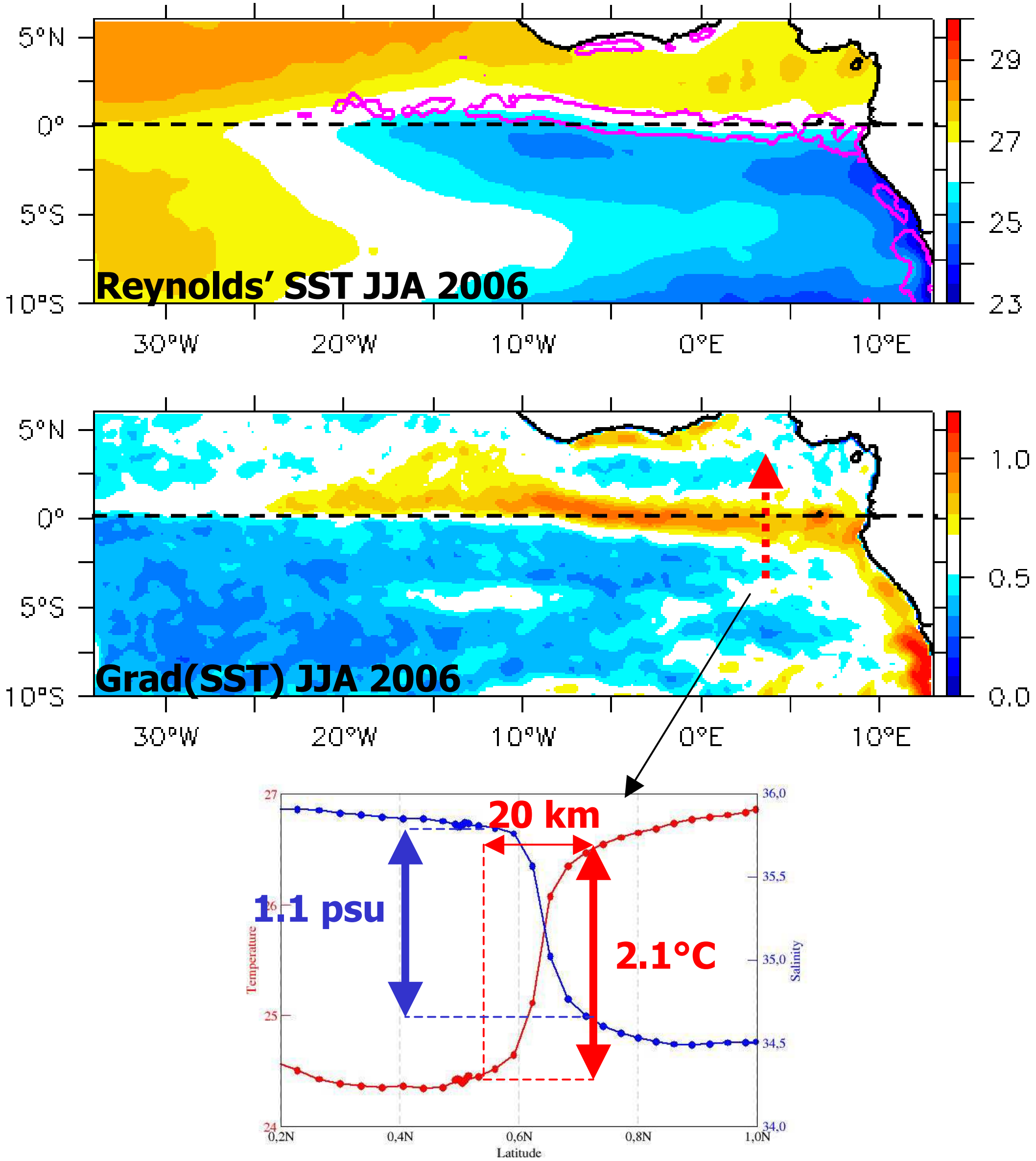
Why is there a Front North of the Atlantic Cold Tongue ?

H. Giordani, G. Caniaux, A. Voldoire

Introduction

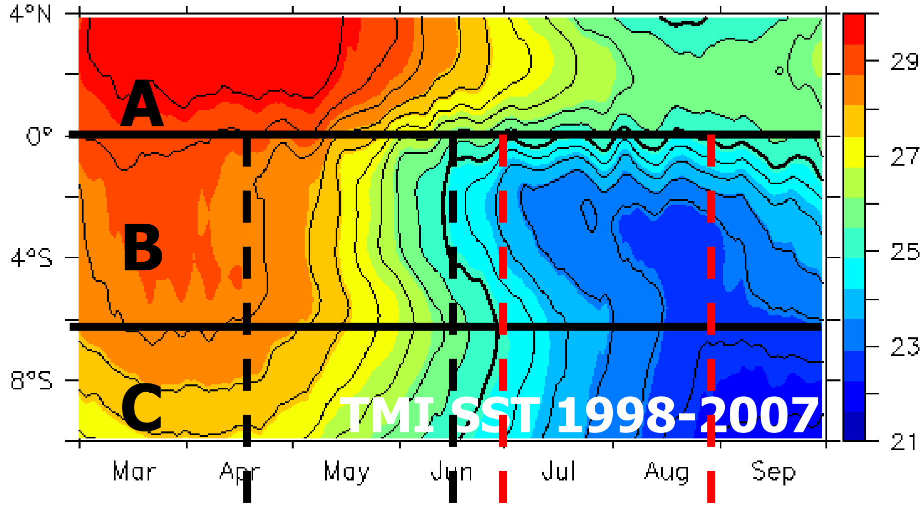


- **In summer, the equatorial cold tongue is well developped south of the equator with a front across the equator**

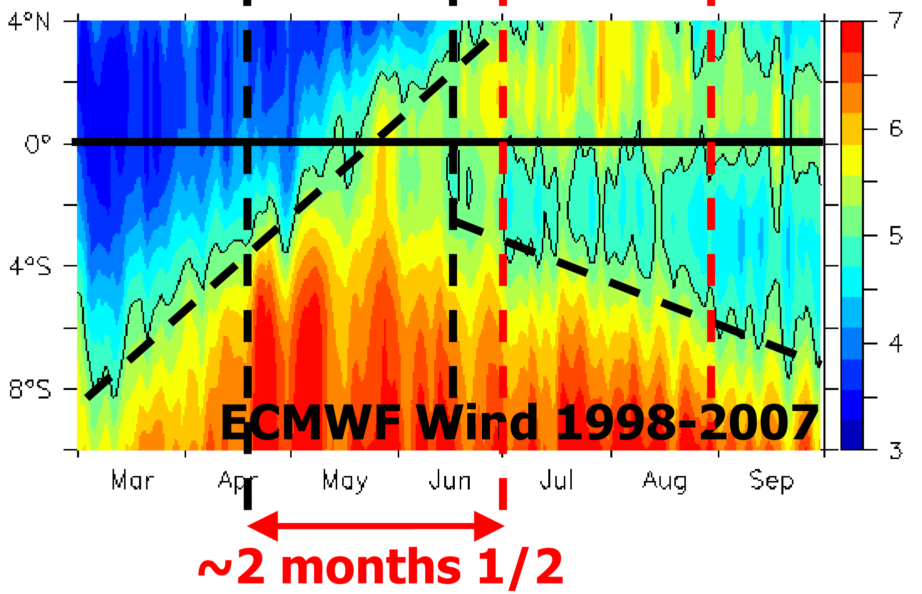
- **In the equatorial front meridional SST gradients reach ~2°C/20 km [Lefèvre *et al.*, 2009]**

- **This front influences the circulation in the MABL, coastal precipitation and the west African monsoon jump [Thorncroft *et al.*, 2011; Caniaux *et al.*, 2011; Nguyen *et al.*, 2011]**

Influence of the CT on the Atmosphere



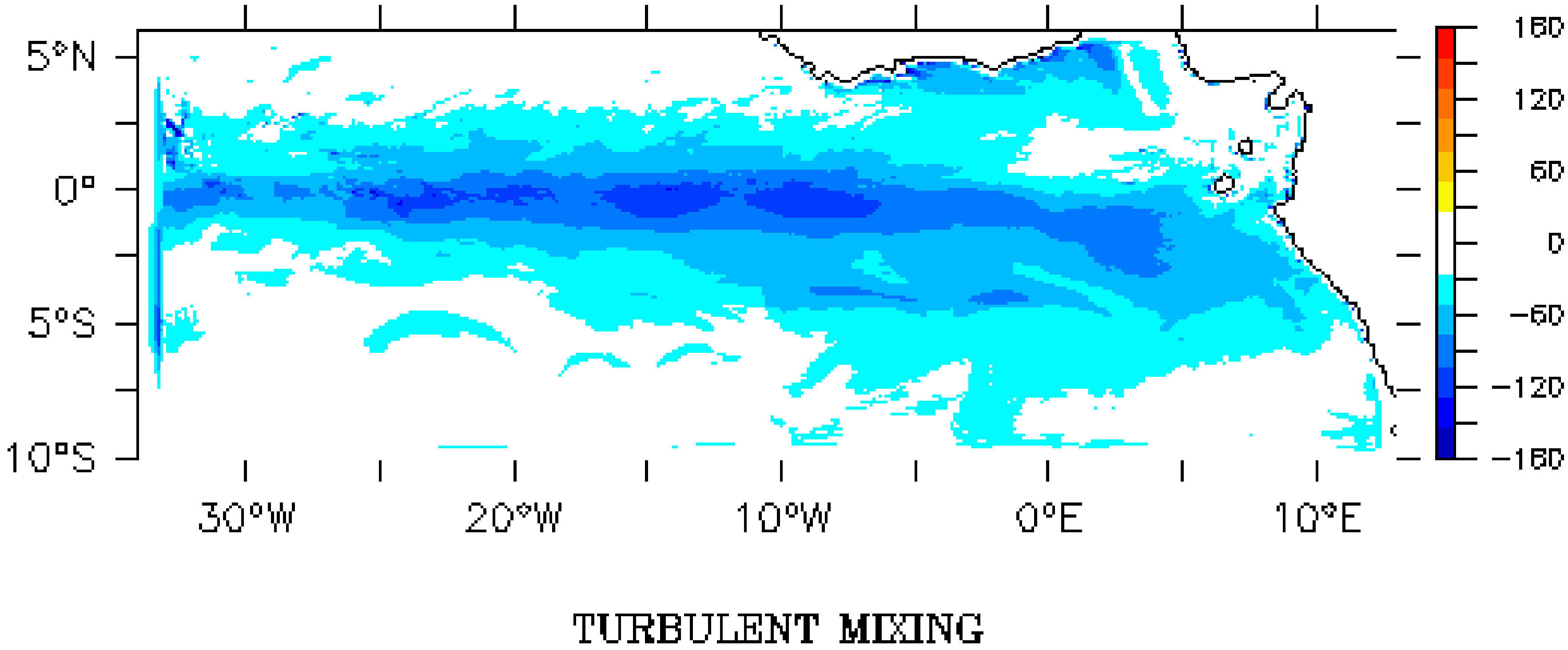
1. **In B, SSTs cool as soon as winds strengthen near 3°S**
2. **In B, cooling increased in May-June**
3. **Sharp SST gradients between A and B**
4. **SST gradients relax in August-September**



1. **S.H. winds increase and reach the N.H., never the contrary**
2. **As soon as a SST gradient threshold is reached, winds:**
   (1) weaken S of the equator;
   (2) strengthen N of the equator up to the continent in July-August

Mixed-Layer Heat Budget - Seasonal Scale

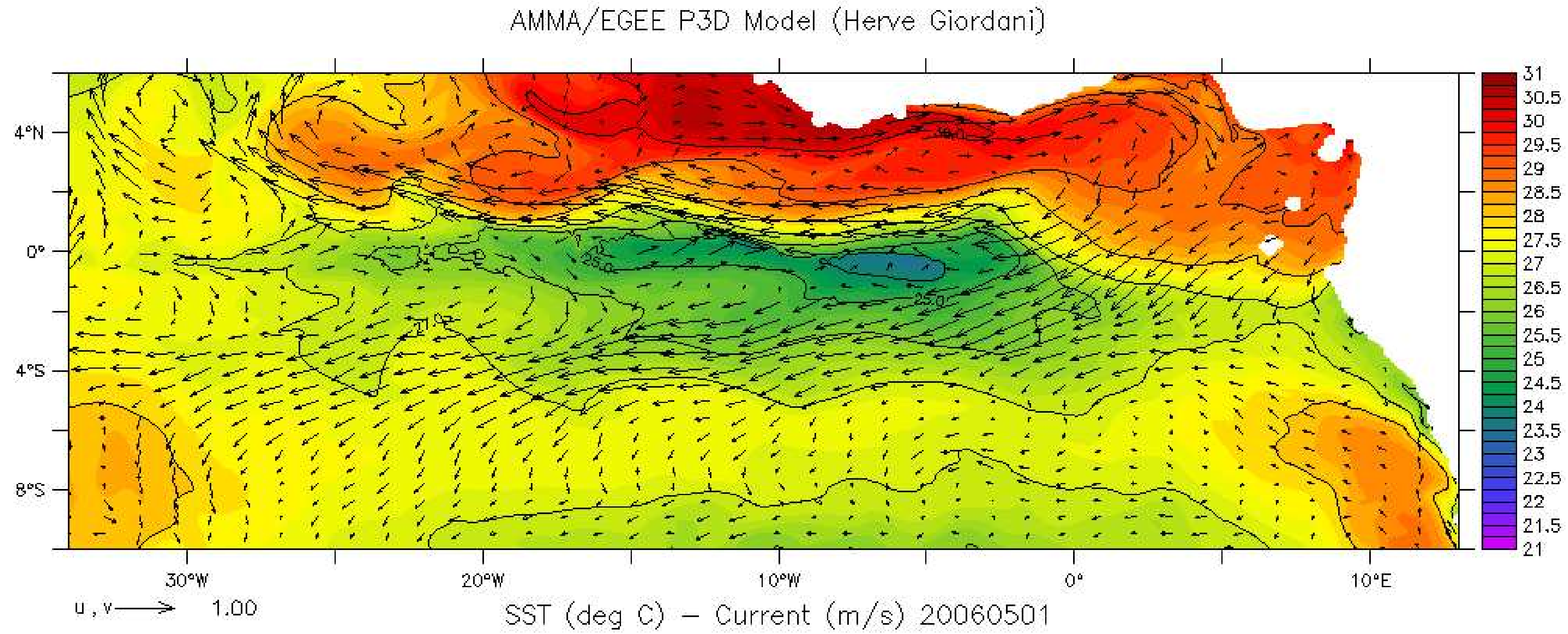
Giordani et al. (2013)



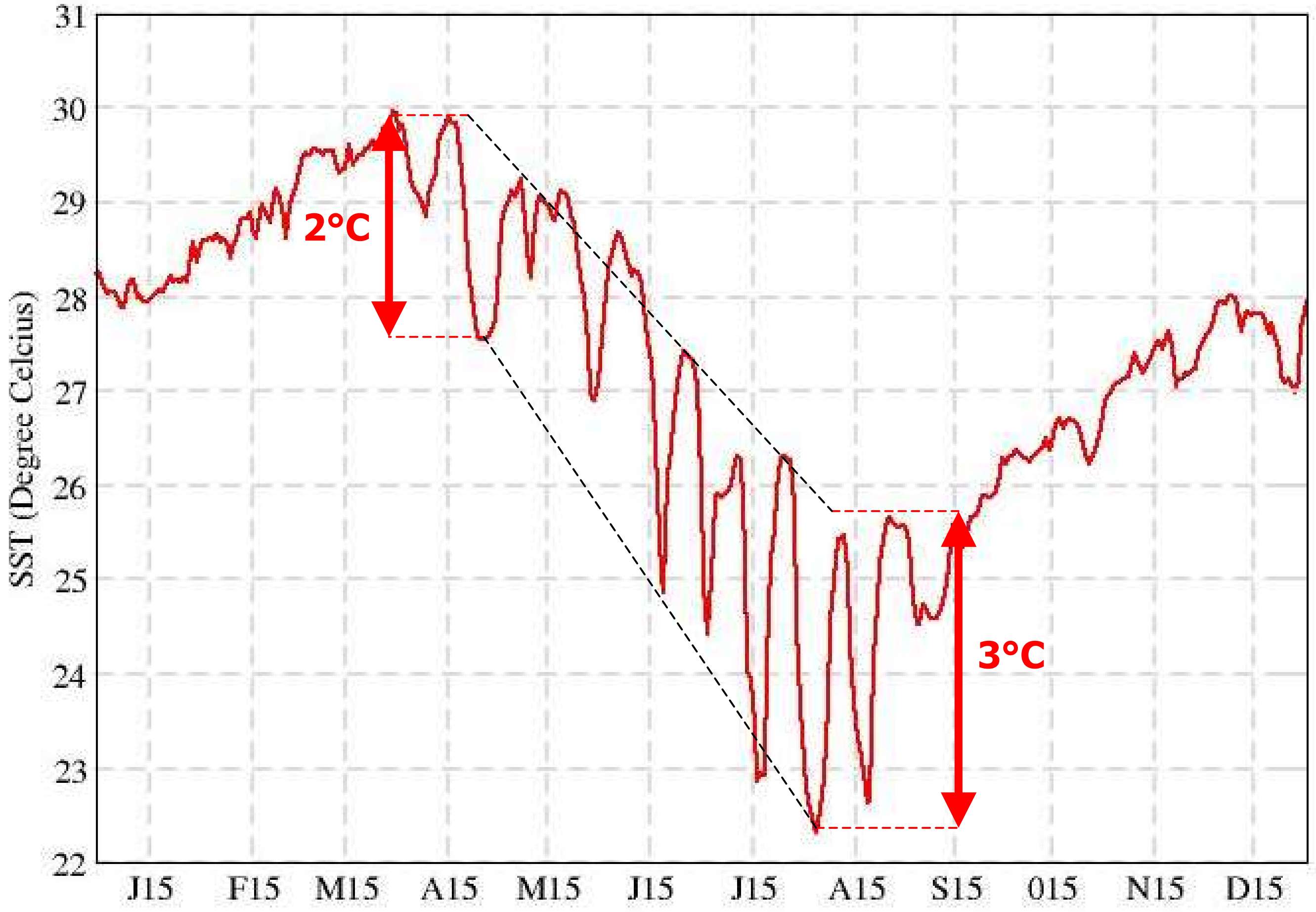
Differential cooling induces a SST front on the Equator ?

The Atlantic Cold Tongue - EGEE 2006

Giordani & Caniaux (2011)



SST PIRATA (0°N;0°E) in 2006



Role of the dynamics in frontogenesis ?

Frontogenesis

Giordani and Caniaux (2014)

Frontogenetic Function $$\frac{1}{2}\frac{d}{dt}\left(\vec{\nabla}\theta\right)^2 = \vec{Q}_h.\vec{\nabla}\theta + \vec{Q}_d.\vec{\nabla}\theta$$

Heat forcing: $\vec{Q}_h$

$$Q_{hx} = \frac{\partial}{\partial x}\left(F_{sol}\frac{\partial I(z)}{\partial z} - \frac{\partial \overline{w'\theta'}}{\partial z}\right)$$

$$Q_{hy} = \frac{\partial}{\partial y}\left(F_{sol}\frac{\partial I(z)}{\partial z} - \frac{\partial \overline{w'\theta'}}{\partial z}\right)$$

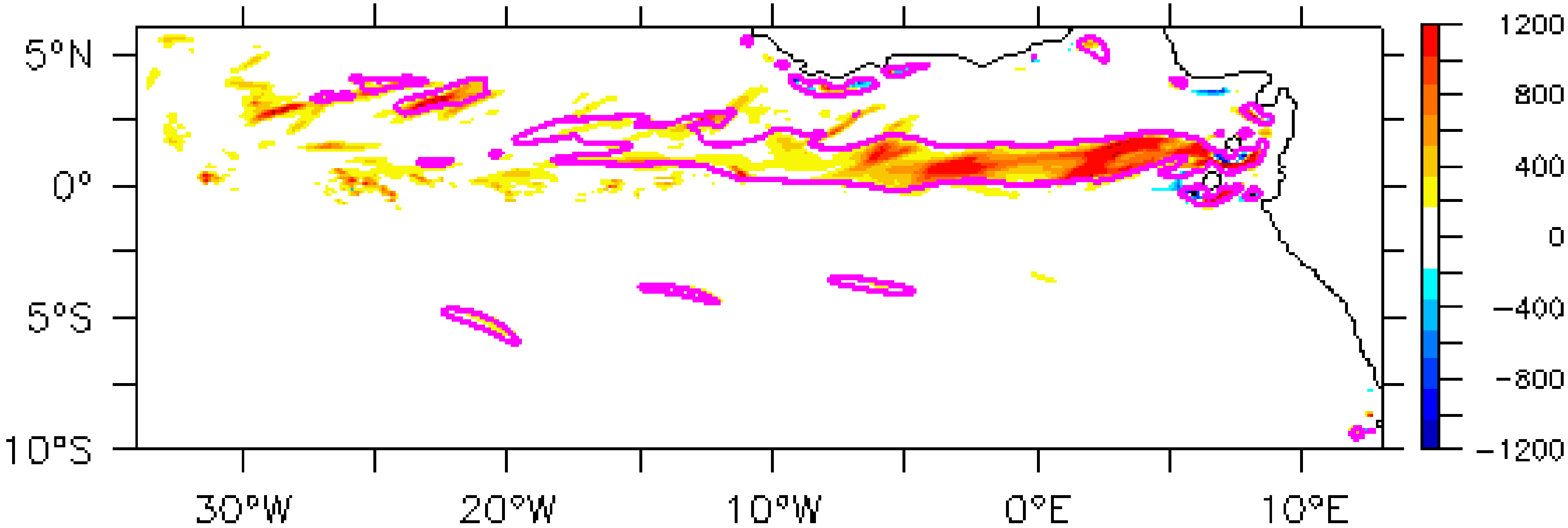
Dynamic forcing: $\vec{Q}_d$

$$Q_{dx} = -\left(\frac{\partial u}{\partial x}\frac{\partial \theta}{\partial x} + \frac{\partial v}{\partial x}\frac{\partial \theta}{\partial y} + \frac{\partial w}{\partial x}\frac{\partial \theta}{\partial z}\right)$$

$$Q_{dy} = -\left(\frac{\partial v}{\partial y}\frac{\partial \theta}{\partial y} + \frac{\partial u}{\partial y}\frac{\partial \theta}{\partial x} + \frac{\partial w}{\partial y}\frac{\partial \theta}{\partial z}\right)$$

Frontogenesis from a regional PE model

Giordani and Caniaux (2014)



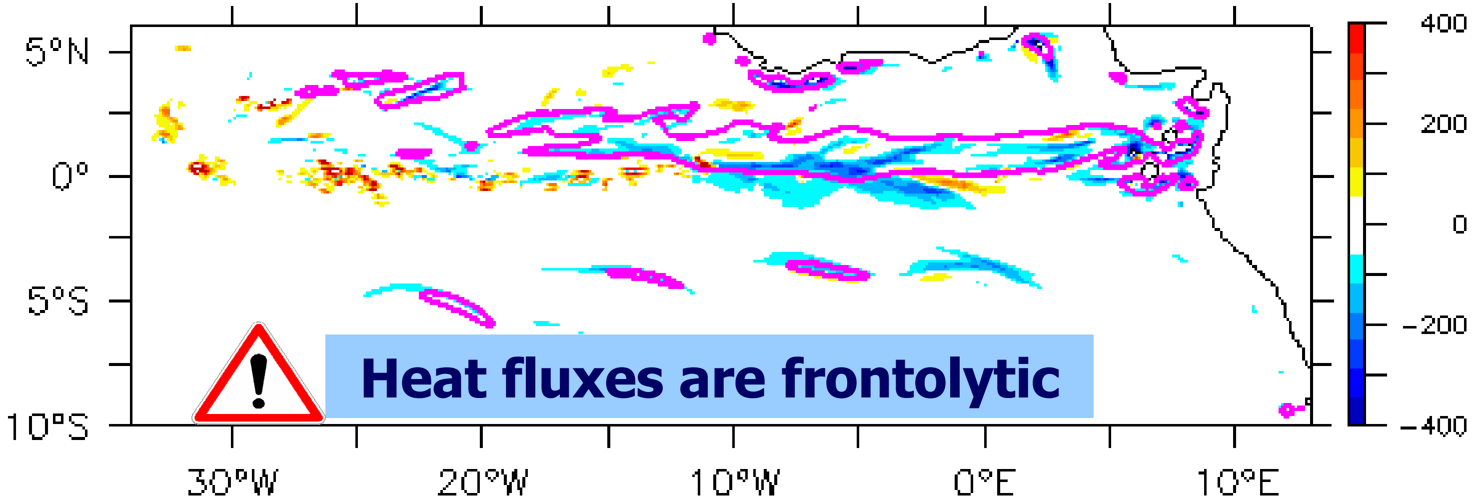
$$\frac{1}{2}\frac{d\left(\nabla T\right)^2}{dt}$$

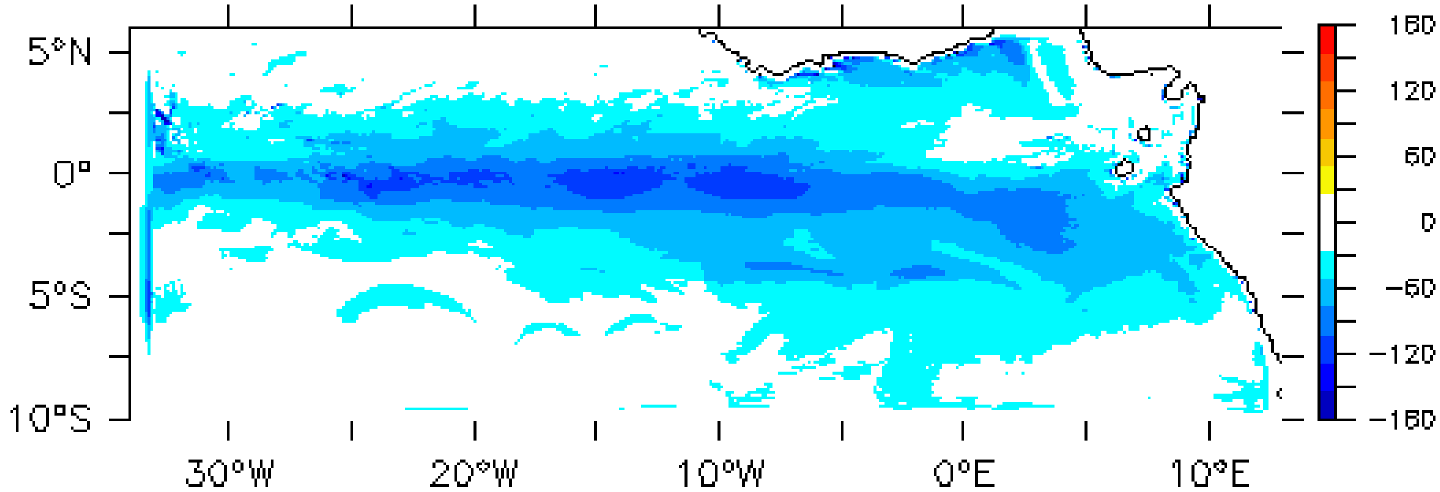
- **Frontogenesis in the longitude band [15°W-5°E] and in the latitude band [1°S-1°N]**

- **Westward of 15°W the frontogenesis vanishes because of weaker SST gradients due to TIW**

Heat forcing

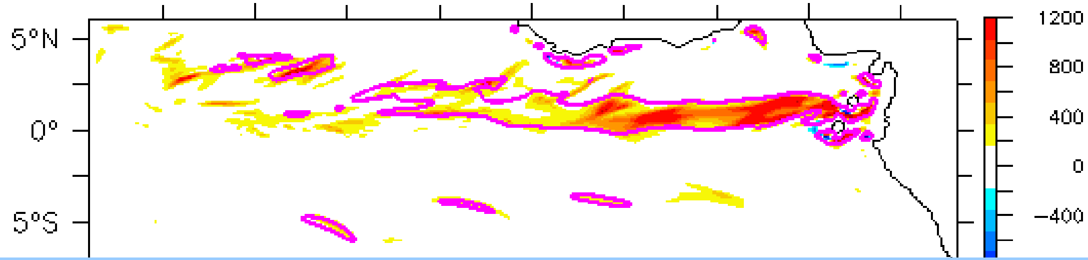
$$Q_{hx} \cdot \frac{\partial \theta}{\partial x} + Q_{hy} \cdot \frac{\partial \theta}{\partial y}$$





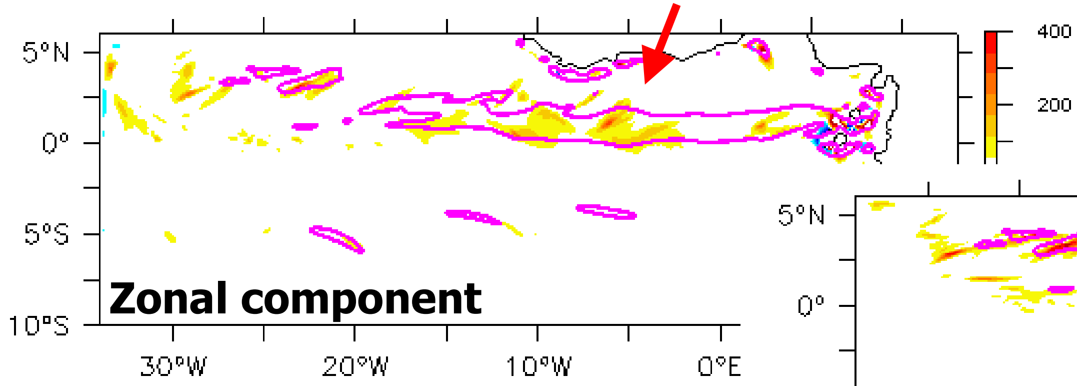
TURBULENT MIXING

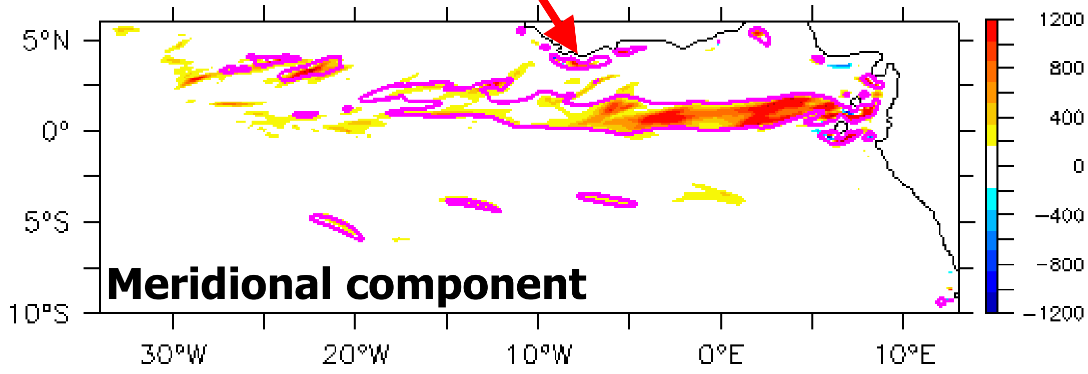
Dynamic forcing



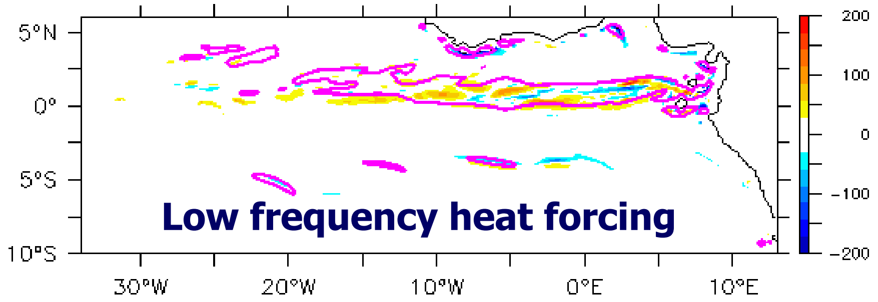
The dynamic forcing is frontogenetic and mainly supported by the meridional component

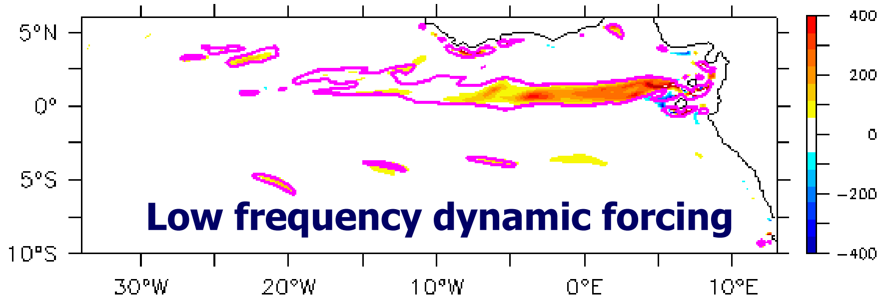
$$\underbrace{Q_{dx}\cdot\frac{\partial\,\theta}{\partial\,x}}_{Zonal}+\underbrace{Q_{dy}\cdot\frac{\partial\,\theta}{\partial\,y}}_{Meridional}$$

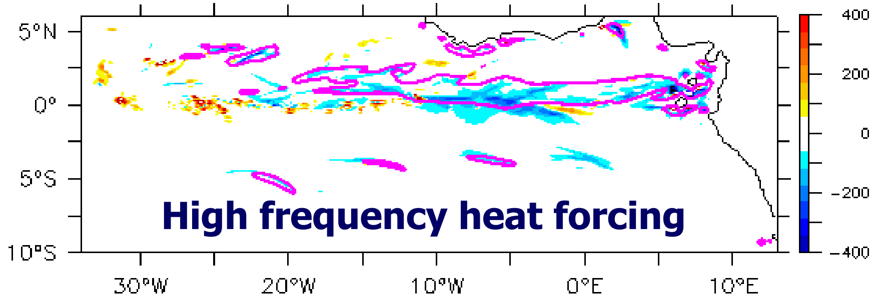


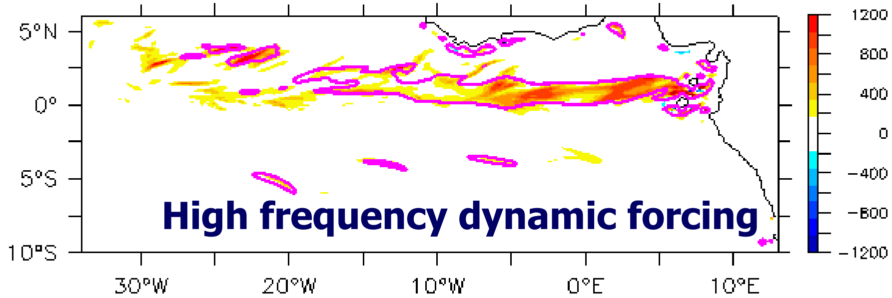


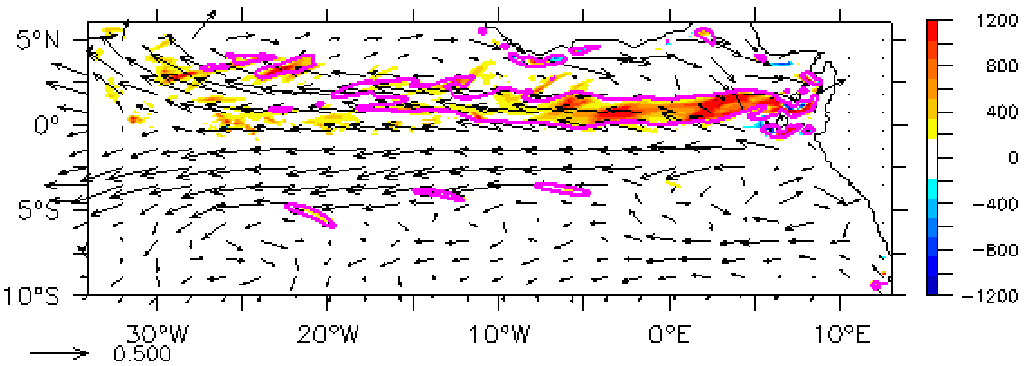
Low-High Frequency Components







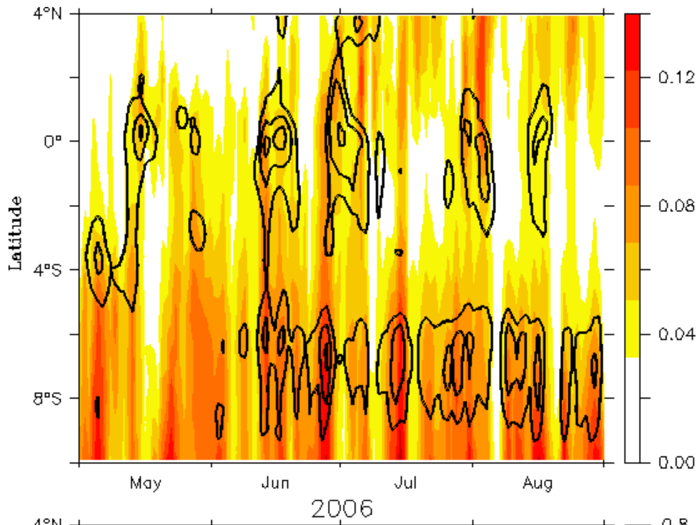


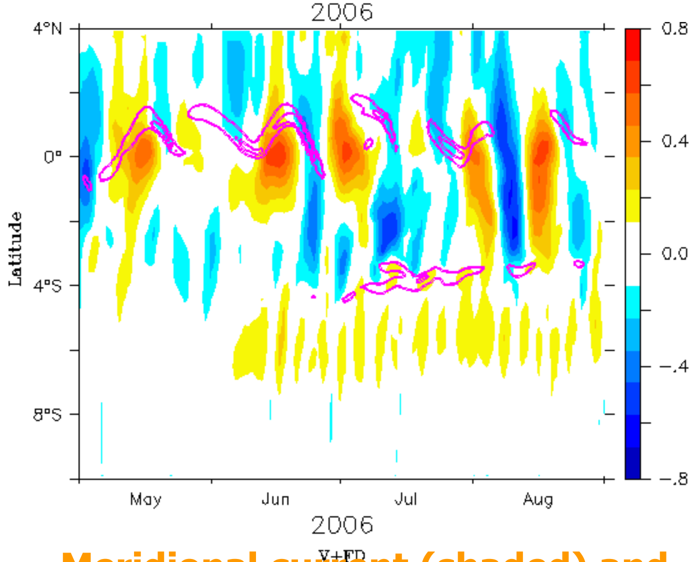


- **The low frequency heat forcing is weakly frontogenetic**
- **The high frequency component of the dynamical forcing is the strongest frontogenetic term**
- **The dynamic forcing is mainly supported by the convergence between the nSEC and the GC**

Origin of the dynamical forcing

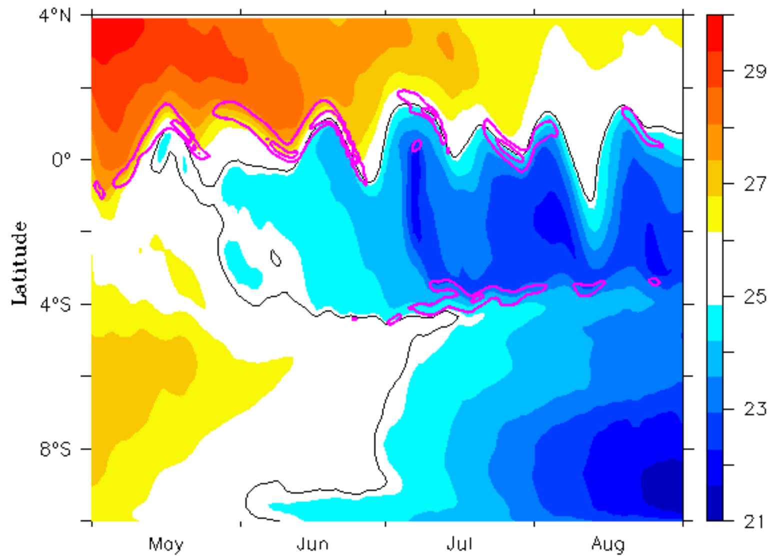
Wind-stress (shaded) and wind energy flux (black)

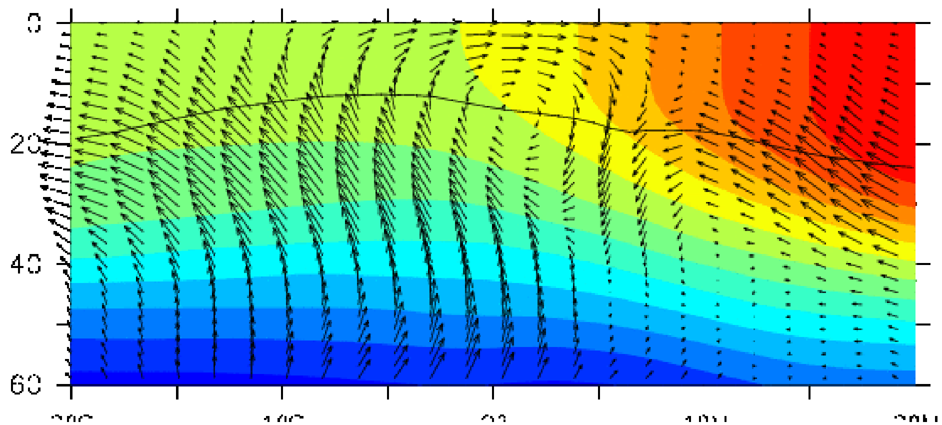




Meridional current (shaded) and dynamic forcing term

SST and dynamic forcing term





2S **Eq** **2N**

Frontogenesis

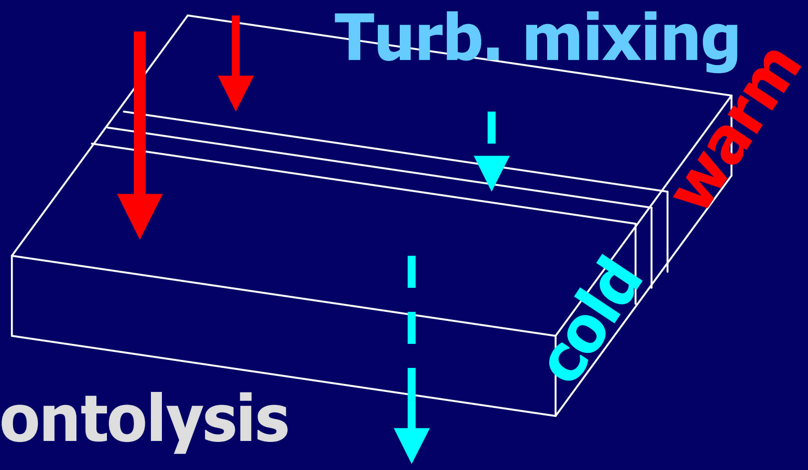
In case of meridional gradients:

$$\frac{1}{2}\frac{d}{dt}\left(\vec{\nabla}\theta\right)^2 \approx \left[\frac{\partial}{\partial y}\left(F_{sol}\frac{\partial I(z)}{\partial z} - \frac{\partial \overline{w'T'}}{\partial z}\right)\frac{\partial T}{\partial y}\right] - \left(\cancel{\frac{\partial u}{\partial y}\frac{\partial T}{\partial x}} + \frac{\partial v}{\partial y}\frac{\partial T}{\partial y} + \cancel{\frac{\partial w}{\partial y}\frac{\partial T}{\partial z}}\right)\frac{\partial T}{\partial y}$$

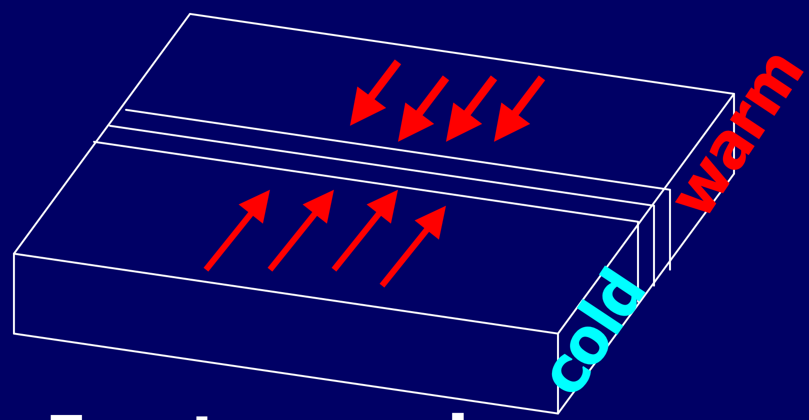
Heat forcing term

Dynamic forcing term

Surf. fluxes

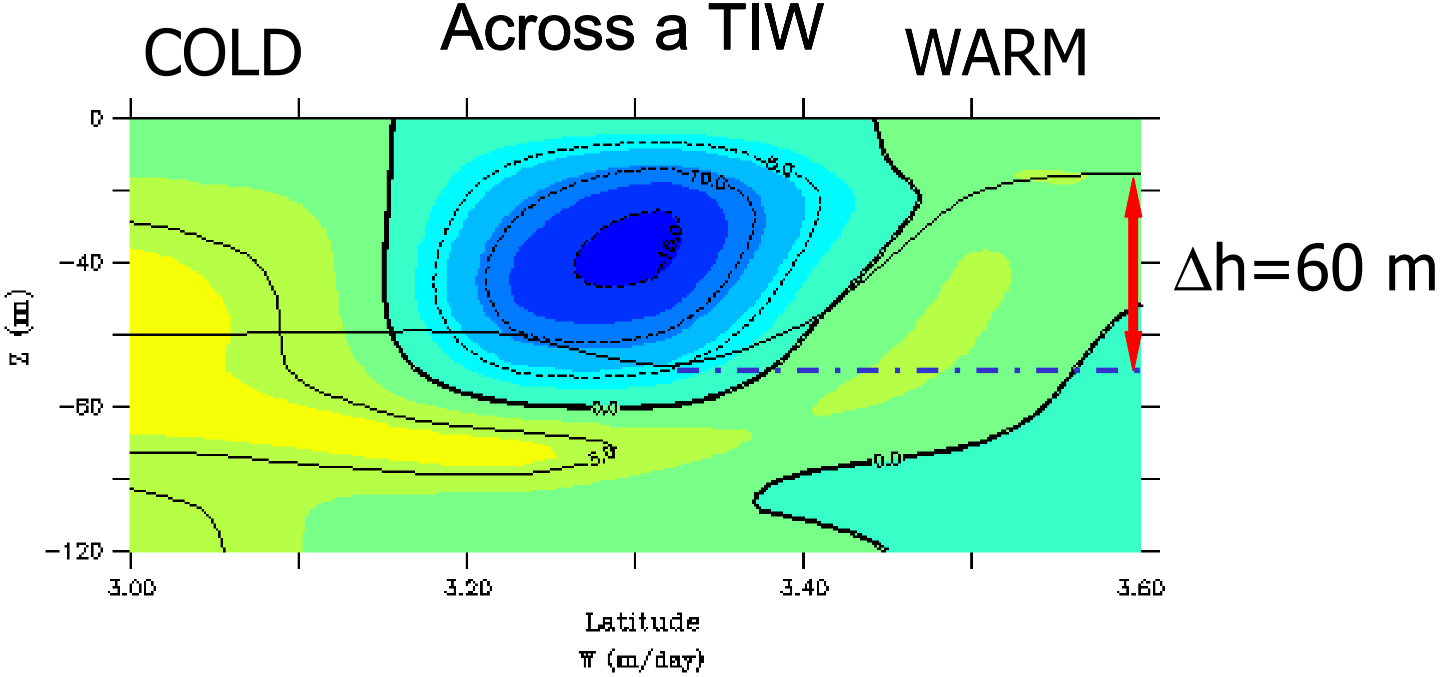


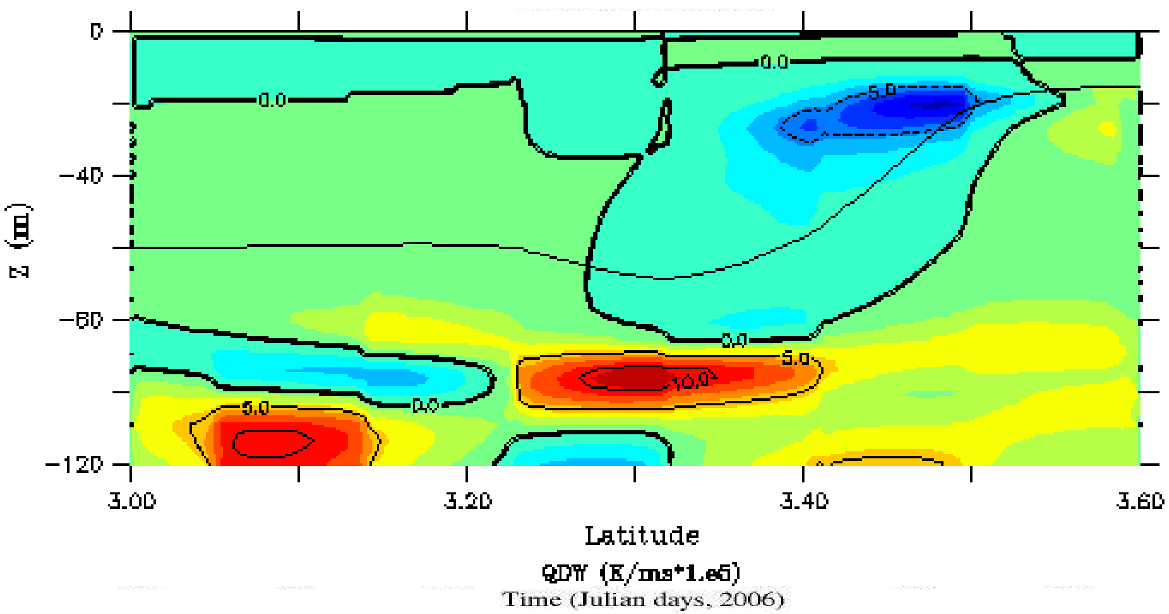
Frontolysis



Frontogenesis

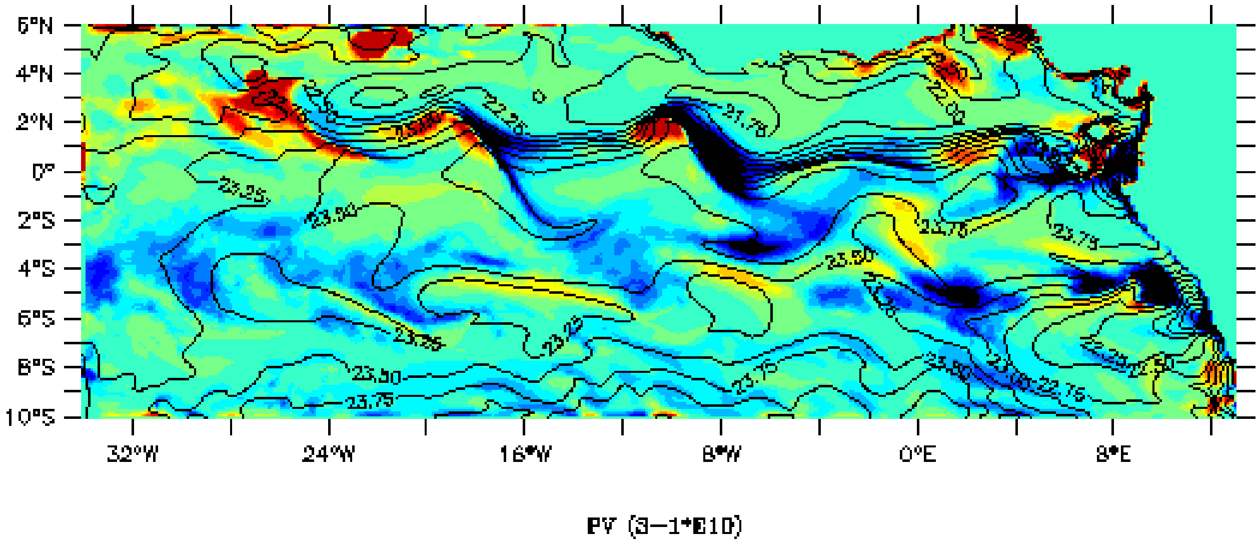
Across a TIW





$$Q_{dy} = -\frac{\partial w}{\partial y}\frac{\partial \theta}{\partial z} < 0$$

PV in TIW



$$q = \underbrace{(\zeta + f)N^2}_{q_v} - \underbrace{f\left(\frac{\partial \vec{U}_g}{\partial z}\right)^2}_{q_h}$$

$q < 0$ in frontal/eddy areas where $q_h << 0$

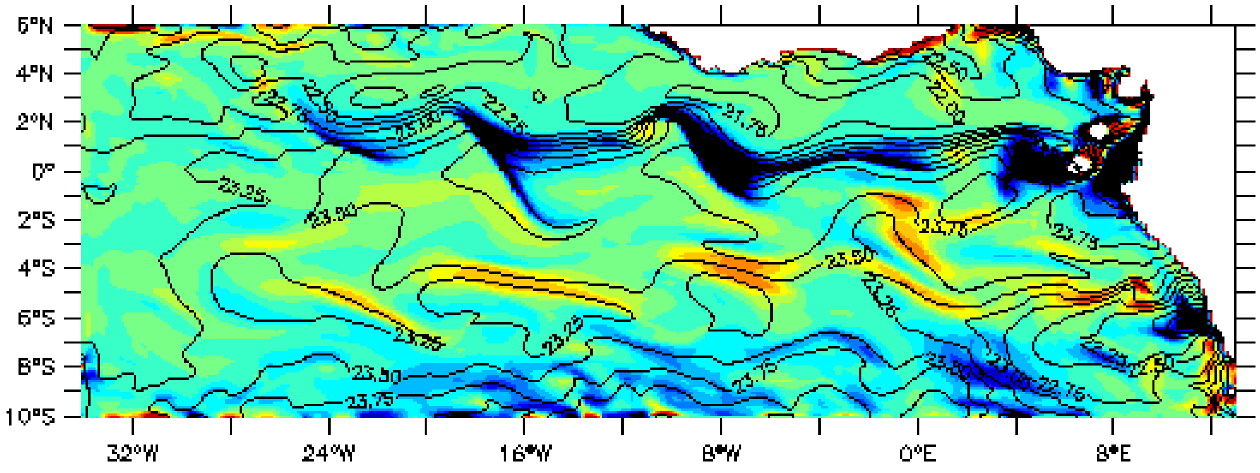
Destruction of Potential Vorticity

$$\frac{\partial q}{\partial t} = \underbrace{- f \frac{\partial \vec{U}_g}{\partial z} \frac{\partial \vec{\tau}}{\partial z}}_{J_{Fric}} + \underbrace{(\zeta + f) \frac{\partial B}{\partial z}}_{J_{Diab}} \underbrace{- \vec{U} \vec{\nabla} q}_{J_{Adv}}$$

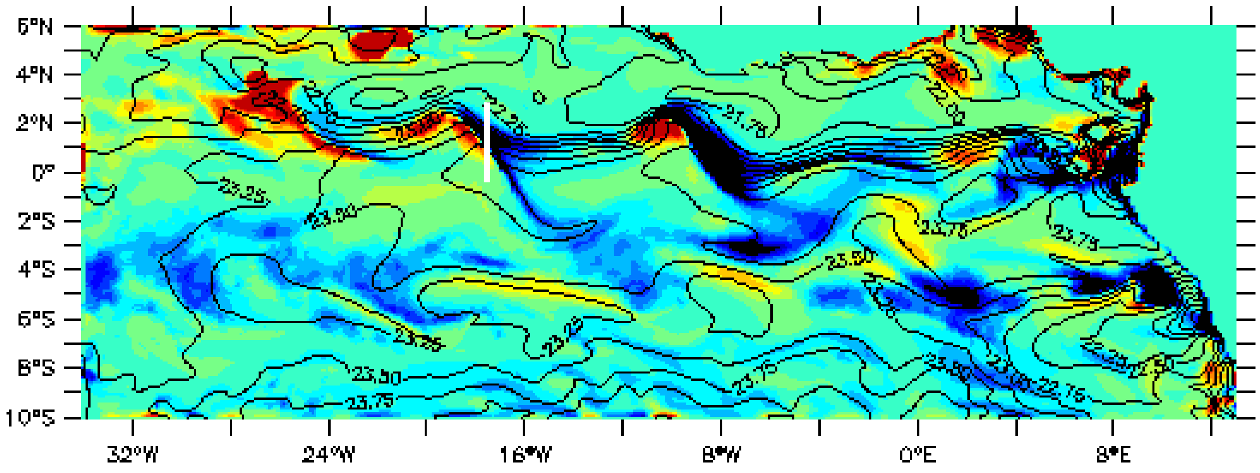
PV destruction:

- ➢ Wind oriented down-front
- ➢ Buoyancy loss from the ocean to the atmosphere

PV in TIW

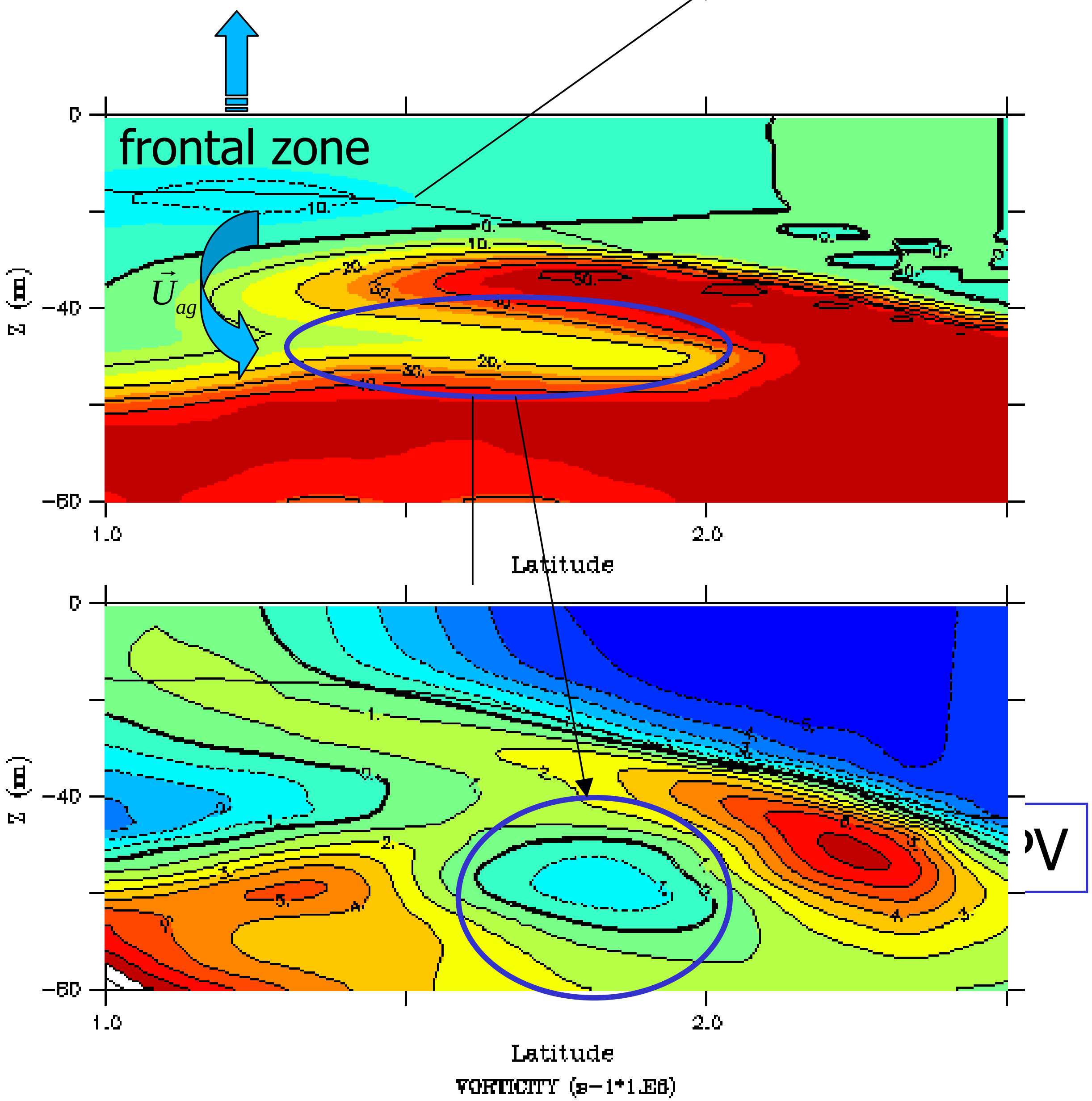


JPV STRESS



PV (S-1*E10)

$$\vec{J}_{fric} = -f \frac{\partial \vec{U}_g}{\partial z} \frac{\partial \vec{\tau}}{\partial z} \vec{k}$$



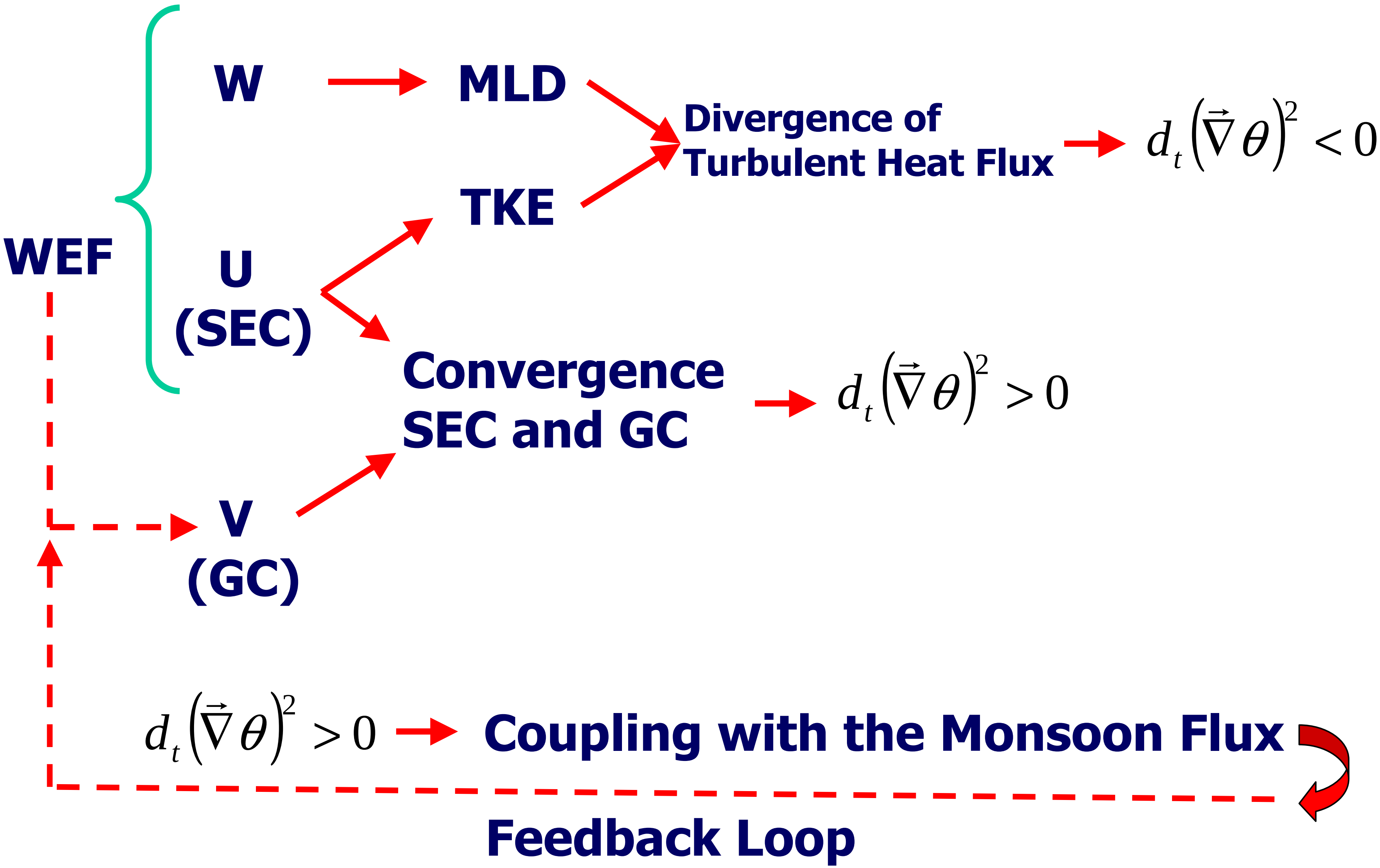
Conclusions

- **The heat forcing term associated with fluxes is frontolytic (*i.e.* weakening of the equatorial front)**

- **Low-frequency heat forcing is frontogenetic and may initiate the equatorial front, which is largely amplified and maintained by the dynamic forcing**

- **Dynamic forcing is the leading term of frontogenesis: it is driven by the meridional convergence between the Guinea Current and the South Equatorial Current**

Conceptual Scheme



Conclusions

- **Intra-thermocline bolus/eddy of low-PV can modify stratification, circulation, vertical/lateral mixing and ML heat/salt budgets**

- **How can we document this with data (PIRATA buoys, Gliders, CTDs …) ?**

Conceptual Scheme