PIRATA 23 Meeting, Marseille, France | 22.10.2018

Near inertial wave induced mixing in the tropical Atlantic Ocean

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PIRATA 23 Meeting, Marseille, France | 22.10.2018

Turbulent mixing and its contribution to the Mixed-Layer heat budget in the tropical Atlantic

R. Hummels

in collaboration with: M. Dengler, P. Brandt, W. Rath, G. R. Foltz, F. Schütte, T. Fischer, B. Bourlés, M. Schlundt

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Turbulent mixing and Mixed Layer Heat Balance in the eastern equatorial Atlantic

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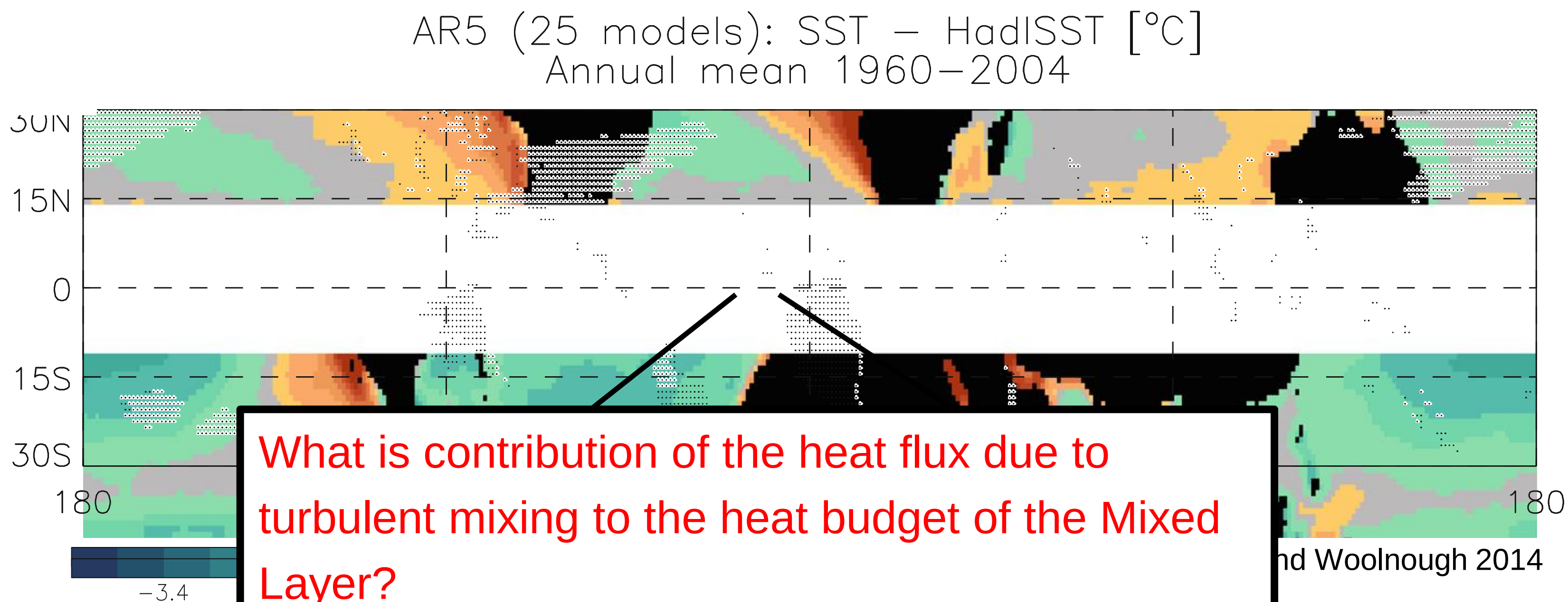
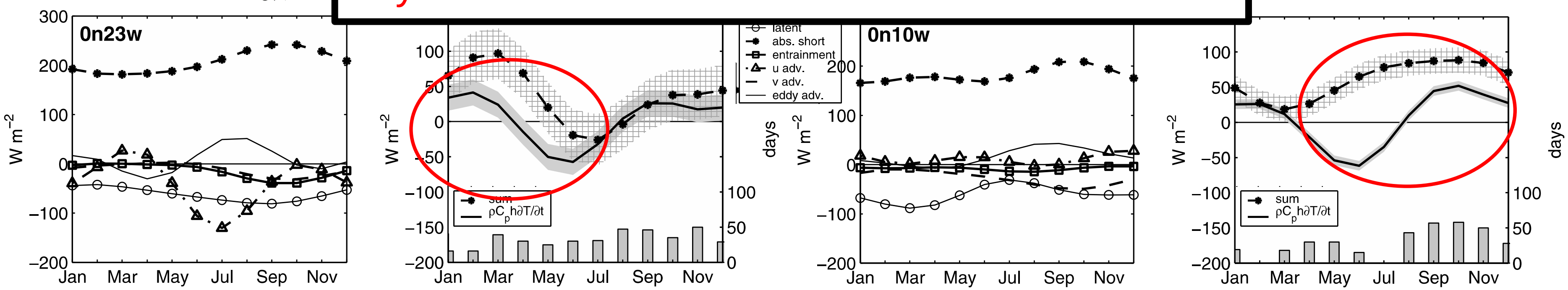


What is contribution of the heat flux due to turbulent mixing to the heat budget of the Mixed Layer?



Foltz et al. 2003

Turbulent mixing and Mixed Layer Heat Balance in the eastern equatorial Atlantic

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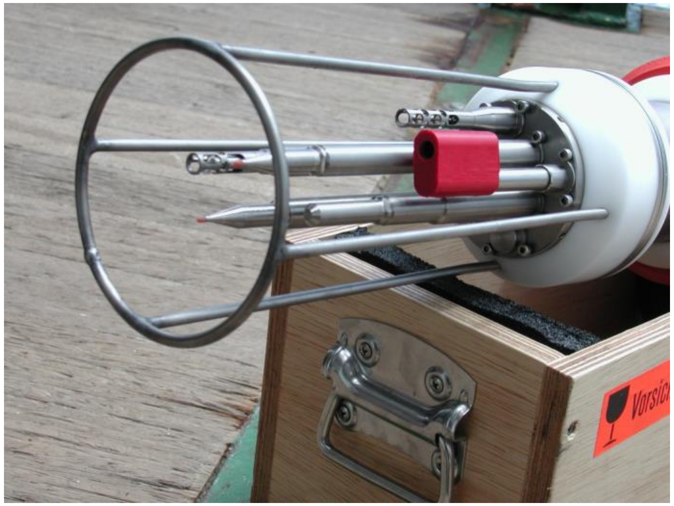


- CTD sensors → T, C, p → $\rho, c_p, \left(\frac{\partial \bar{\theta}}{\partial z}\right), N^2$
- Shear sensors → $\left(\frac{\partial u'}{\partial z}\right)$ → J_{heat}
- Dissipation rate of turbulent kinetic energy for isotropic turbulence is given by: $\varepsilon = 7.5\nu\overline{\left(\frac{\partial u'}{\partial z}\right)^2}$

- Eddy diffusivities for mass:

$$K_\rho = \Gamma \frac{\varepsilon}{N^2}, \quad \Gamma = R_f/(1-R_f) \approx 0.2$$

(Osborn, 1980)

- Diapycnal heat flux due to turbulence:

$$J_{heat} = -\rho c_p K_\rho \left(\frac{\partial \bar{\theta}}{\partial z}\right)$$

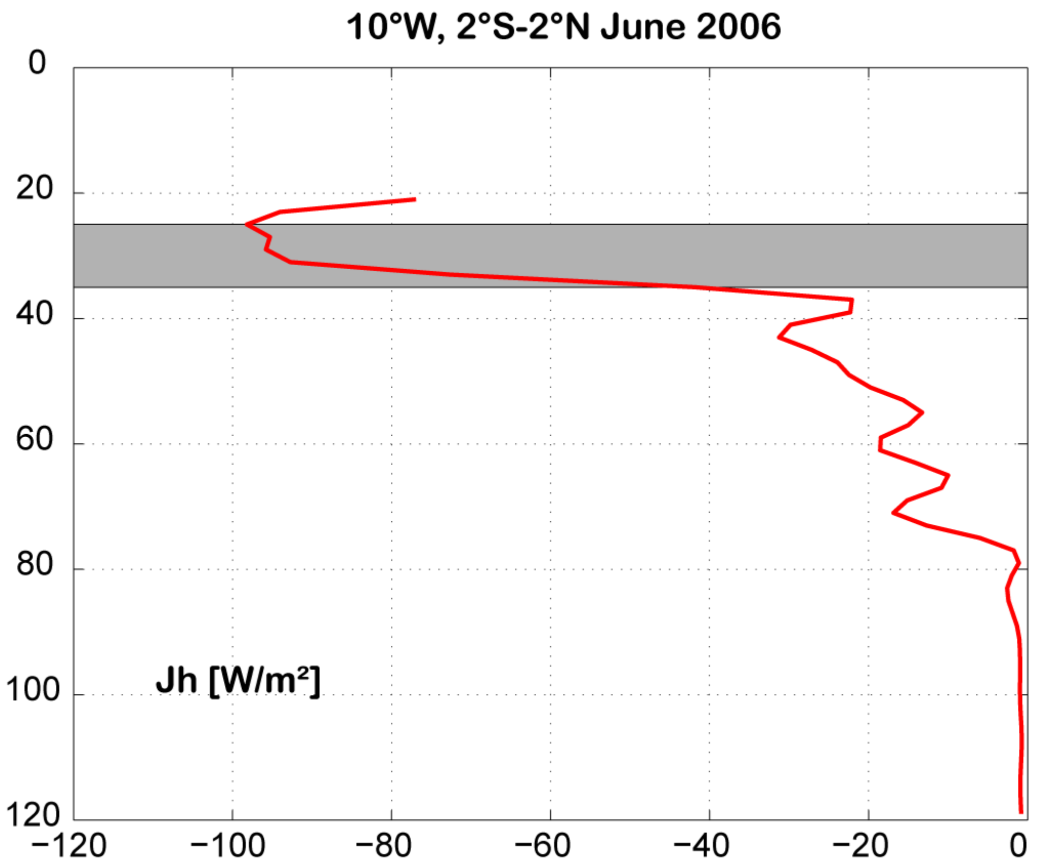
(Osborn and Cox, 1972)

Turbulent mixing and Mixed Layer Heat Balance in the eastern equatorial Atlantic

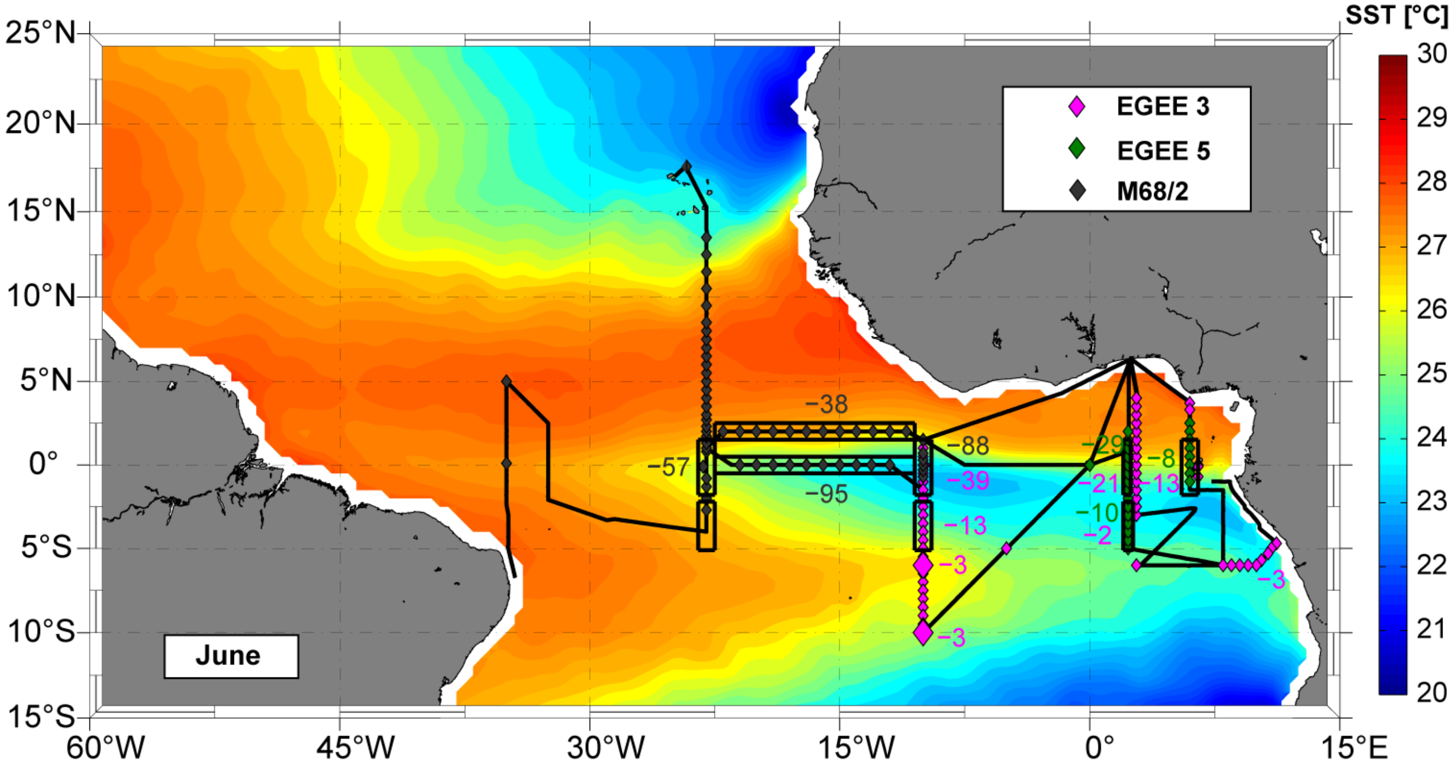
MLD →

- Divergent profile of diapycnal heat flux

- heat loss of the ML due to diapycnal mixing is defined as diapycnal heat flux in thin layer below the ML
  (MLD+5 m – MLD +15 m)



Turbulent mixing and Mixed Layer Heat Balance in the eastern equatorial Atlantic

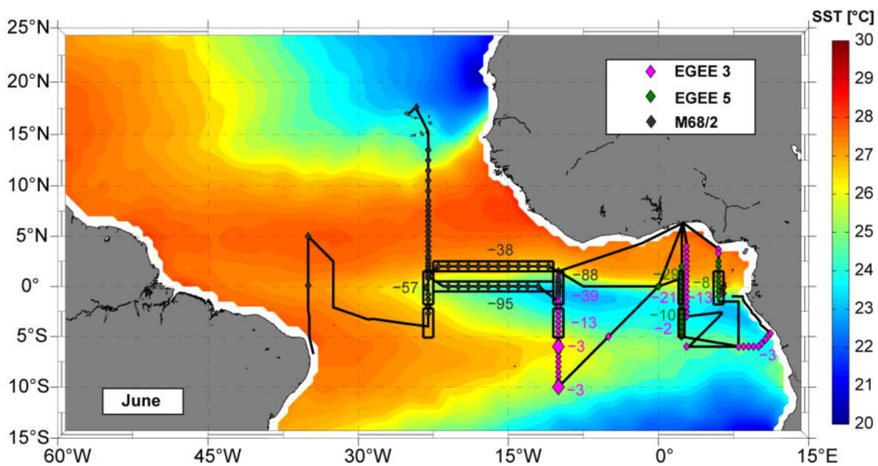


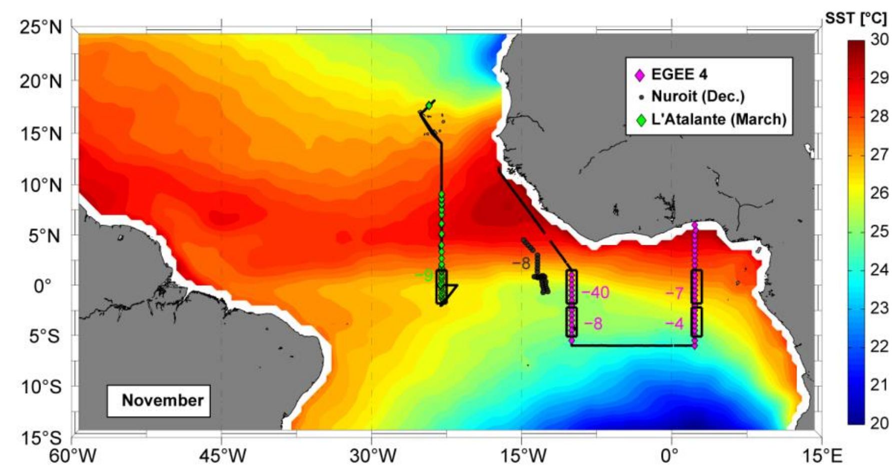
Hummels et al. 2013

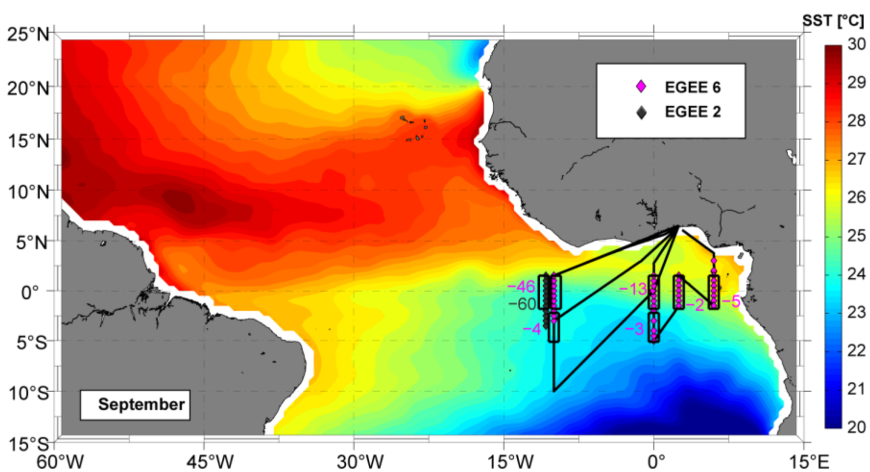
<u>Elevated turbulent heat loss of the mixed layer (ML)</u>

- within the equatorial region
- in the western equatorial region compared to the east

Turbulent mixing and Mixed Layer Heat Balance in the eastern equatorial Atlantic







Hummels et al. 2013

Elevated turbulent heat loss of ML

- within the equatorial region
- in the western equatorial region compared to the east
- in early summer compared to September and November

Turbulent mixing and Mixed Layer Heat Balance in the eastern equatorial Atlantic

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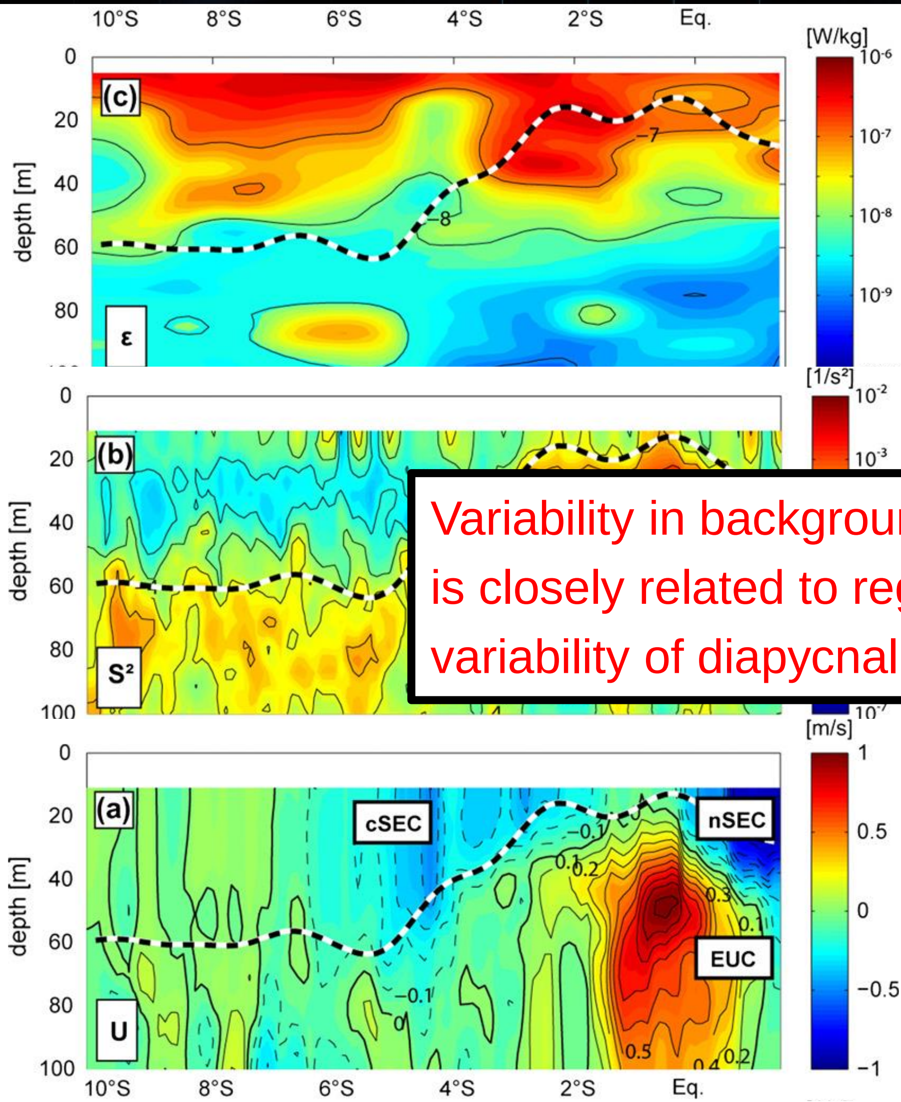

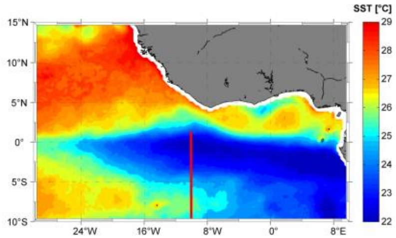

4°S-2°N (equatorial region)

- flat MLDs
- strong currents (EUC,cSEC,nSEC)

$$S^2 = \left(\frac{du}{dz}\right)^2 + \left(\frac{dv}{dz}\right)^2$$

Variability in background shear and stratification is closely related to regional and seasonal variability of diapycnal heat loss of the ML

- 10°S-4°S (southern ACT):
- deep MLDs
- no strong current bands
- moderate shear levels
- background ϵ below MLD

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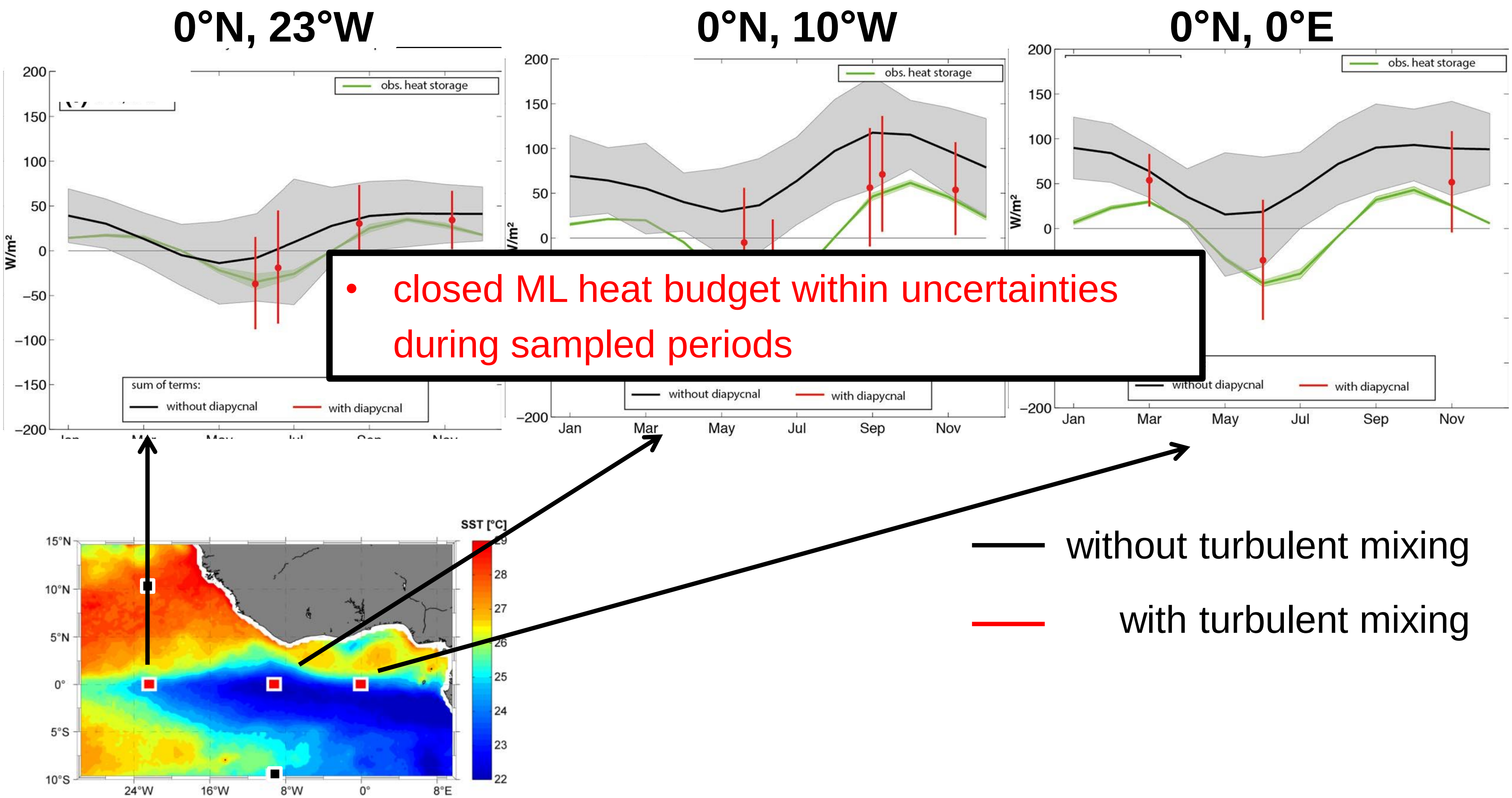
Turbulent mixing and Mixed Layer Heat Balance in the eastern equatorial Atlantic



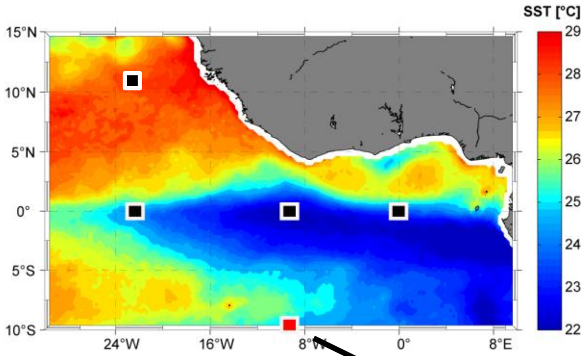
- closed ML heat budget within uncertainties during sampled periods

without turbulent mixing

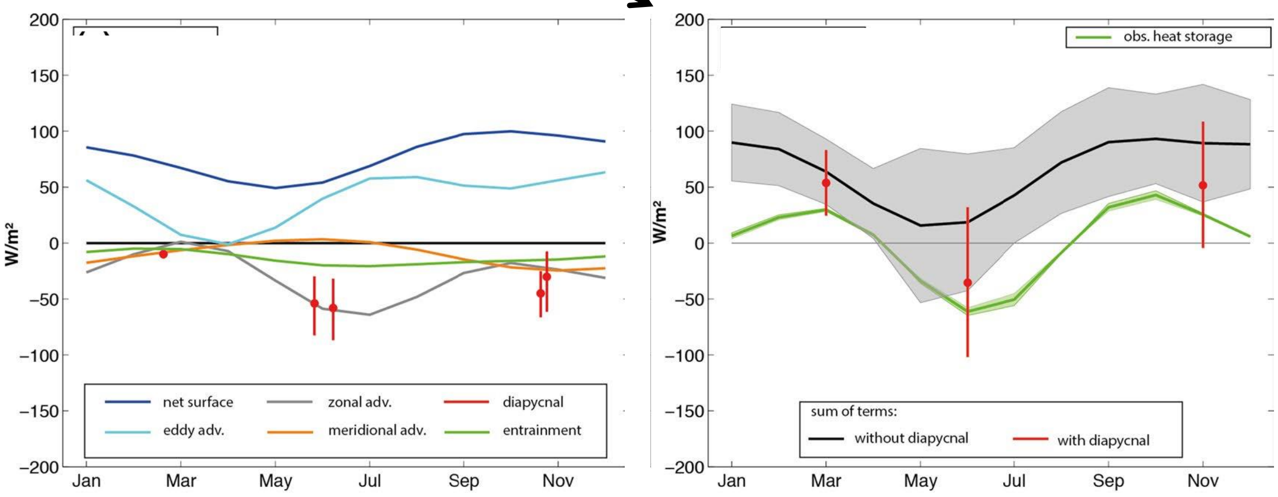
with turbulent mixing

Hummels et al. 2014

Turbulent mixing and Mixed Layer Heat Balance at off-equatorial locations



10°S, 10°W

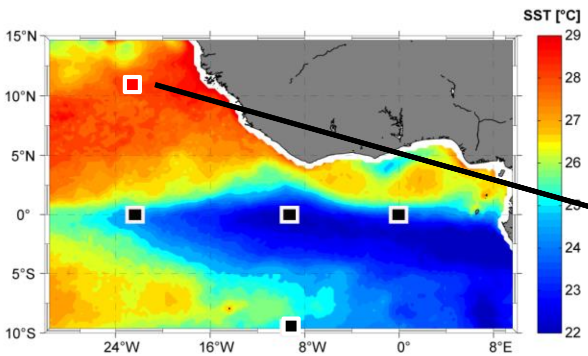


without turbulent mixing

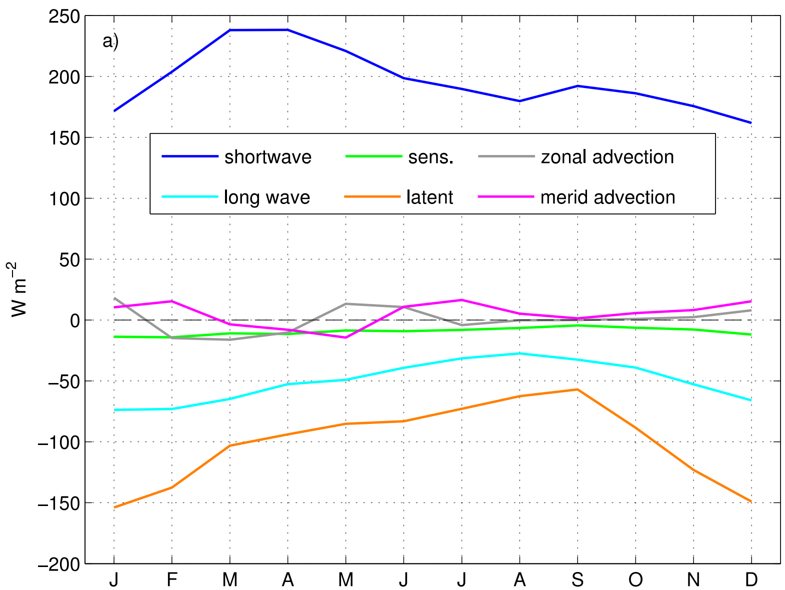
with turbulent mixing

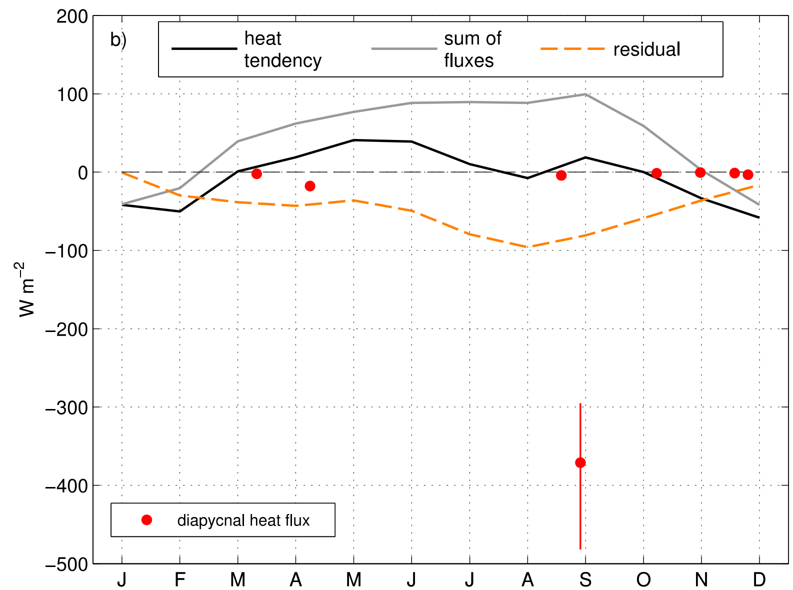
Hummels et al. 2014

Turbulent mixing and Mixed Layer Heat Balance at off-equatorial locations



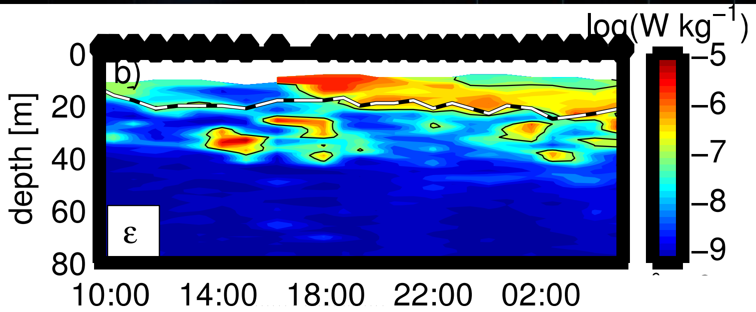
11.5°N, 23°W

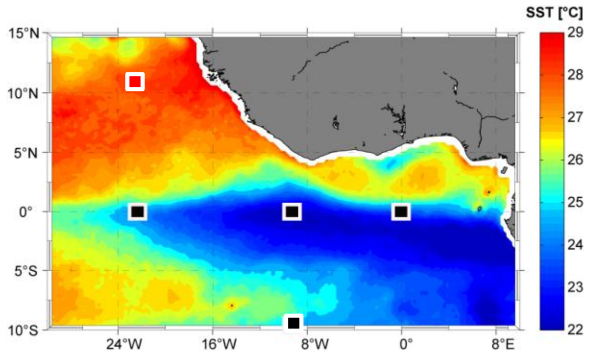




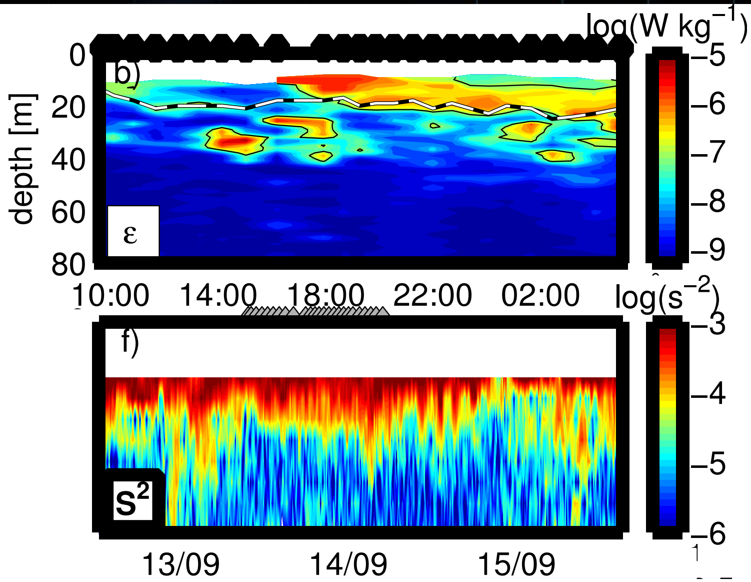
Hummels et al. 2018, submitted

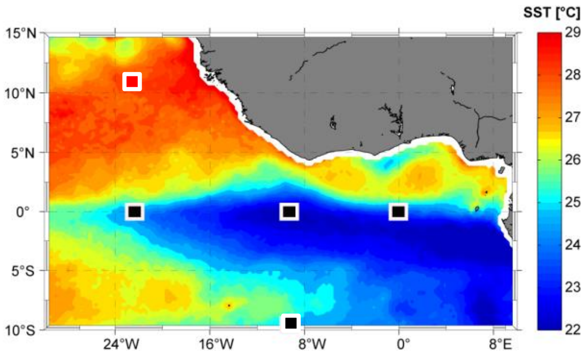
Turbulent mixing and Mixed Layer Heat Balance at off-equatorial locations



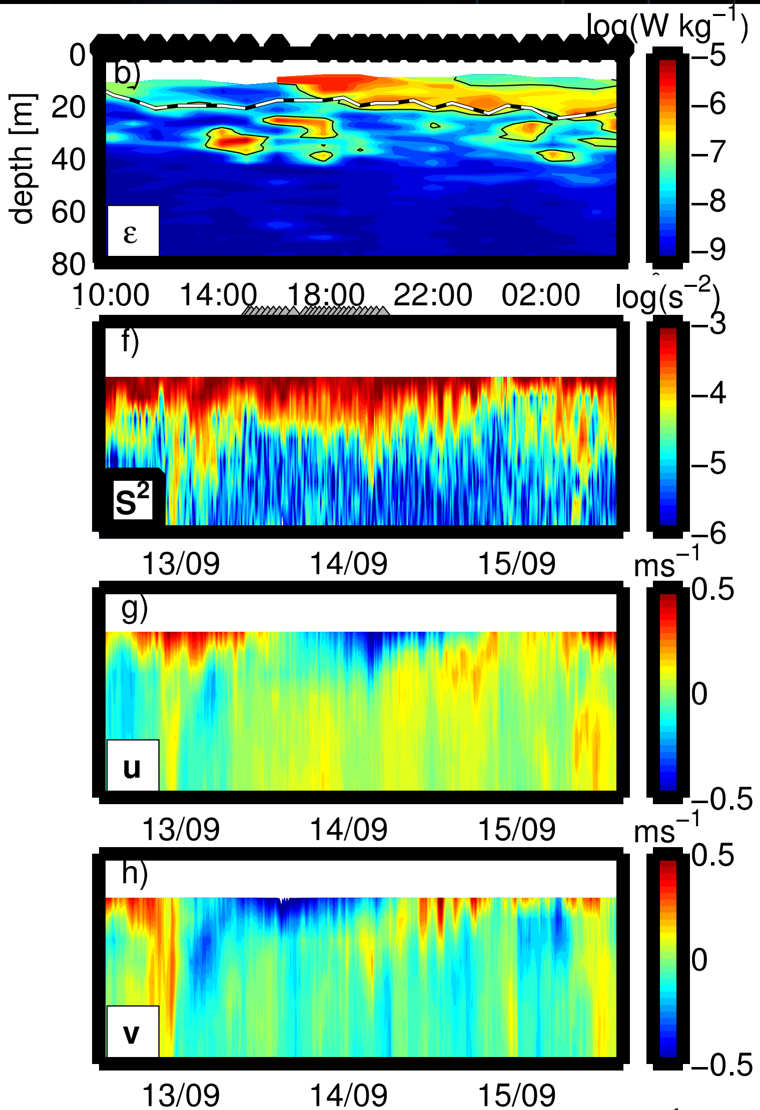


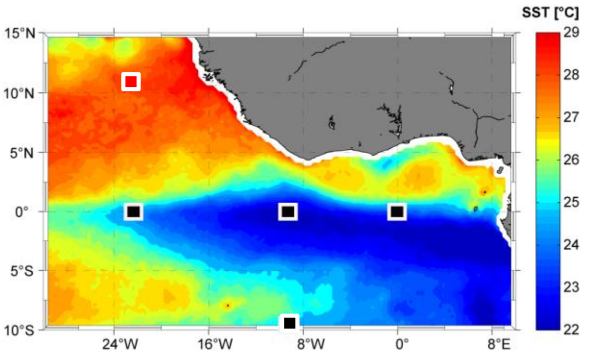
Turbulent mixing and Mixed Layer Heat Balance at off-equatorial locations





Turbulent mixing and Mixed Layer Heat Balance at off-equatorial locations

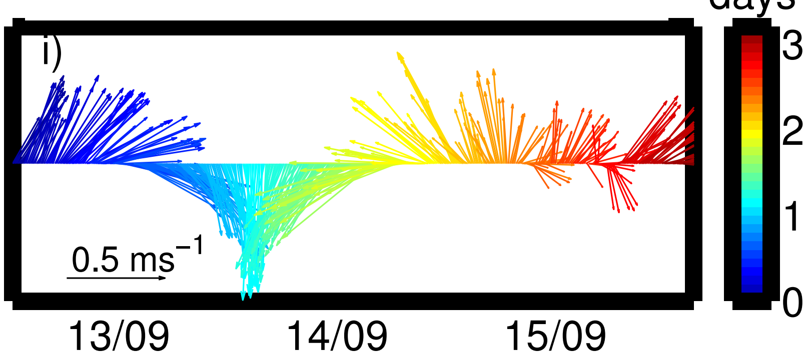




Near inertial period at 11.5°N:

2-2.5 days (1-1.2 x f)

T = 2.4 days



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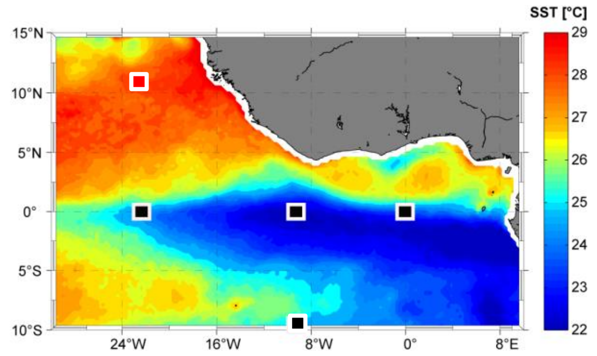
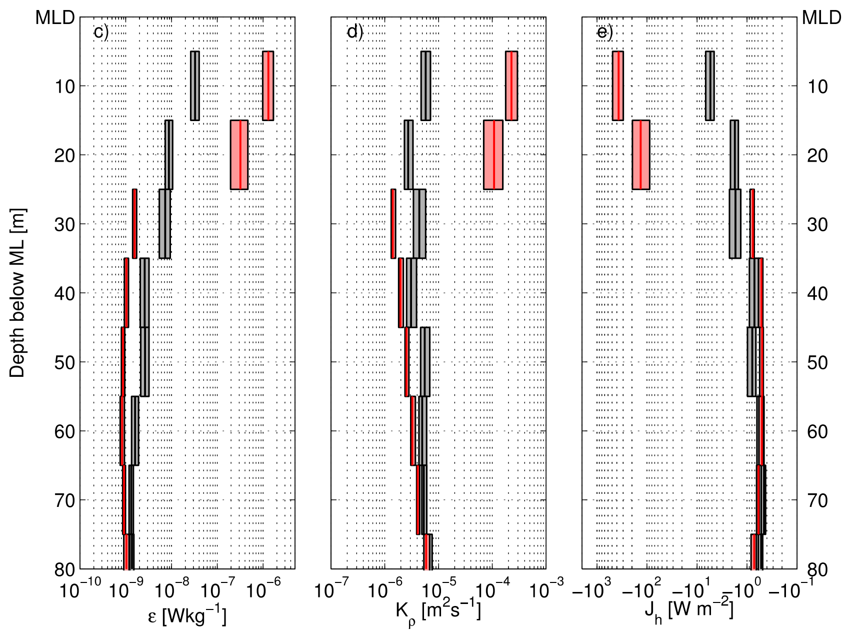
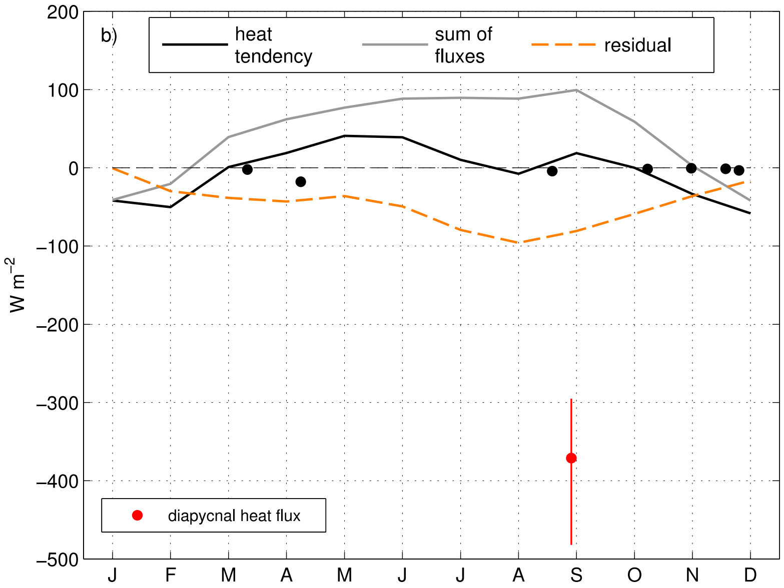


— background turbulent mixing

— NIW induced turbulent mixing





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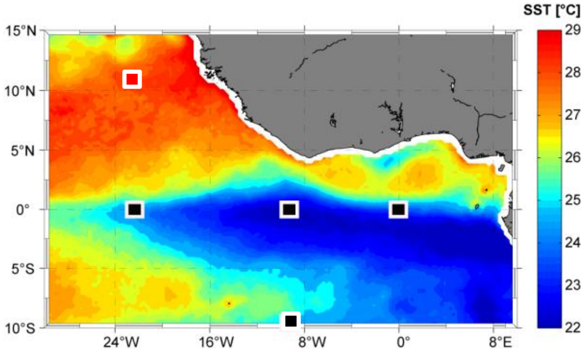
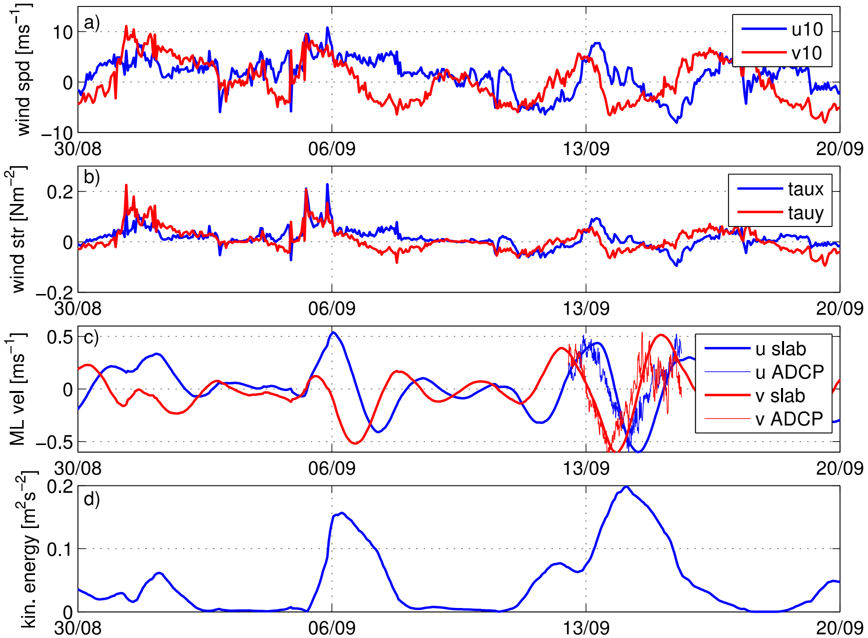
Tune Slab Ocean model to PIRATA ML velocities at 12m



- PIRATA winds
- Smoothed ePIRATA Mixed Layer Depth
- Damping time scale 5 days



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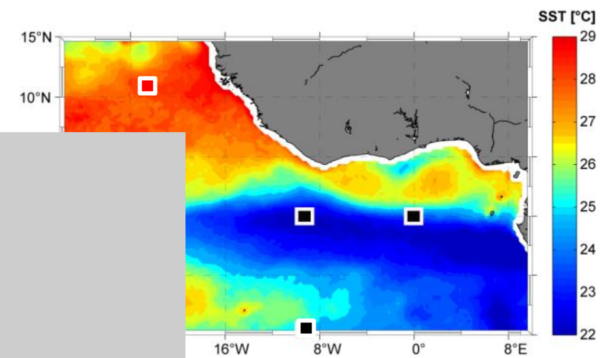

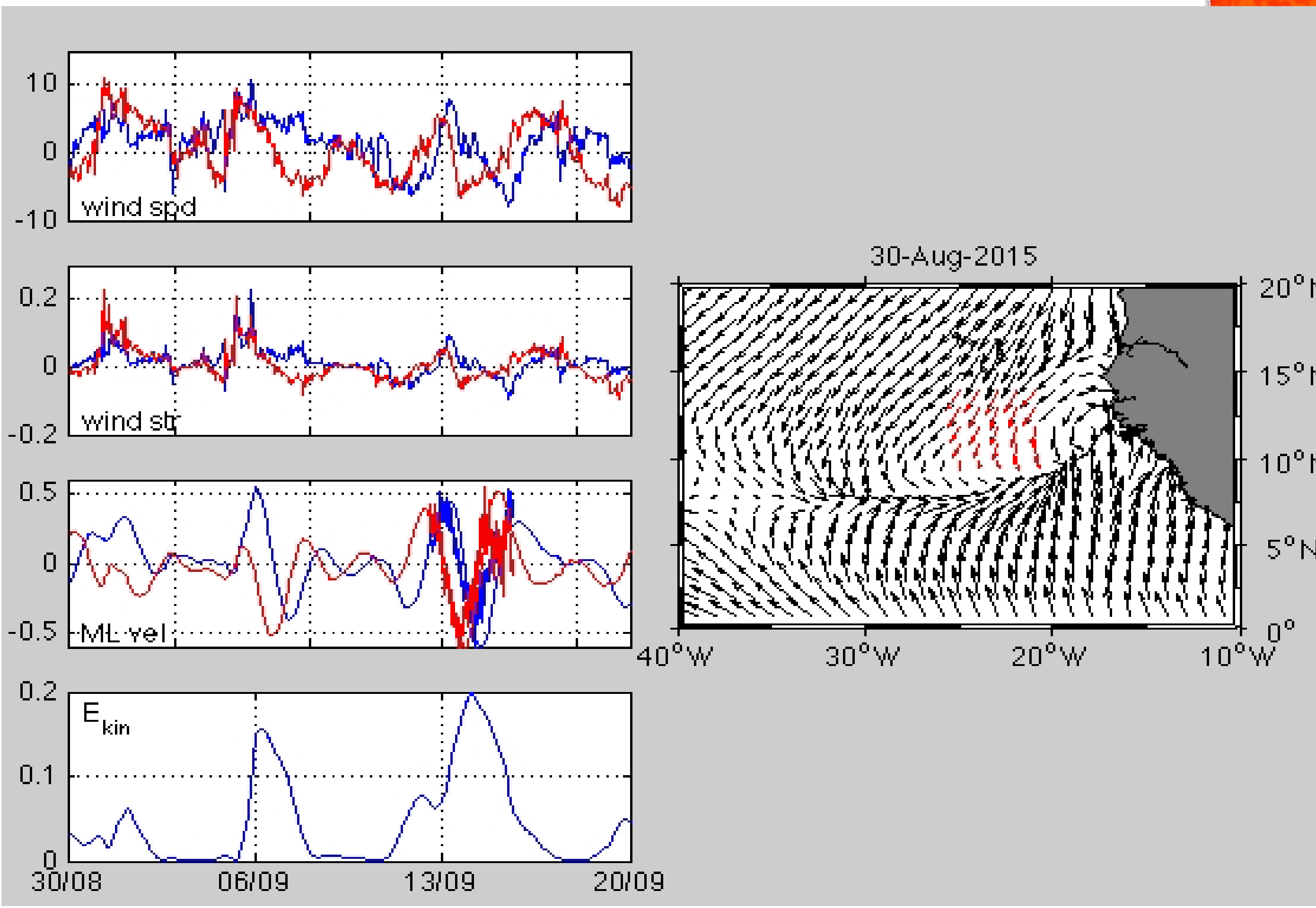

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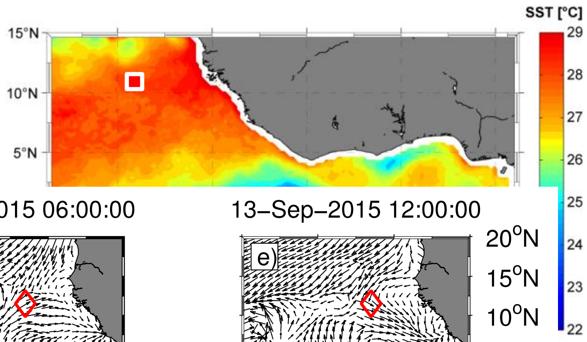

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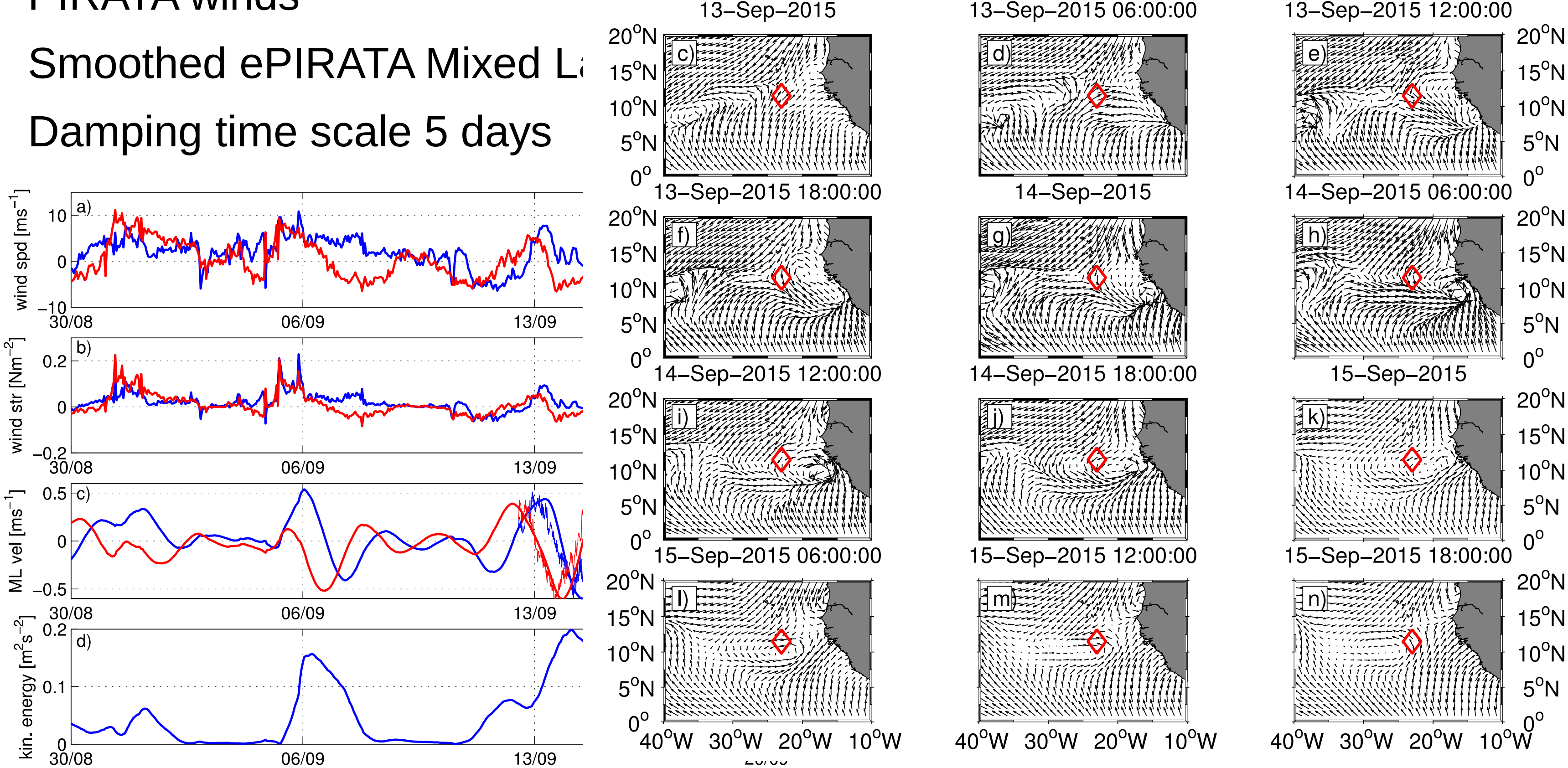

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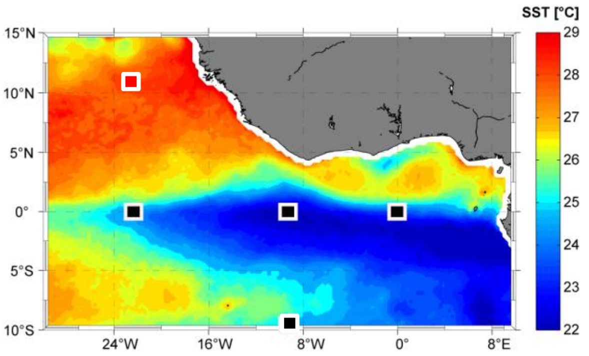
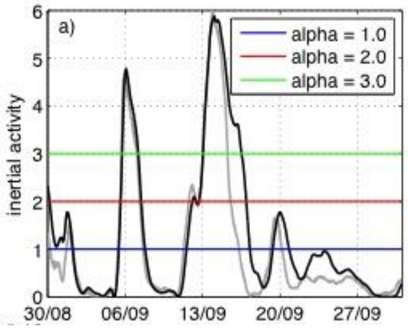
How often do similar events occur?



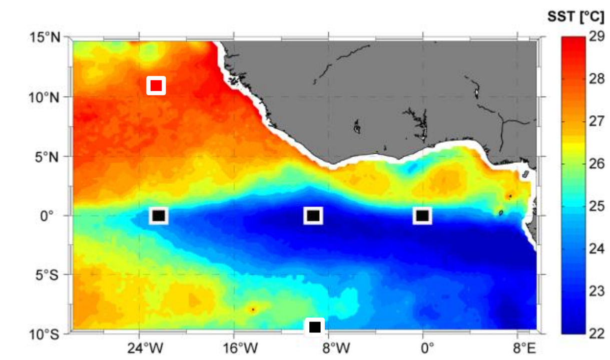
- Design a filter based on Slab Ocean Model Equations for the quanity „Inertial Activity“ (IA)
- Count events crossing a threshold of IA = monthly prevalence of Near Inertial Event

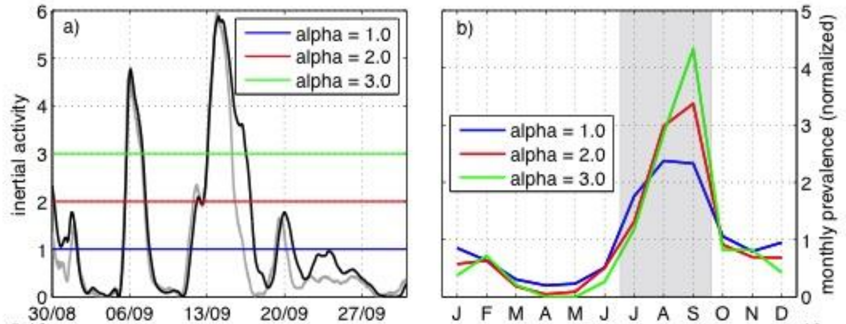


Turbulent mixing and Mixed Layer Heat Balance at off-equatorial locations

How often do similar events occur?

- Design a filter based on Slab Ocean Model Equations for the quanity „Inertial Activity“ (IA)
- Count events crossing a threshold of IA = monthly prevalence of Near Inertial Event
- Seasonal cycle of monthly prevalence independent of threshold value





Turbulent mixing and Mixed Layer Heat Balance at off-equatorial locations

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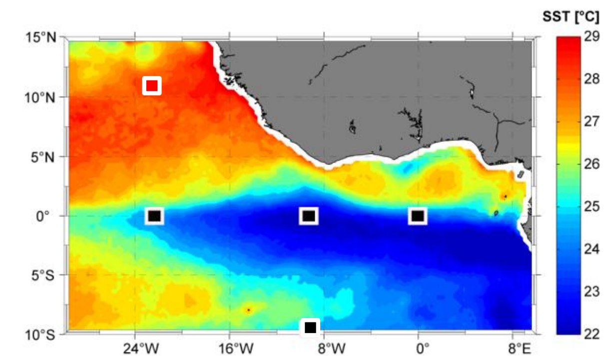
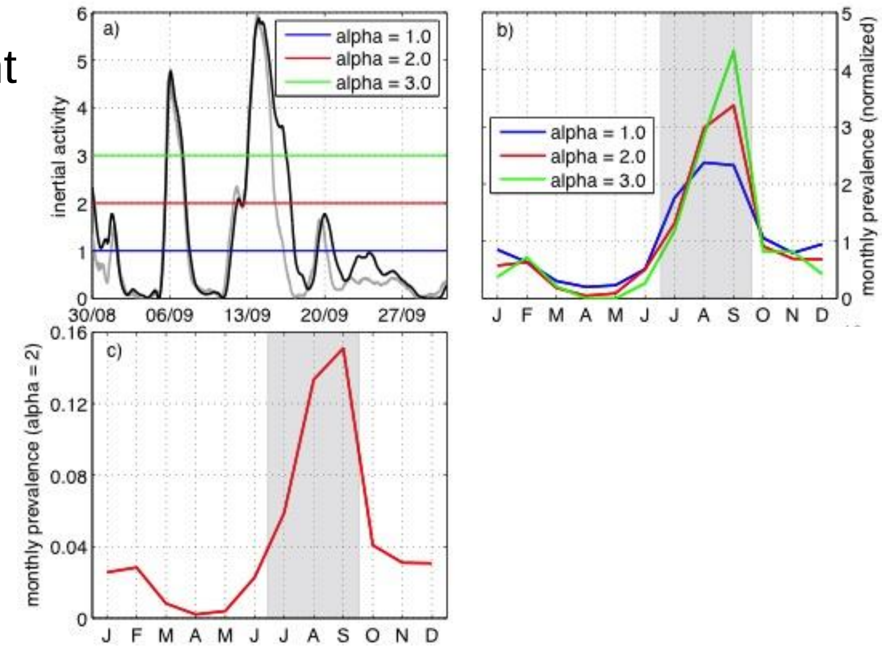
How often do similar events occur?

- Design a filter based on Slab Ocean Model Equations for the quanity „Inertial Activity“ (IA)
- Count events crossing a threshold of IA = monthly prevalence of Near Inertial Event
- Seasonal cycle of monthly prevalence independent of threshold value
- Peak in monthly prevalence during JAS





Turbulent mixing and Mixed Layer Heat Balance at off-equatorial locations

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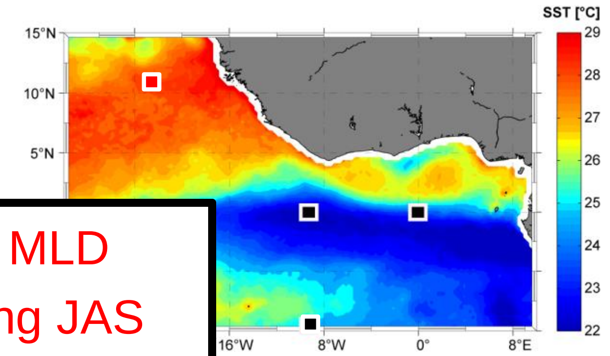
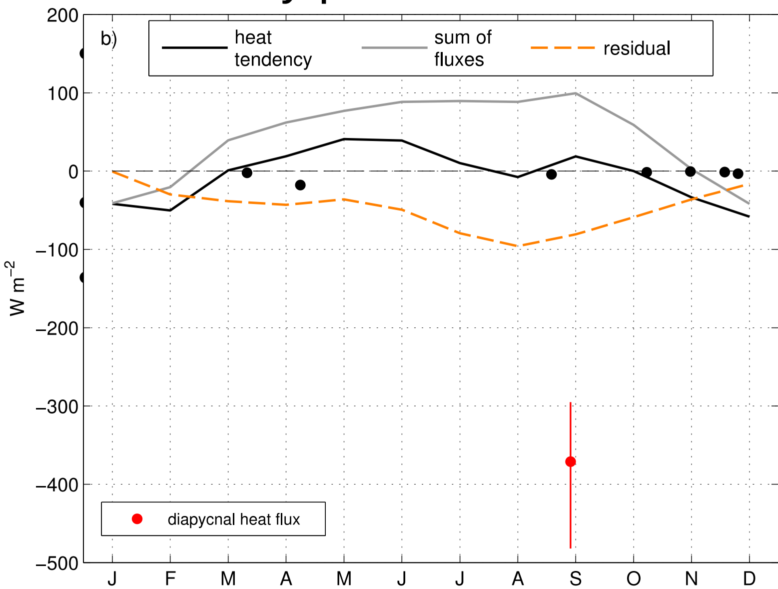
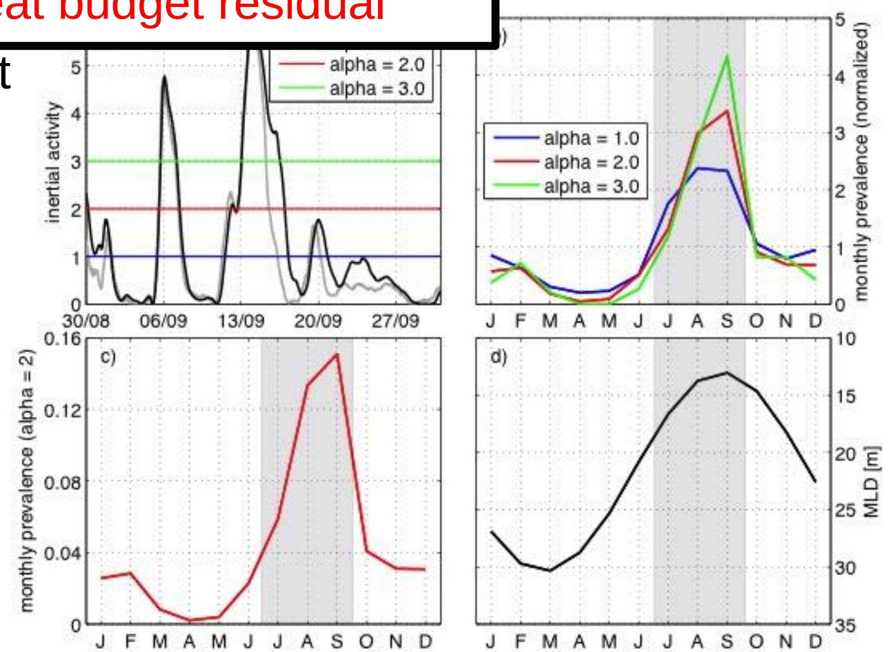
How often do similar events occur?



- Design a filte
  for the quanit
- Count events
  monthly prevalence of Near Inertial Event
  valence
  e
  uring JAS

- Seasonal cycle in wind variability and MLD favor strong NIW induced mixing during JAS
- Season of largest ML heat budget residual





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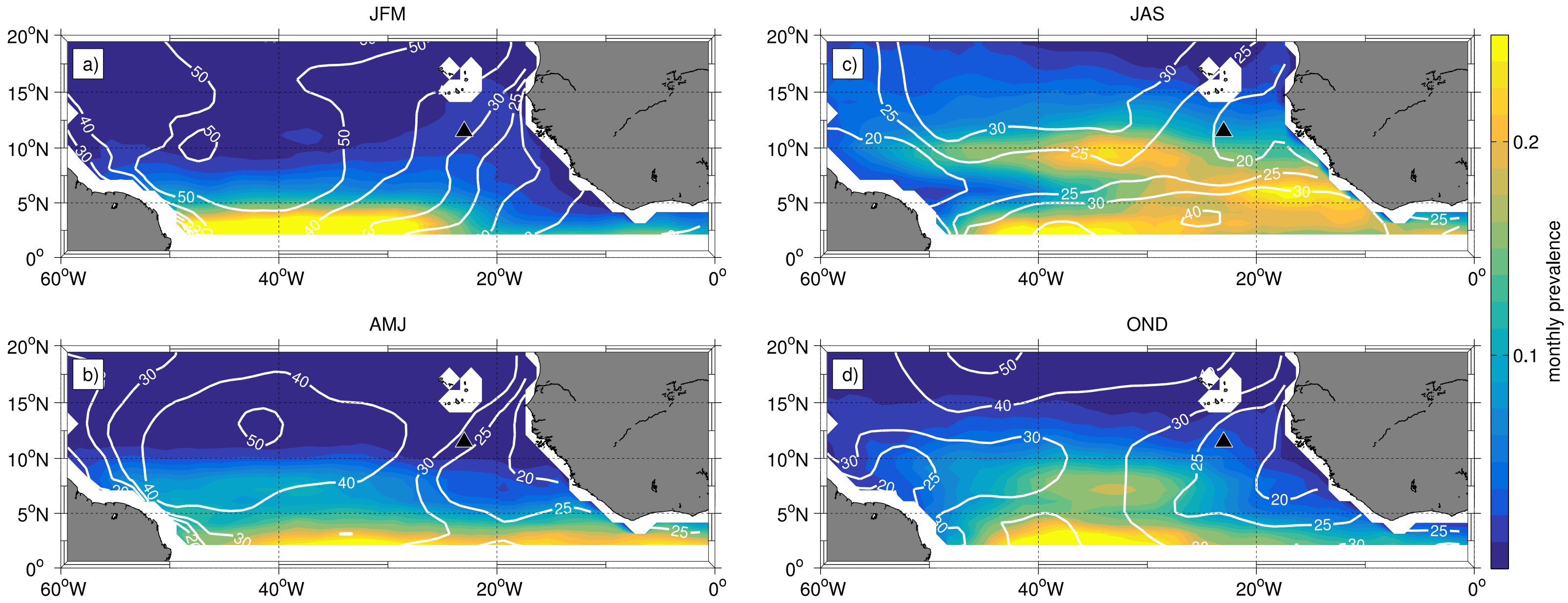
Turbulent mixing and Mixed Layer Heat Balance at off-equatorial locations



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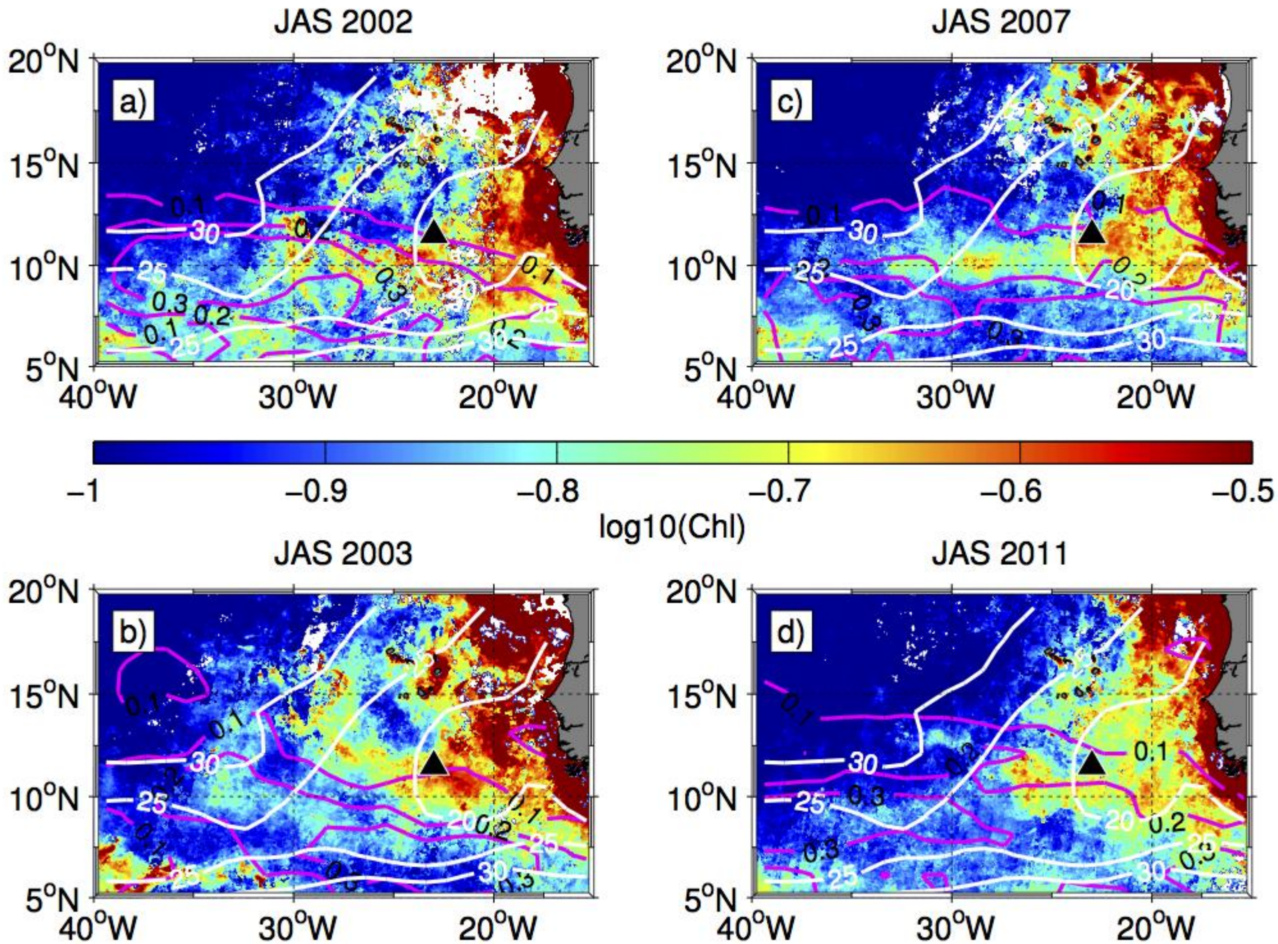
Due to

- seasonal variability in the wind forcing and
- seasonal variability in MLD
- NIW induced mixing is most likely crucial for the ML heat balance in the entire eastern tropical North Atlantic

Turbulent mixing and Mixed Layer Heat Balance at off-equatorial locations



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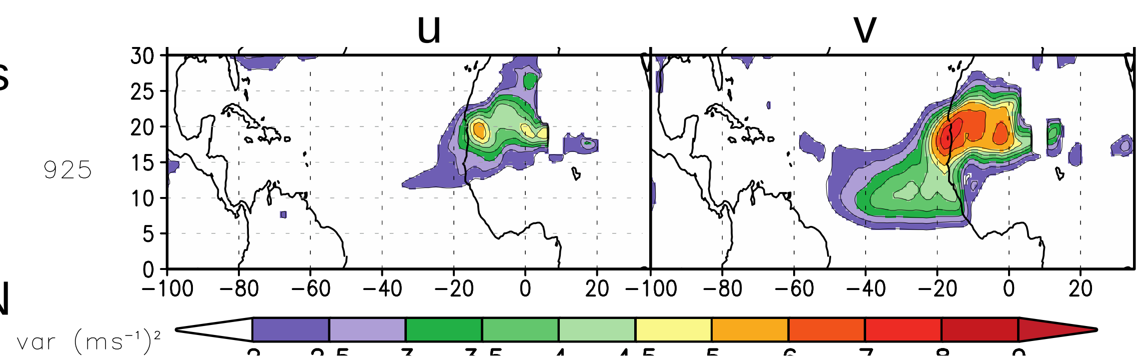
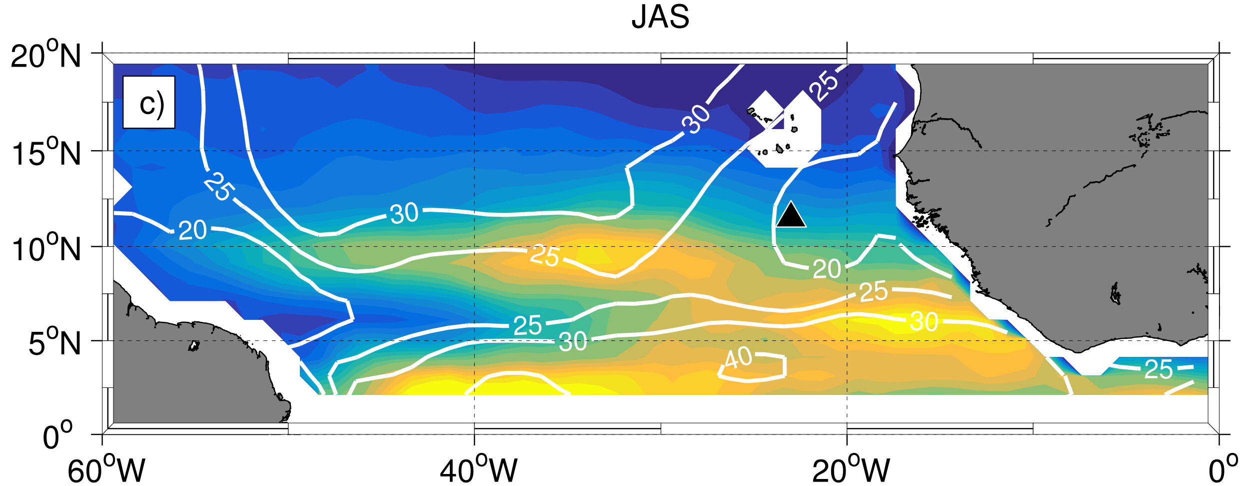
During JAS African Eastery Waves (AEWs) exist

- with periods of 2-10 days
- wave track between 5°N – 15°N



- practically no more AEW energy at periods smaller than 2 days



NIW requirements

- Overlap between atmospheric forcing and the inertial period
- $T_{inertial}$ at 5°N / 10°N / 15°N is 4.8 – 5.7 / 2.4 – 2.9 / 1.6 – 1.9 days

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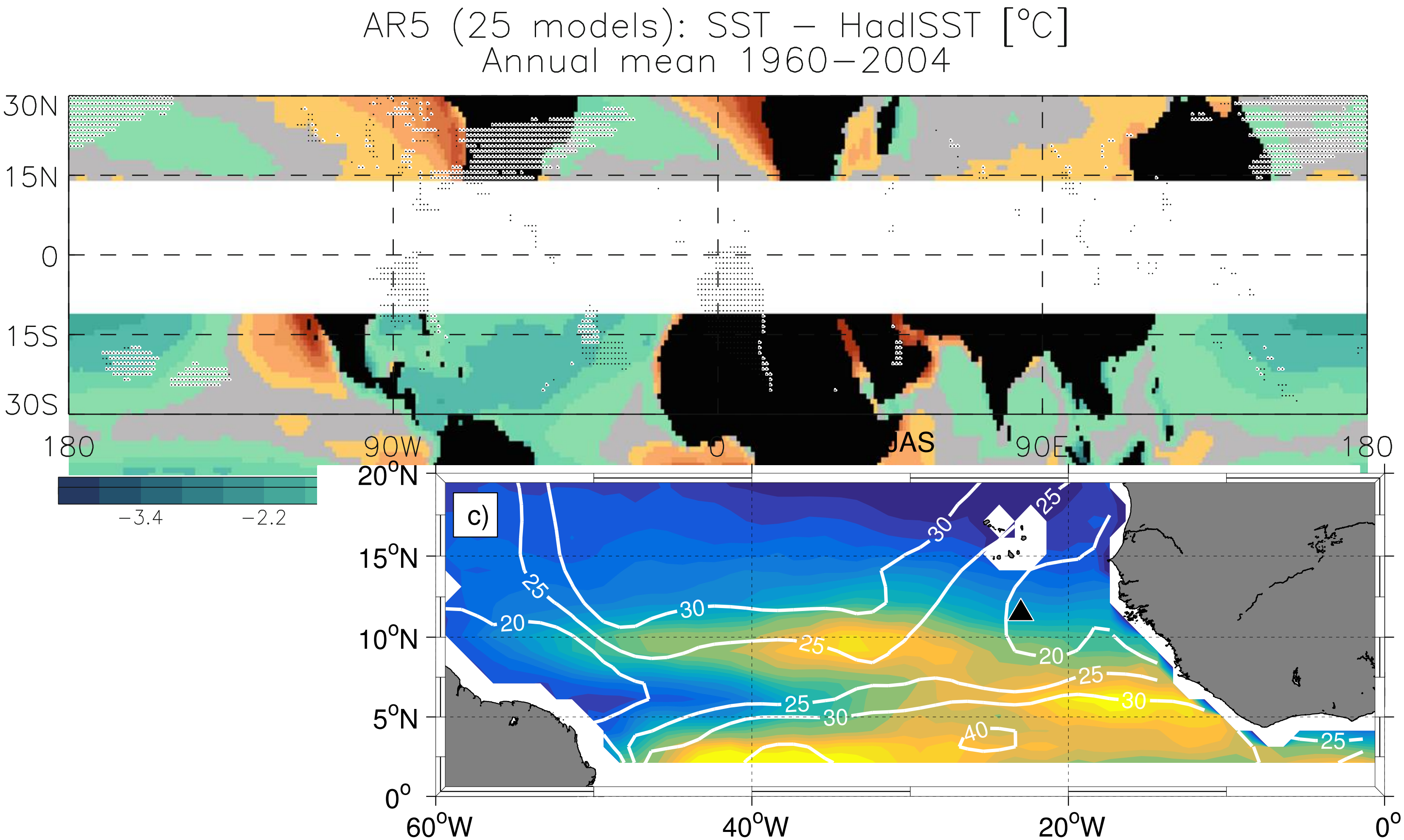
Summary

Equatorial Atlantic	• Large scale mean shear of energetic equatorial currents • Shear instabilities and elevated diapycnal mixing • Diapycnal heat loss among largest terms in ML heat budgets • Diapycnal heat loss explains the residuals in ML heat budgets
Southern tropical Atlantic (10°S,10°W)	• Diapycnal heat loss neglegible • ML heat budget driven mainly by net surface heat fluxes
Northern tropical Atlantic	• AEWs trigger NIW if atmospheric forcing overlaps with $T_{inertial}$ • NIWs induce shear at ML base • NIW induced shear will be larger, when ML is shallow • Rare events of strongly elevated diapycnal heat loss • Impacts the vertical distribution of nutrients (biology) • Most likely explains residual in ML heat budget

Summary



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