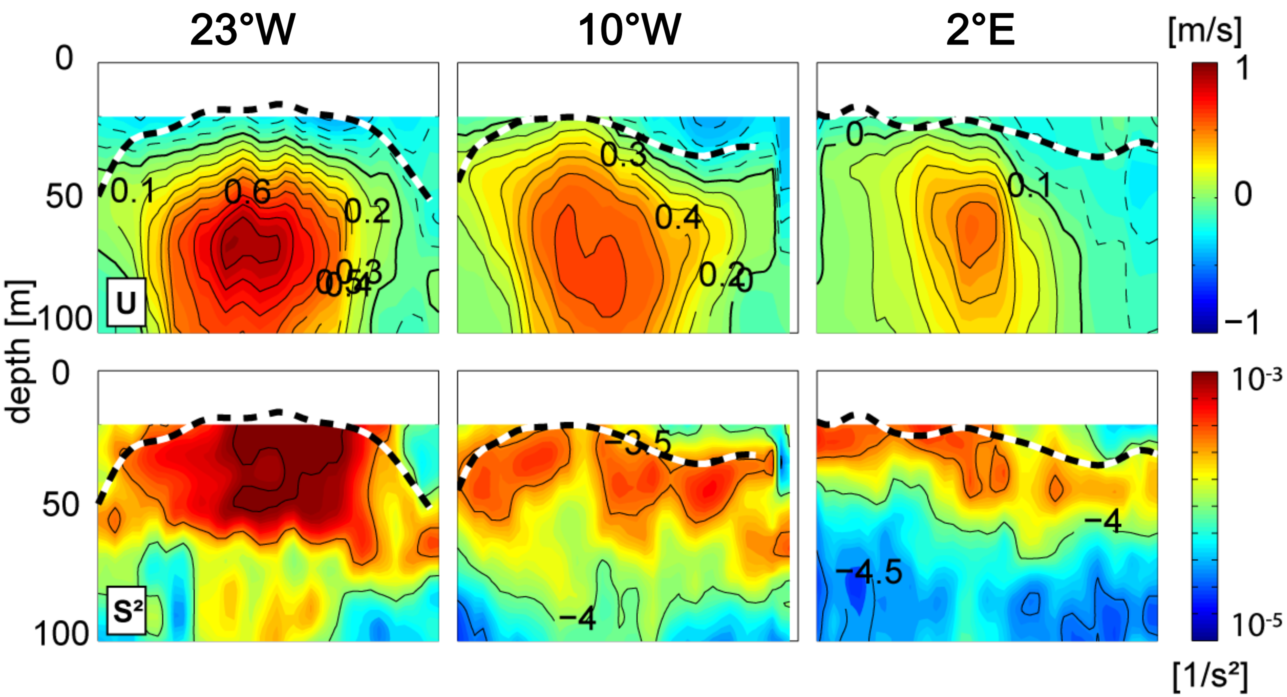
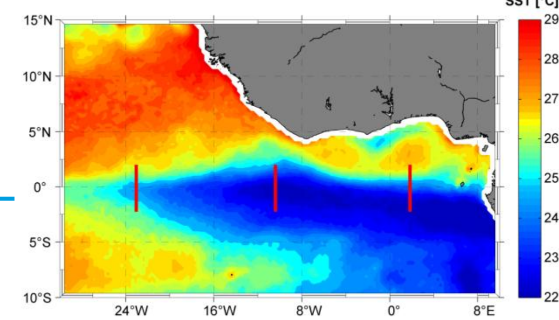
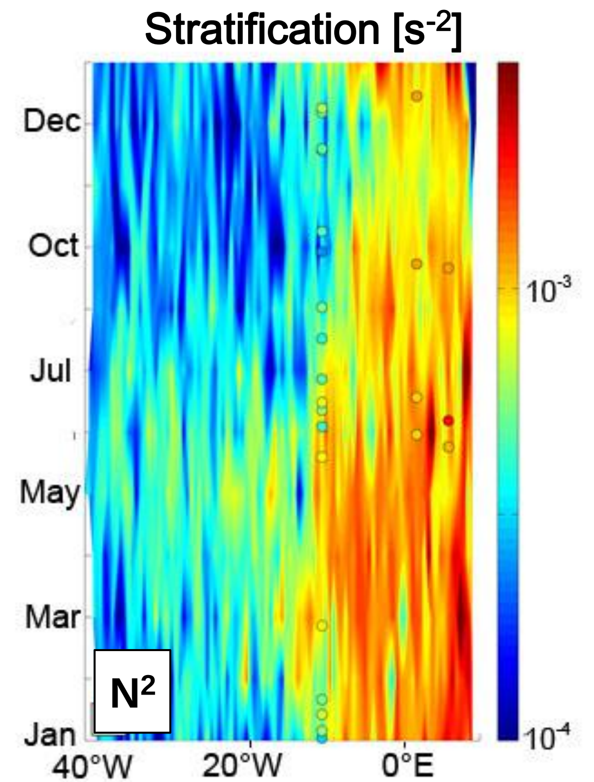
EUC shear and stratification at different longitudes







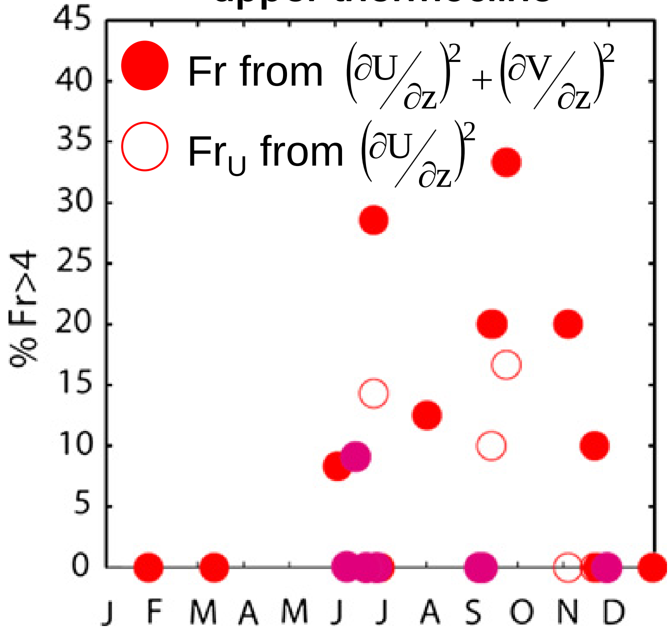
(Hummels et al, 2013)

- reduced EUC and SEC velocities and thus shear levels in the east
- upper ocean stratifications elevated in the east

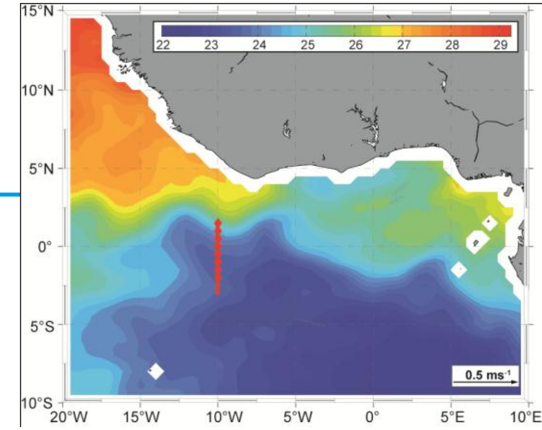
➢ less upper thermocline mixing in the eastern equatorial Atlantic.

Tropical Instability Waves and mixing

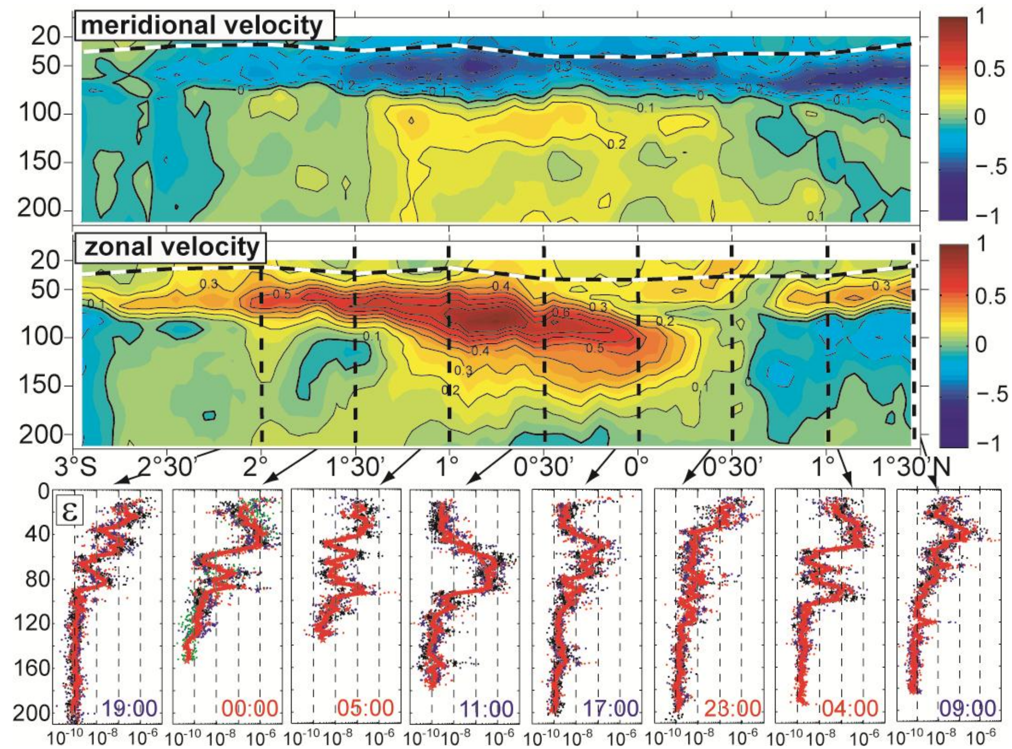
Froude number (Fr) in the upper thermocline



- meridional shear from e.g. TIW's frequently contributes to shear instability and thus enhances mixing



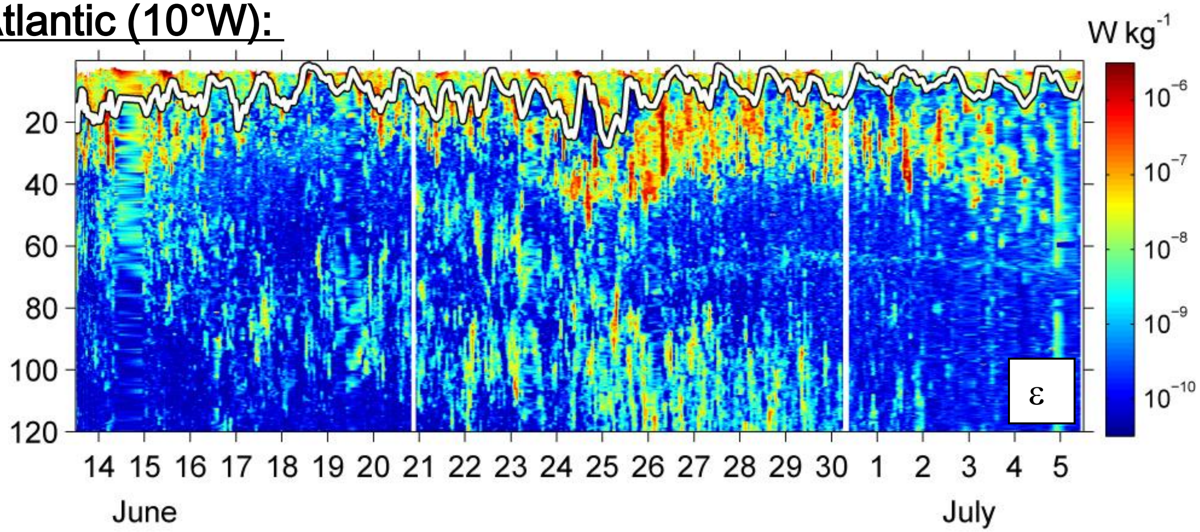
10°W Section (Sep '05)



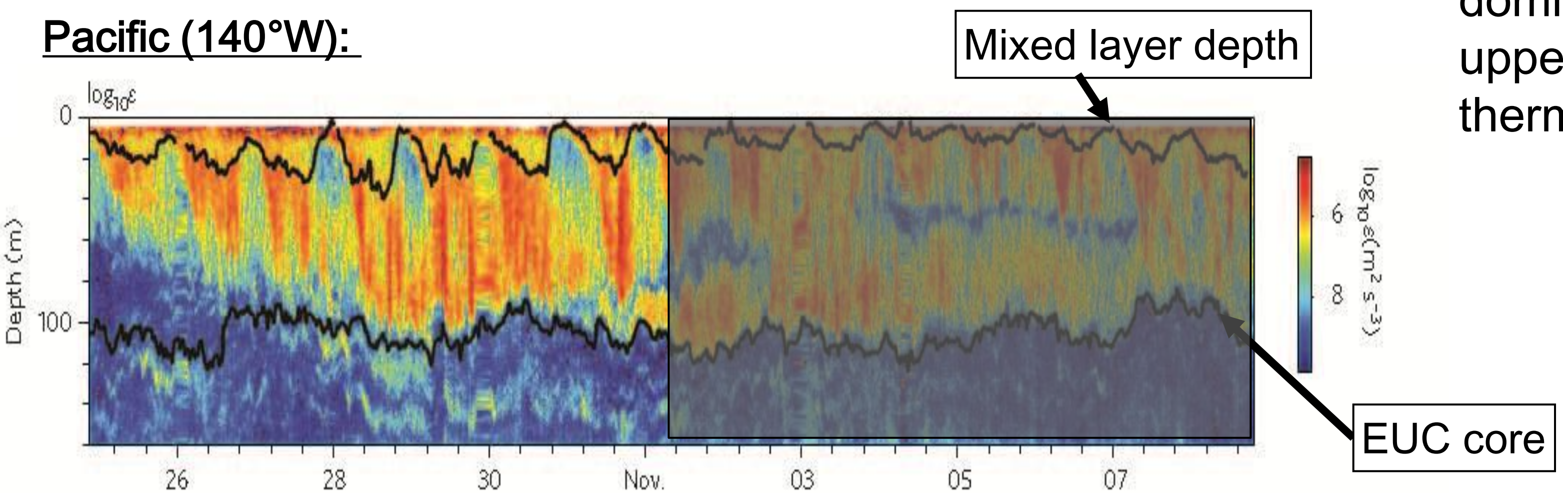
(Hummels et al, 2013)

Turbulent dissipation rate time series from the equatorial Atlantic and Pacific

Atlantic (10°W):



Pacific (140°W):



(Moum et al., 2009)

- elevated mixing region extends deeper in the Pacific
- diurnal variability dominant in the upper thermocline

Deep cycle turbulence in the Pacific (140°W)

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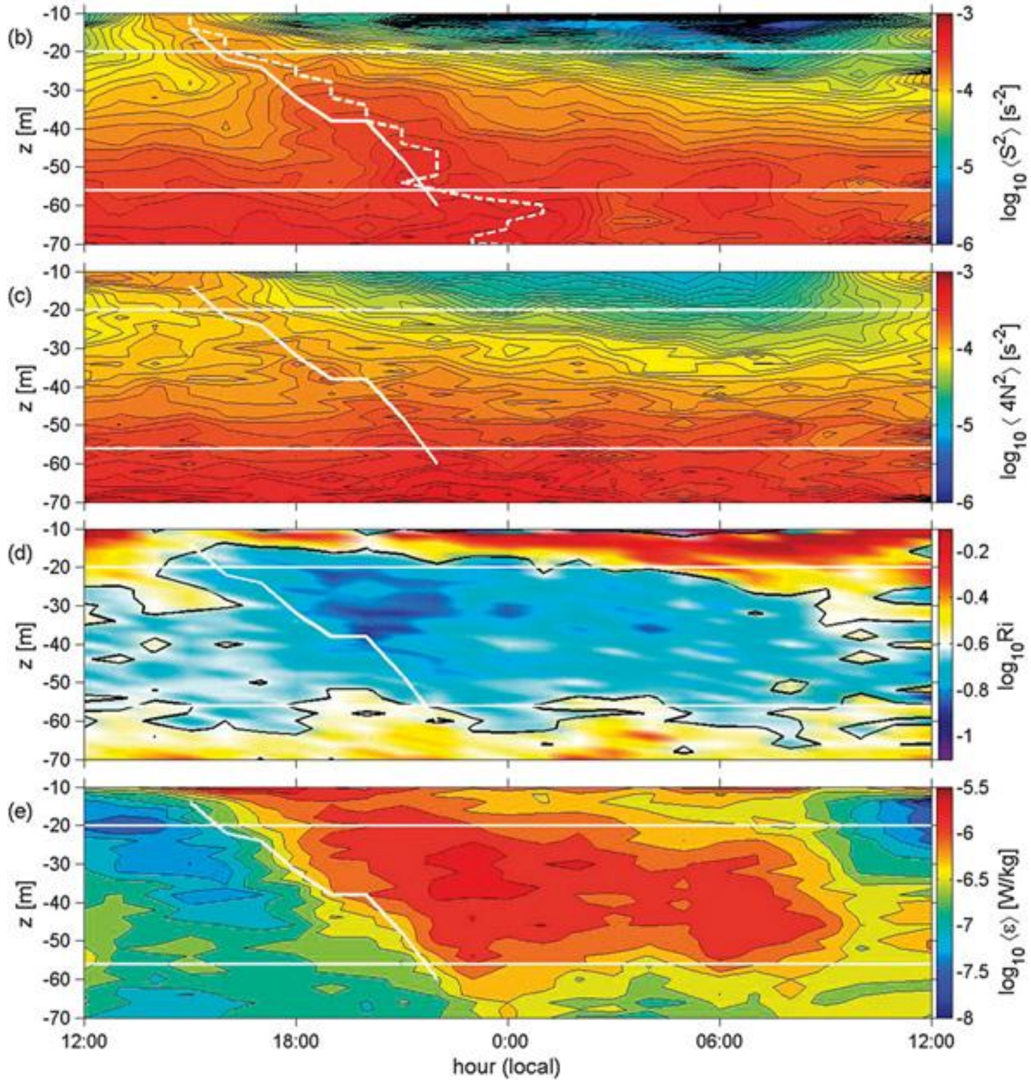

Shear variance
$S^2=(du/dz)^2+(dvdz)^2$

Stratification $4N^2$

Richardson Number ($\log_{10}$)

Turbulent dissipation rate

(Smyth et al., 2013)

- Smyth et al., (2013) propose local shear instability mechanism triggered by descending shear layer
- Pacific diurnal differences in dissipation rates one order of magnitude

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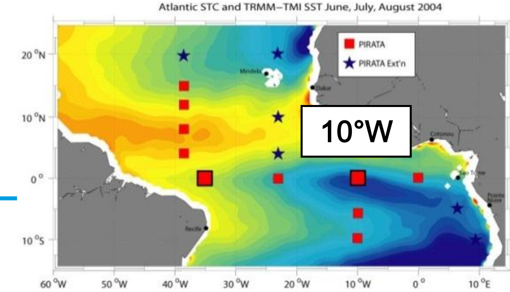
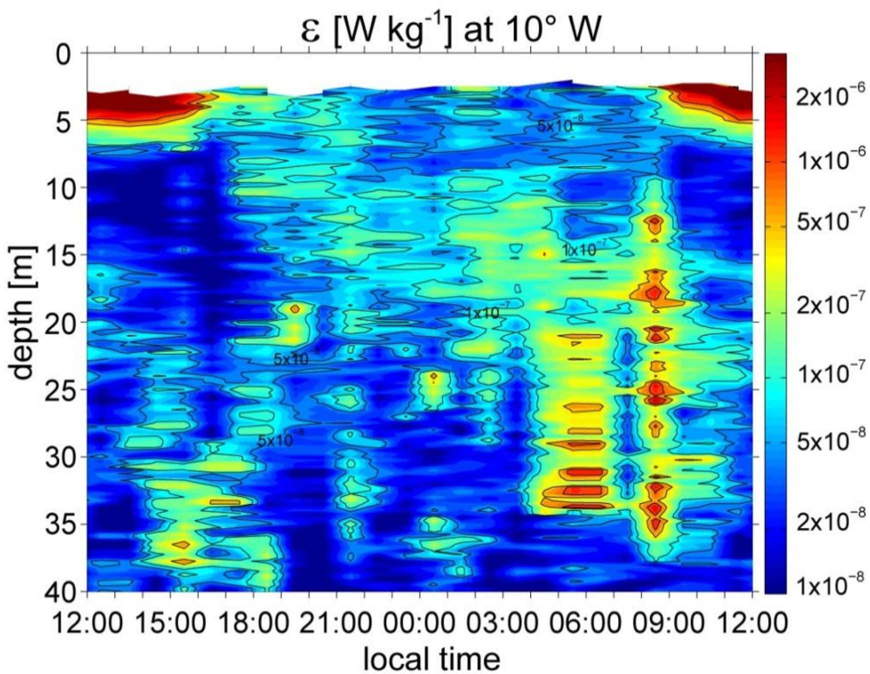
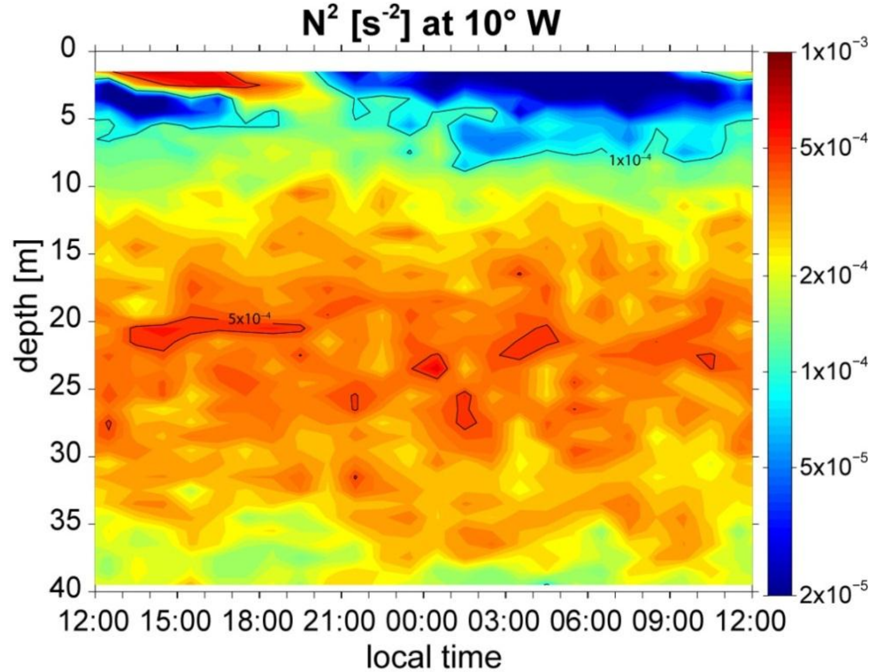
Deep cycle turbulent in the Atlantic (10°W)







- data are in agreement with local shear instability triggered by descending shear layer when daytime stratification weakens
- however, Atlantic deep cycle turbulence is less pronounced than in the Pacific (perhaps due to baroclinic tides)

The role of mixing in the 4.5-year climate cycle

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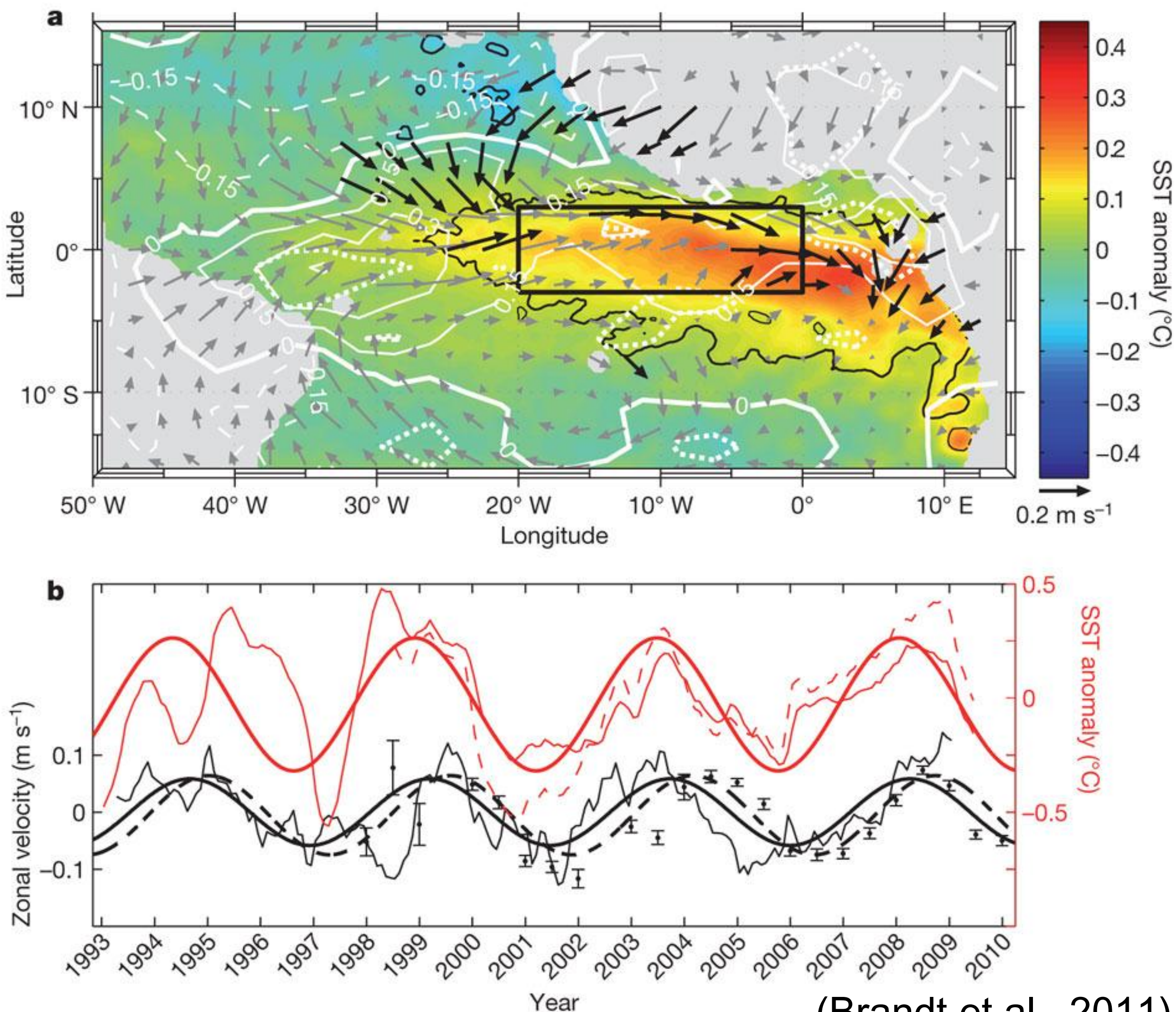

Correlated wind anomaly

Hadley Center SST

Satellite SST

4.5y SST harmonic

Surface zonal velocity anomaly (Satellite Alt.)

4.5y surface velocity

1000m velocity (ARGO)

4.5y 1000m velocity

(Brandt et al., 2011)

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The role of mixing in the 4.5-year climate cycle

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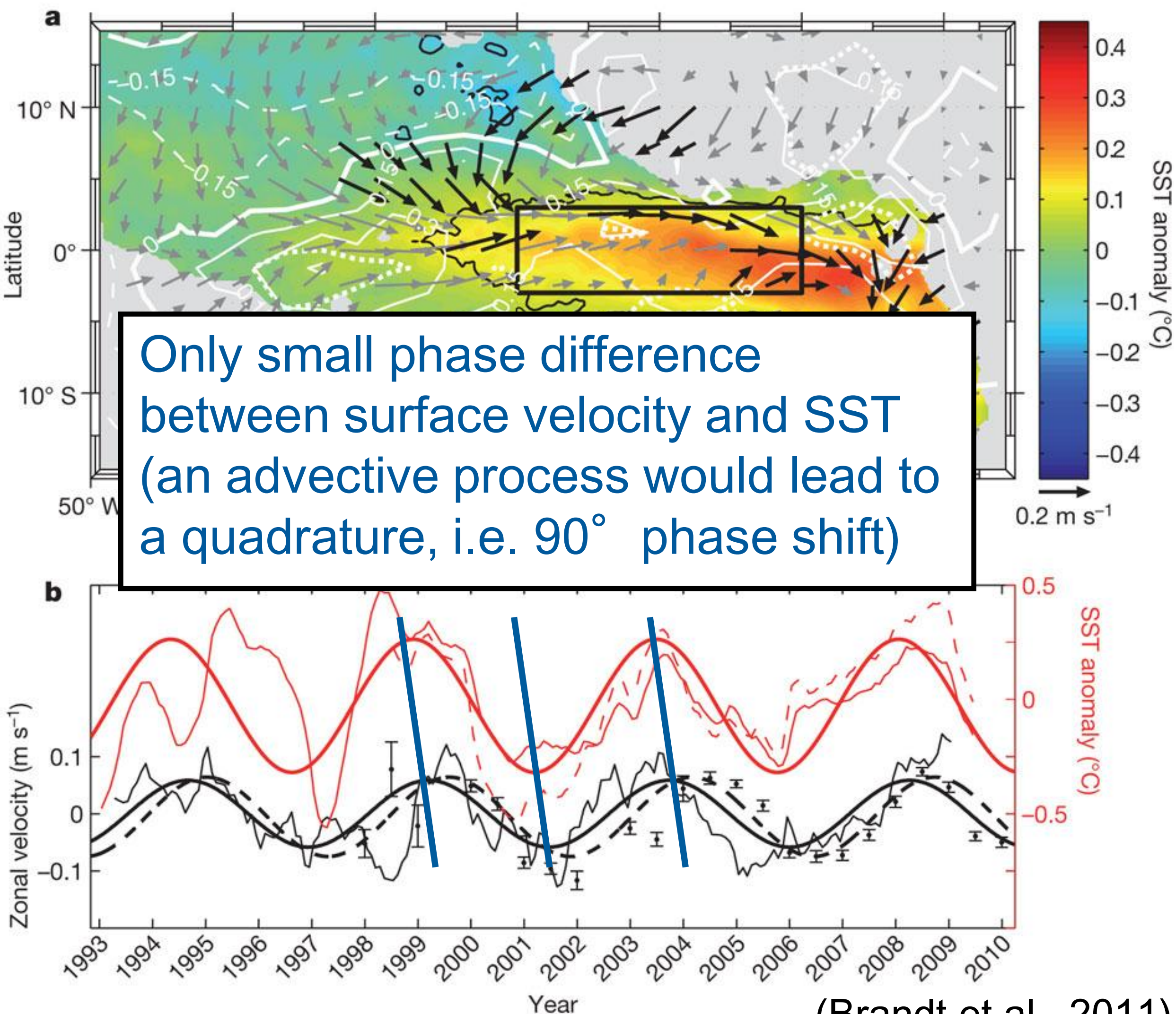

Only small phase difference between surface velocity and SST (an advective process would lead to a quadrature, i.e. 90° phase shift)

Correlated wind anomaly

Hadley Center SST

Satellite SST

4.5y SST harmonic

Surface zonal velocity anomaly (Satellite Alt.)

4.5y surface velocity

1000m velocity (ARGO)

4.5y 1000m velocity

(Brandt et al., 2011)

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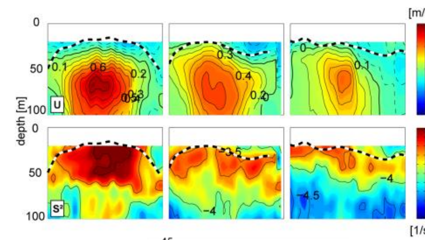
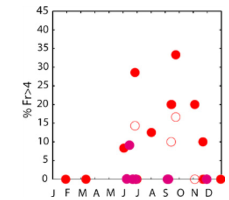
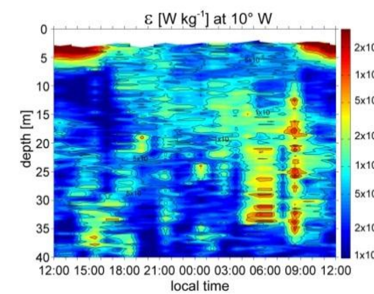
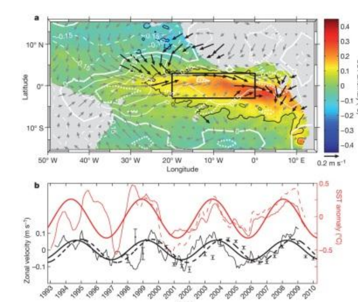
Conclusions

- Geographic upper ocean mixing variability is set by background shear and stratification. Less mixing in the eastern equatorial Atlantic
- Dominant mixing processes in the equatorial Atlantic are mostly similar to what is known from the equatorial Pacific
- Atlantic deep cycle turbulence is reduced by a factor of 3 compared to the Pacific
- Thermocline mixing contributes to interannual SST variability within the 4.5 year climate cycle

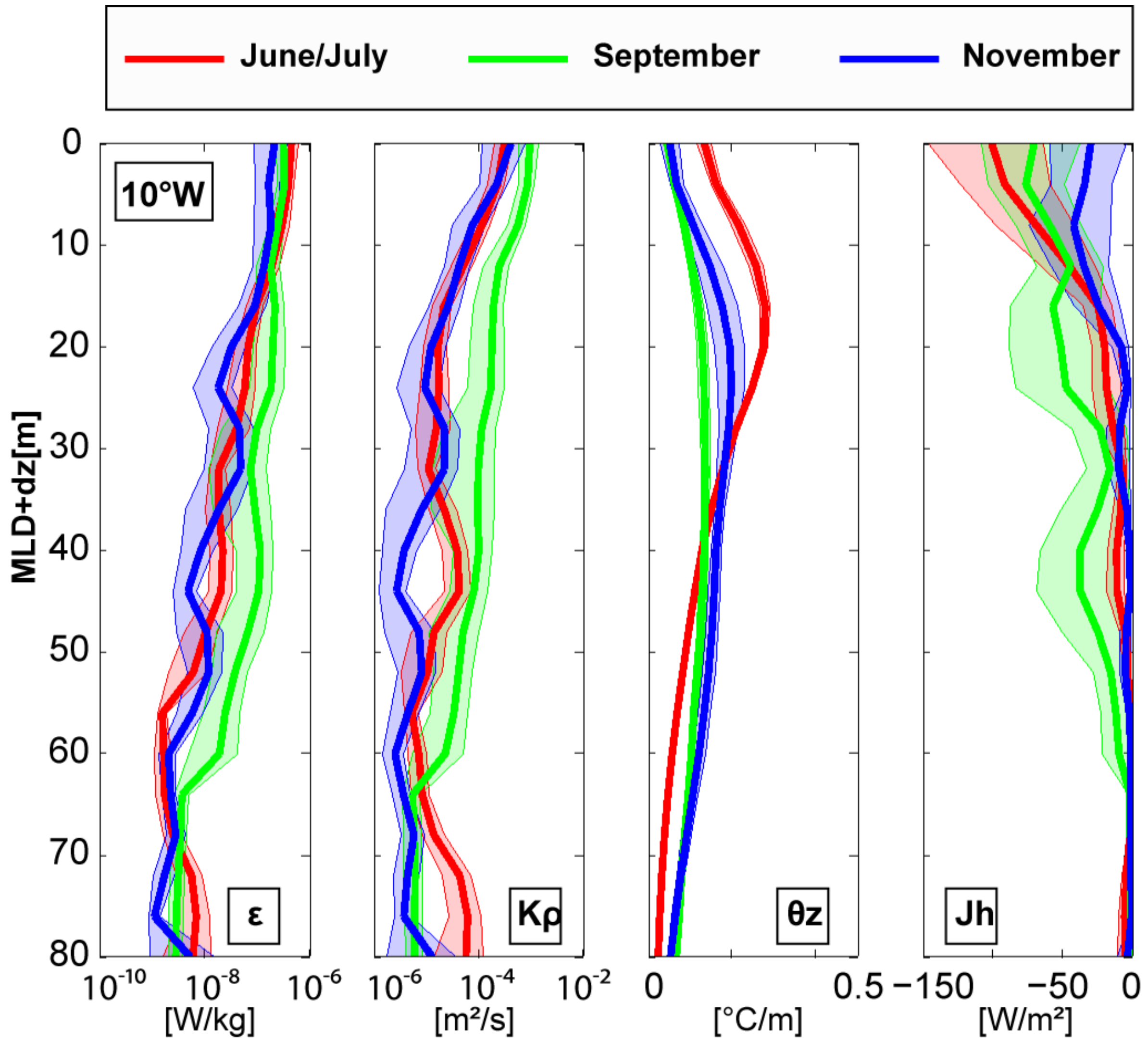








Seasonal Variabilty of Mixing Parameters



- At the equator (10°W) elevated dissipation rates from June to November resulting in a significant heat flux below the MLD