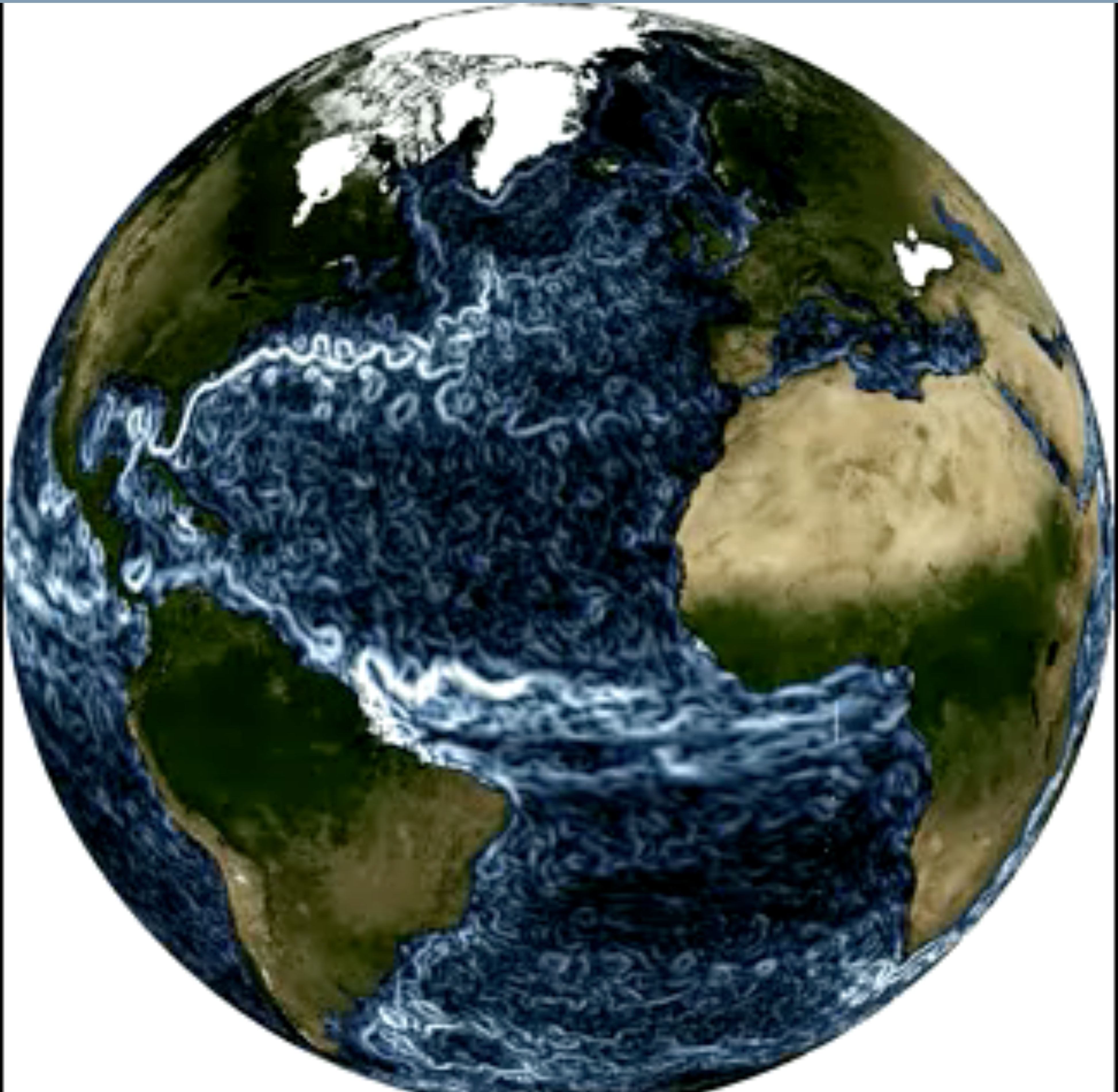
Paradoxes and overlooked constraints of the dynamics and thermodynamics of EBUS

Alban Lazar

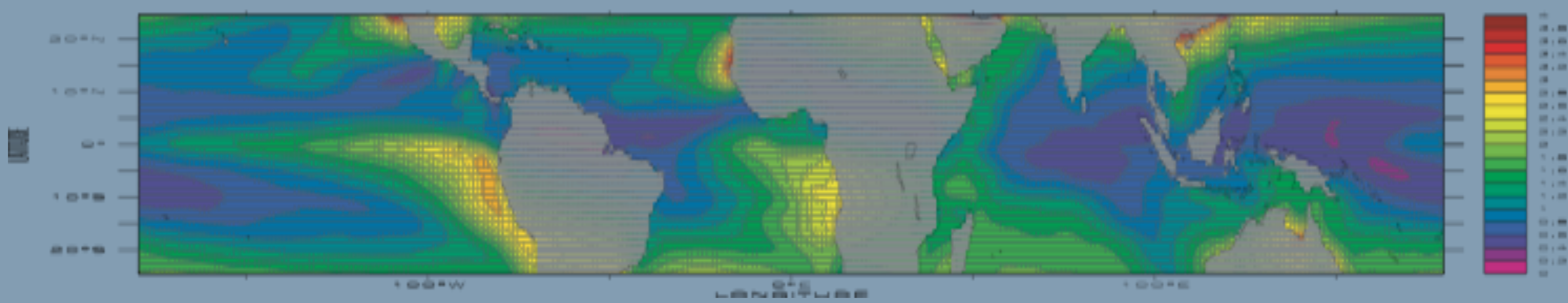
july 2019

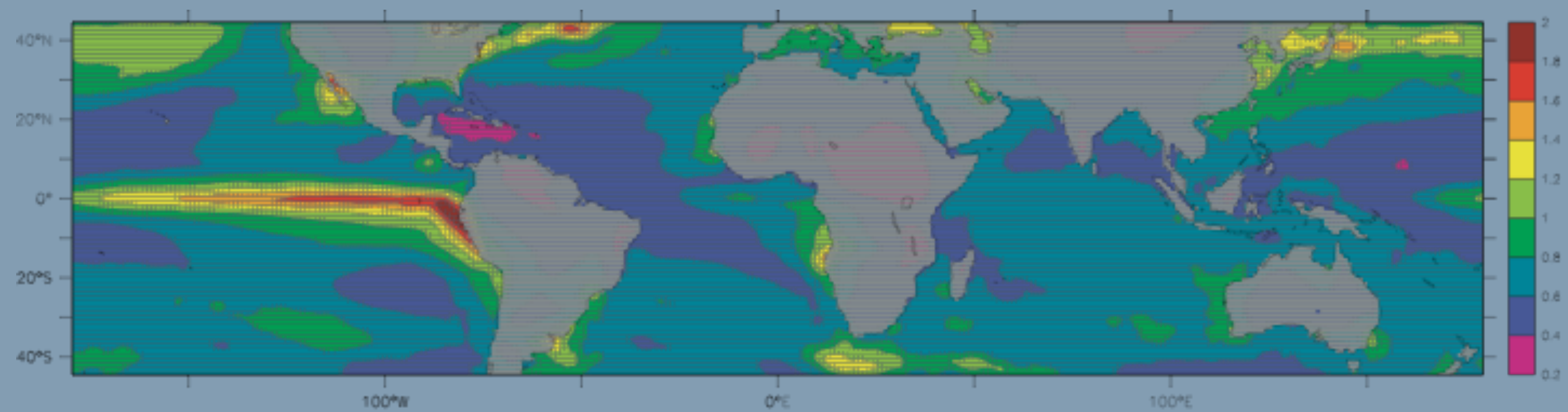
ICTP Trieste

high frequency circulation

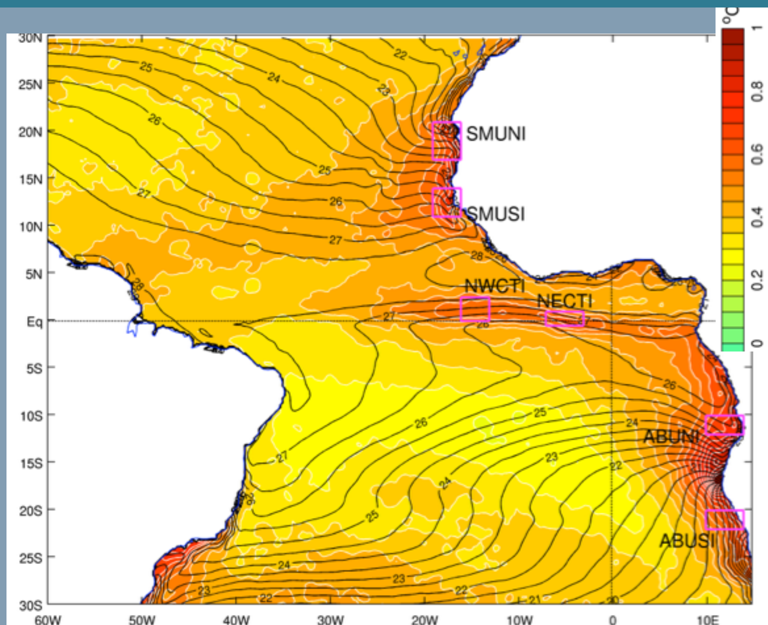


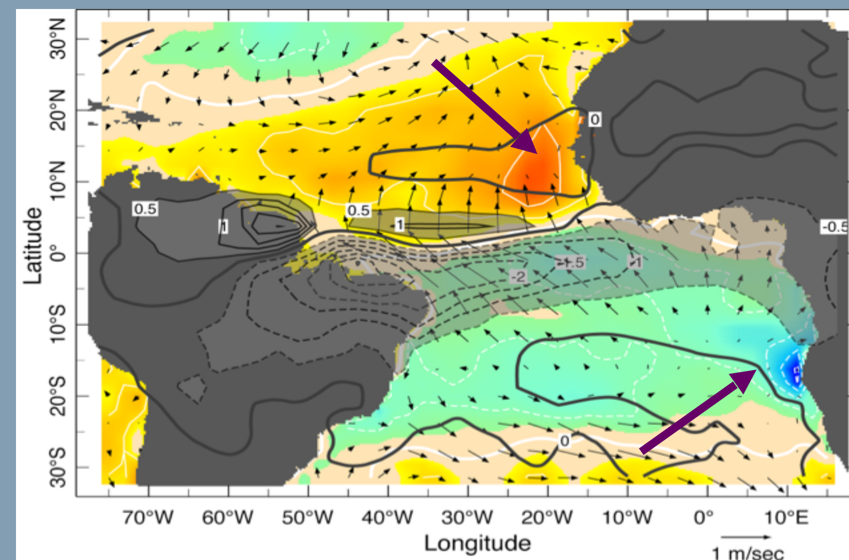
low frequencies:
common large spatial patterns…
of SST variance

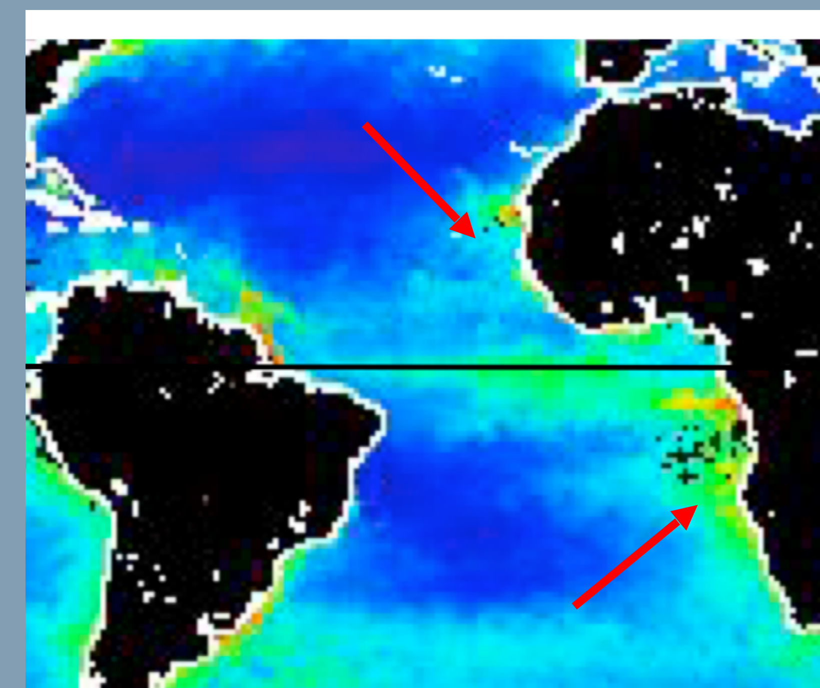


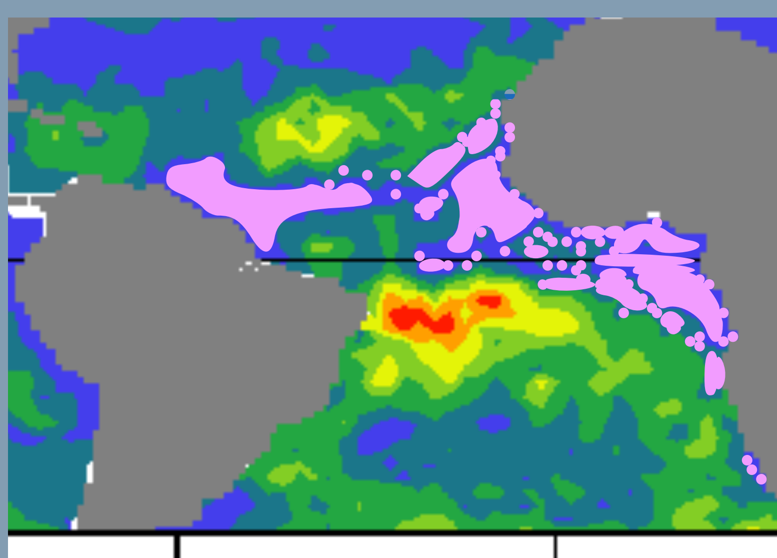


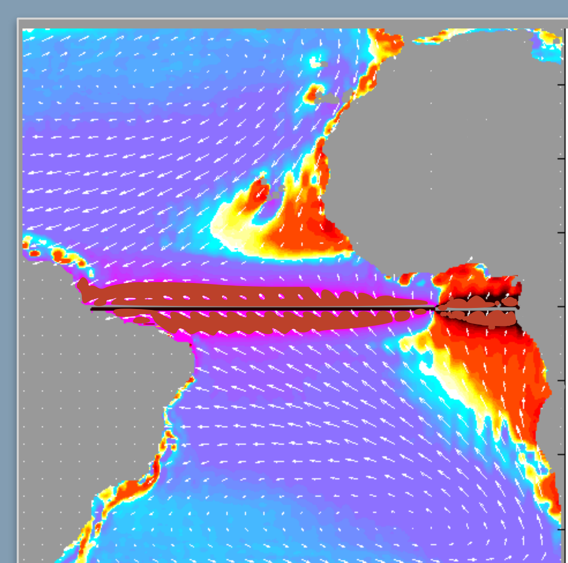
low frequencies: common large spatial patterns... of SST variance

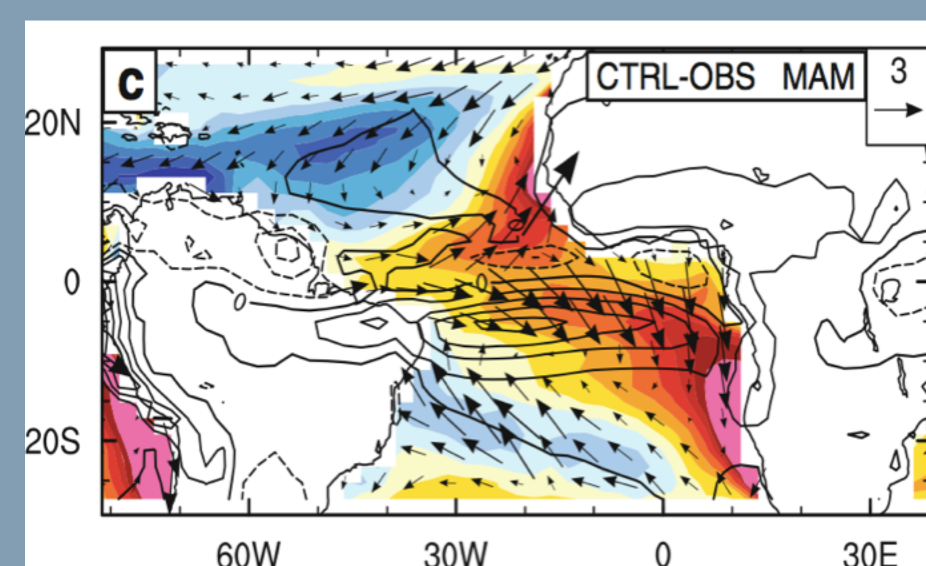




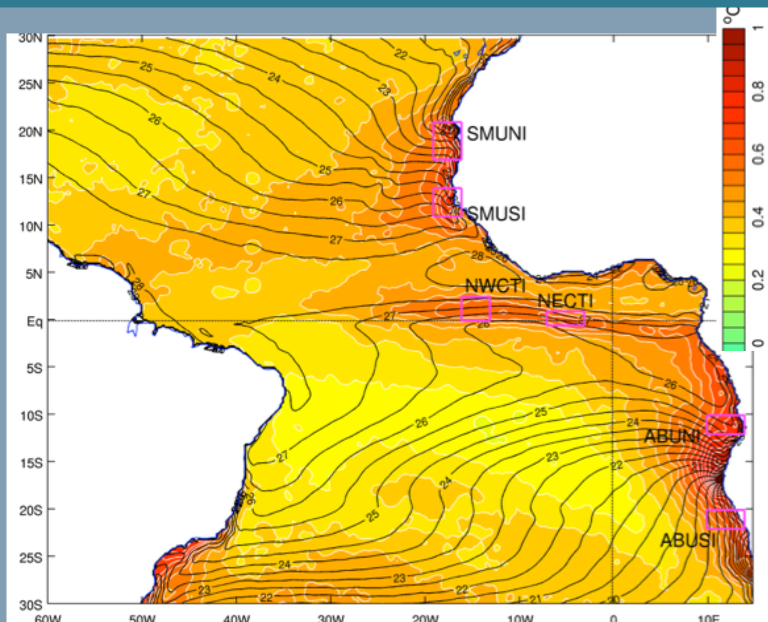




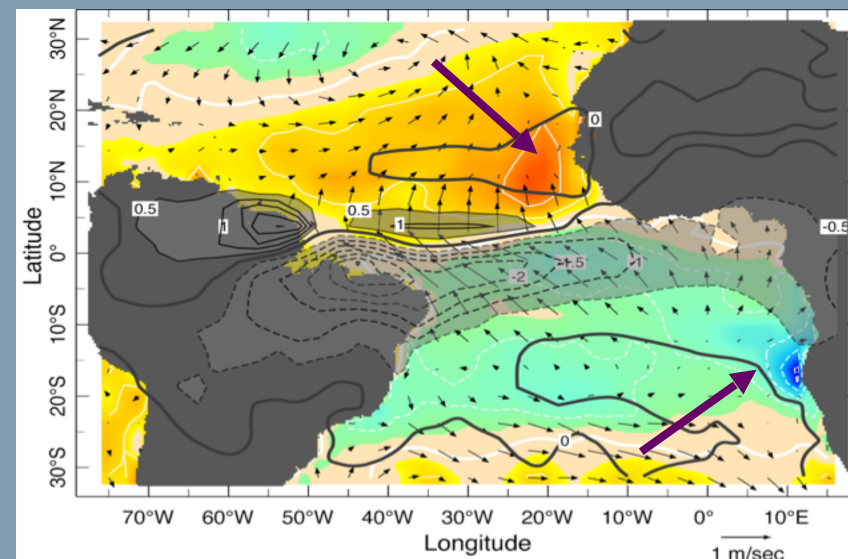




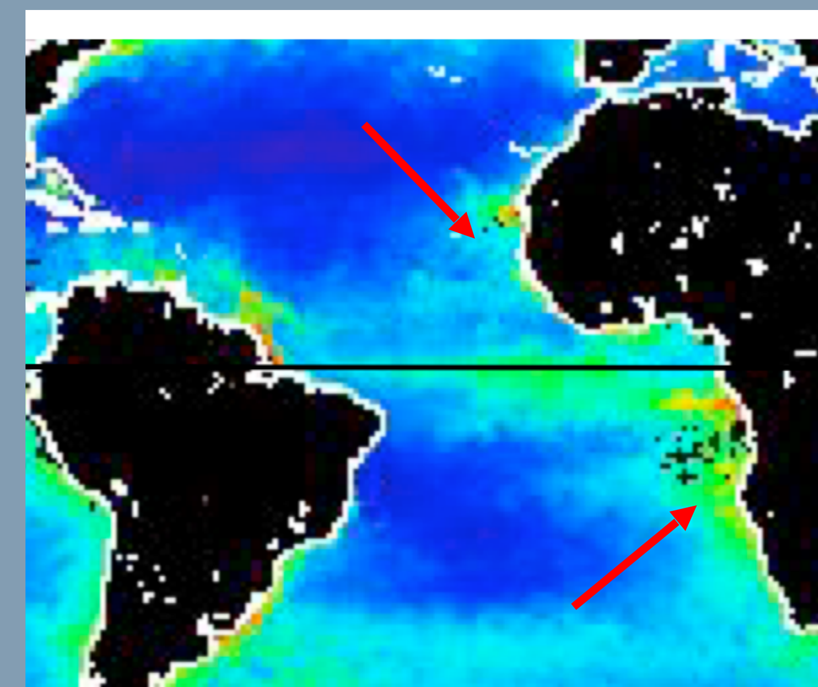
which constrain explains these pattern ?

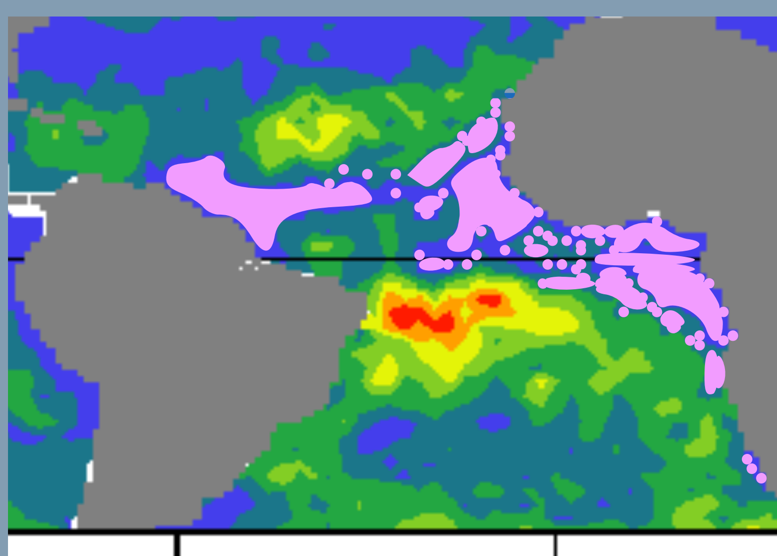


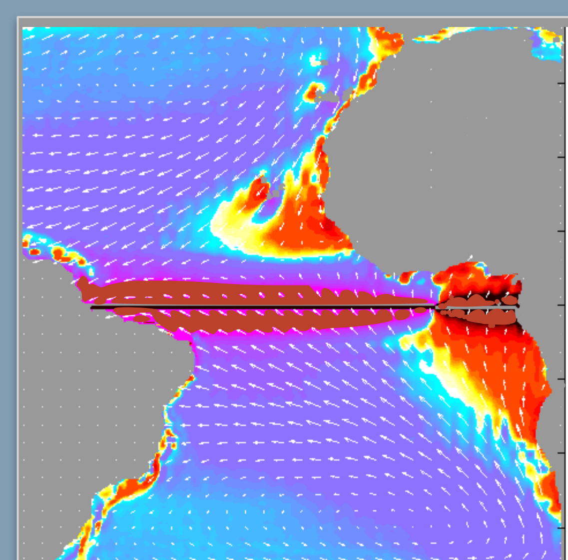
SST intra-seasonal variability
(Diakhaté et al. 2015)

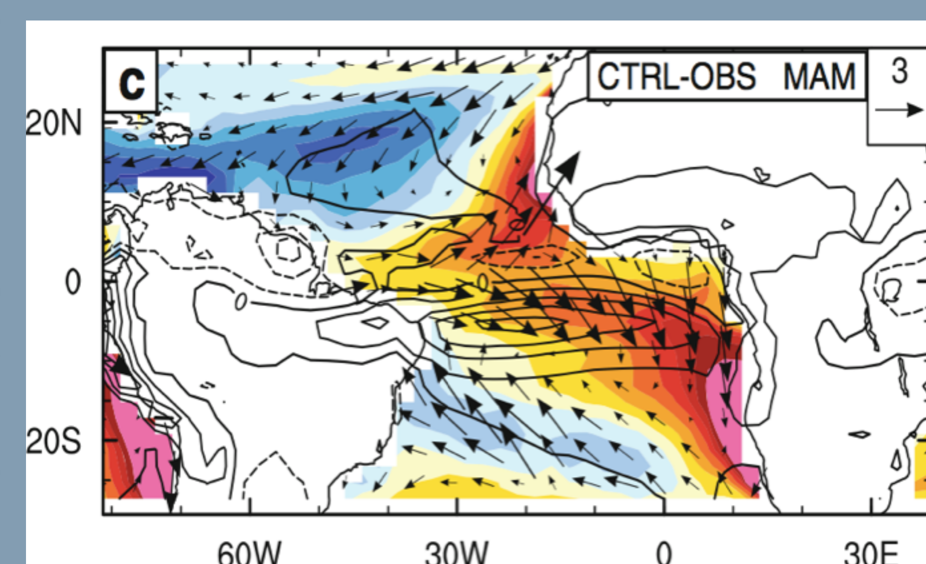


interannual climate variability
(Kushnir 2003)


bioactivity (Seawifs)


mixed layer minima
(De Boyer et al. 2004)


Ekman vertical pumping



CCM error maps (Richter, Xie 2008)

model : Nemo

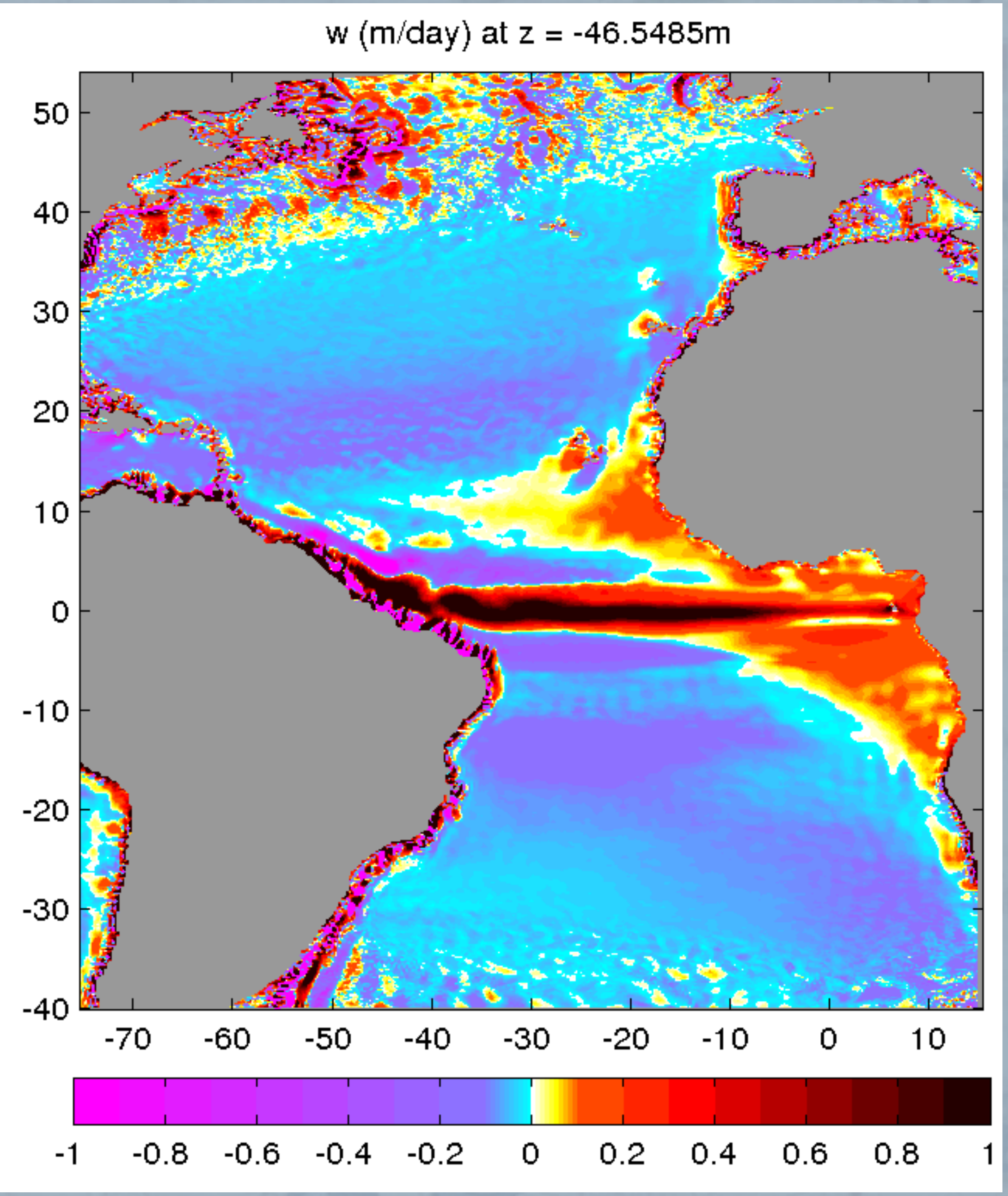
config : ORCA025-G70

– (DRAKKAR reference simulation)

horizontal resolution: from 27 km (1/4° at equator) to 12 km (Arctic)

vertical resolution : 46 levels, spaced from 6 m (surface) to 250 m (bottom)

average 1980-2004



Questions - outline

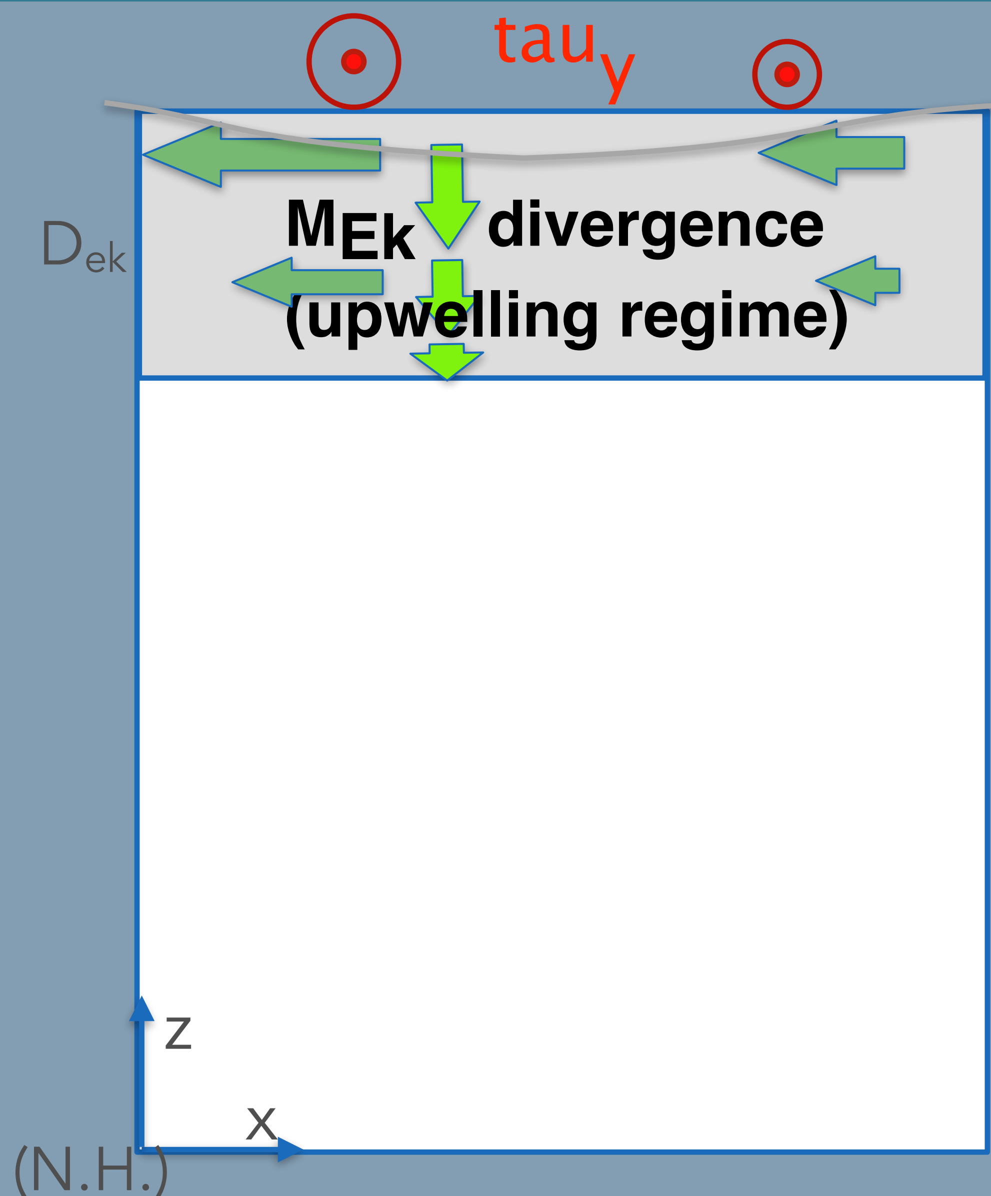
I. vertical velocity at low frequency:

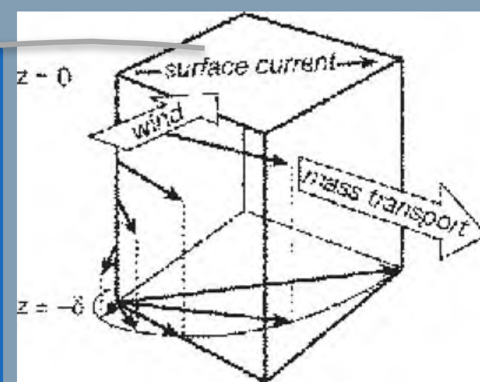
- What determine vertical movements within and below the Ekman layer?
- In an upwelling, is the Ekman velocity really upwards?
- How is its surface mass divergence balanced
- is geostrophic flow divergent?
- What is behind the Sverdrup integral balance?

II. Control of the sea surface temperature in a large upwelling system

- Various variabilities
- Are surface temperature always cooled by upwelling?
- How much salinity may controls the mixed layer and its temperature?

Ekman pumping





Ekman (vertically integrated) transport

$$\mathbf{M}_{Ek} = \frac{\tau_{wind} \times \hat{\mathbf{z}}}{f}$$

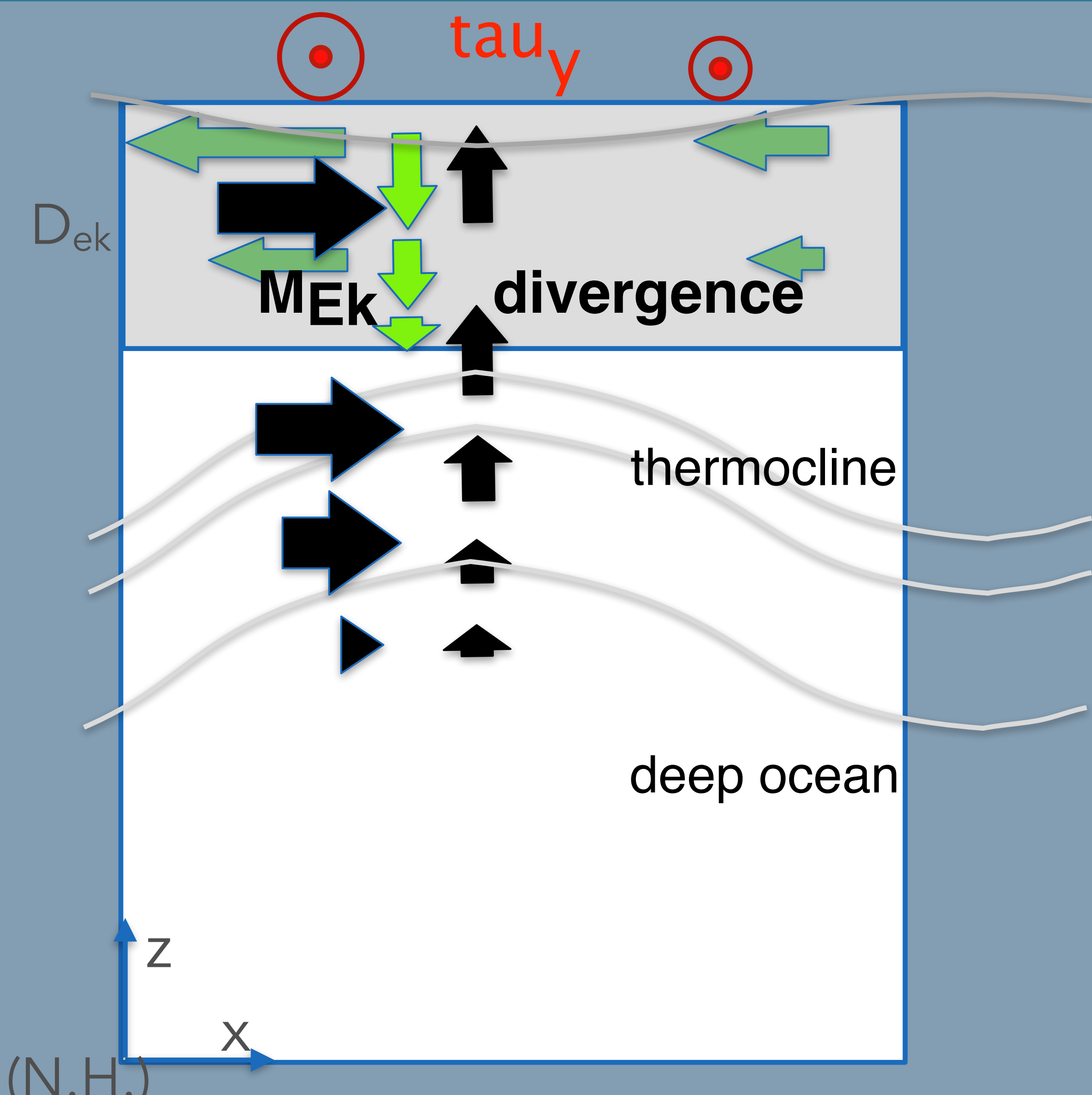
Ekman currents horizontal divergence generates downward vertical velocities

- in an upwelling state, *wind driven* currents subtract mass, corresponding initially to downward vertical velocity W_{wind} (!)
- when steady state is reached, sea surface is stable, <=> W_{wind} + $\mathbf{W_{Ek}}$ = 0 (boundary condition : z=0)

> What determine vertical movements within and below the Ekman layer?

,

Ekman pumping



Ekman (vertically integrated) transport

$$\mathbf{M}_{Ek} = \frac{\tau_{wind} \times \hat{\mathbf{z}}}{f}$$

Ekman currents horizontal divergence generates vertical velocities

- in an upwelling state, *wind driven* currents subtract mass, corresponding initially to downward vertical velocity W_{wind} (!)

  M_{Ek} divergent

- when steady state is reached, sea surface is stable,

  <=> $W_{Ek} = - W_{wind}$ (z=0)

$$w_{Ek} = \frac{1}{\rho_{ref}} \nabla_h \cdot \mathbf{M}_{Ek}$$

$$= \frac{1}{\rho_{ref}} \hat{\mathbf{z}} \cdot \nabla \times \left(\frac{\tau_{wind}}{f} \right)$$

$$= \frac{1}{\rho_{ref}} \left(\frac{\partial}{\partial x} \frac{\tau_{wind_y}}{f} - \frac{\partial}{\partial y} \frac{\tau_{wind_x}}{f} \right)$$

What determine vertical movements within and below the Ekman layer?

geostrophy …

…and its divergence

- How is its surface mass divergence balanced and geostrophic flow divergence :

$$fvg = \frac{1}{\rho}\frac{\partial p}{\partial x} \qquad fug = -\frac{1}{\rho}\frac{\partial p}{\partial y}$$

(1) (2)

$$\frac{\partial u}{\partial x}+\frac{\partial v}{\partial y}+\frac{\partial w}{\partial z}=0$$

$$\frac{\partial (2)}{\partial x}+\frac{\partial (1)}{\partial y}=-\frac{\partial w}{\partial z}$$

How is Ekman transport divergence balanced and is geostrophic flow so non-divergent?

geostrophy …

…and its divergence…

leads to

$$fvg = \frac{1}{\rho}\frac{\partial p}{\partial x} \quad (1) \qquad fug = -\frac{1}{\rho}\frac{\partial p}{\partial y} \quad (2)$$

$$\frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} + \frac{\partial w}{\partial z} = 0$$

$$\frac{\partial (2)}{\partial x} + \frac{\partial (1)}{\partial y} = -\frac{\partial w}{\partial z}$$

$$\beta v_g = f.\frac{\partial w}{\partial z}$$

(df/dy=beta)

Linear vorticity balance

geostrophy …

…and its divergence…

leads to

$$fv_g = \frac{1}{\rho}\frac{\partial p}{\partial x} \qquad fu_g = -\frac{1}{\rho}\frac{\partial p}{\partial y}$$

(1) (2)

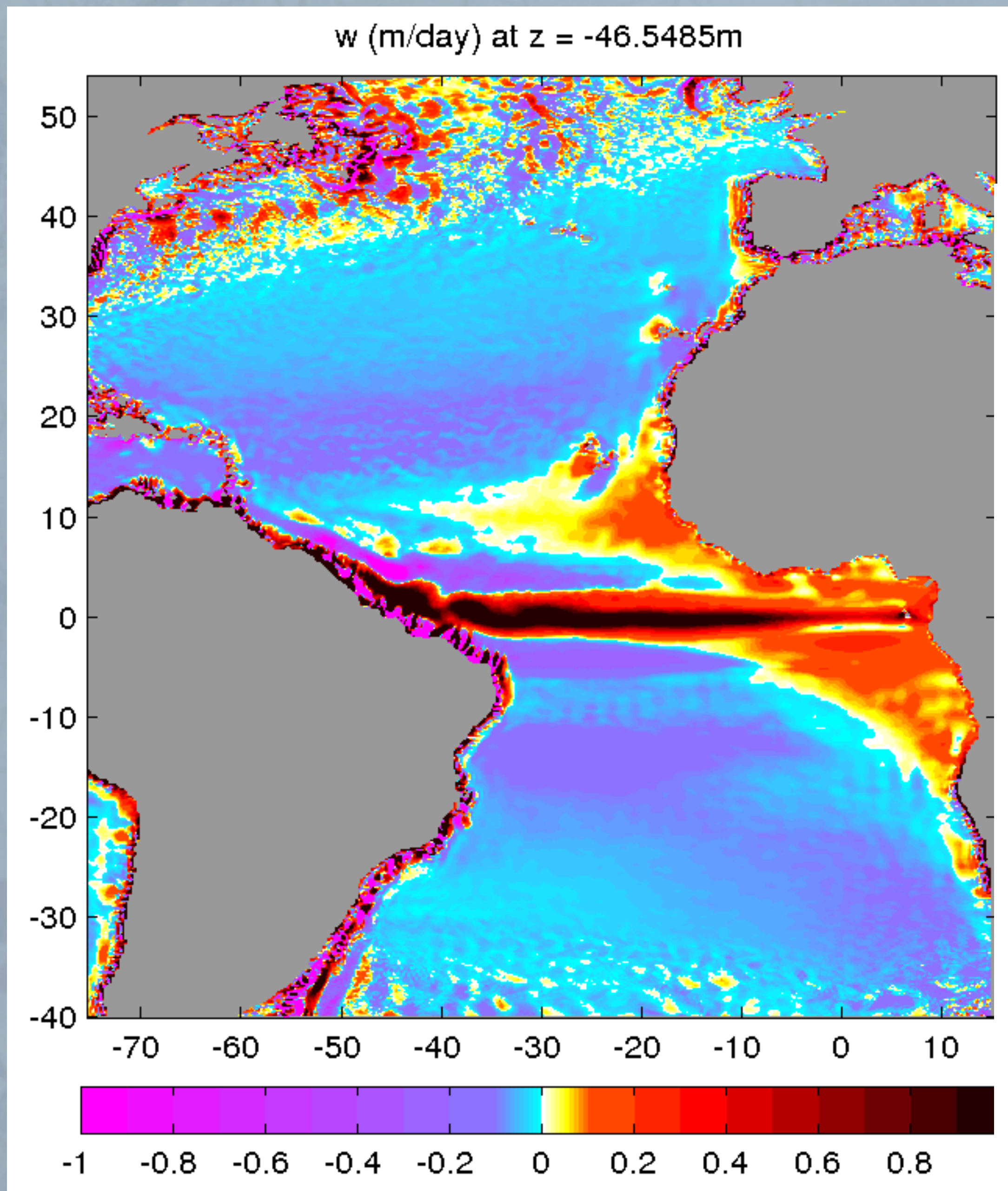
$$\frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} + \frac{\partial w}{\partial z} = 0$$

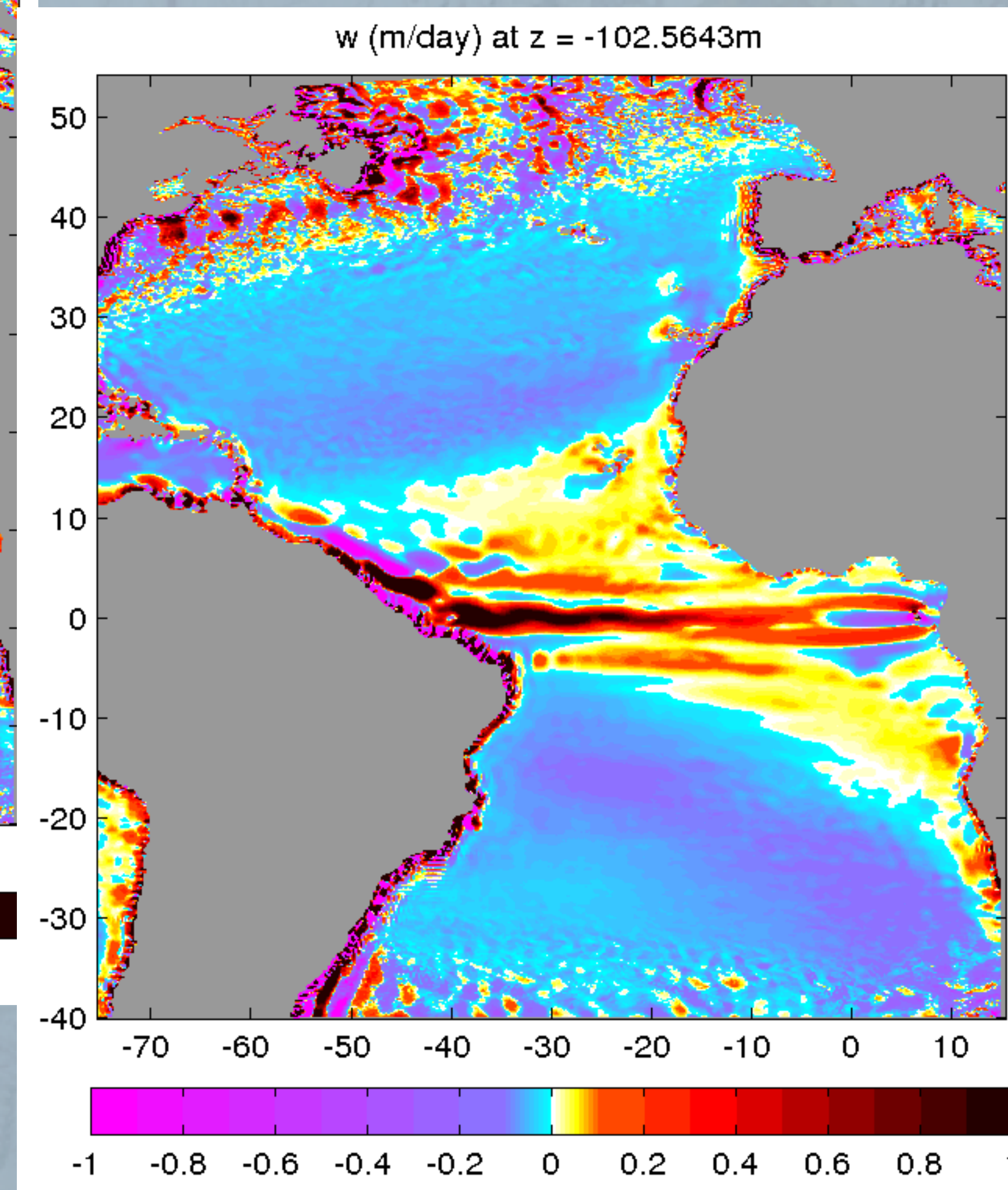
$$\frac{\partial(2)}{\partial x} + \frac{\partial(1)}{\partial y} = -\frac{\partial w}{\partial z}$$

$$\beta v_g = f.\frac{\partial w}{\partial z} \quad \Rightarrow \quad w(z) = \int_{z'=h}^{z'=z} \frac{\beta v}{f} dz' + w(h)$$

Linear vorticity balance

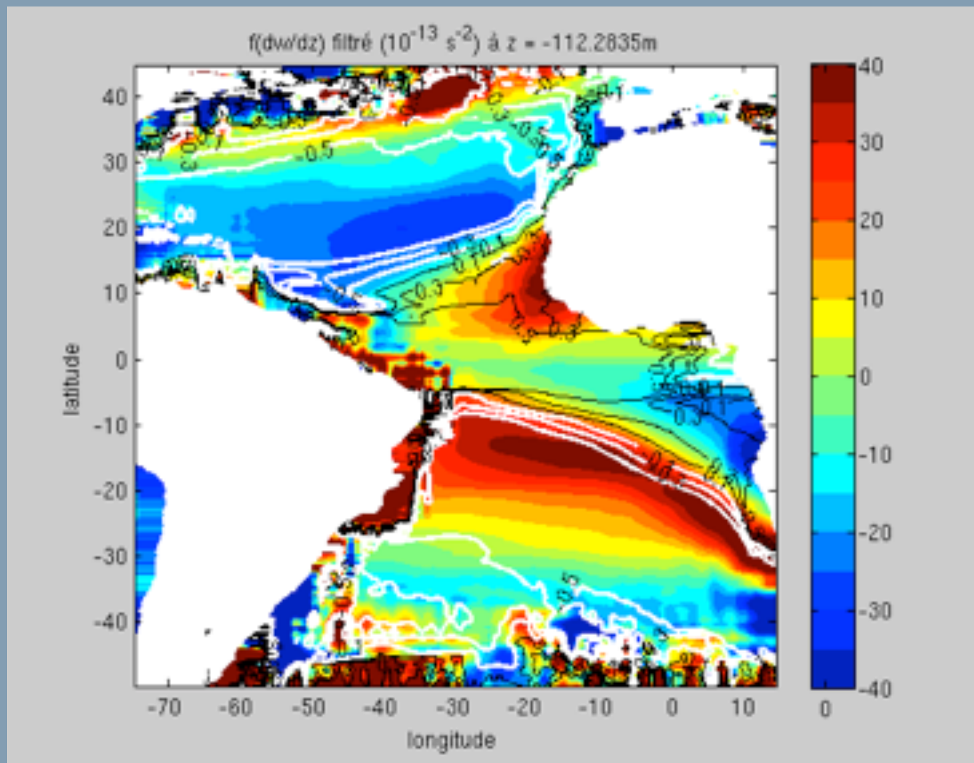
…and **VERTICAL VELOCITY**

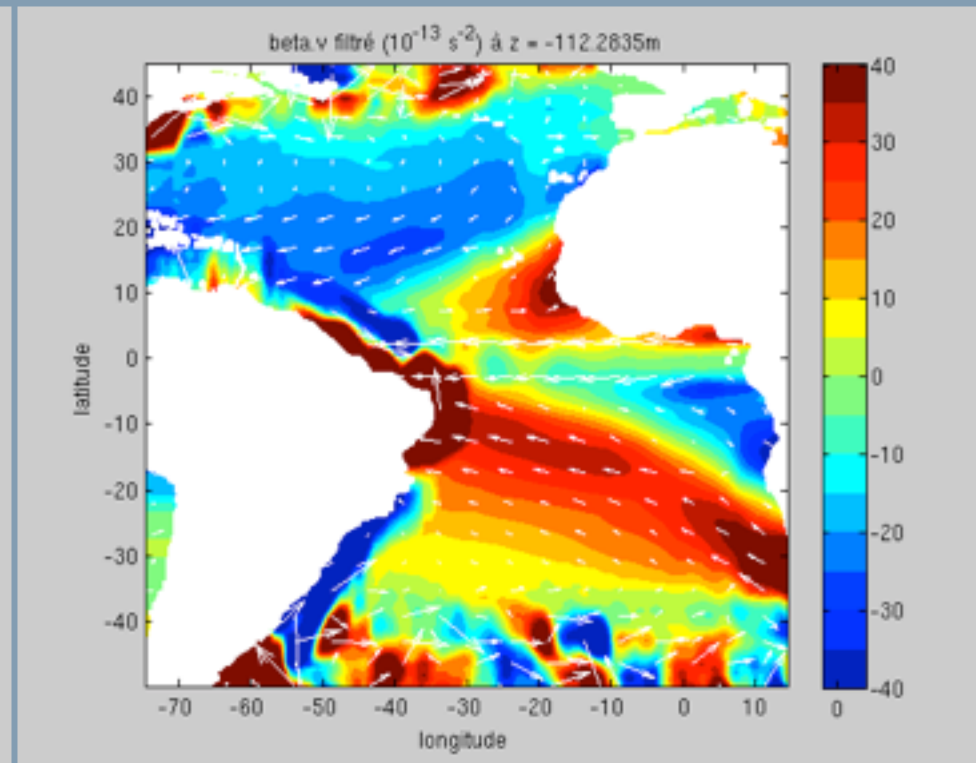

w (m/day) at z = -46.5485m
50
40
30
20
10
0
-10
-20
-30
-40
-70 -60 -50 -40 -30 -20 -10 0 10
-1 -0.8 -0.6 -0.4 -0.2 0 0.2 0.4 0.6 0.8


w (m/day) at z = -102.5643m
50
40
30
20
10
0
-10
-20
-30
-40
-70 -60 -50 -40 -30 -20 -10 0 10
-1 -0.8 -0.6 -0.4 -0.2 0 0.2 0.4 0.6 0.8 1

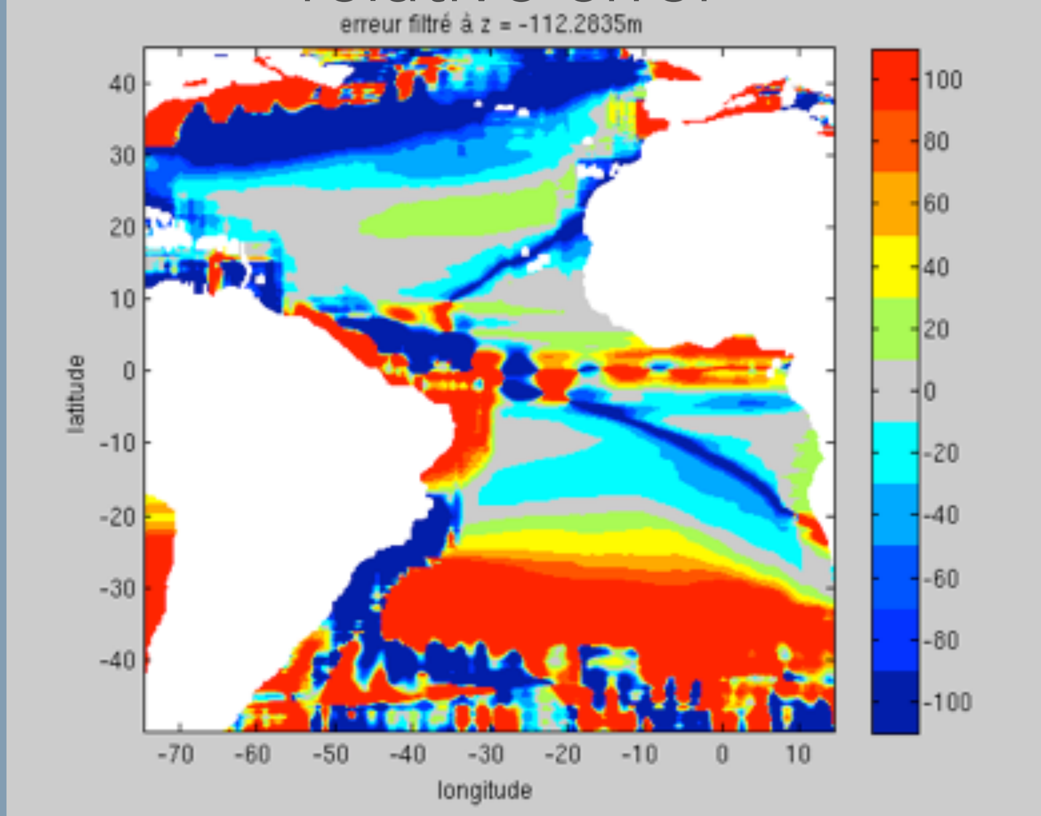
Large scale w (model) controlled by linear vorticity balance ?

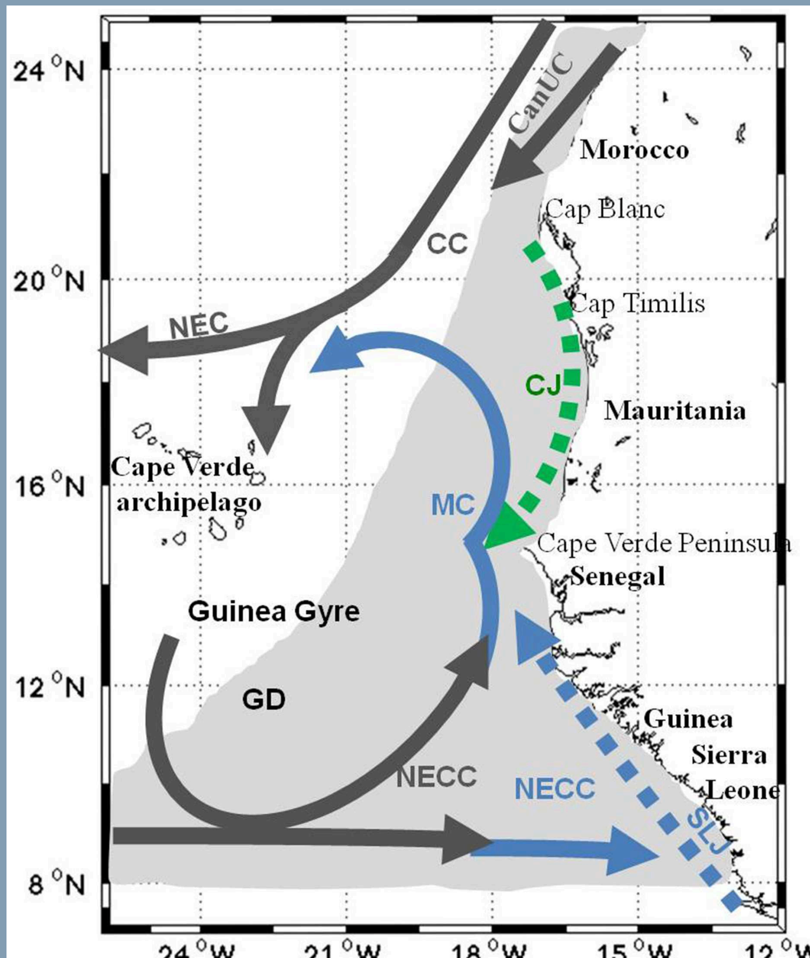
$f\,\partial w/\partial z = \beta\, v$?



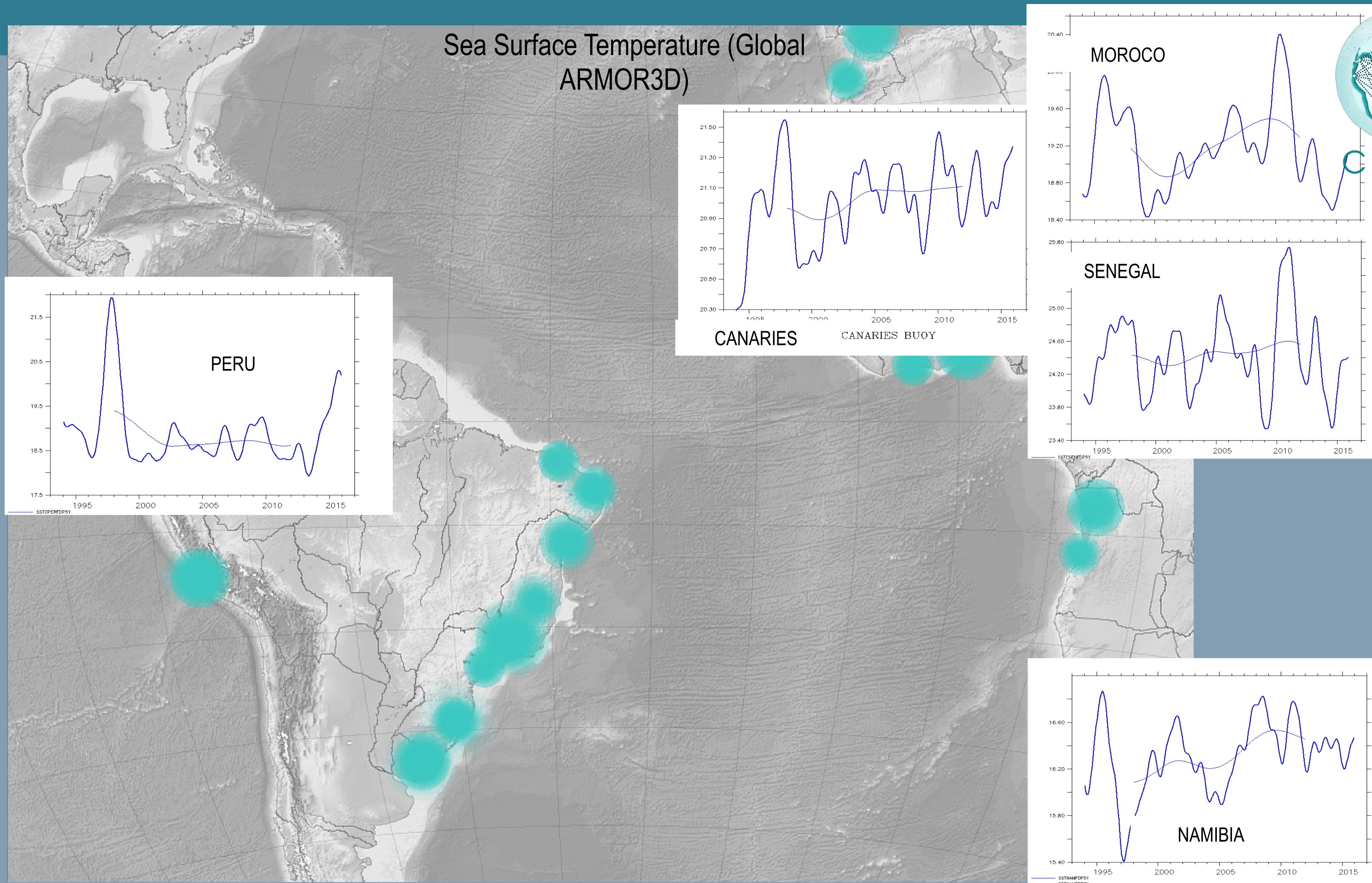


relative error

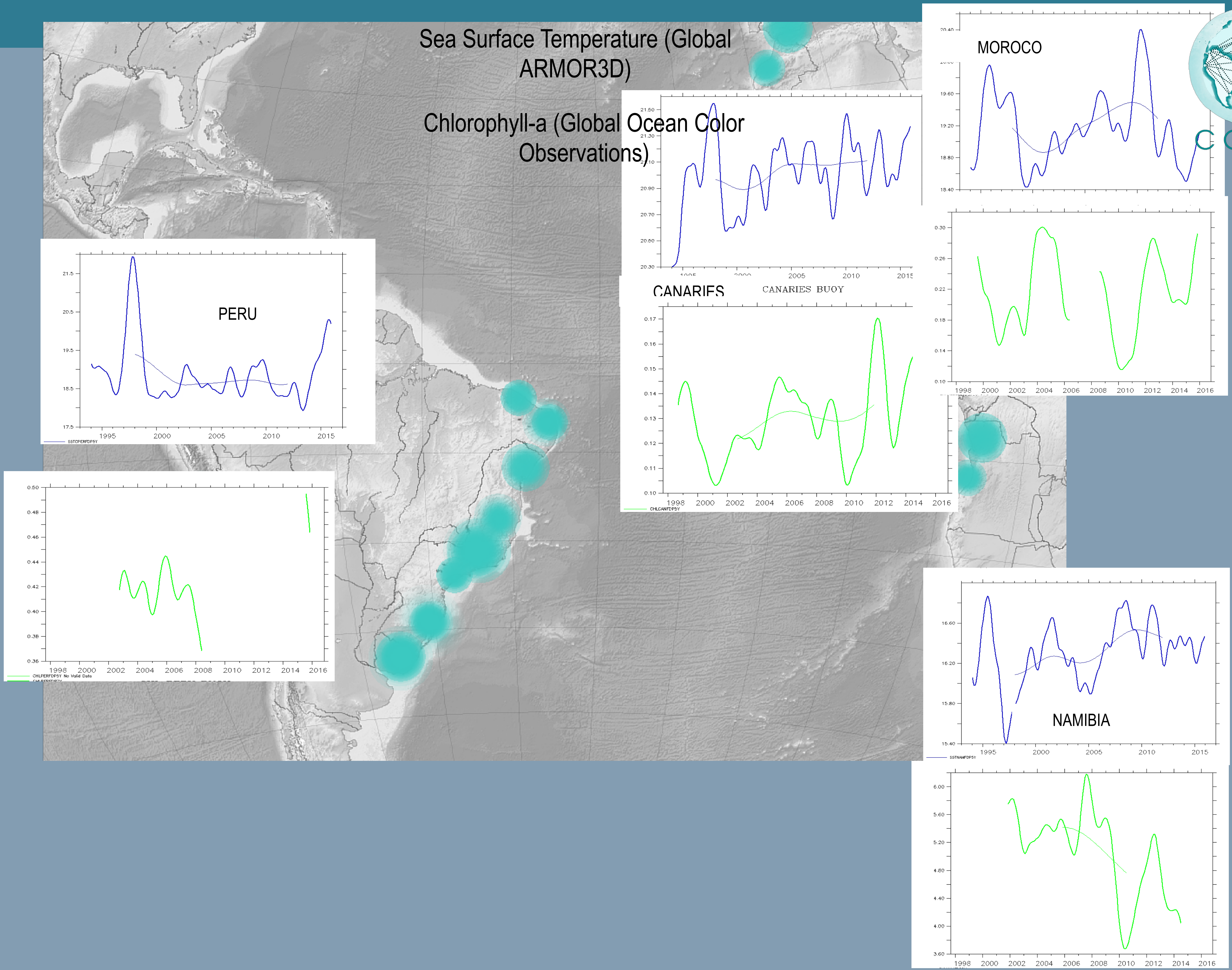




II. Control of the sea surface temperature in a large upwelling systems

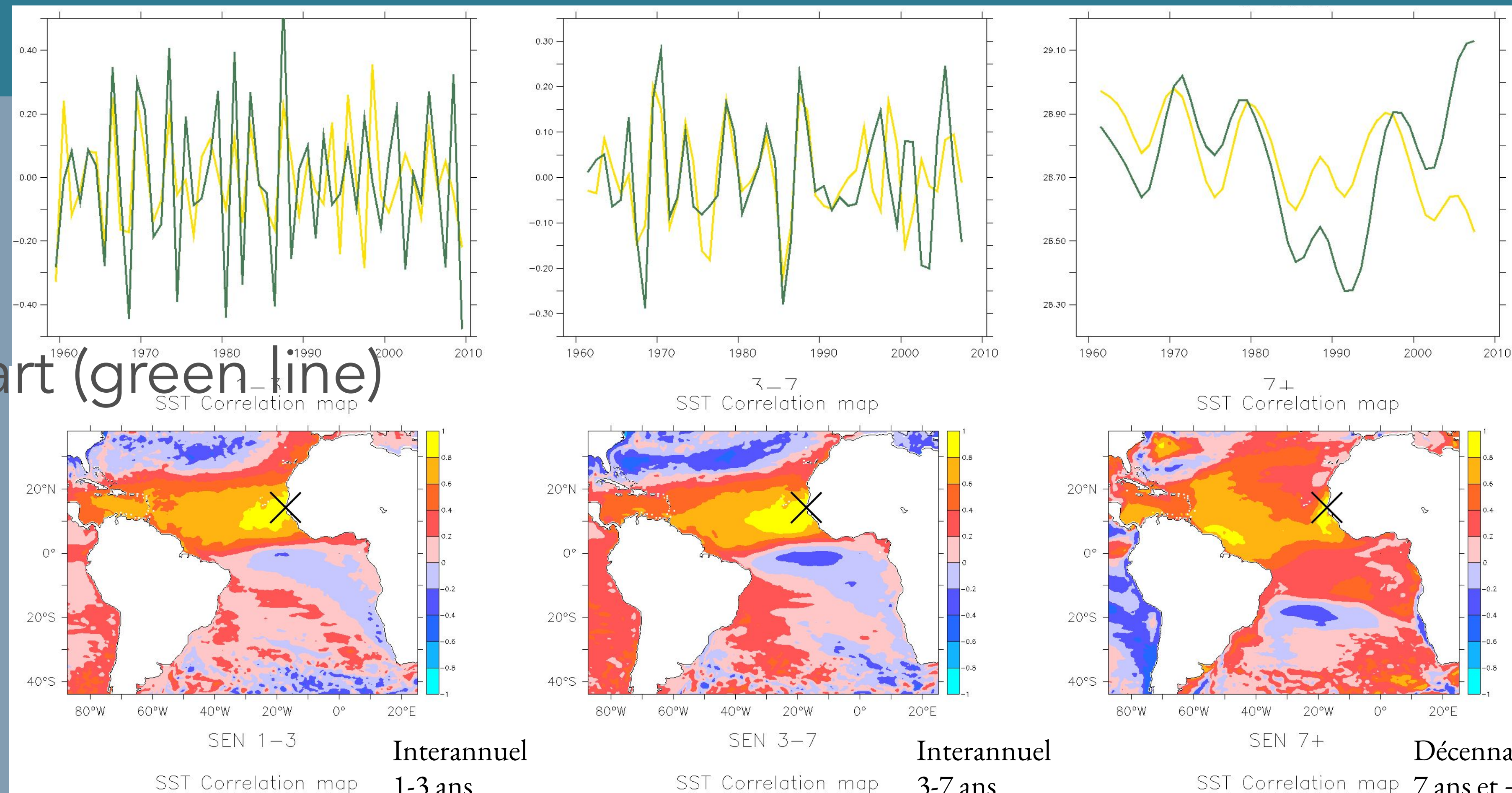


II. Control of the sea surface temperature in a large upwelling systems

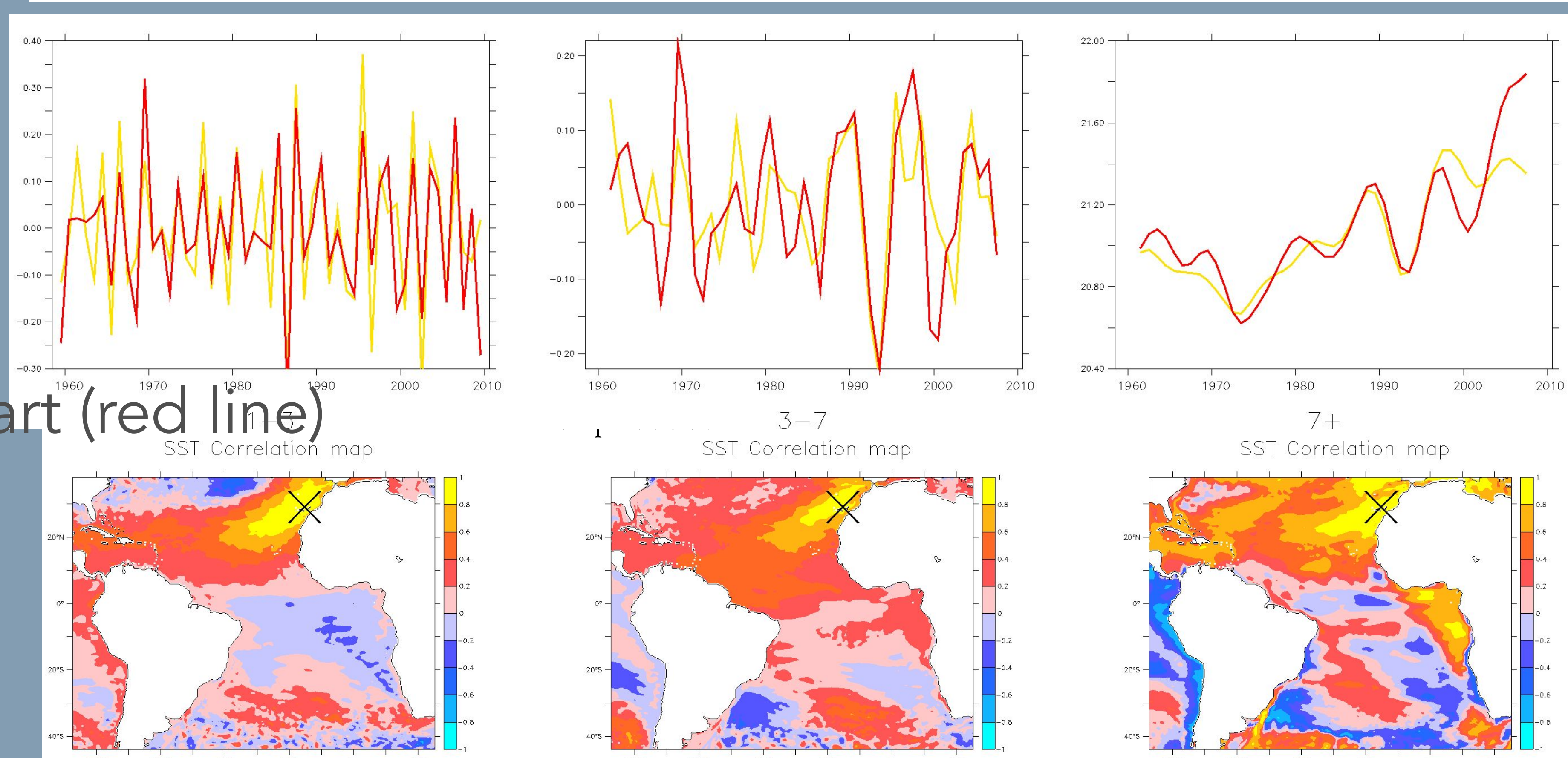


large scale signals in the Canary EBUS : inter annual to decadal SST variability

Southern part (green line)



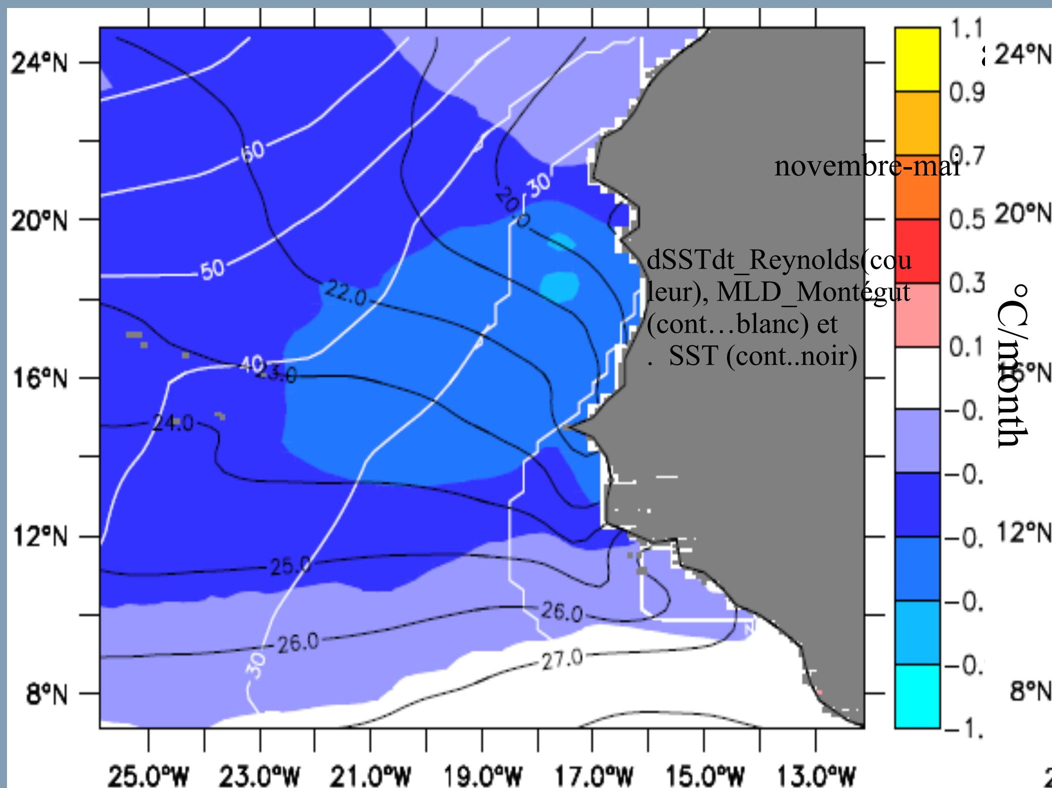
Northern part (red line)

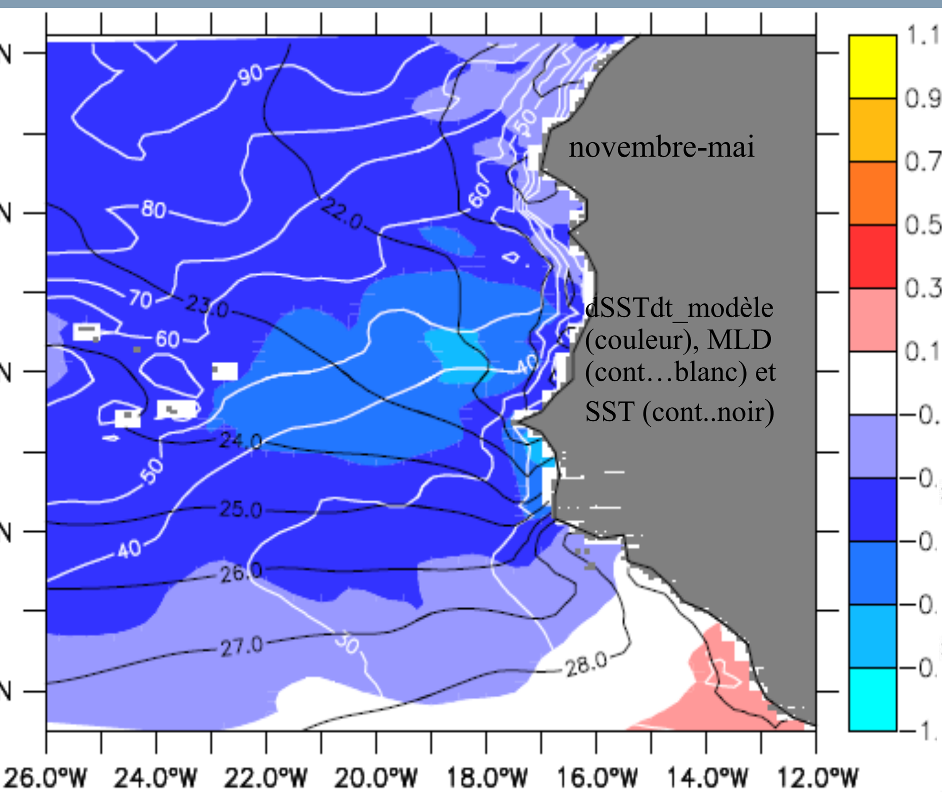


Seasonal cycle in the Canary EBUS

dSST/dt

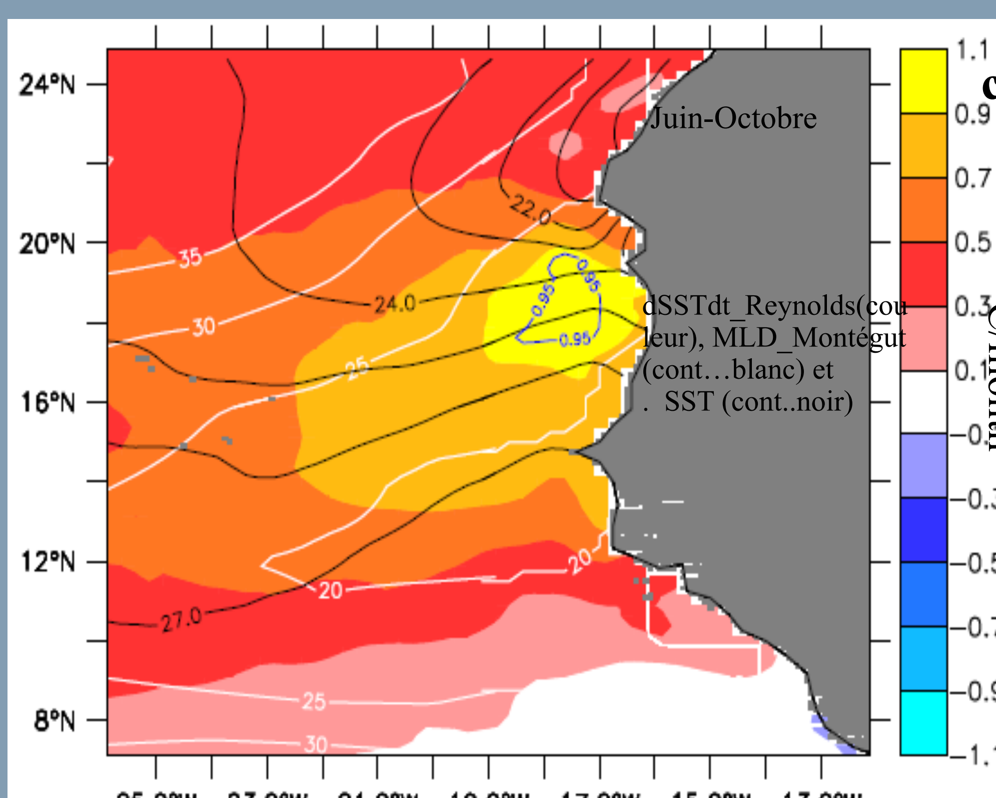
Cooling season Nov-May

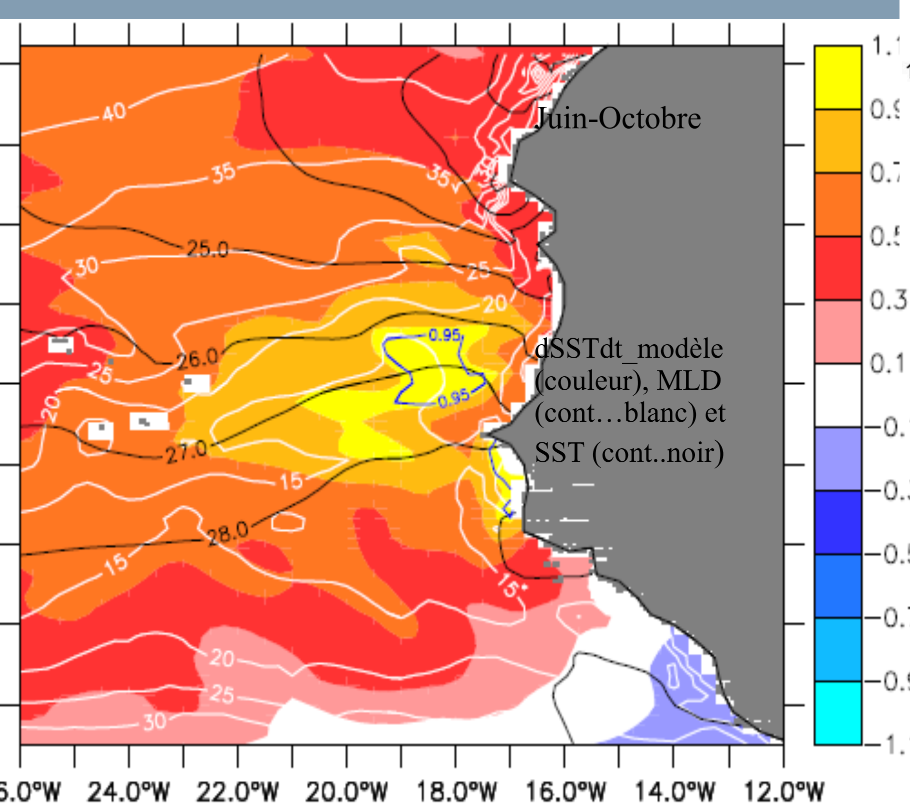


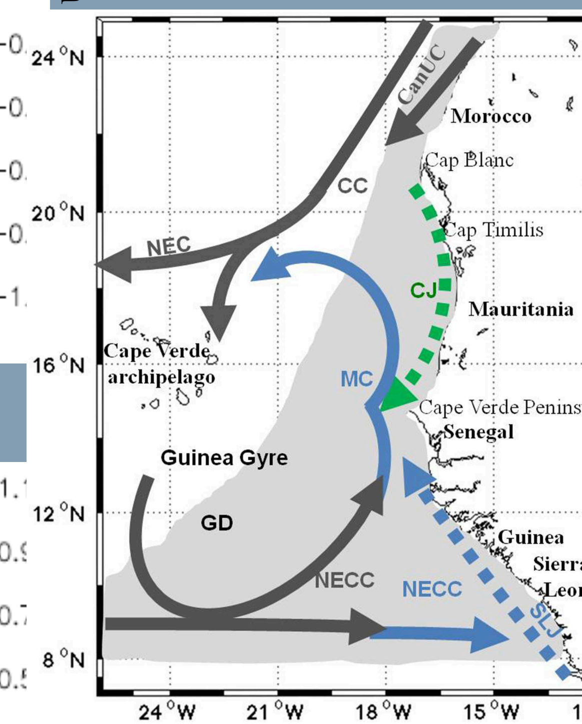


Observations **Model**

Warming season Jun-Oct







Faye et al. 2015

Seasonal cycle in the Canary EBUS

dSST/dt

dSST/dt = ocean effect + atmosphere effect

horizontal dynamics

subsurface fluxes

$$\partial_t \langle T \rangle = -\langle u.\partial_x T \rangle - \langle v.\partial_y T \rangle + \langle D_l(\langle T \rangle) \rangle - \frac{1}{h}\frac{\partial h}{\partial t}(\langle T \rangle - T_{z=h}) - \langle w.\partial_z T \rangle - \frac{1}{h}(K_z \partial_z T)_{z=h} + \frac{Q^* + Q_s(1 - f_{z=h})}{\sigma_0 C_p h}$$

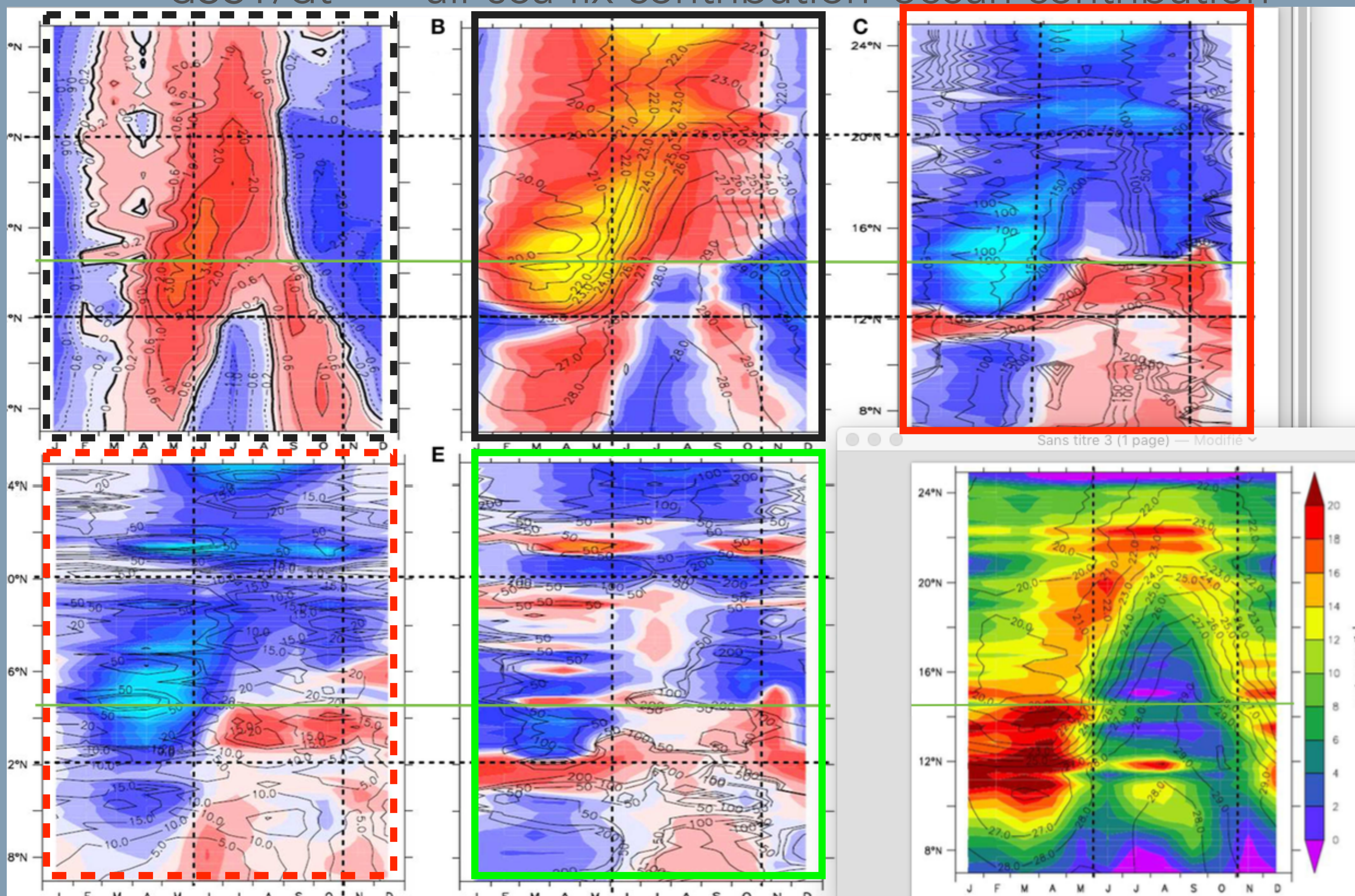
SST Seasonal cycle in the Canary EBUS

dSST/dt = ocean effect + atmosphere effect

horizontal dynamics | subsurface fluxes

$$\partial_t\langle T\rangle = -\langle u.\partial_x T\rangle - \langle v.\partial_y T\rangle + \langle D_l(T)\rangle - \frac{1}{h}\frac{\partial h}{\partial t}(\langle T\rangle - T_{z=h}) - \langle w.\partial_z T\rangle - \frac{1}{h}(K_z\partial_z T)_{z=h} + \frac{Q^* + Q_s(1-f_{z=h})}{\sigma_0 C_p h}$$

dSST/dt | air-sea flx contribution | ocean contribution



MODEL
Faye et al. 2015

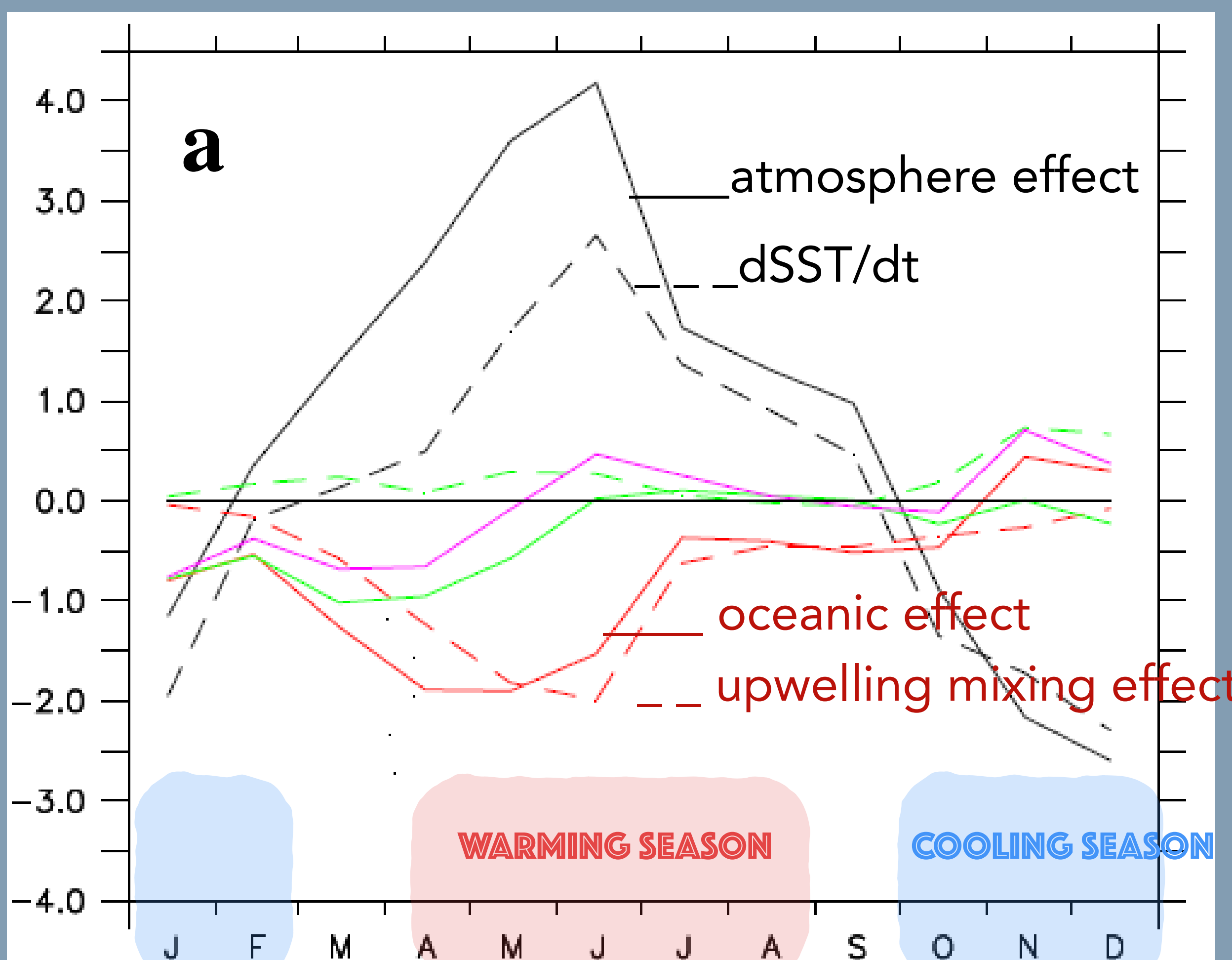
vertical ocean | horizontal ocean | Ekman pumping

SST Seasonal cycle in the Canary EBUS: focus on the southern part (South Senegal)

dSST/dt = ocean effect + atmosphere effect

horizontal dynamics — subsurface fluxes

$$\partial_t\langle T\rangle = -\langle u.\partial_x T\rangle - \langle v.\partial_y T\rangle + \langle D_l(T)\rangle - \frac{1}{h}\frac{\partial h}{\partial t}(\langle T\rangle - T_{z=h}) - \langle w.\partial_z T\rangle - \frac{1}{h}(K_z\partial_z T)_{z=h} + \frac{Q^* + Q_s(1-f_{z=h})}{\sigma_0 C_p h}$$



14°20’N

model response :

atmosphère dominates !

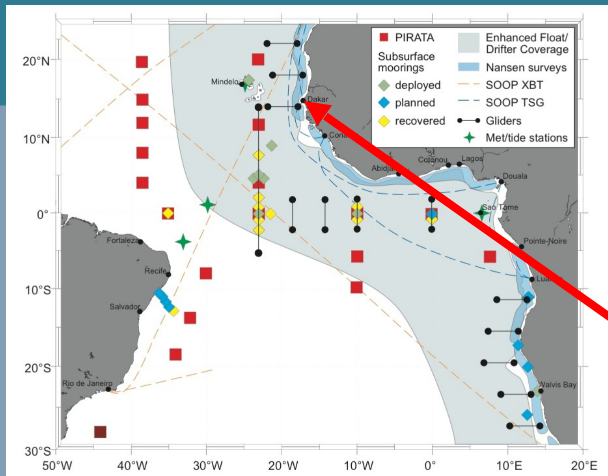
ocean may warm the surface during the first phase of the cooling seasons !!

Truth, or model error ??

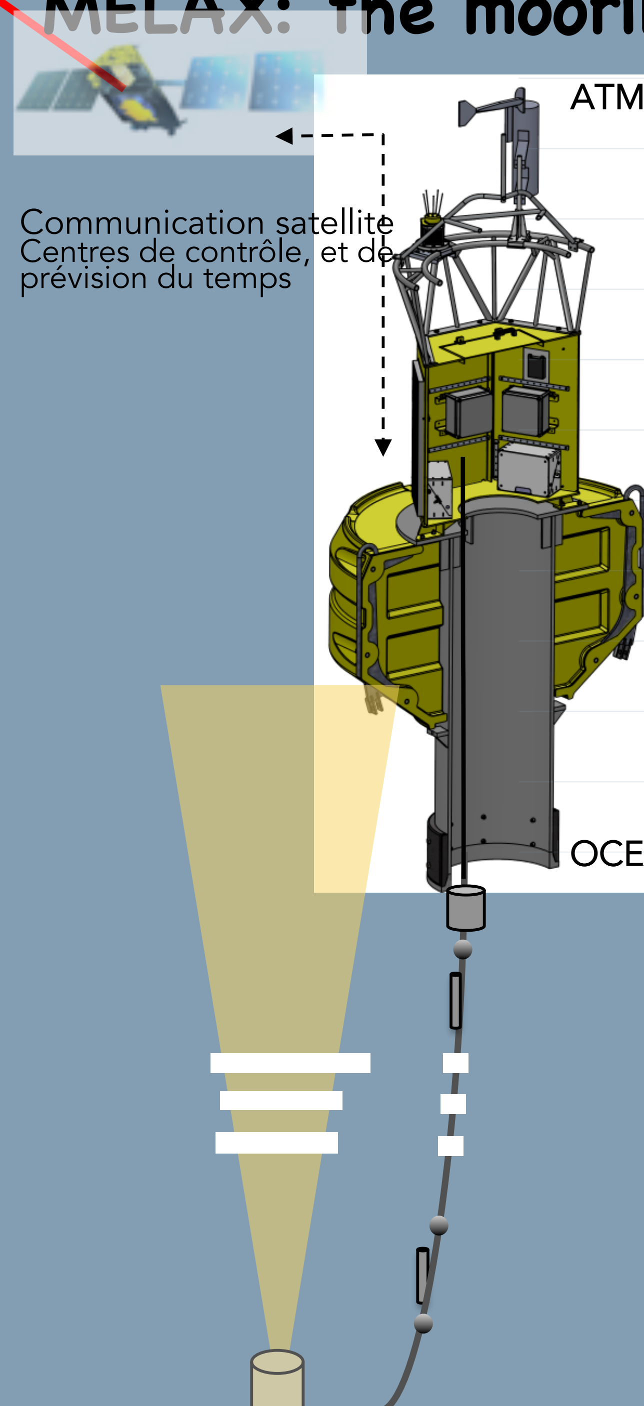
—> verification with MEASURES

(Faye et al. 2015)

SST Seasonal cycle in the Canary EBUS : focus on the southern part (South Senegal)



MELAX: the mooring characteristics



ATMOSPHERE (de surface)

- Température de l'air
- Humidité relative
- Pression
- Vent
- Radiations
- Précipitation

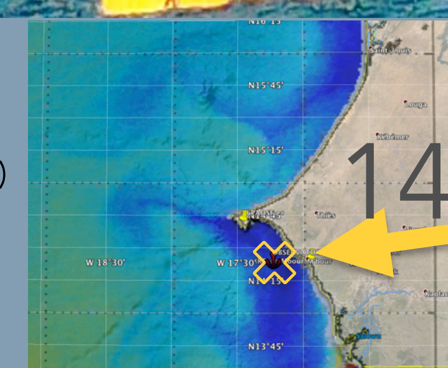
Période d'acquisition de 2mn, transmission satellite chaque 2h

OCEAN (Surface -> 30 mètres)

- Température (11 profondeurs)
- Salinité (surface et fond)

Période d'acquisition de 10mn, transmission satellite chaque 2h

- Courants (profil continu chaque 90mn)
- Oxygène de fond
- Carbone (à venir en 2015)



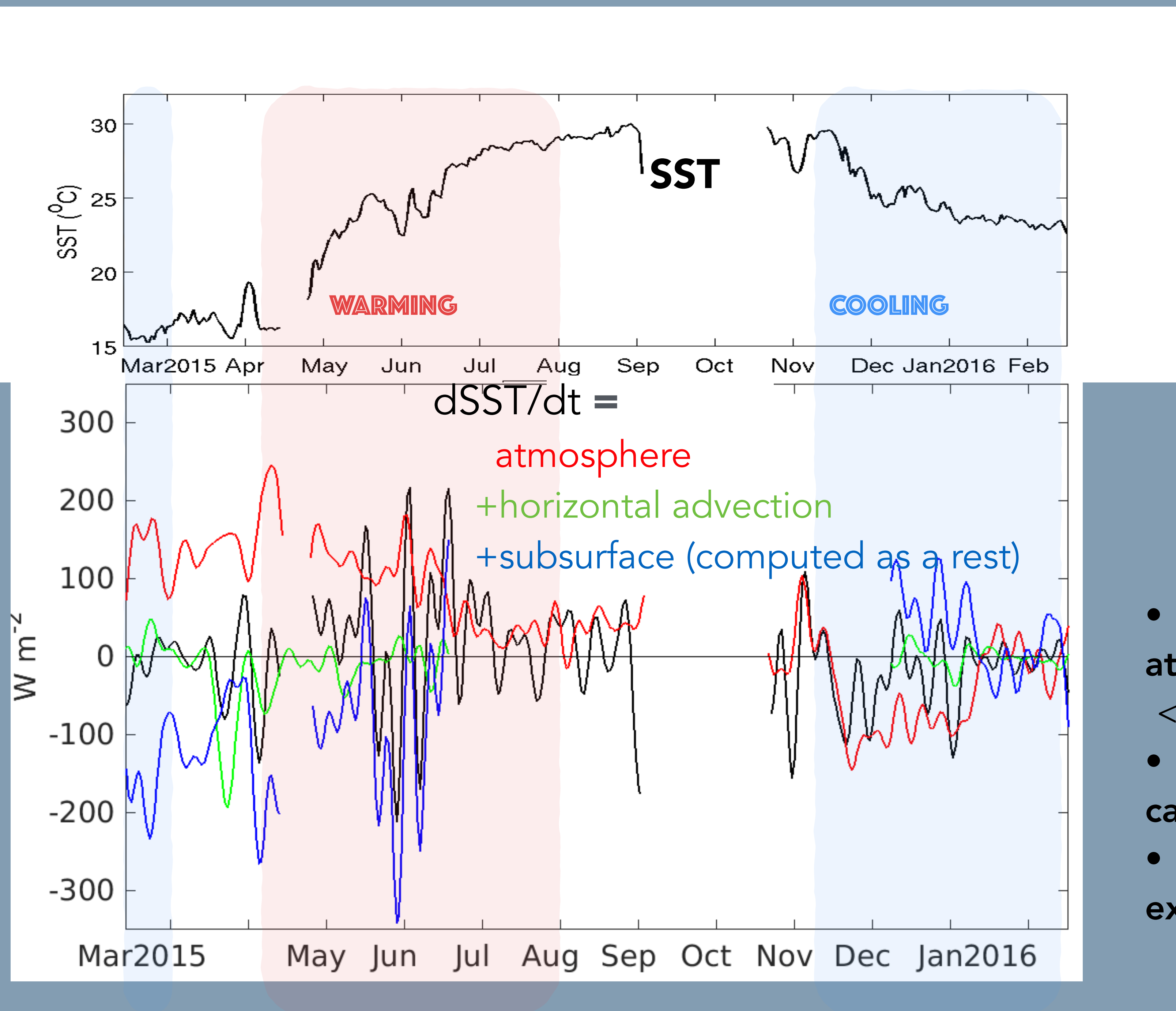
Position de MELAX à proximité de Dakar ,Sénégal. Fond : températures de la mer en saison d'upwelling fort

Anchored off Dakar, by 30m depth, in the core of the upwelling, the 11th of February 2015

SST Seasonal cycle in the Canary EBUS: focus on the southern part (South Senegal)

BUDGET ESTIMATE FROM IN SITU+REMOTE MEASUREMENTS

14°20’N



- **NDJ cooling:**

atmosphere cools and ocean warms confirmed

<=dry continental air + temperature inversions

- **JFM cooling:**

canonical upwelling dynamics cooling

- **AMJJ warming:**

explained by decrease of the upwelling cooling