AN ASSESSMENT OF OCEANIC LARGE SCALE VERTICAL VELOCITIES IN THE TROPICAL ATLANTIC : AN ANALYSIS OF THE VORTICITY BUDGET

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1-Introduction (1/3)

Importance of vertical velocities in the ocean

→ Explains primary production

→ Regulates the climate (carbon oxygen cycle)

→ Explains the water ventillation

Etc...

Analysis of vertical velocities in the ocean

→ Scalling : $\nabla U = \partial_x u + \partial_y v + \partial_z w = 0$; **$w \approx 10^{-5}$ m/s** ; **very small**

→ Difficult to do direct measurements

→ In numerical models: w are so noisy that they are considered difficult to analyze, **Lu and Stammer, 2004**

1-Introduction (2/3)

Analysis of vertical velocities in the ocean

Cummins et al., 2016 analyze w of the world ocean from the Linear Vorticity Balance (**LVB**) from the Vg Argo network and compared them to a coupled Atmosphere-Ocean model

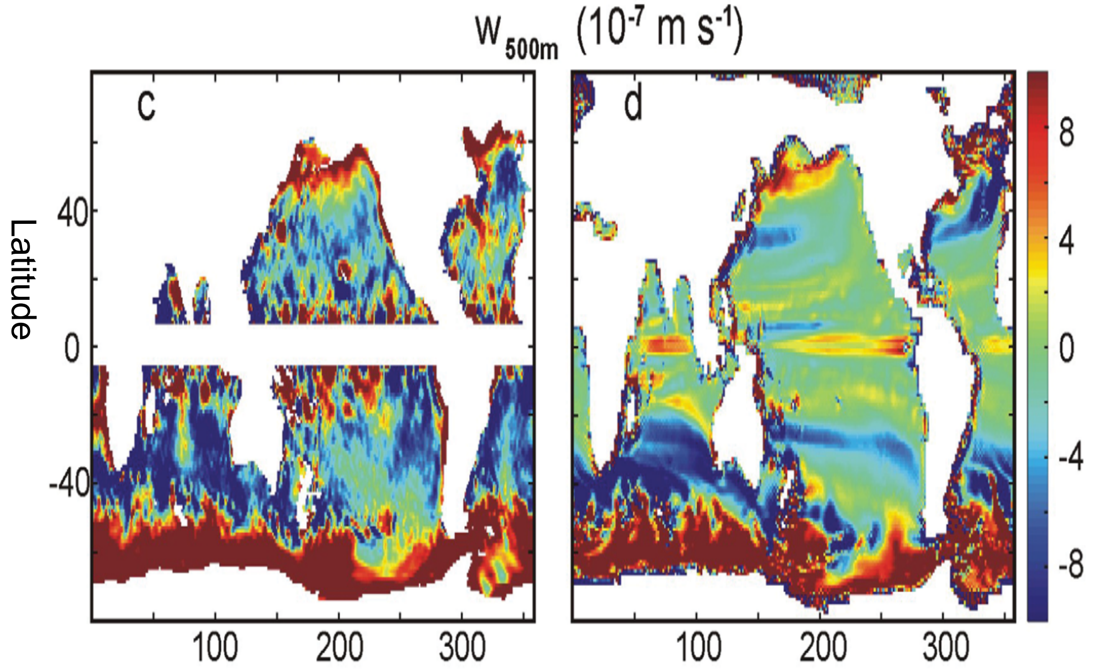

Figure:Vertical velocity at 500 m: c) observation and d) diagnosed from the LVB (Cummins et al., 2016)

- Wide spatial variation of w,
- Large-scale consistency between w of the model and that estimated from LVB

Analysis of vertical velocities in the ocean

Goals

- **Identify the areas of validity of the linear vorticity balance (LVB)**

- **Rewrite the conservation absolute voticity budget to see the possible causes of the non-validity**

- **Reconstruct w by integrating the LVB with the bottom and surface boundary conditions.**

2-Data and Methods (1/2)

→ Model : Nucleus for European Modelling of Ocean (NEMO), **Madec, 2008**

→ Configurations :

- ORCA025, a climate average simulation of the DRAKKAR project (**Talandier et al., 2003 ; Brodeau et al., 2010)**.
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- ALTROP025, an inter-annual simulation in the tropical Atlantic **(Martin del Rey, M., A. Lazar, 2019)**.

→ Horizontale resolution: 0.25°x0.25°

→ Verticale resolution : 46 levels spaced 6 m apart in the first layers and 250 m at the bottom)

→ Period: 25 years (1980-2004), data are time-averaged over the whole period.

→ 15 grid point XY low pass filter that retains scales > 300 km

2-Data and Methods (2/2)

Absolute vorticity conservation equation ($\xi + f$)

$$\partial_t(\xi+f) + \beta v + u\partial_x\xi + v\partial_y\xi + w\partial_z\xi + (\partial_x w\partial_z v - \partial_y w\partial_z u) = f\partial_z w + \xi\partial_z w + \partial_z(A_{mz}\partial_z\xi) + \nabla^2(A_{mh}\nabla^2\xi)$$

Temporel Variation of (ξ+f)

Advection of (ξ+f)

Twisting

Vortex stretching (linear / nonlinear)

Viscosity (vertical / horizontal)

Hypotheses for the flow to verify the LVB

- Steady state : $\partial_t(\xi+f) = 0$
- In large scale: ξ neglected
- far from the friction layer: neglected viscosities
- β plan
- Around the characteristic Rossby radius (Ro << 1): Neglected nonlinear terms (advection, torsion, nonlinear vortex stretch)

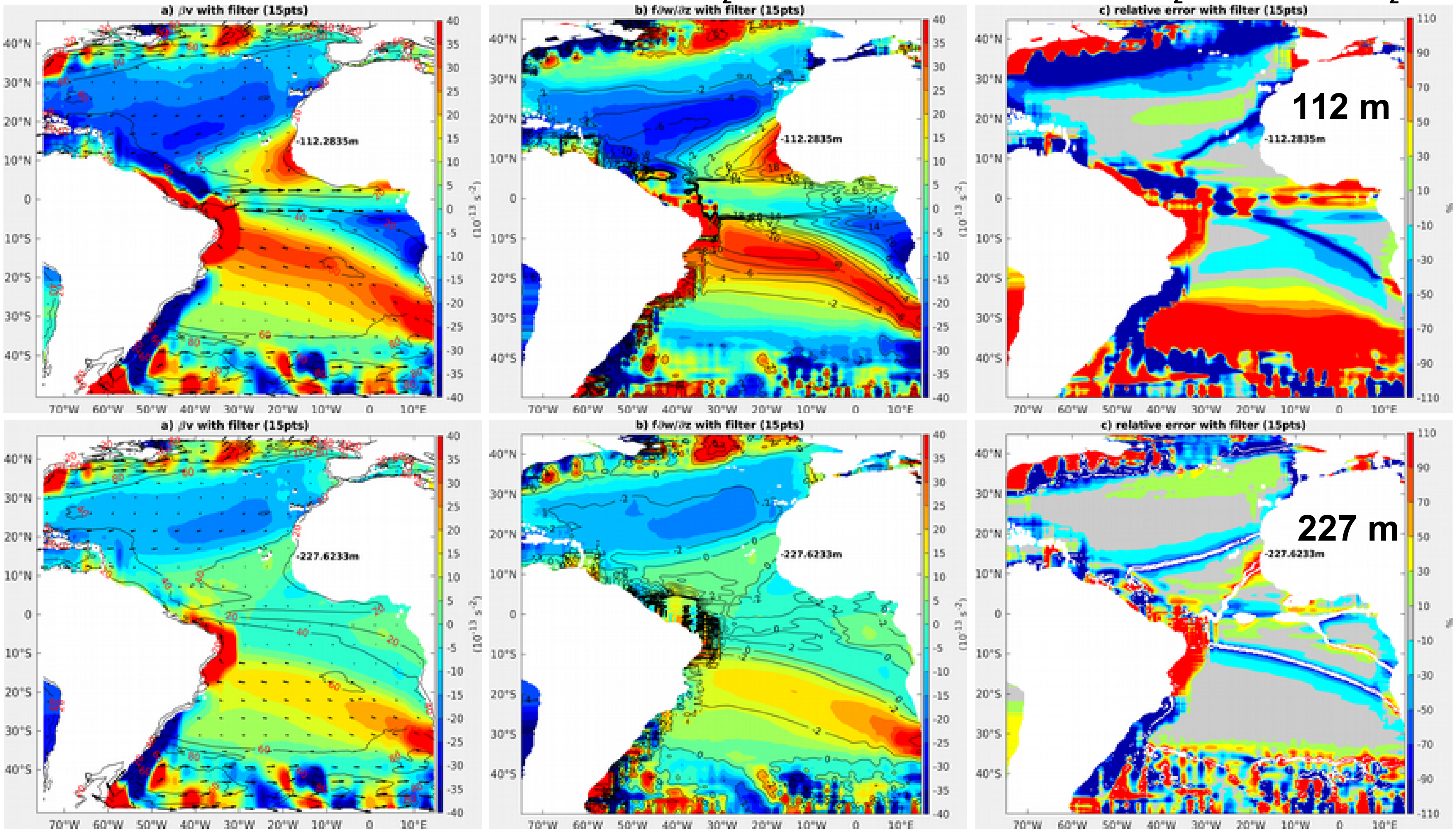
Linear Vorticity Balance (LVB)

$$\beta v = f\partial_z w$$

3-Results and discussions (1/6)

Investigation of the regions of validity

βv | $f\partial_z w$ | $100*(\beta v - f\partial_z w)/0.5(|\beta v|+|f\partial_z w|)$



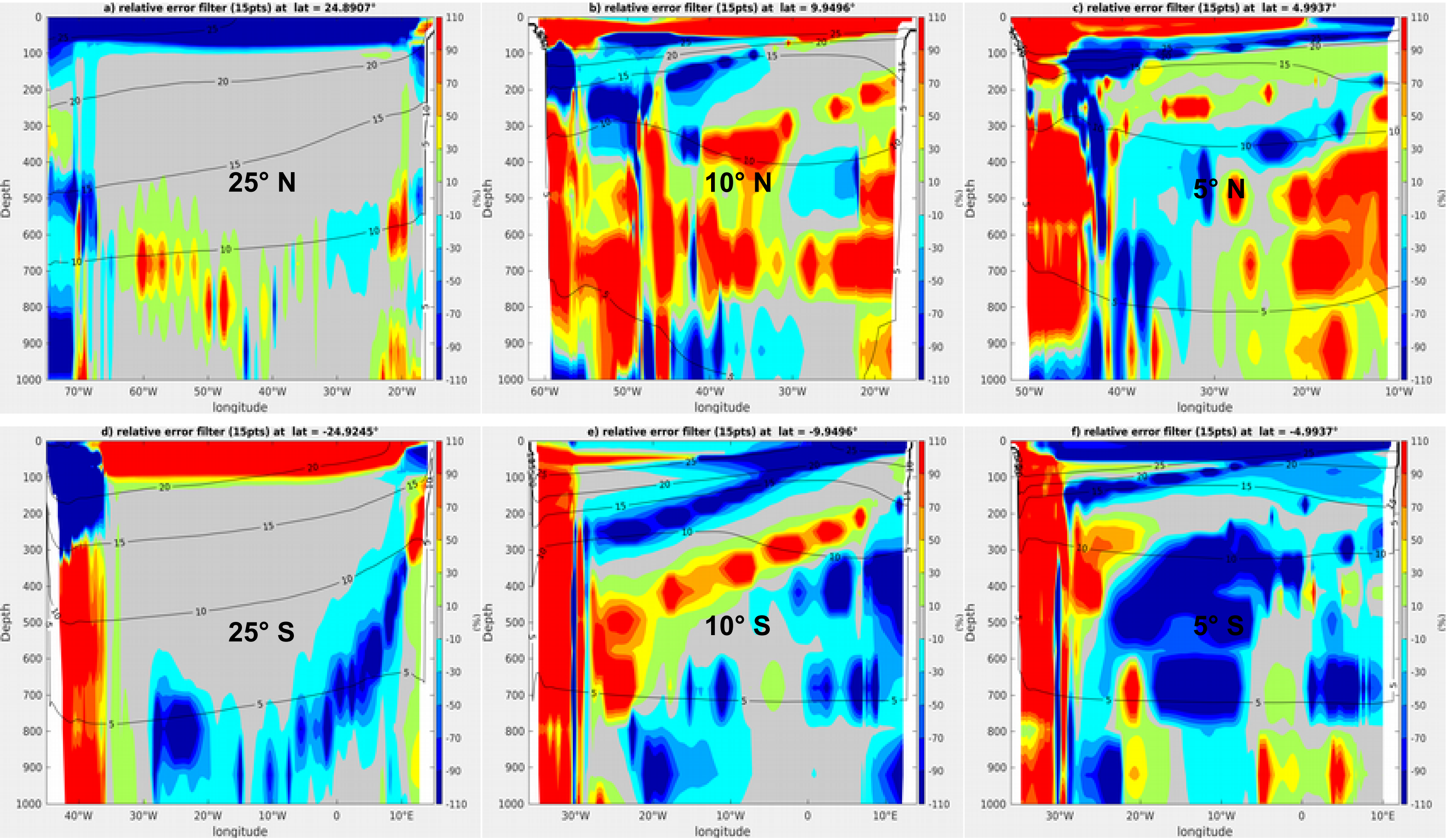
- ± 10% errors in tropical and and subtropical gyres,

- No balance in the hight latitude, the WBCs, some eastern boundary and near the equator

3-Results and discussions (2/6)

Area validity of the LVB in the Atlantic Ocean

Vertical sections of the relative error $(100*(\beta v - f\partial_z w)/0.5(|\beta v|+|f\partial_z w|)$

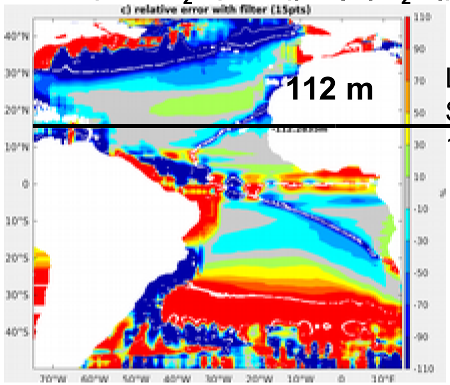


- The balance holds down to the bottom of the subtrpical gyres (see 25° N)
- LVB holds large parts of the thermocline in tropical gyres but not where V changes sign (see at 10° N-S)
- Don't holds near the equator, as expected from the passage by zero of the vrtex streching term

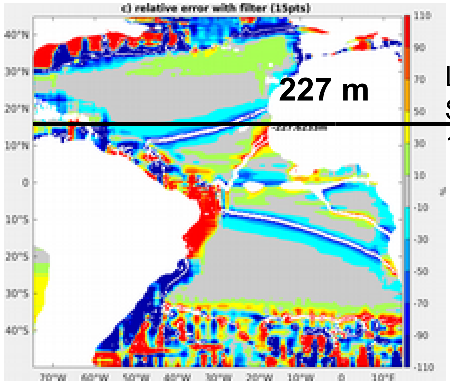
Invalidity causes of the LVB

$$\partial_t\xi + \beta v + u\partial_x\xi + v\partial_y\xi + w\partial_z\xi + (\partial_x w\partial_z v - \partial_y w\partial_z u) = f\partial_z w + \xi\partial_z w + \partial_z(A_{mz}\partial_z\xi) + \nabla^2(A_{mh}\nabla^2\xi)$$

$100*(\beta v - f\partial_z w)/0.5(|\beta v|+|f\partial_z w|)$

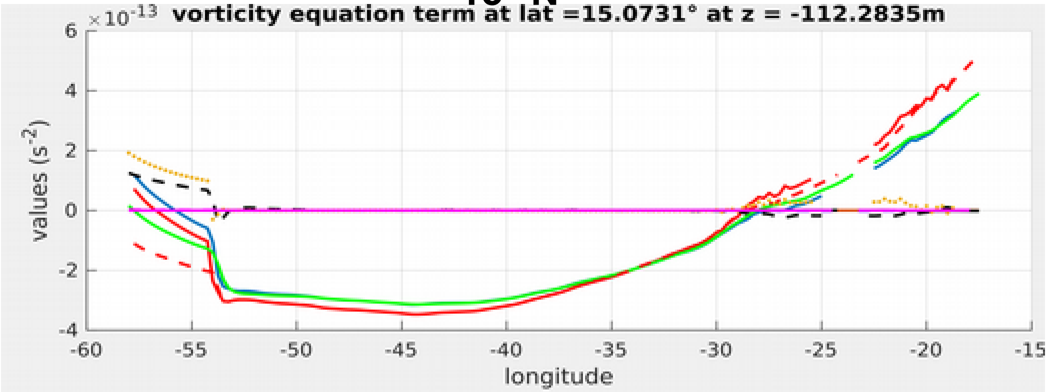


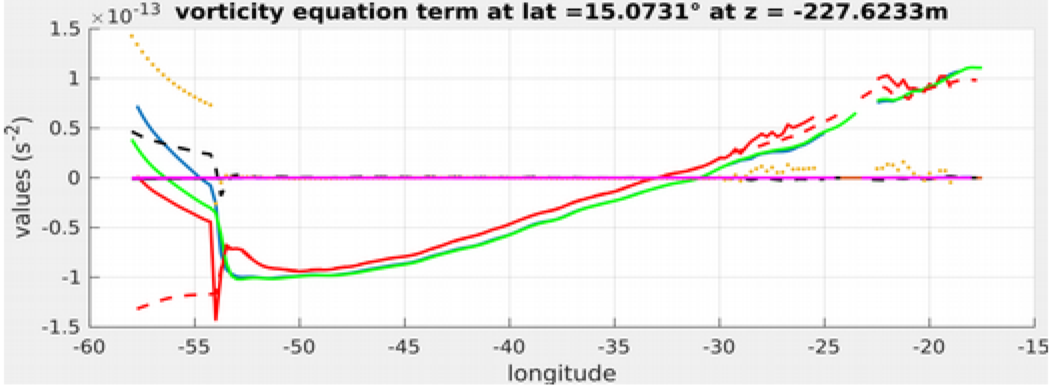
Longitudinal Section at 15°N



Longitudinal Section at 15°N

15° N





- Offshore, LVB works: the term βv (green curve) balance $f\partial_z w$ (red dashed), all other terms are too weak.

- In the the WBCs, diffusion and horizontal advection tend to break the balance,

-Large errors due to zero crossing of the two terms,

-the budget is not closed (offline calculation of the different terms)

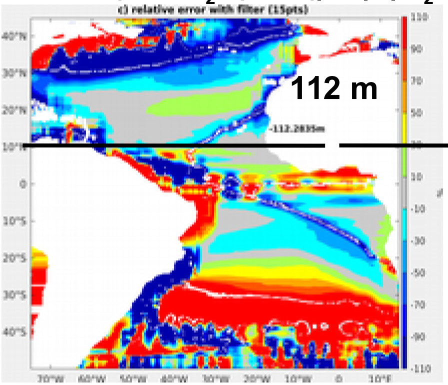
3-Results and discussions (4/6)

Invalidity causes of the LVB

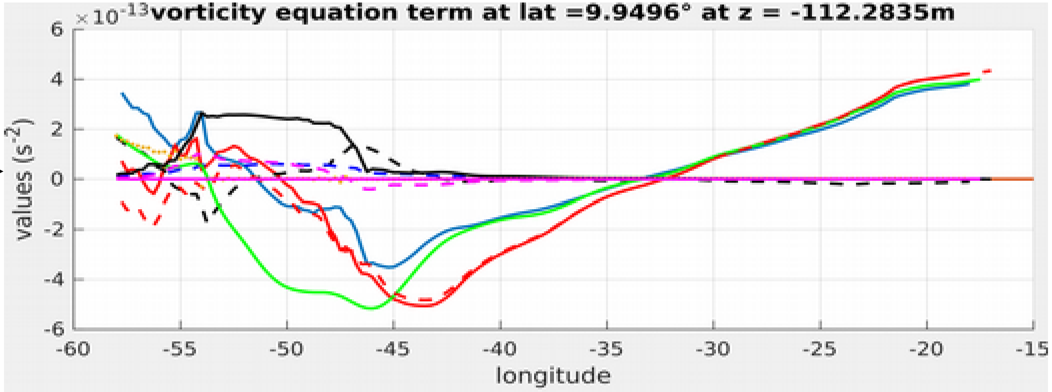
$$\partial_t\xi + \beta v + u\partial_x\xi + v\partial_y\xi + w\partial_z\xi + (\partial_x w\partial_z v - \partial_y w\partial_z u) = f\partial_z w + \xi\partial_z w + \partial_z(A_{mz}\partial_z\xi) + \nabla^2(A_{mh}\nabla^2\xi)$$

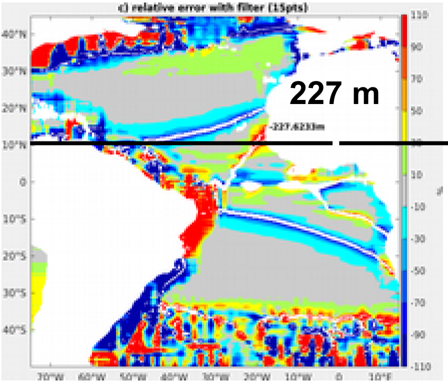
10° N

$100*(\beta v - f\partial_z w)/0.5(|\beta v|+|f\partial_z w|)$

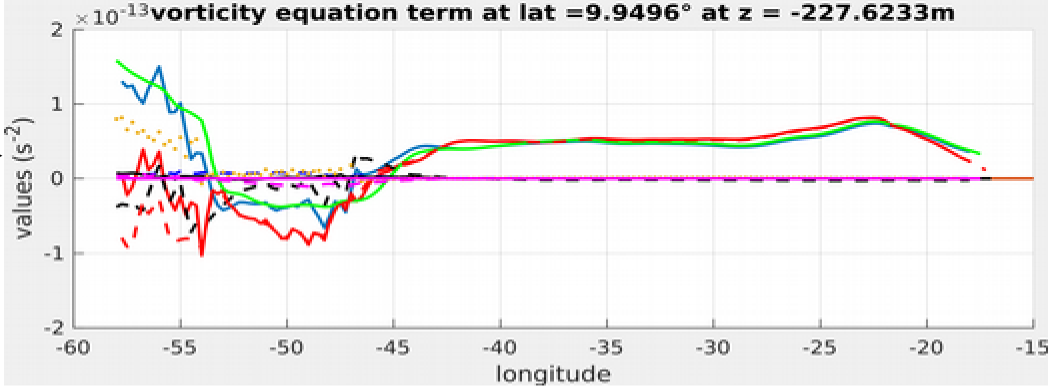


Longitudinal Section at 10°N





Longitudinal Section at 10°N



- **important twesting term in the western part of the North Equatorial Current (45-55°W),**
- **Angola dome: βv balance $f\partial_z w$**
- **Horizontal advection and diffusion are always important in WBCs**

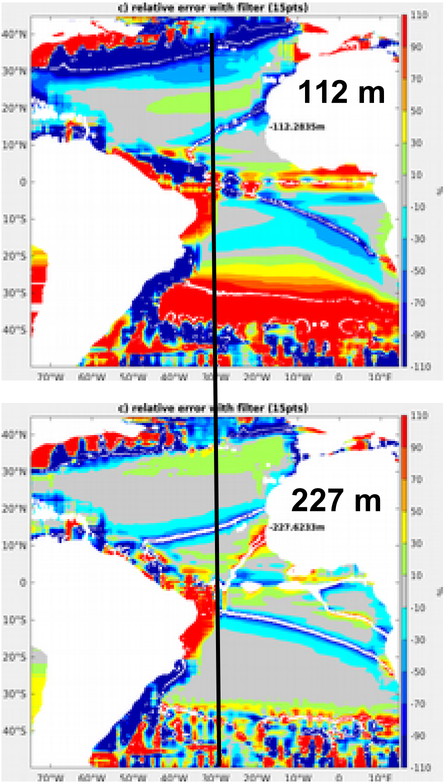
3-Results and discussions (5/6)

Invalidity causes of the LVB

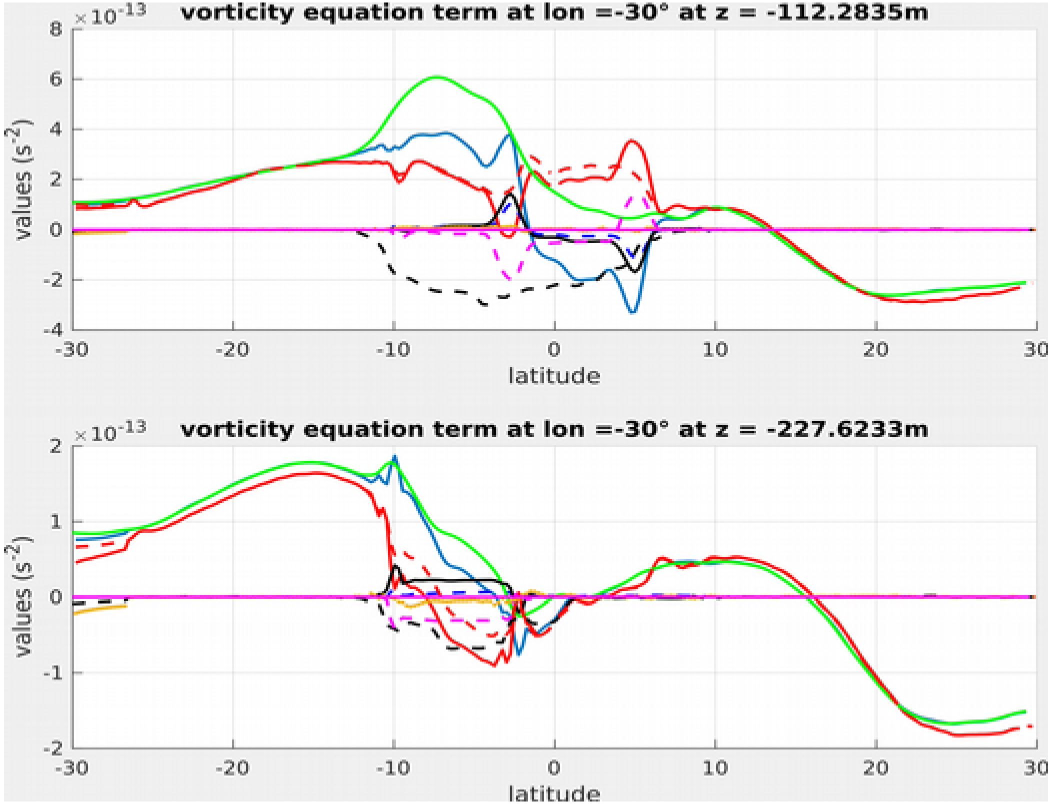
$$\partial_t\xi + \beta v + u\partial_x\xi + v\partial_y\xi + w\partial_z\xi + (\partial_x w\partial_z v - \partial_y w\partial_z u) = f\partial_z w + \xi\partial_z w + \partial_z(A_{mz}\partial_z\xi) + \nabla^2(A_{mh}\nabla^2\xi)$$

30° W

$100*(\beta v - f\partial_z w)/0.5(|\beta v|+|f\partial_z w|)$



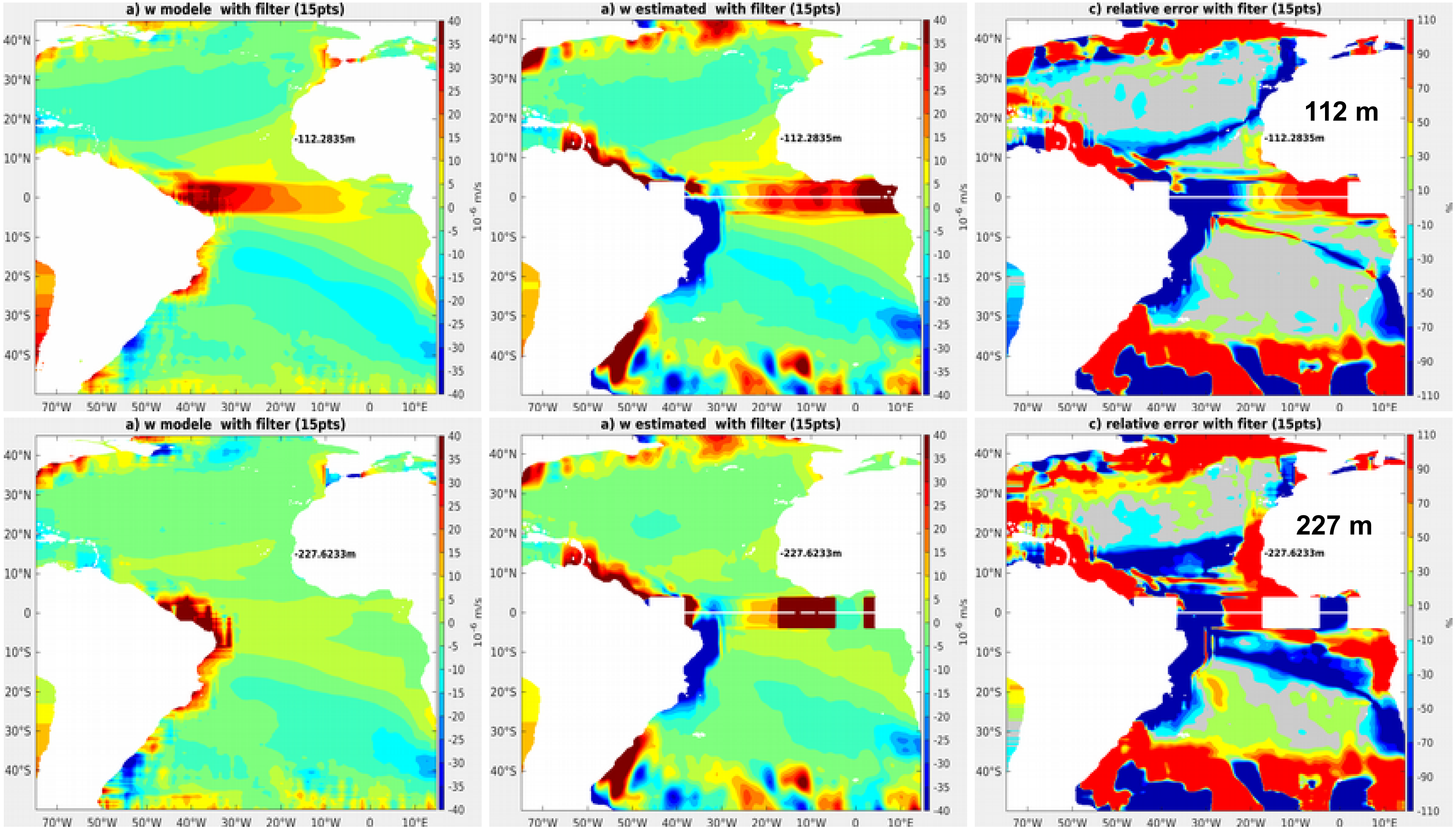
Meridional Section at 30° W



- Near the equateur: nonlinear vortex stretching (magenta dashed), twesting term (black curve), horizontal advection (black dashed) and diffusion (brown dashed) are important

3-Results and discussions (6/6)

Reconstruction of w from the LVB with boundary condition: $w_{bottom}=w_{model}(1000m)=0$



-Good estimate of w in regions where the LVB was valid (tropical and subtropical gyres),

-Bad estimate at high latitudes (,near the equator, WBCs and some eastern boundary

4-Conclusions and perspectives (1/2)

Conclusions:

- The LVB dominates: in the upper thermocline (except in the mixing layer) at the level of the tropical gyres (Guinea and Angola domes) and extends up to 1000m at the level of the subtropical gyres (north and south).

- Nobalance: inter-gyres, at high latitudes, in the WBCs, and near the equator.

- Nonlinear equatorial dynamics: twesting, horizontal advection and nonlinear vortex stretching are important.

- WBCs: advection horizontale, torsion, diffusion are strong.

- A general consistency between the w estimated from LVB and those from the model is observed.

4-Conclusions et perspectives (2/2)

Perspectives:

- High resolution sigma coordinate configuration (To have a high viscosity and a good representation of the topography).
- The calculation of integration of the LVB starting at the bottom with the kinematic dynamics (the vertical velocity can be different from zero at 1000 m).
- The integration calculation of the EVL starting at the surface with the boundary condition $w_{surface} = w_{ekman}$ choosing an optimal ekman layer depth.
- Reconstitute w in regions where LVBs is valid with observation data (especially the Argo network).

Thank you for your attention