Dynamics of the Dense Water Formation in the NorthWestern Mediterranean during the HyMeX/ASICS Experiment: A PV-Perspective

H. Giordani and C. Lebeaupin-Brossier

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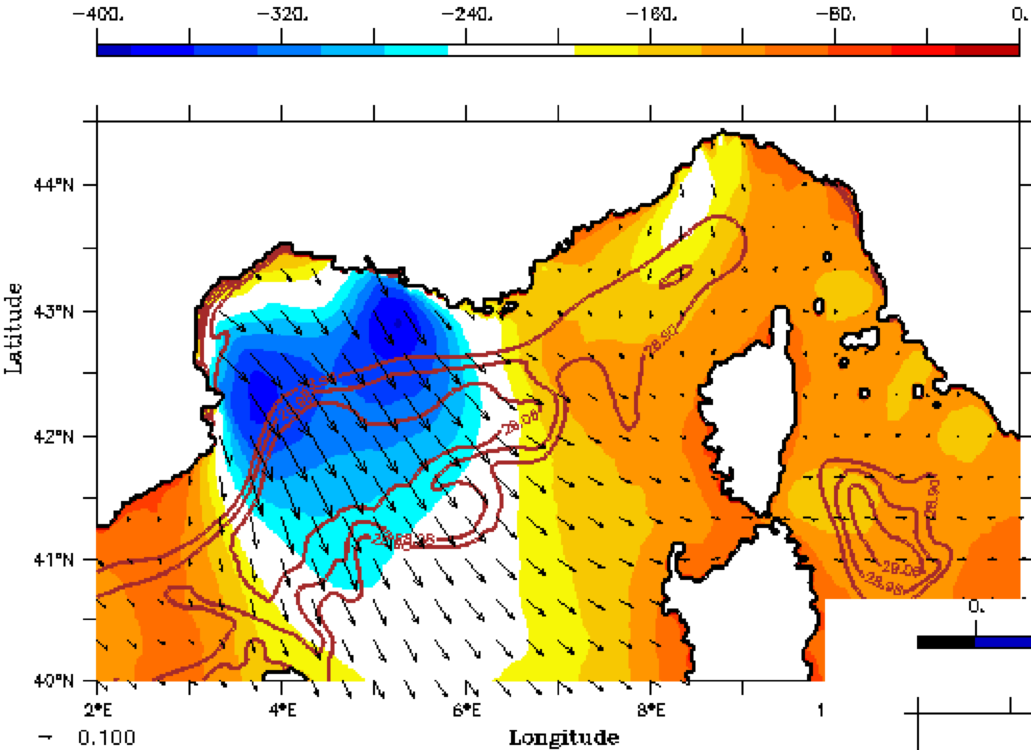
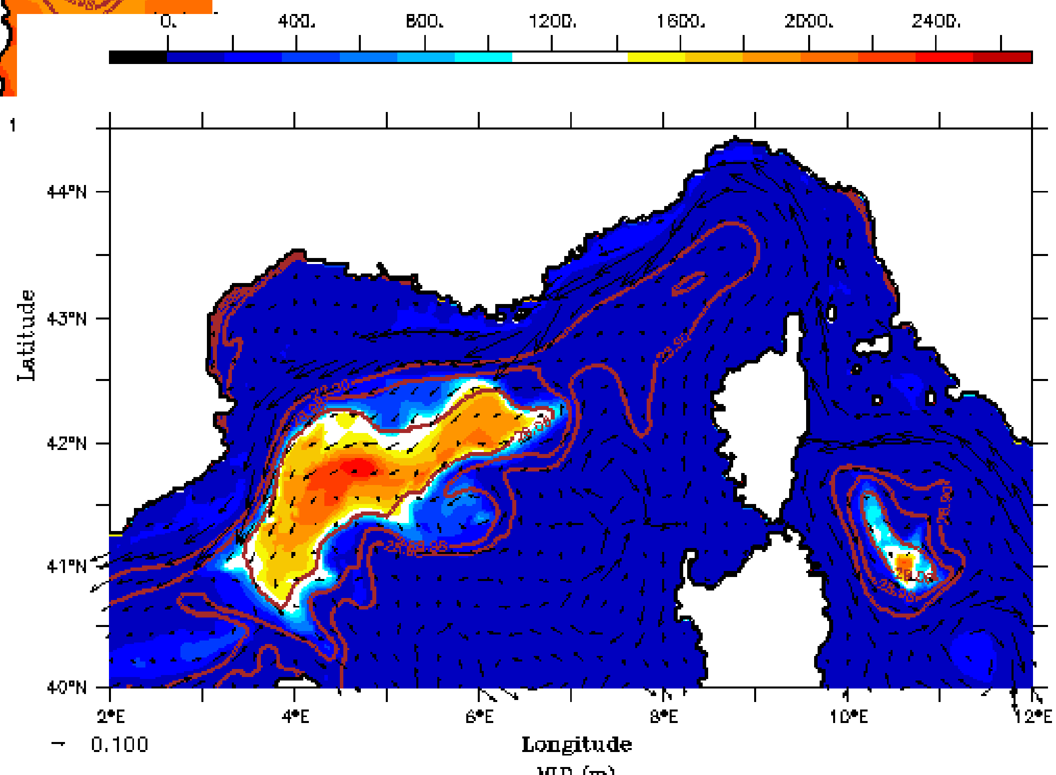


Month-average surface Buoyancy flux ~ -400W/m^2

Deep Mixed-Layer Depths ~ 2500 m



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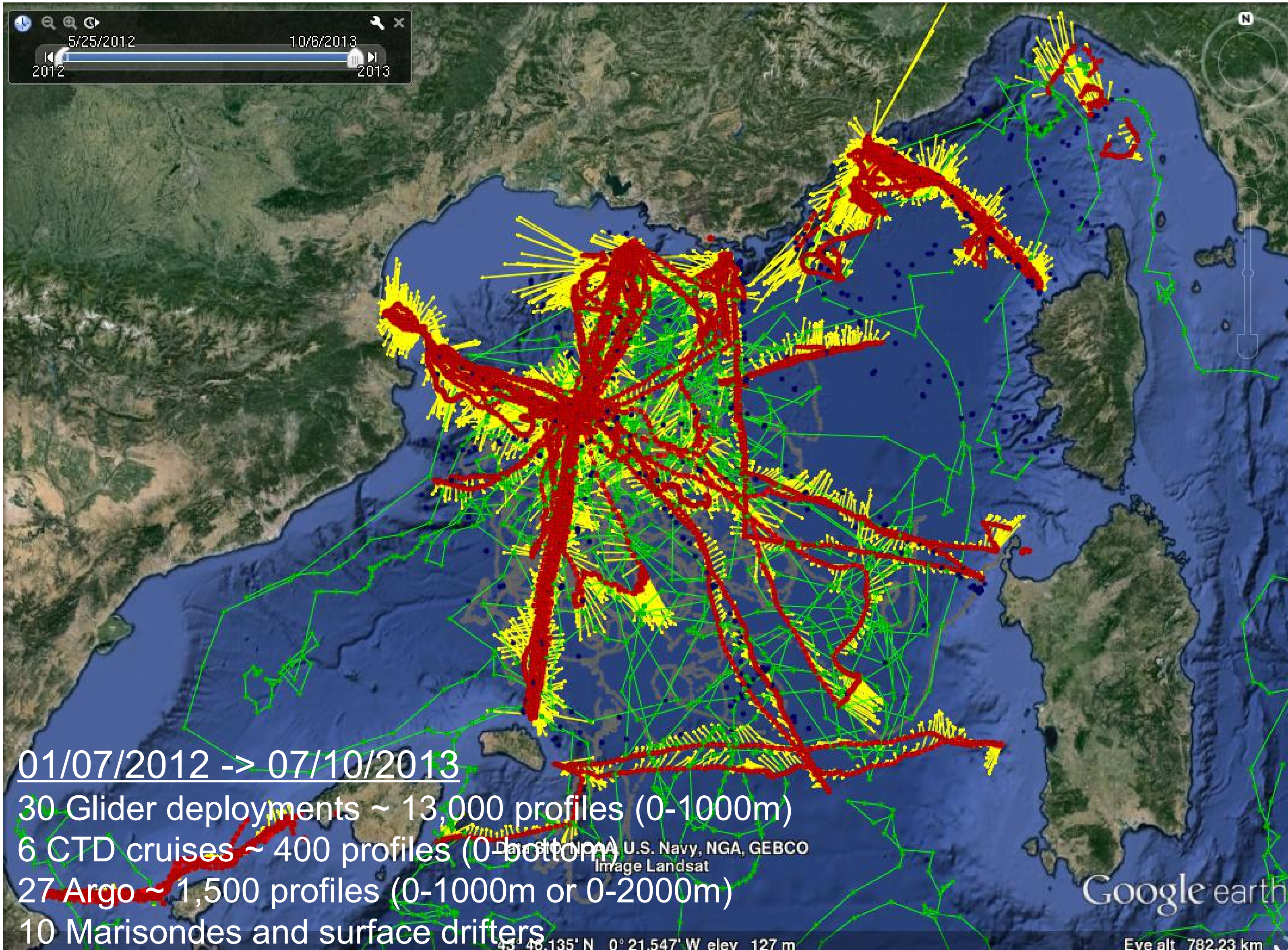
Gliders, Profiling floats, Marisondes, Cruises…

Courtesy, P. Testor



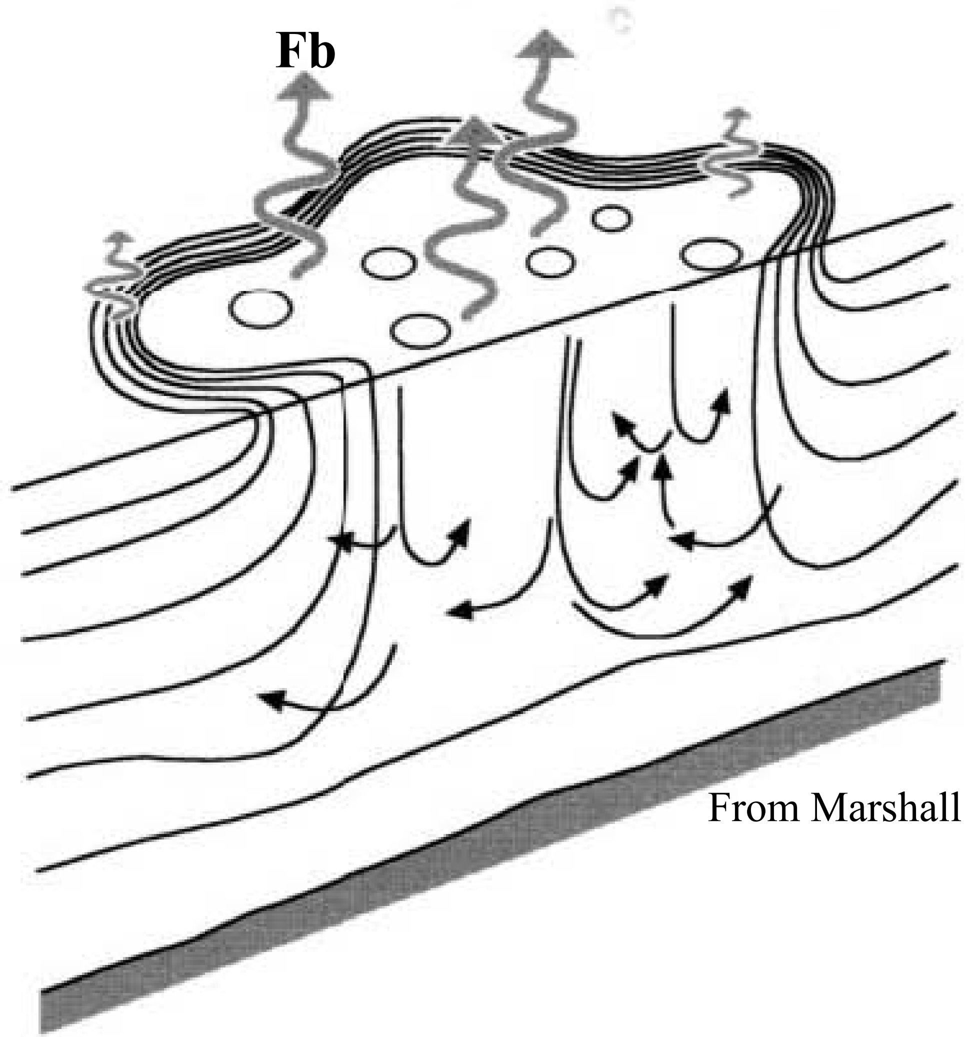
ASICS-MED

ASICS-MED : Oceanographic Component of the **HyMeX** Program

Two Scientific questions:

1. How the strong wind events interact with the mesoscale & submesoscale oceanic structures ?

2. What are the processes of dense water formation in these mesoscale structures ?



From Marshall & Shott, 1999

What Dynamics in frontal region ?

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Ocean model: NEMO-WMED36 (Lebeaupin-Brossier et al., 2015)

code: *NEMO v3_2 [Madec, 2008]*
SIMED [Arsouze et al., 2012]

grid: *760 x 480 x 50 z-levels*
Δx=*1/36° ORCA grid (from 2.2 to 2.5km)*
bathymetry: *v10 Mercator-LEGOS*
Δt=*240s*

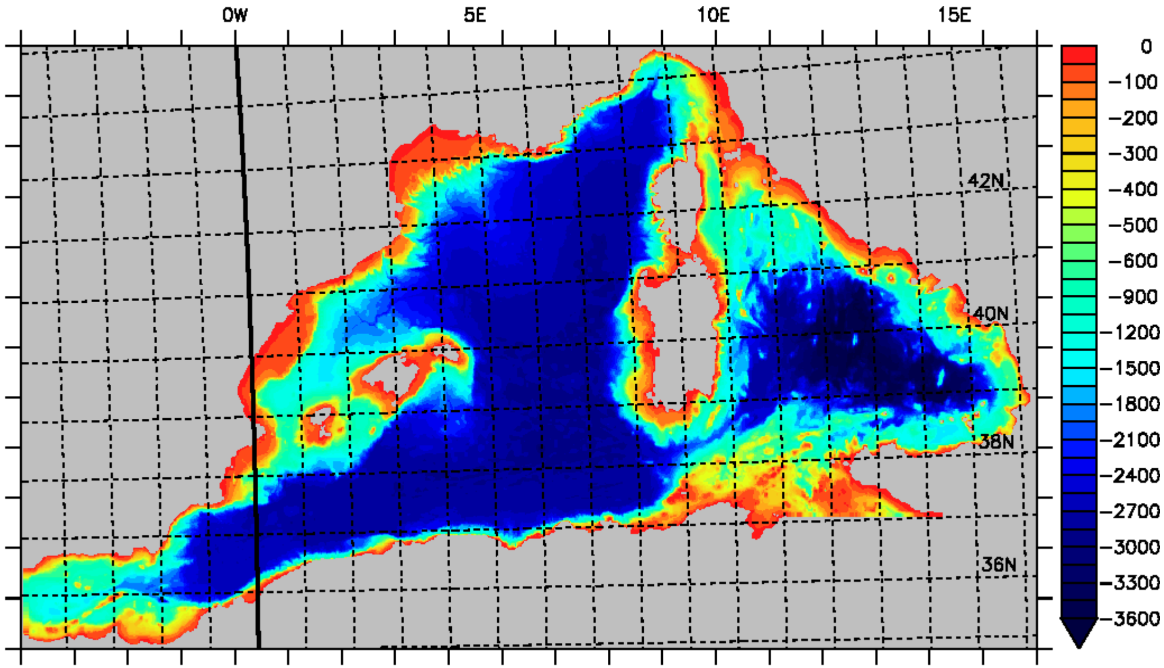
2 open-boundaries: *Alboran Sea (East of the Strait of Gibraltar) and Sicily Channel*

river runoff: *climatology [Beuvier et al., 2010]*

atmospheric surface forcing: *hourly AROME-WMED forecasts [Fourrié et al., 2015]*

initial and boundary conditions: *Mercator Analysis*

Simulation: *Sept 1 to March 15*



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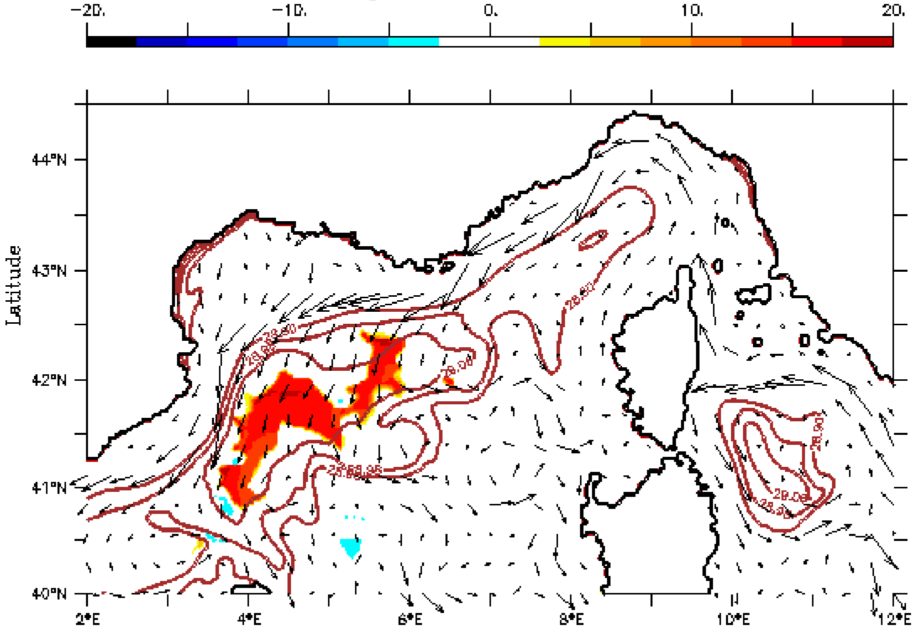
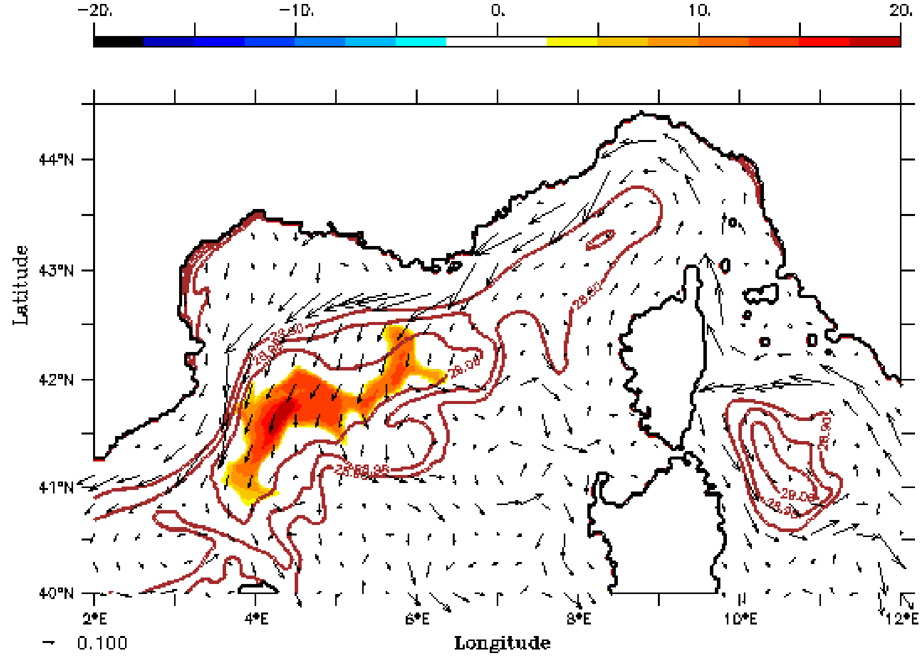
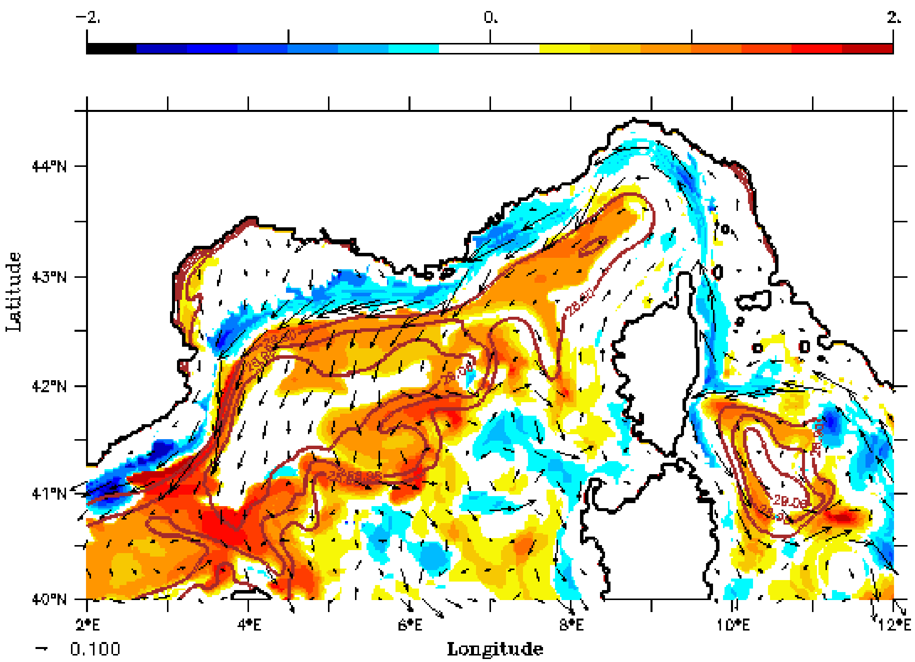
DWF ρ > 29.0 kg/m3



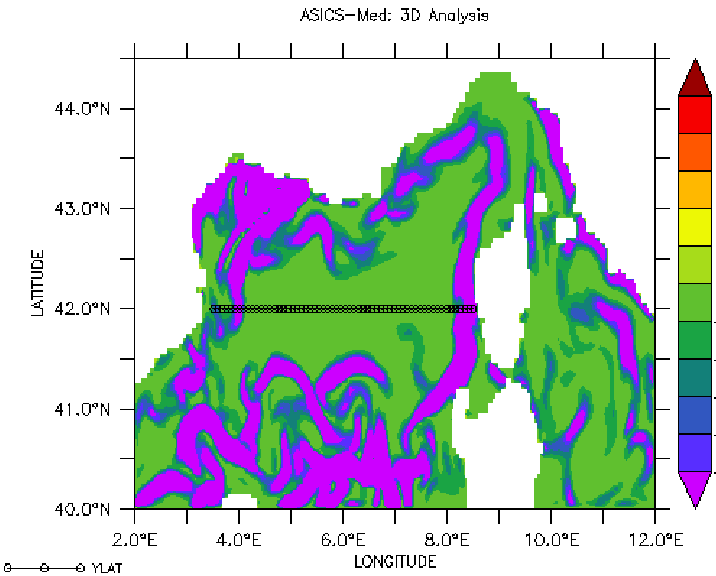
Vol Buoyancy (Tziperman, 1986)



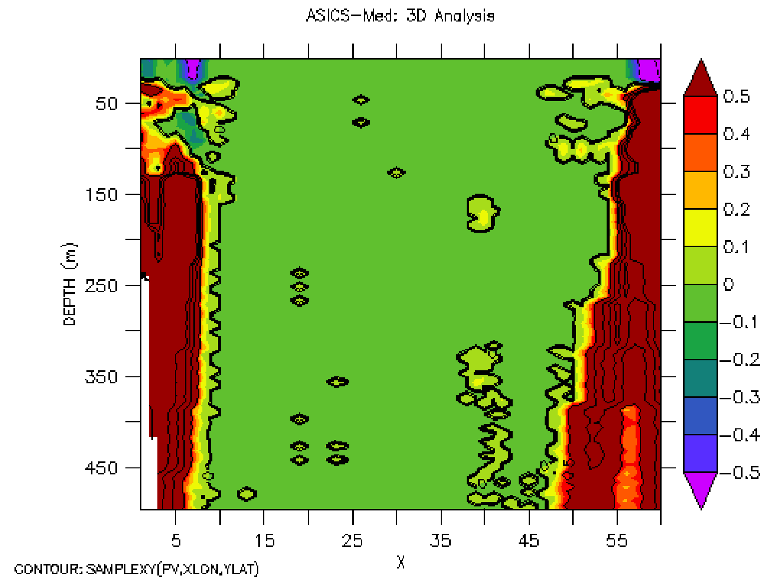


Dynamics & Forcings of DWF in Frontal region ?

Dense Waters characterized by Low PV



Ertel Potential Vorticity (s−3*E10)

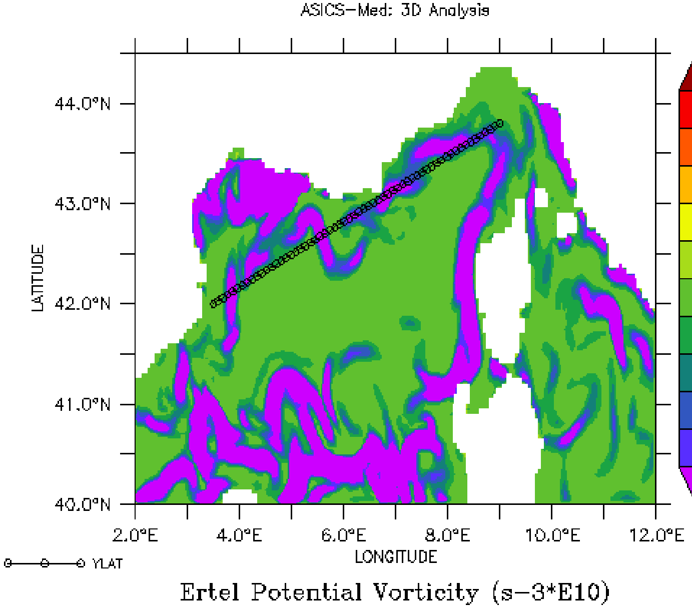


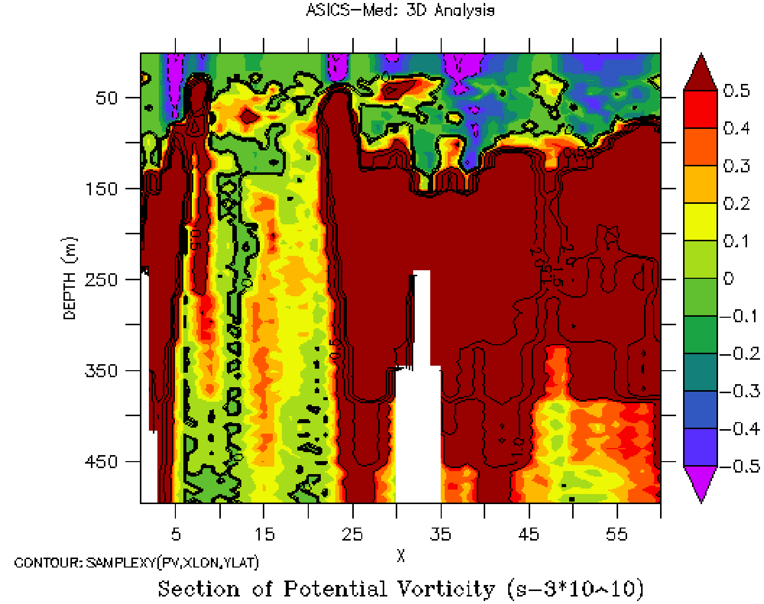
Section of Potential Vorticity (s−3*10^10)

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

Generation of low-PV water critical to the formation of dense water

Dense Waters characterized by Low PV

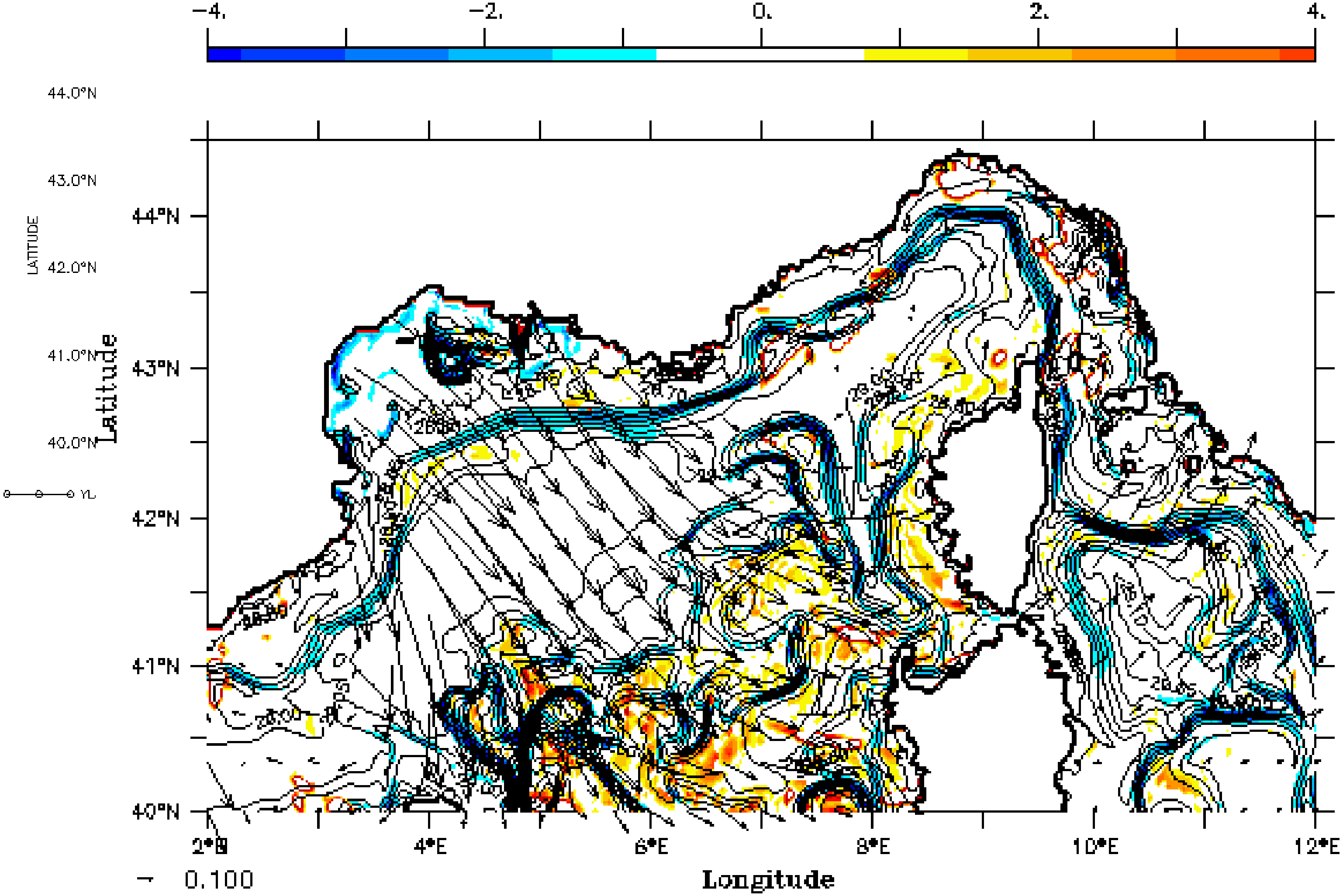




$$q = \underbrace{(\zeta + f) N^2}_{q_v} \underbrace{- f \left(\frac{\partial \vec{U}_g}{\partial z} \right)^2}_{q_h}$$

Generation of low-PV water critical to the formation of dense water

Role of the Wind in PV-Destruction in Frontal region ?



Generation of low-PV water critical to the formation of dense water

Destruction of Potential Vorticity : Implications for the Formation of Deep Water

$$\frac{\partial q}{\partial t} = -\vec{\nabla}.\vec{J}$$

PV-Flux

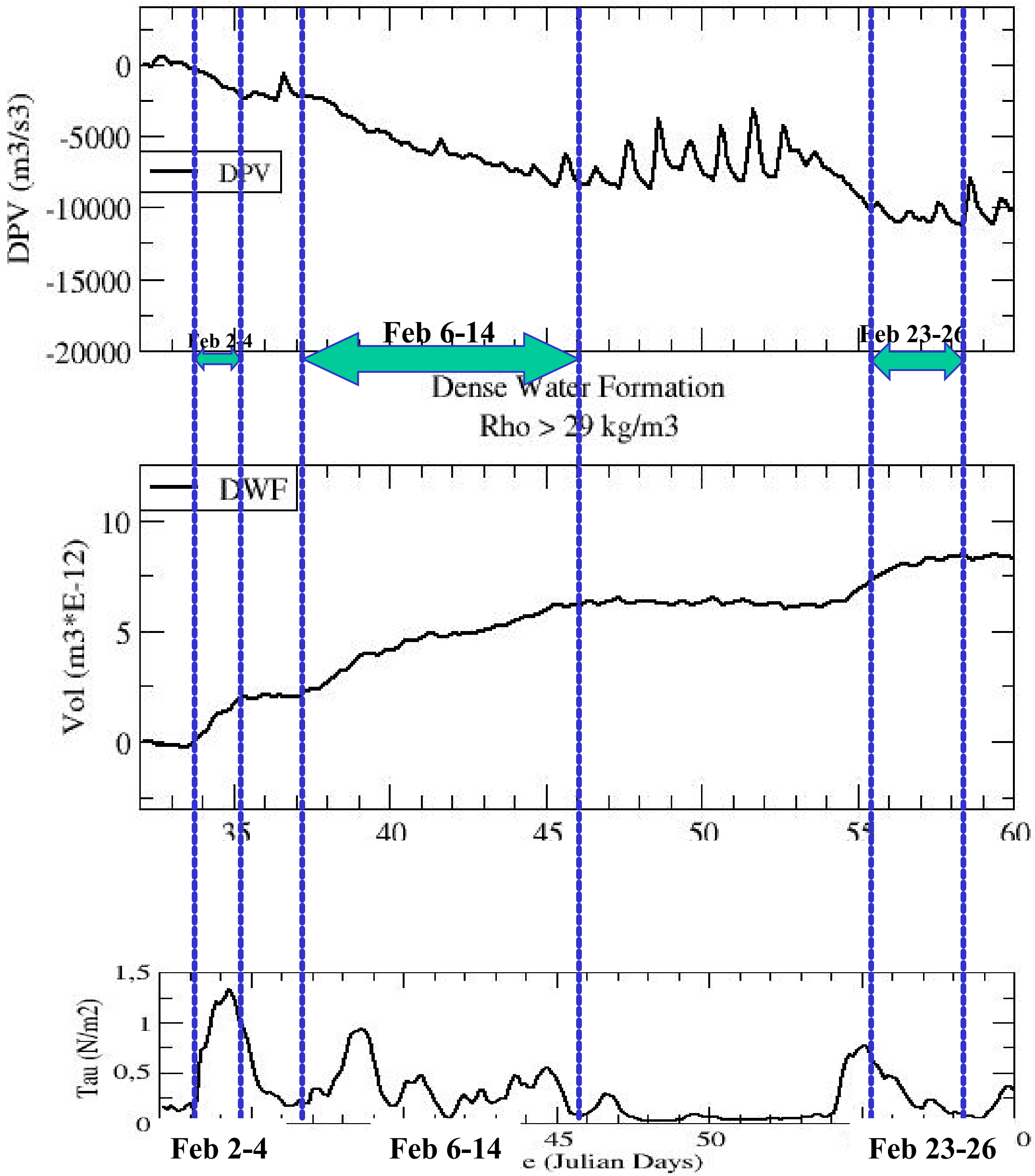
$$\begin{cases} \vec{J}_{Fric} = f\,\dfrac{\partial U_g}{\partial z}\dfrac{\partial \vec{\tau}}{\partial z}\vec{k} \\ \vec{J}_{Diab} = -(\zeta + f)\dfrac{\partial B}{\partial z}\vec{k} \\ \vec{J}_{Adv} = \vec{U}q \end{cases}$$

Haynes and McIntyre, 1987

PV destruction:

- Wind oriented down-front
- Buoyancy loss from the ocean to the atmosphere
- PV-Flux Divergence changes the Stratification

PV budget on the volume bounded by ρ > 29.0 kg/m³



PV Destruction

Dense Water Formation

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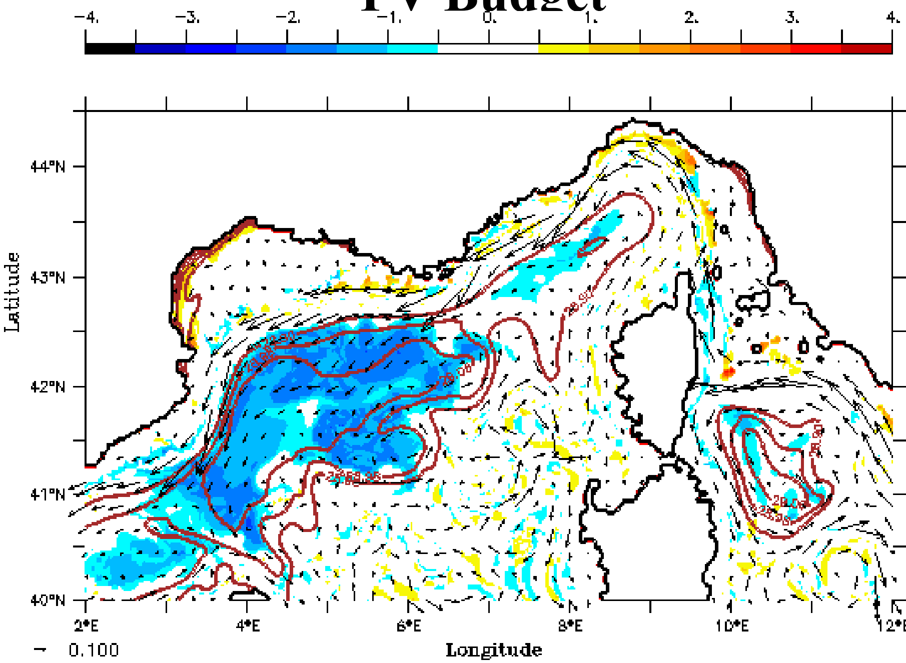
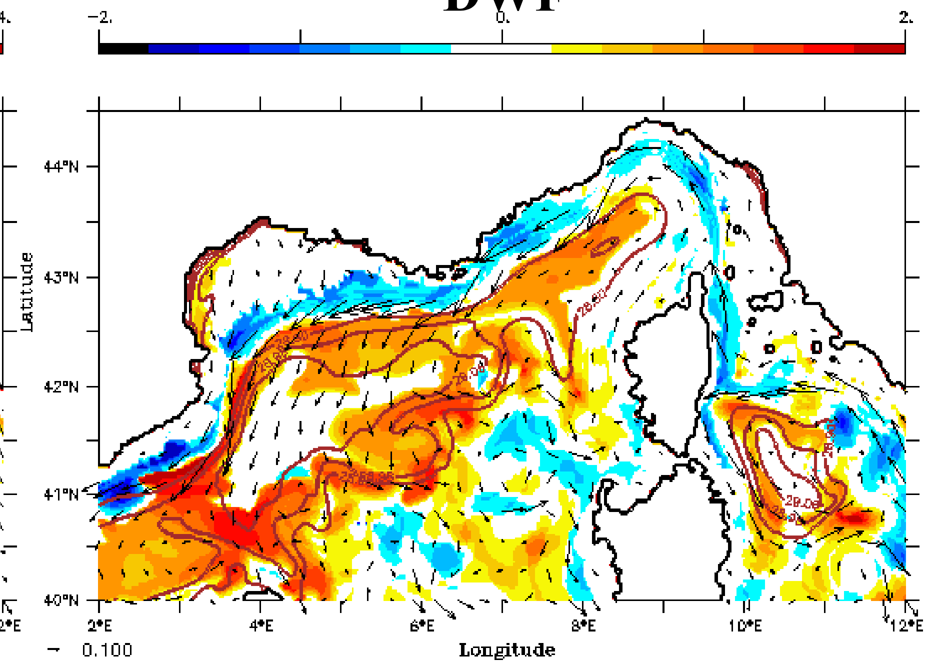
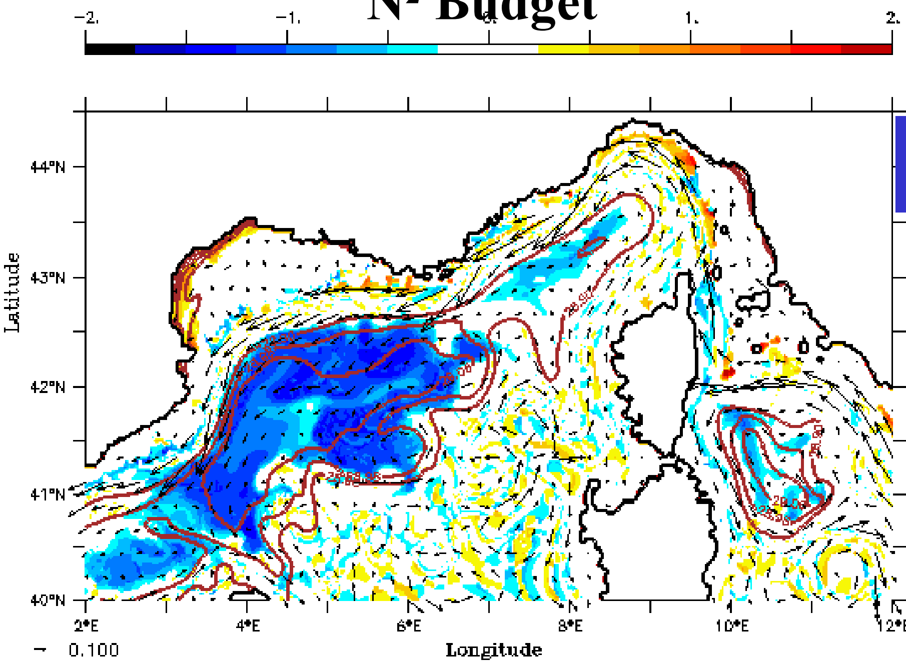
PV Budget



DWF



N^2 Budget



Connection PVdestruction - DWF

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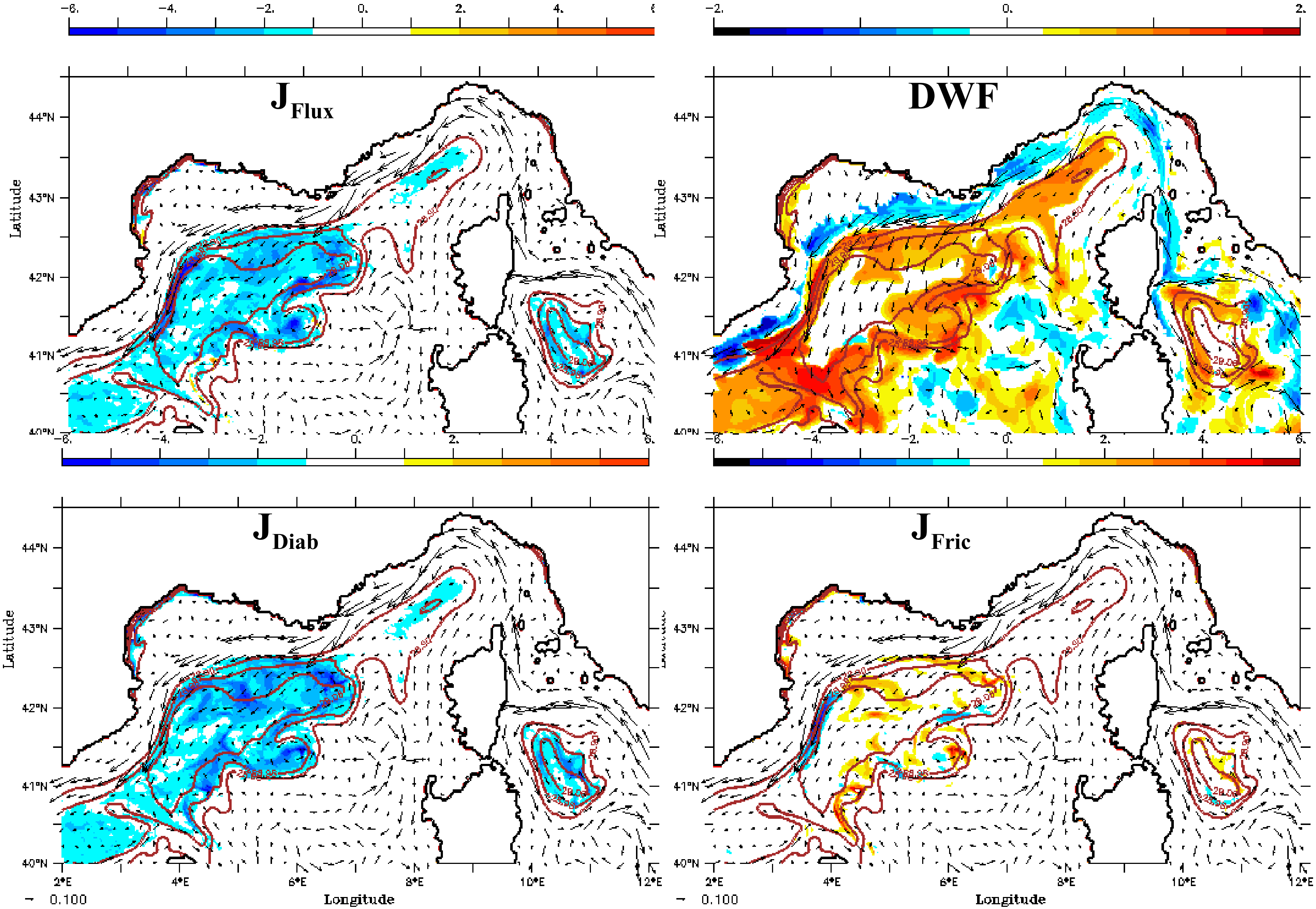
PV budget in the Frontal Zone



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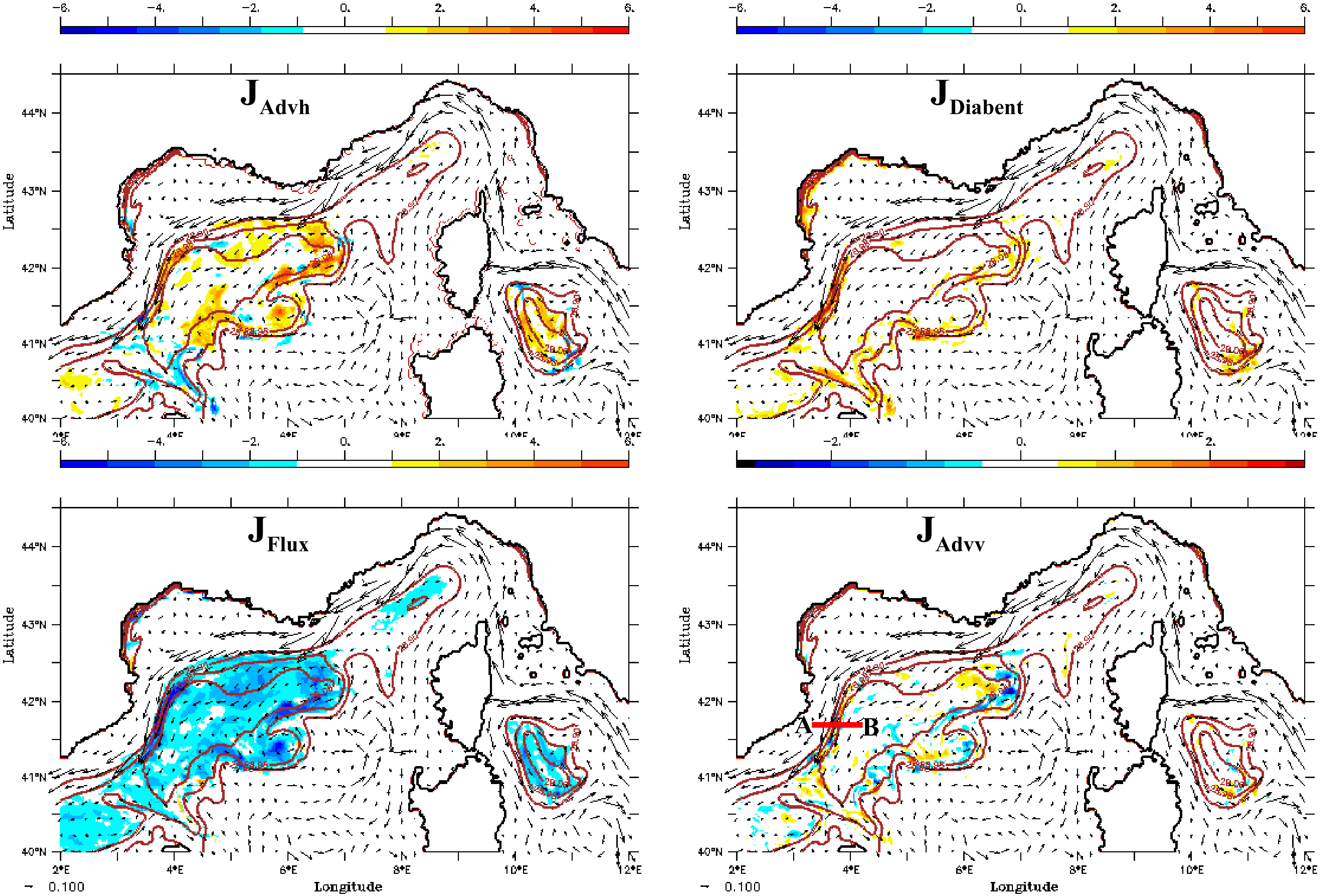
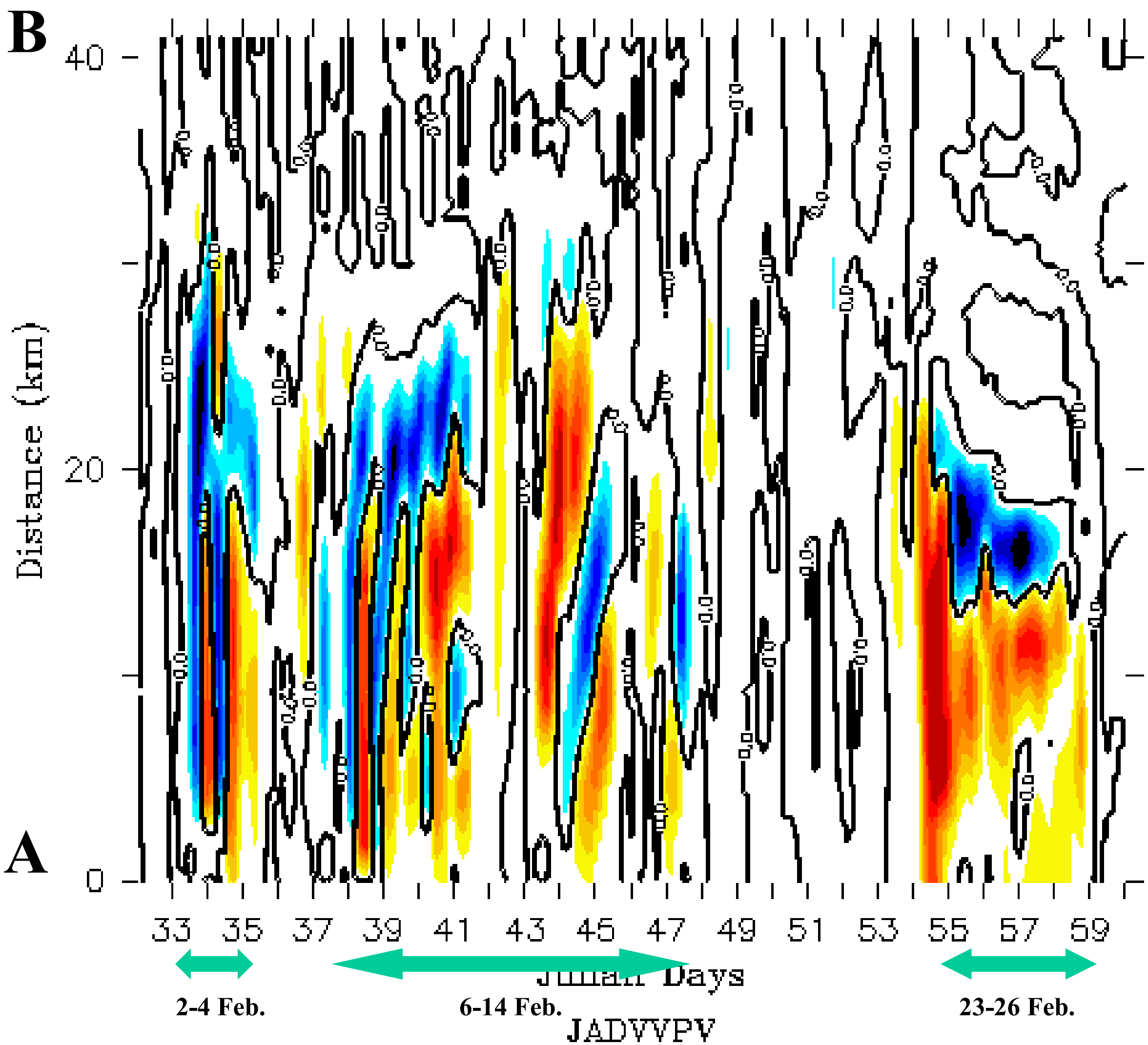
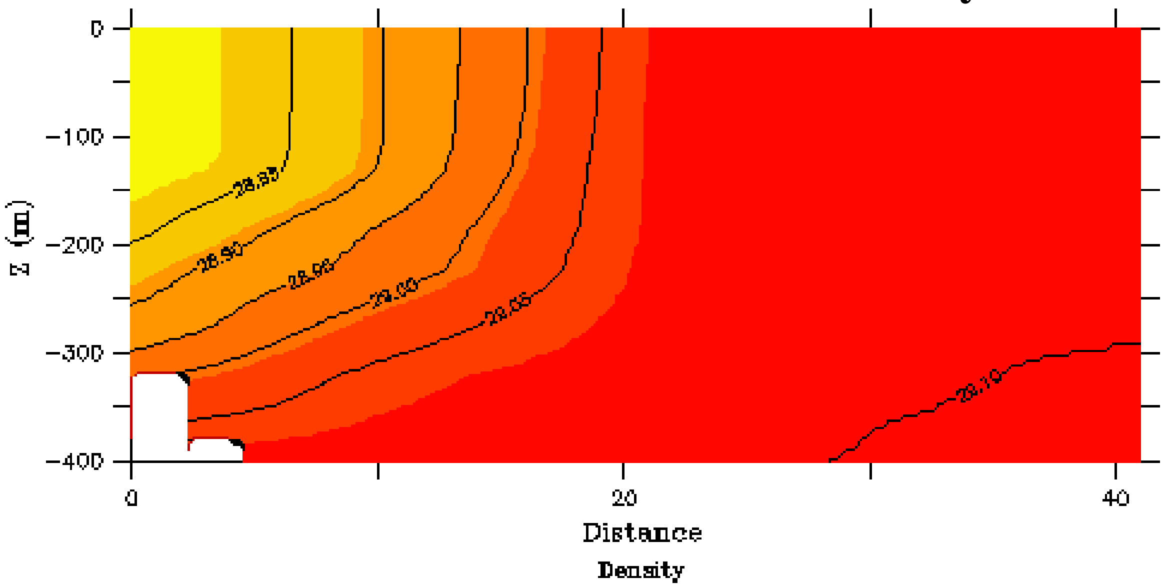


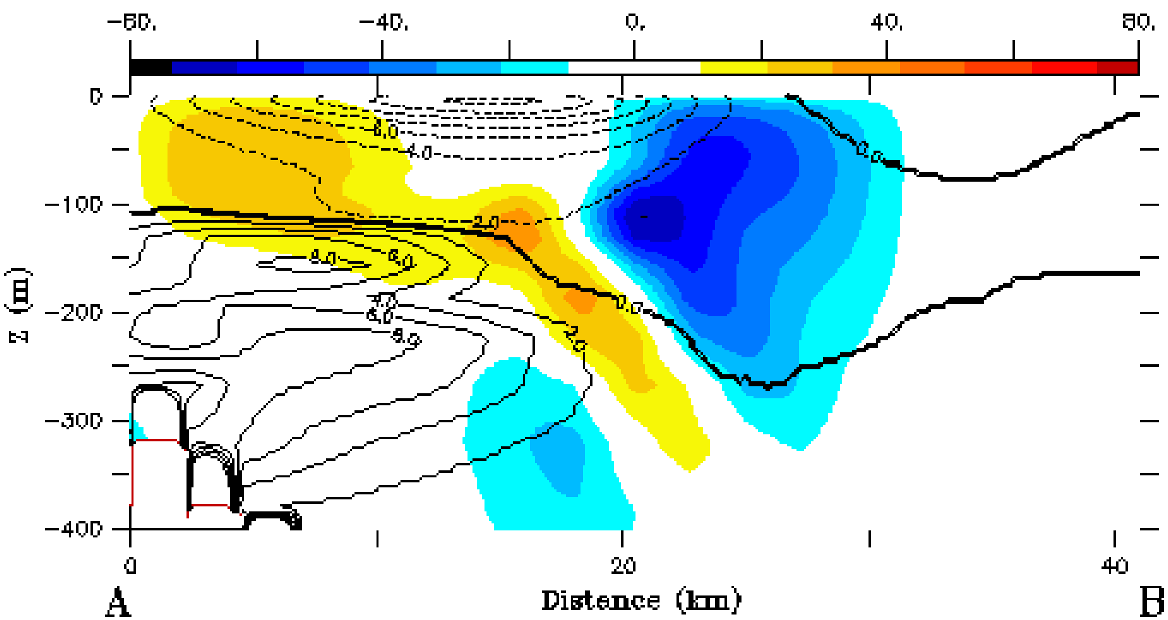
J_{Advh}
$J_{Diabent}$
J_{Flux}
J_{Advv}
A
B
Latitude
Longitude
44°N
43°N
42°N
41°N
40°N
2°E
4°E
6°E
8°E
10°E
12°E
0.100

Vertical PV-Advection in the Frontal Section [A-B]



Western Frontal Section February

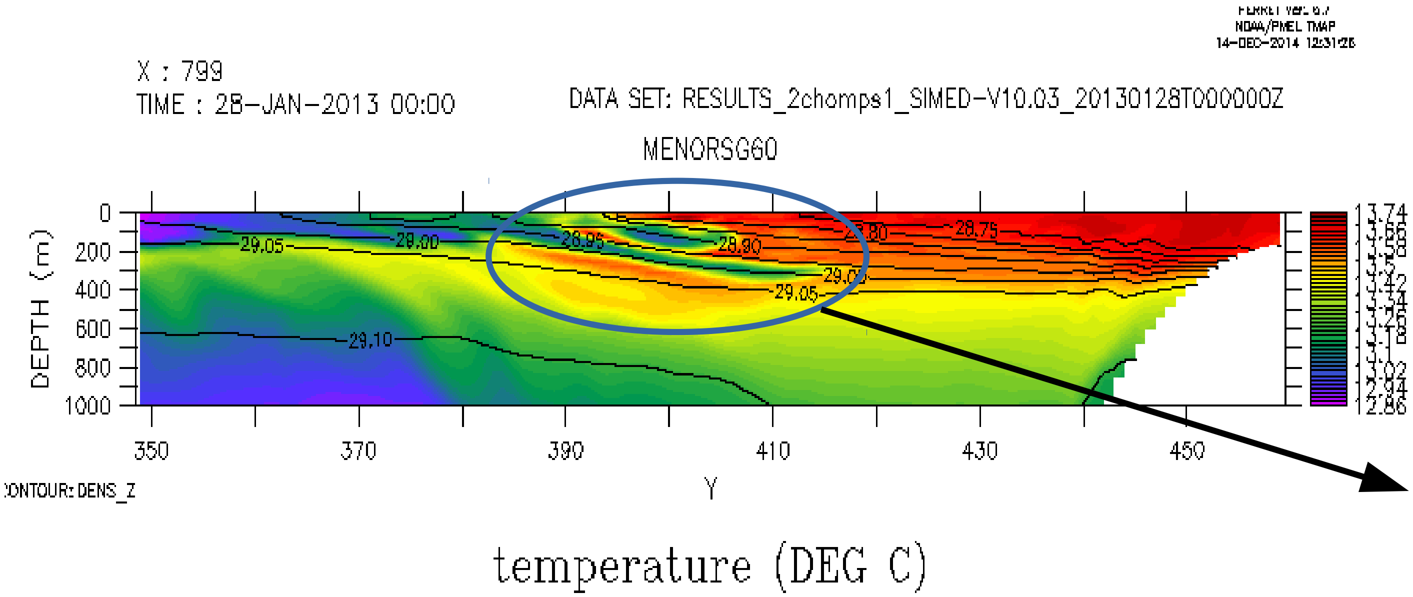




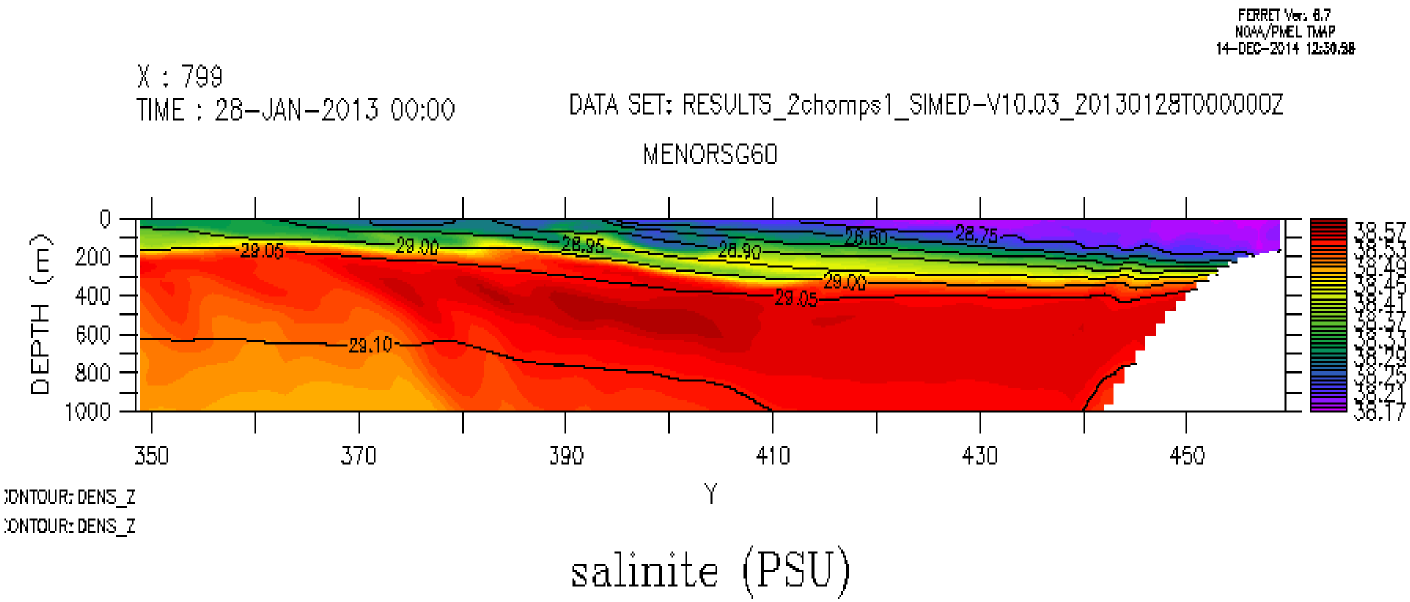
MARS-MENOR

Δx=400 m

(P. Garreau)



Cold Intrusions
Symmetric Instability



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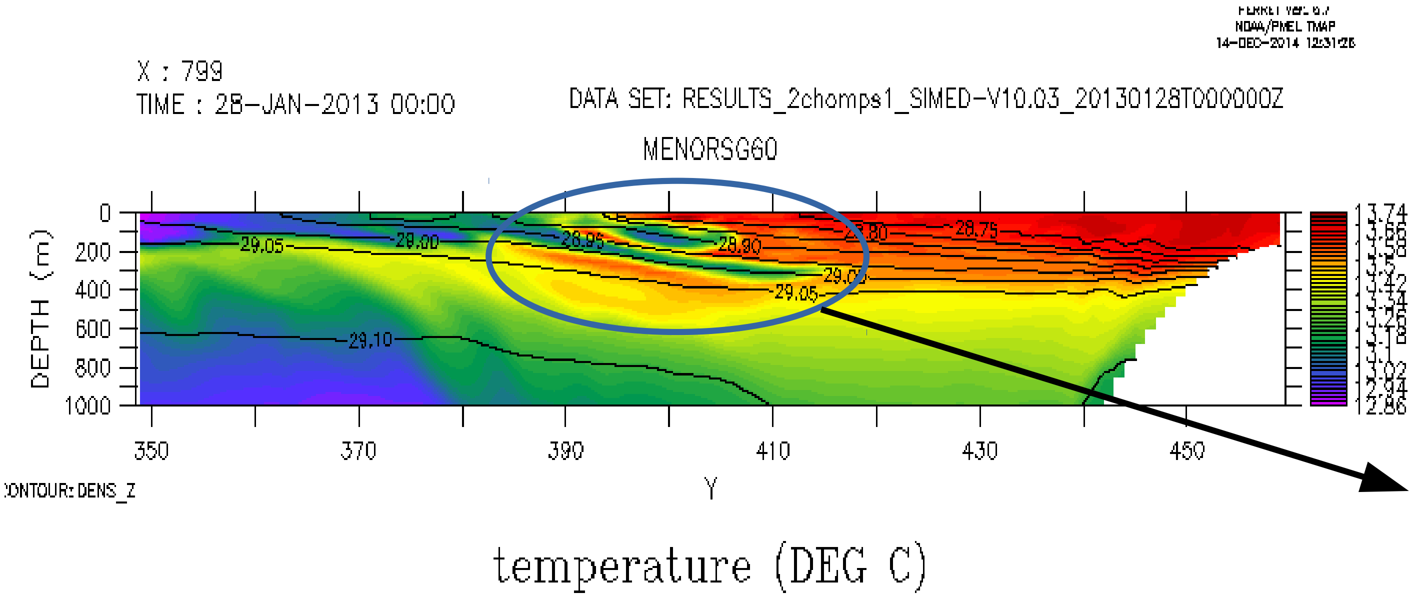

Cold Intrusions
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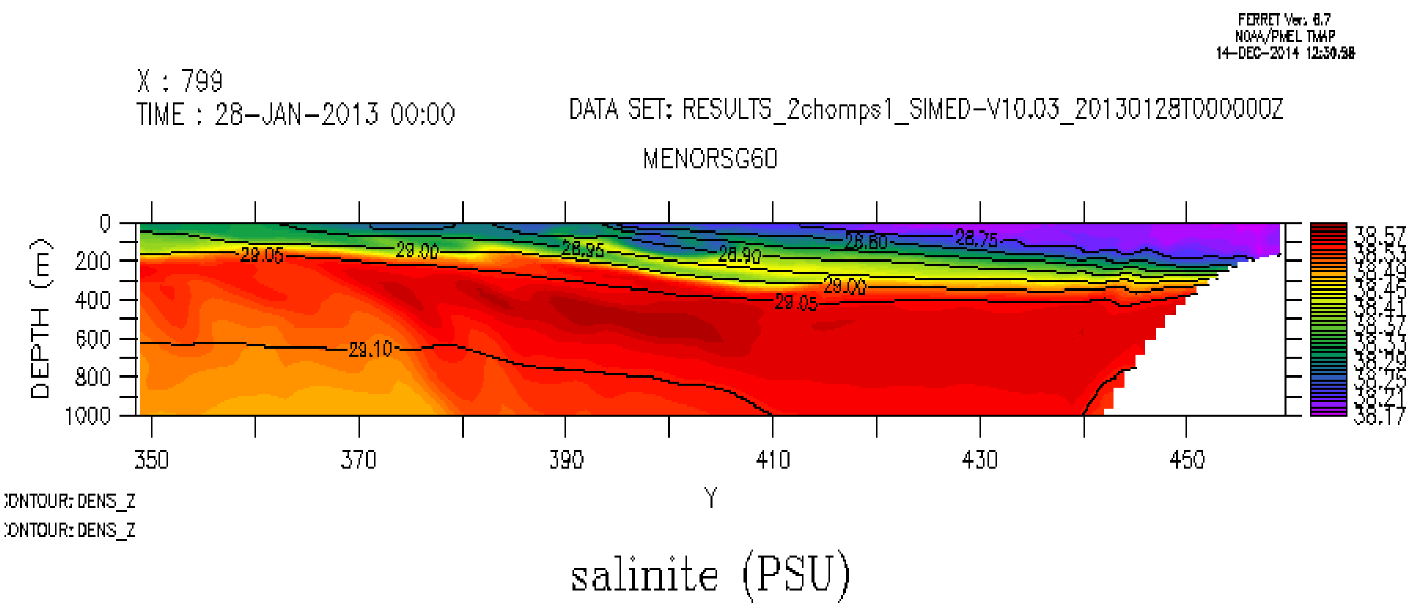
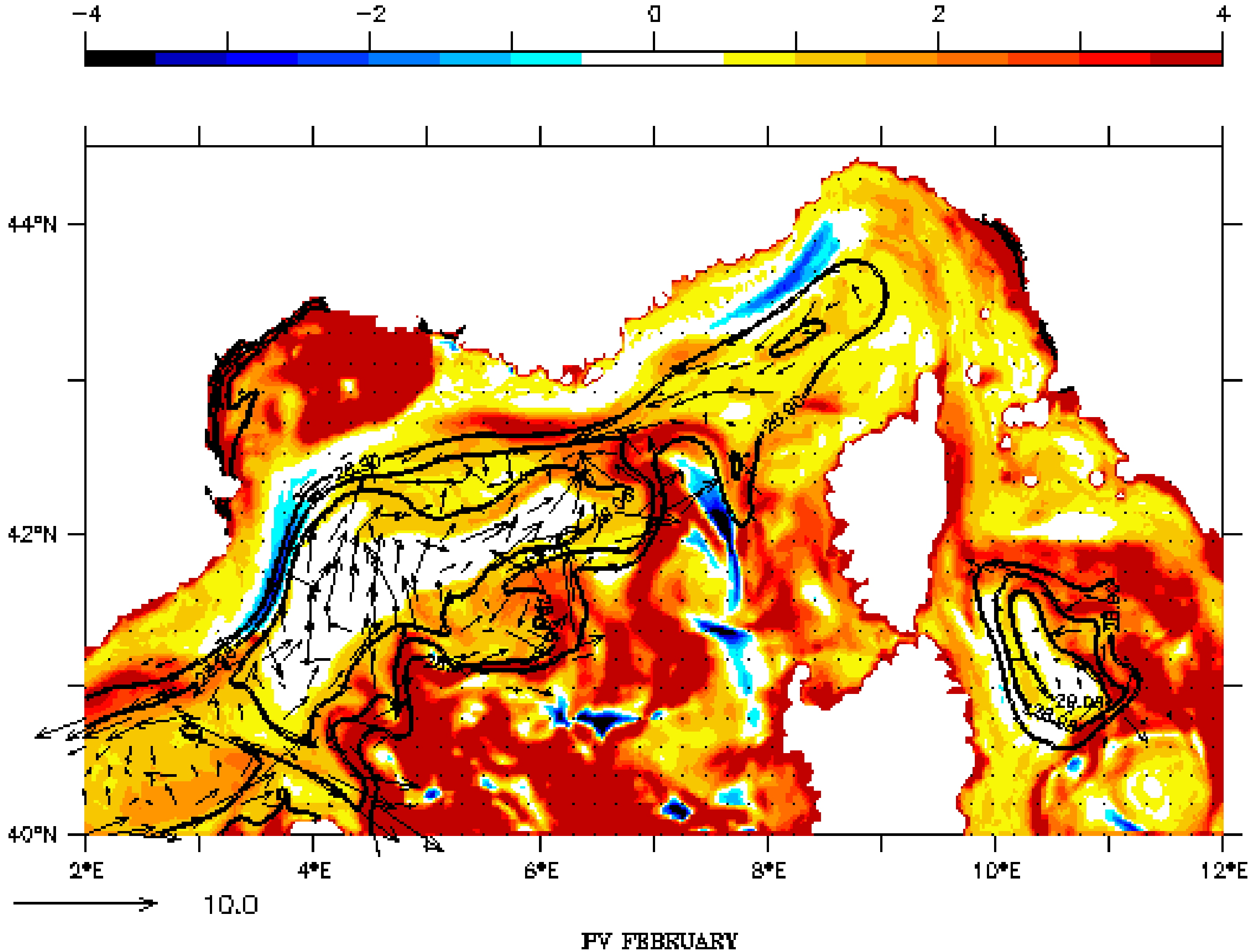


Eddy PV-Flux

$$V\left(\overline{u'q'};\overline{v'q'}\right)$$



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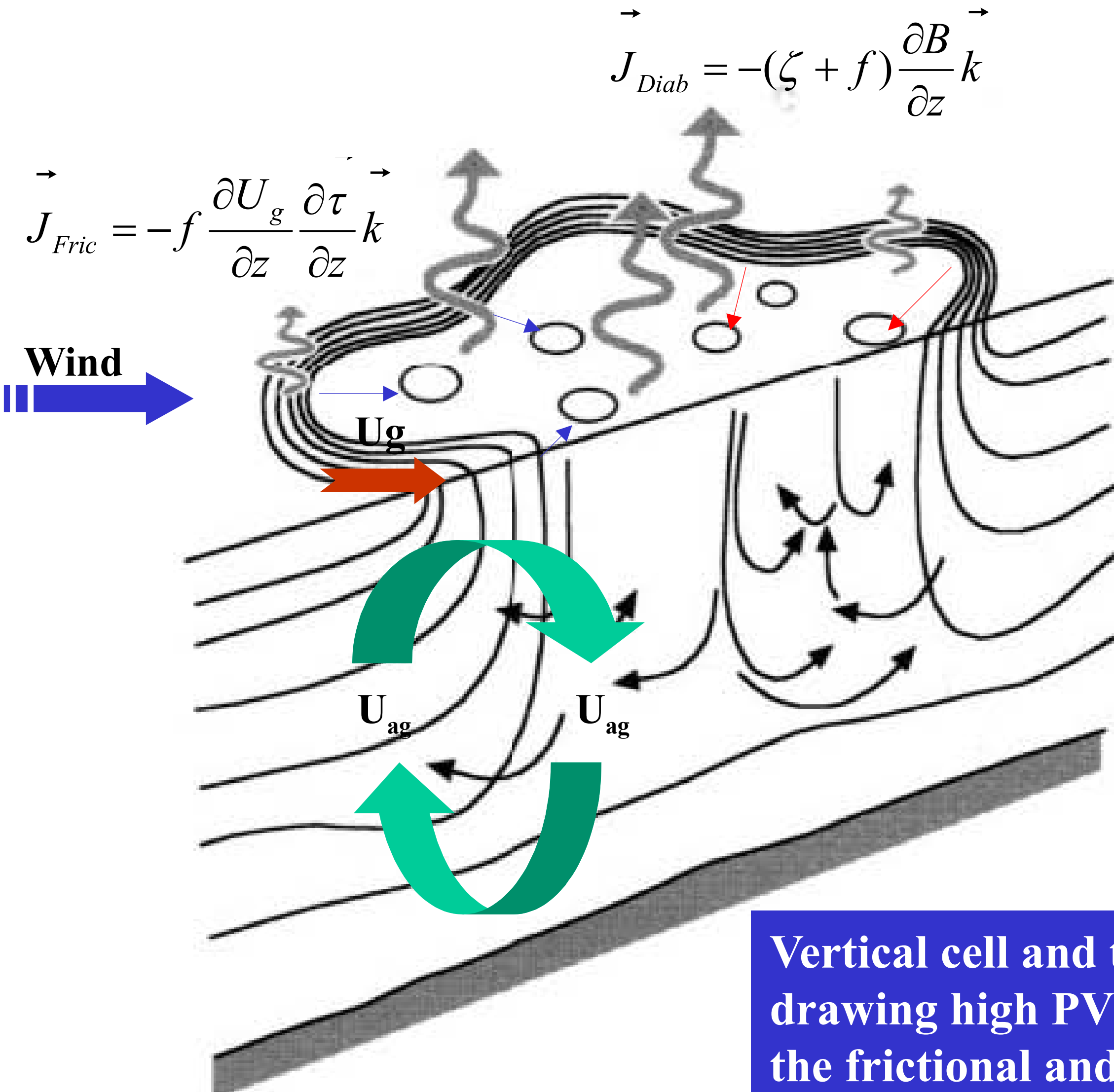
Conceptual Scheme



Vertical cell and turbulence act as a PV pump drawing high PV from the pycnocline to limit the frictional and diabatic PV-destruction at the surface (Giordani et al., 2017)

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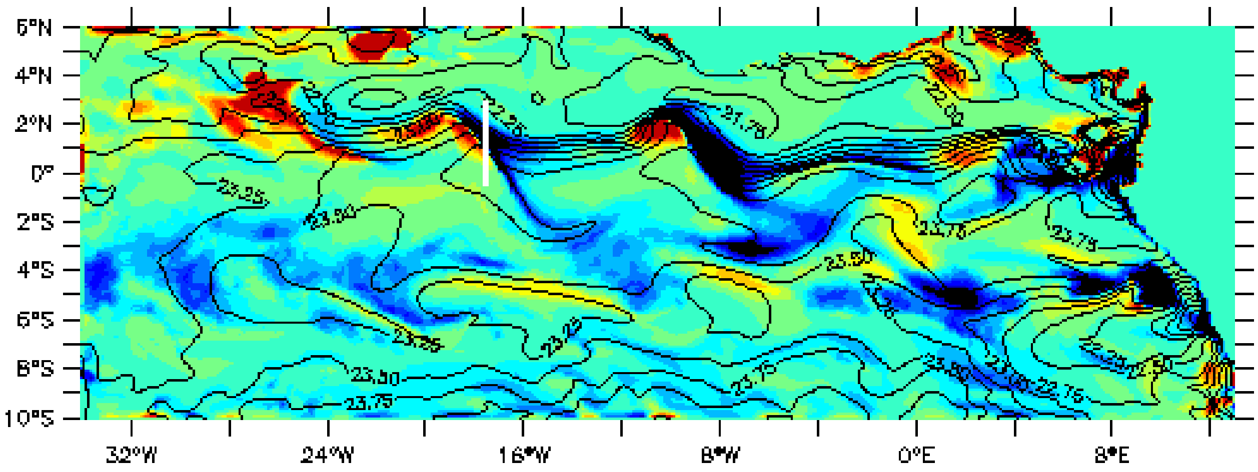
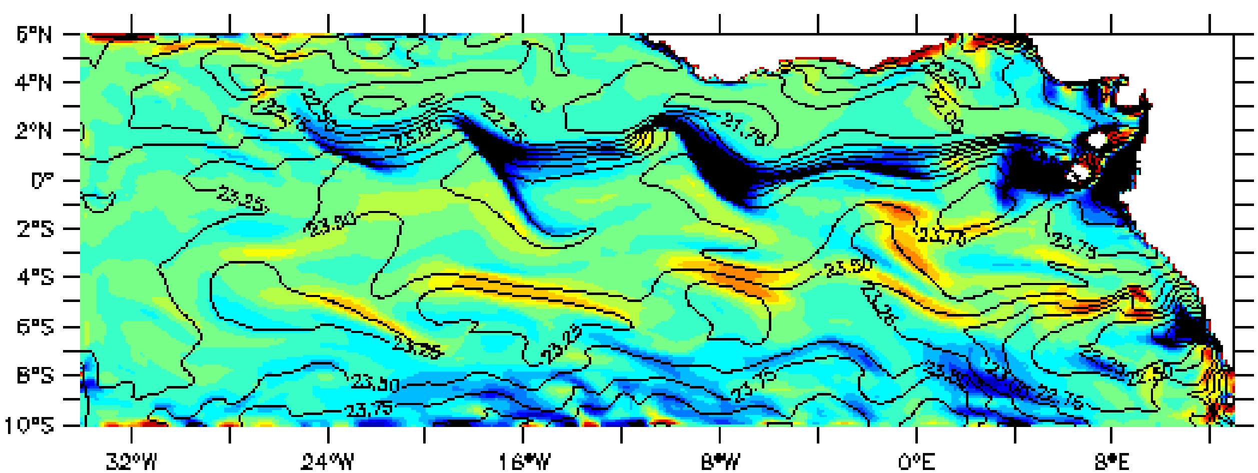
PV in TIW (Giordani et al., 2015)



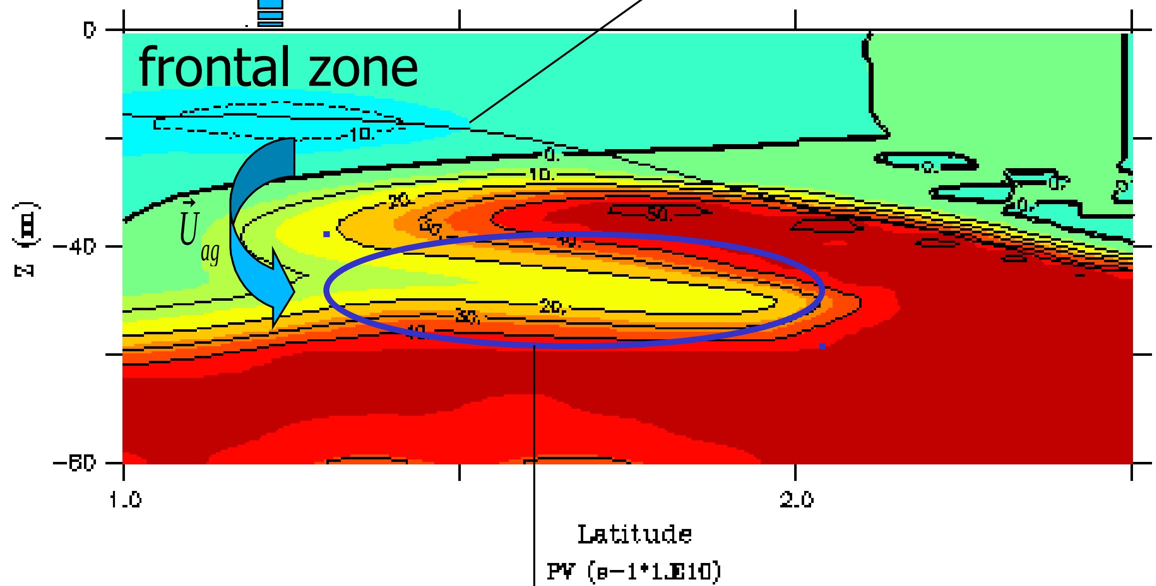
PV (S-1*E10)



JPV STRESS

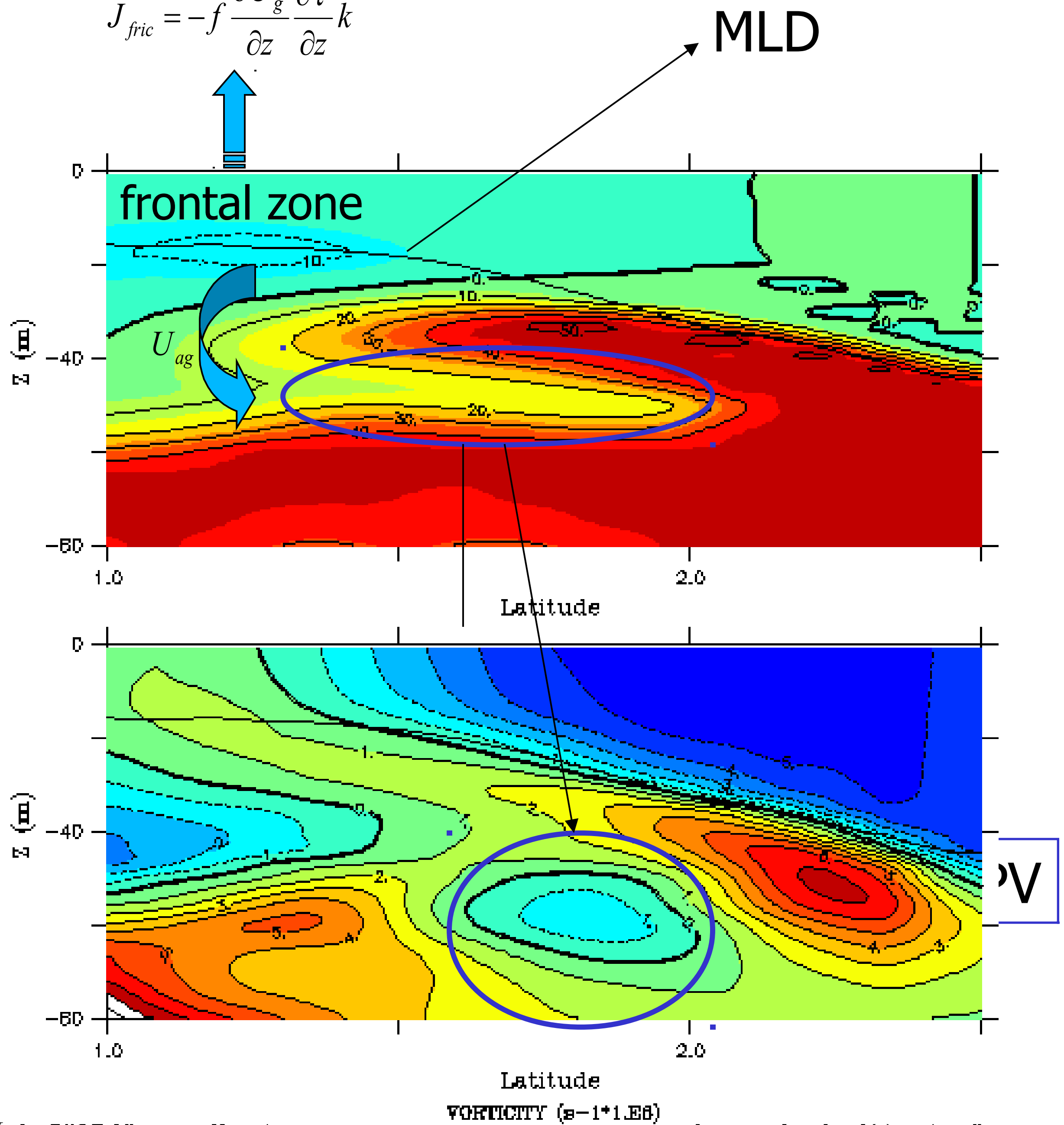
$$\vec{J}_{fric} = -f \frac{\partial \vec{U}_g}{\partial z} \frac{\partial \vec{\tau}}{\partial z} \vec{k}$$

MLD

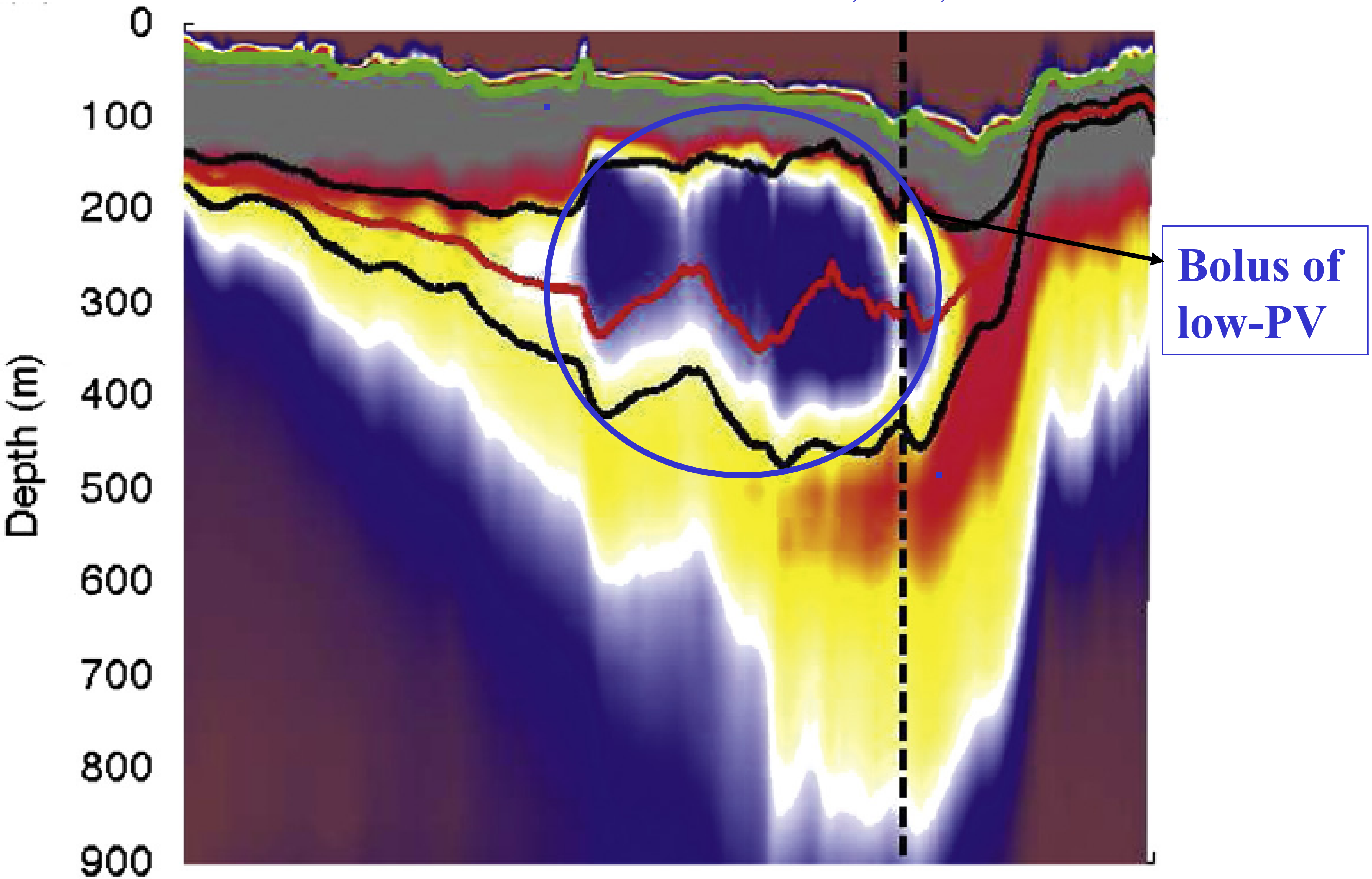


Intra-Thermocline bolus/eddy of low-PV

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



NAC & EDW Formation – Mazé et al., 2011, 2013



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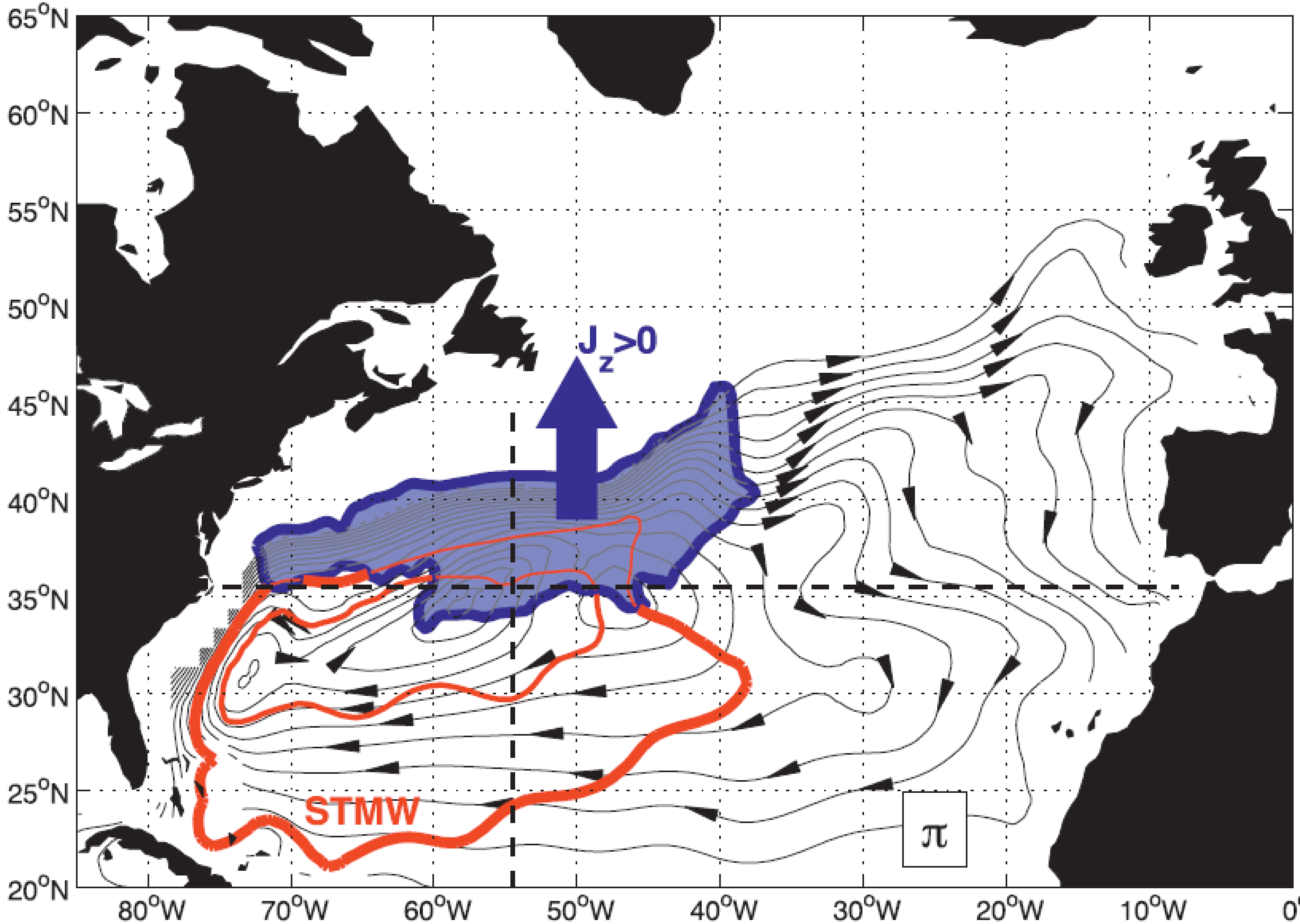
NAC – EDW Mazé et al., 2011, 2013



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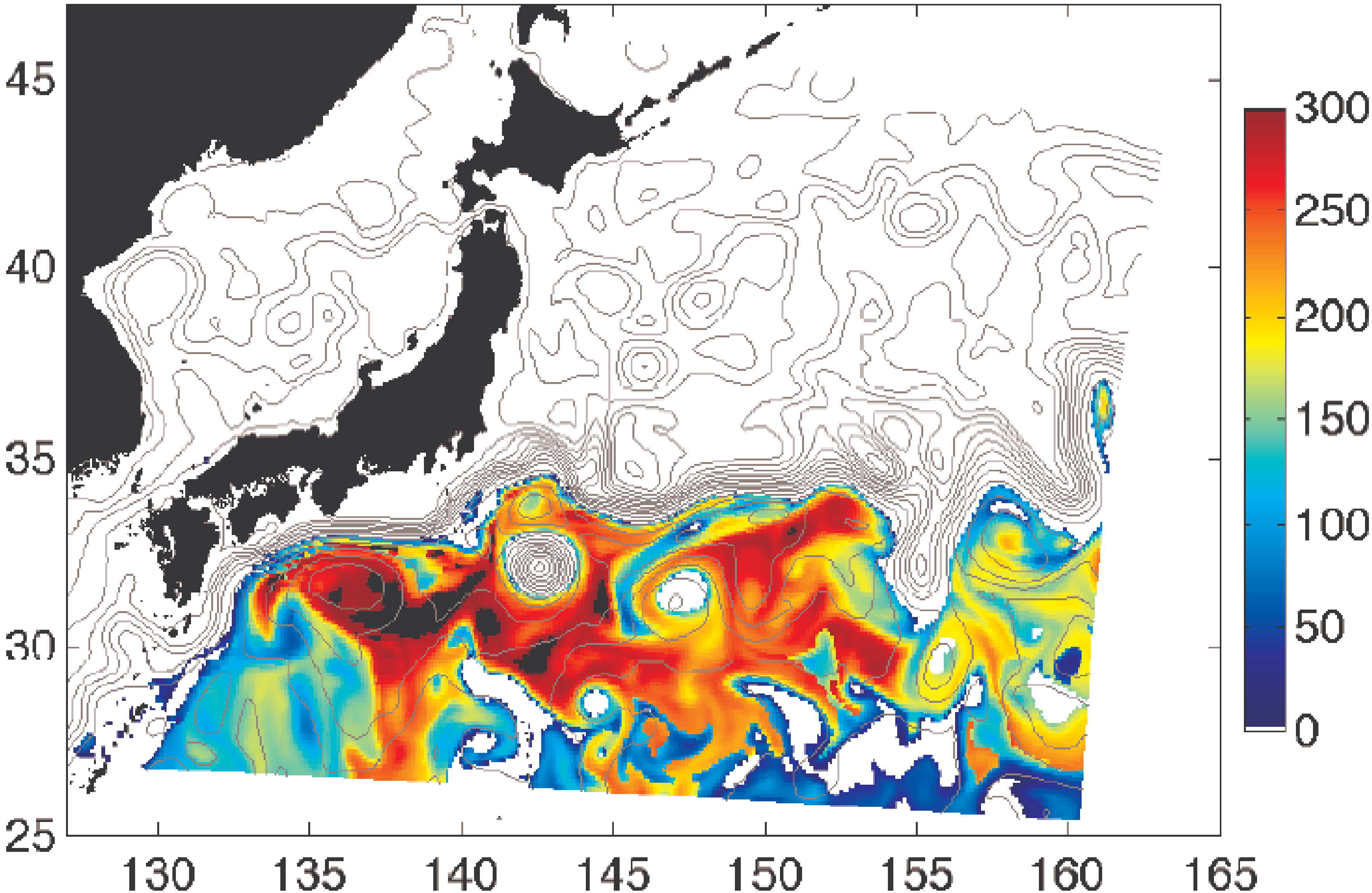
Kuroshio – STMW Rainville et al.



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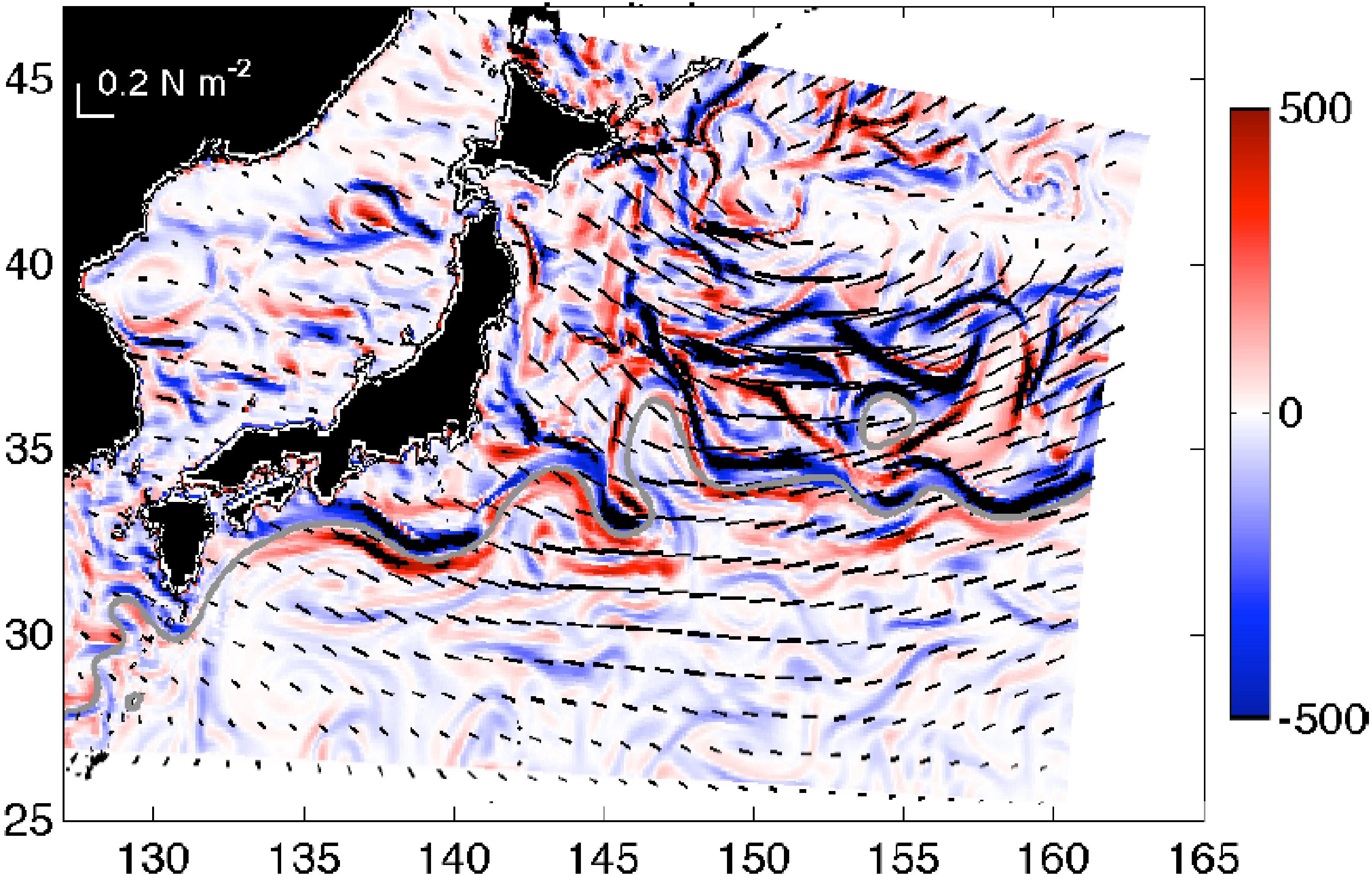
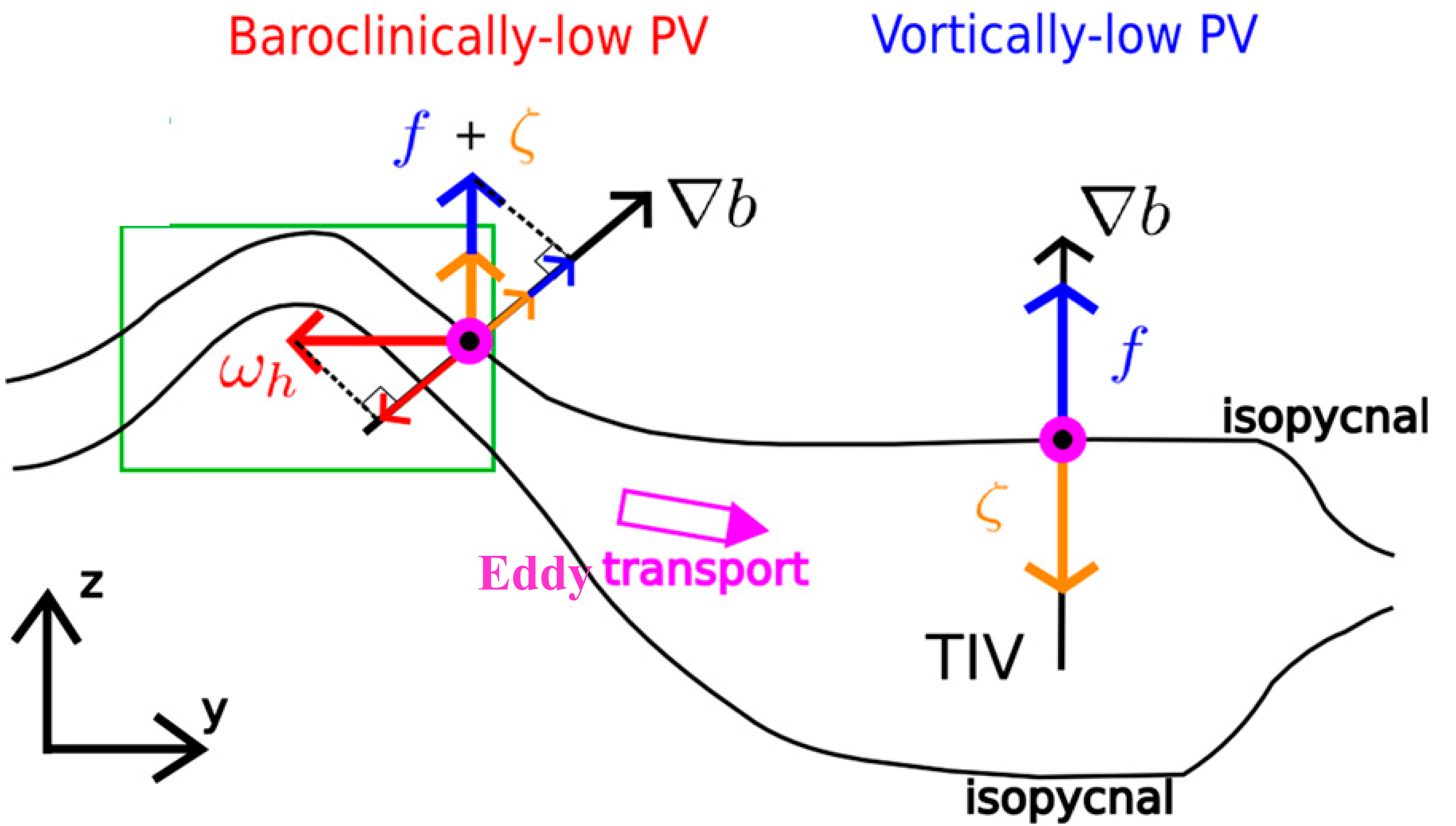


Conceptual Scheme



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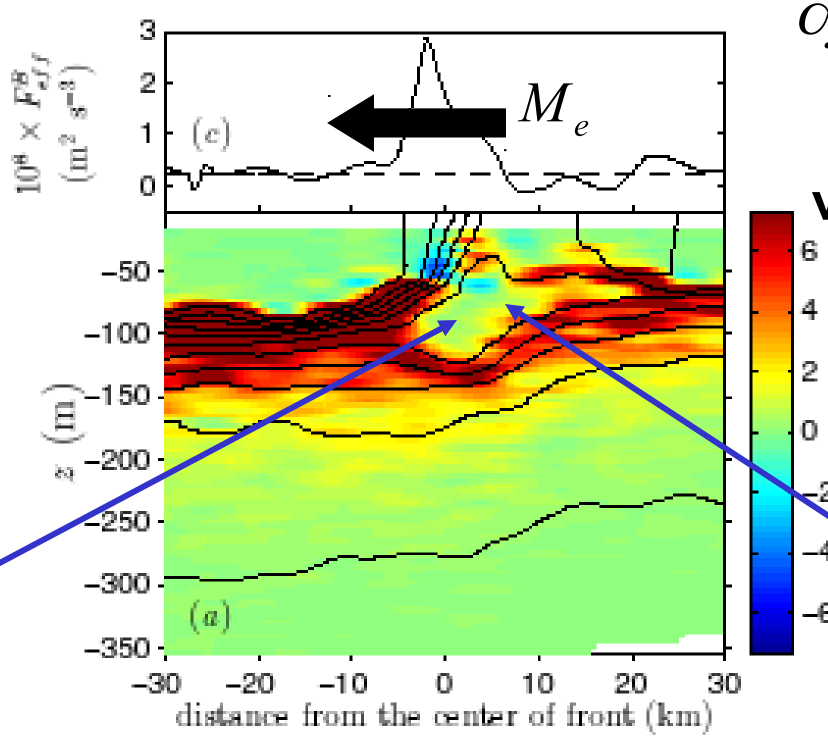
Conditions favorable à la destruction de EPV par la tension de surface: **conséquences énergétiques** des « cold-air outbreaks » dans les grands systèmes frontaux
(Joyce et al., 2010)

$$F^B_{eff} = F^B_{atm} + M_e \frac{\partial b}{\partial y}$$

$$F^B_{atm} = 500W.m^{-2}$$

$$M_e \frac{\partial b}{\partial y} = 5000W.m^{-2}$$



⊙
vent & courant

Destruction de PV

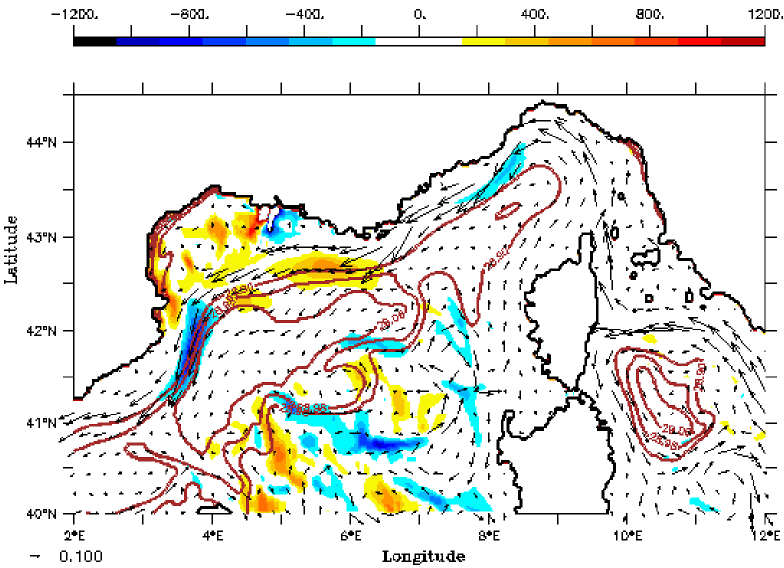
Subduction

Energetics
Equivalent Buoyancy Flux
(Giordani et al., 2017)

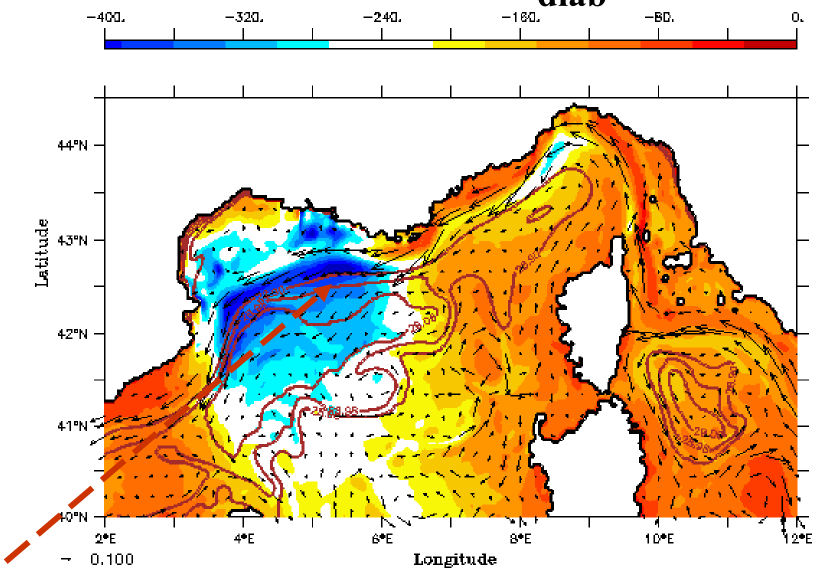
$$\begin{cases} EBF_{fric} = \dfrac{\rho C_p}{\alpha g} \vec{\tau}_0 \dfrac{\partial U_g}{\partial z} & \textbf{Friction} \\[2ex] EBF_{diab} = \dfrac{\rho C_p}{\alpha g} B_0 \left(1 + R_o\right) & \textbf{Diabatic} \end{cases}$$

Energetics

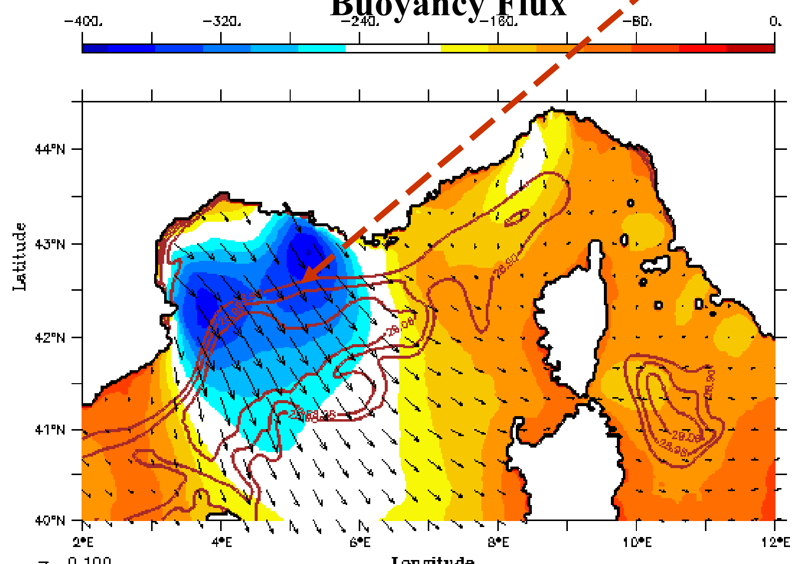
EBF_{fric}



EBF_{diab}



Buoyancy Flux



- Appropriate Δx to resolve energy trapping in fronts and eddies

- Parameterize EBF in climate models ?

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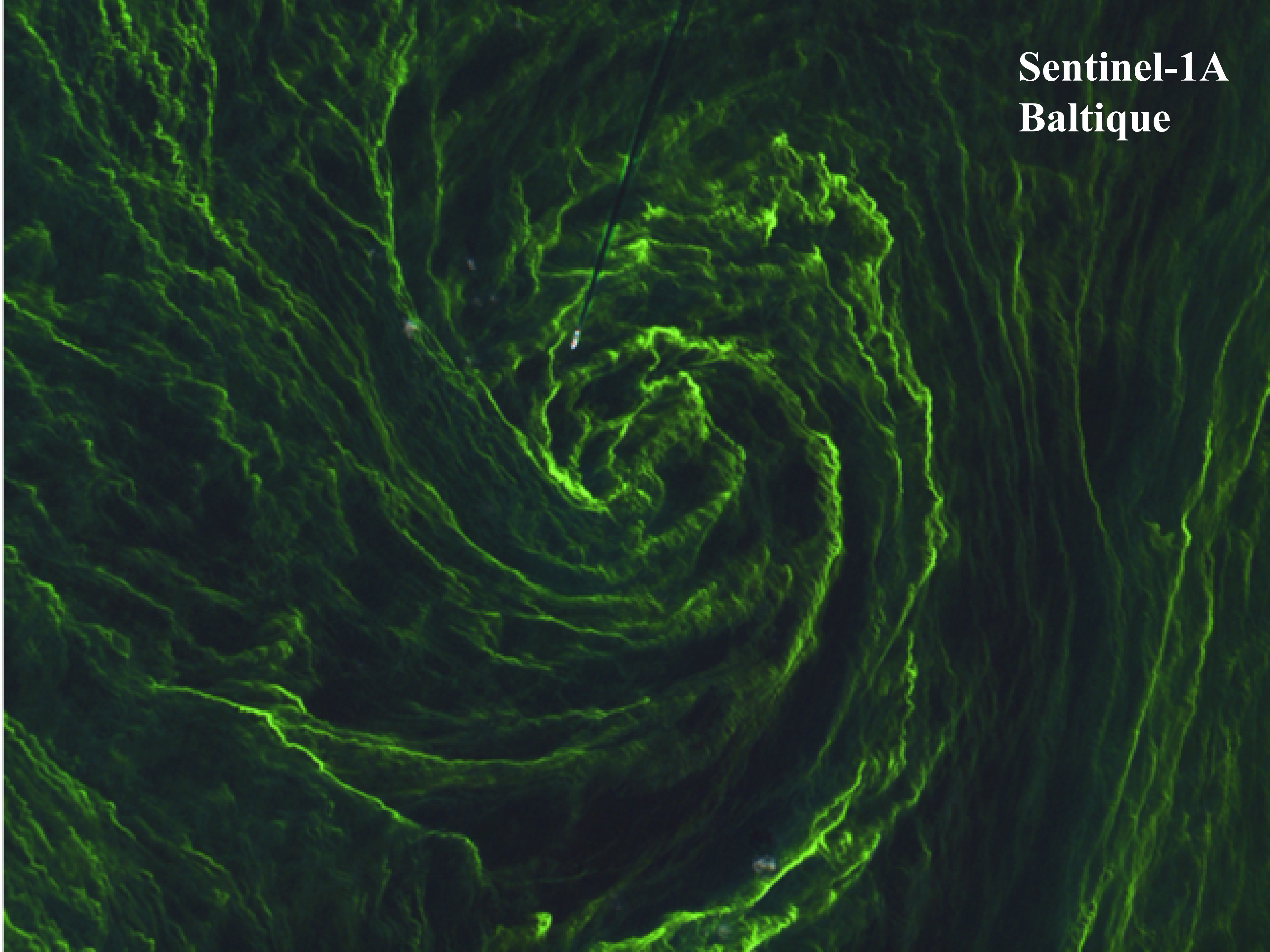
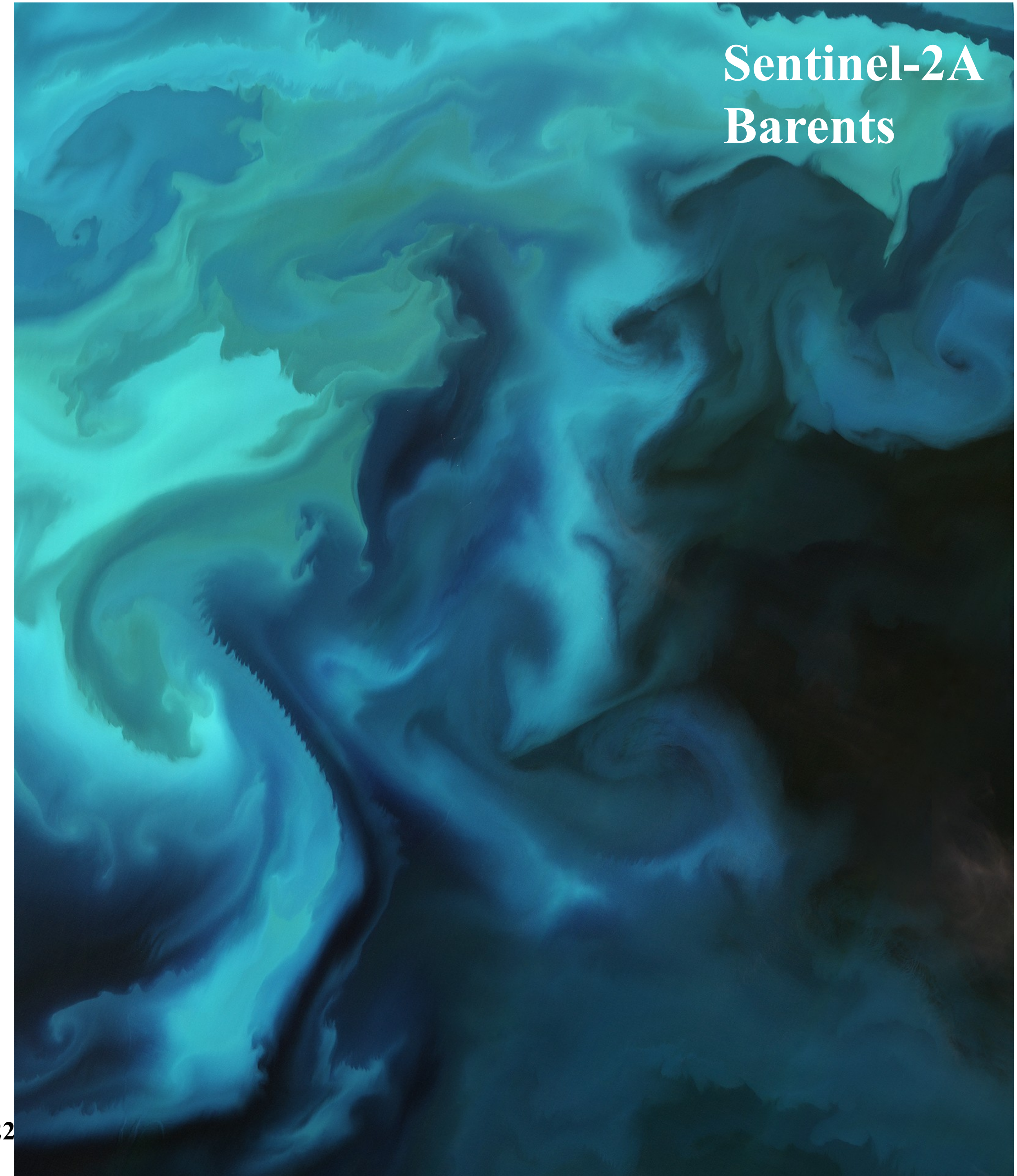
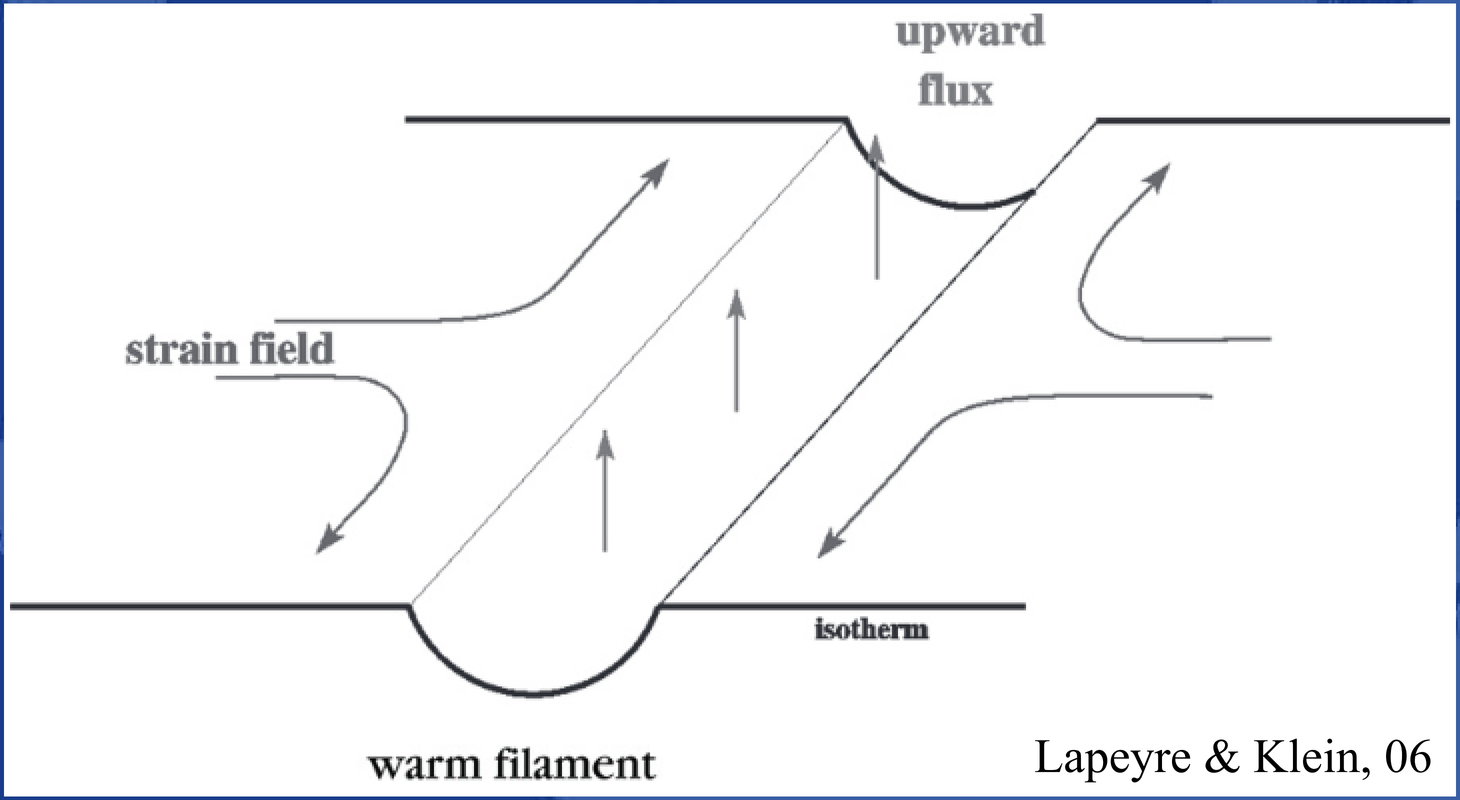

Sentinel-1A
Baltique


Sentinel-2A
Barents



SST gradients at small-scale are as energetic as large scales
(Held et al., 95; Lapeyre & Klein, 06; Tulloch & Smith, 09)

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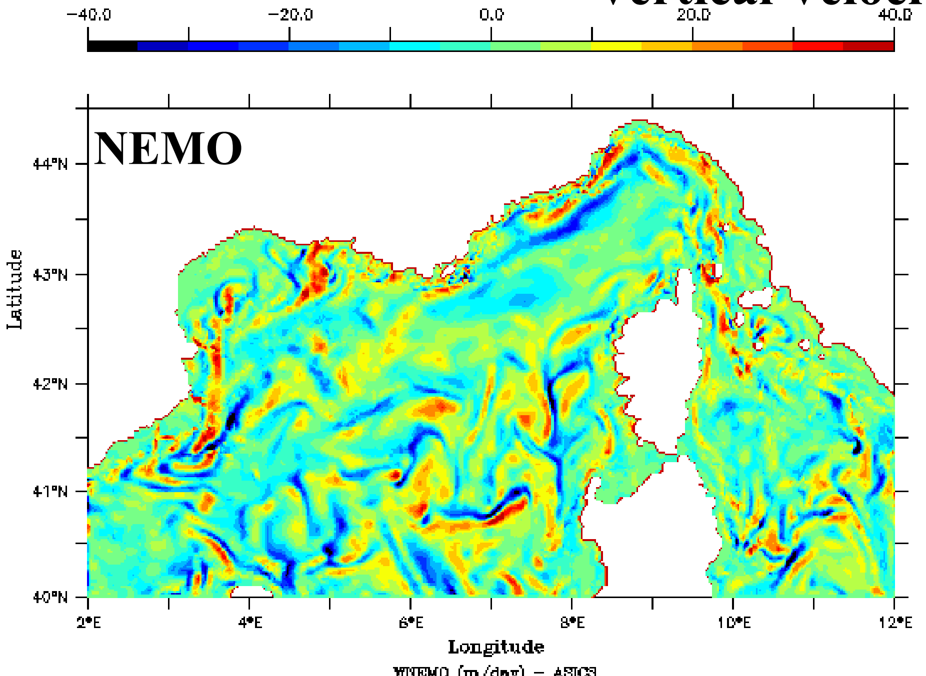
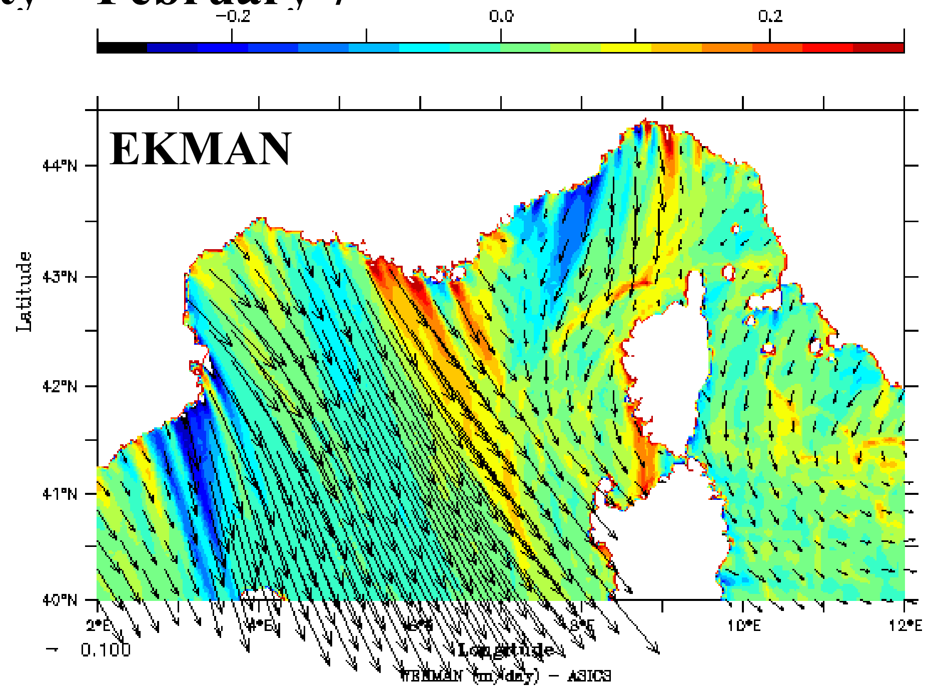
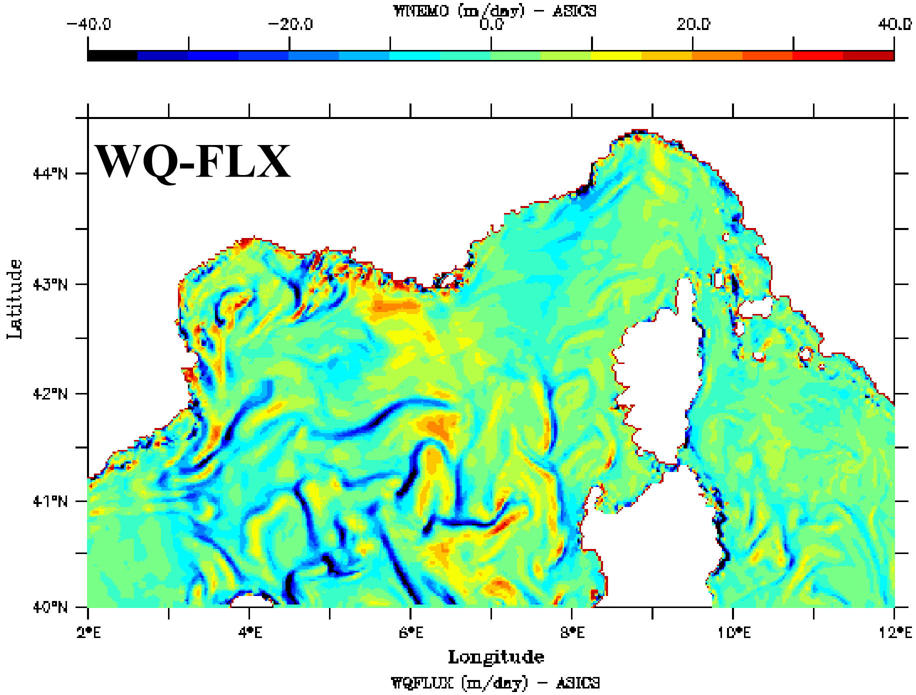
Vertical Velocity – February 7







Strain field associated with the flux-structures interactions induces intense vertical motion

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Conclusions

- ASICS-MED: alternative approach based on the PV-flux to estimate the processes of DWF along the cyclonic gyre in the WestMed

- PV-Budget : Turbulence and ageostrophic cell act as PV pump drawing high PV water from the pycnocline to limit the frictional and buoyancy PV-destruction at the surface. Horizontal Advection also limits the PV-destruction at the surface

- Frictional and diabatic EBF result from wind and submesoscale interactions (Scale selection in OA coupling) and involve **KOLOSSAL** energy exchanges at the surface

- **OA coupling is not limited to surface fluxes**

- How to restore the dynamics of the oceanic deserts in models ?

-> NH-Model **CROCO**

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