Winter frontal variability at submesoscale in the Gulf of Lions as observed with gliders and simulated by a very-high resolution model

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P. Damien[3], C. Estournel[3], P. Marsaleix[3], L. Prieur[4]

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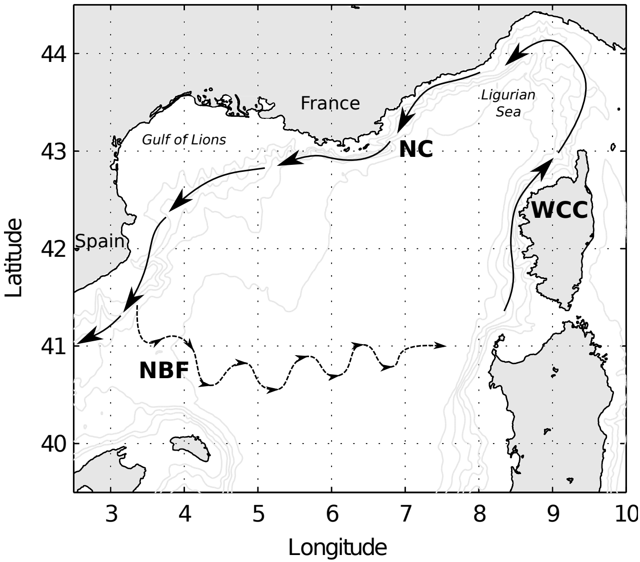
SYNBIOS Workshop, Paris, July 6–8 2015

Plan

Mean oceanic circulation of the NWMED:



Basin-scale Cyclonic Circulation:

- Northern Current (∼ 1–2 Sv)
- North-Balearic Front (driven by mesoscale varirability)
- Western Corsica Current

⇒ large-scale preconditioning to deep mixing

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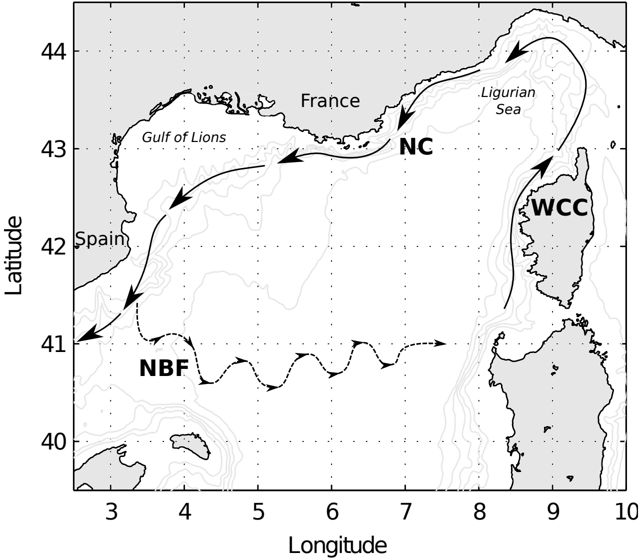

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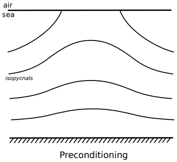

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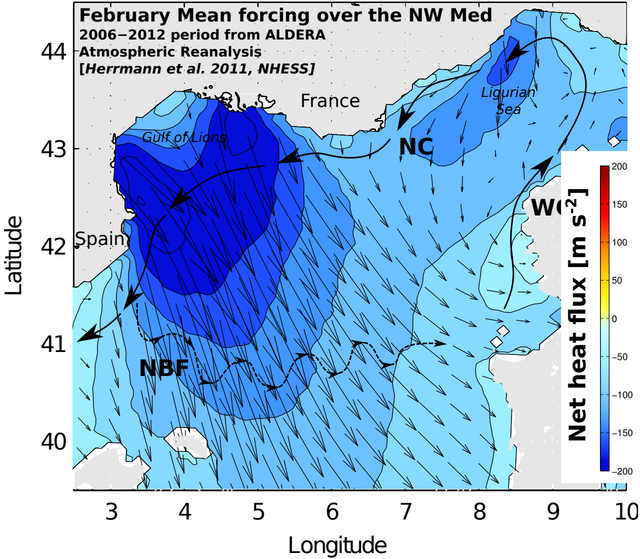
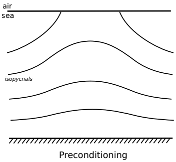


Strong winter conditions with very intense air-sea fluxes:

- intense and dry northerlies drive net heat fluxes up to < -1000 W m^{-2}

⇒ large-scale preconditioning to deep mixing



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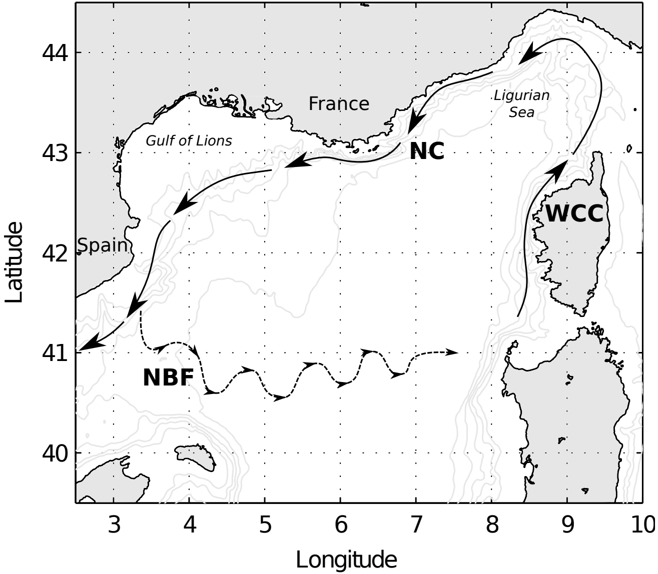

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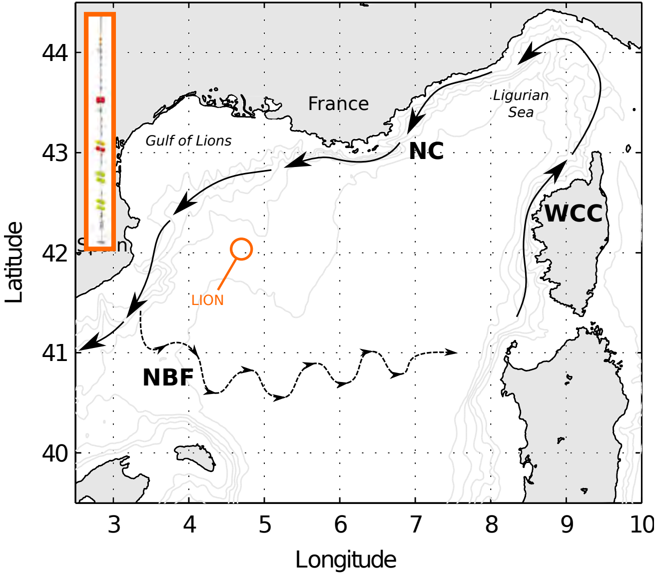

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11 microcats + 5 currentmeters

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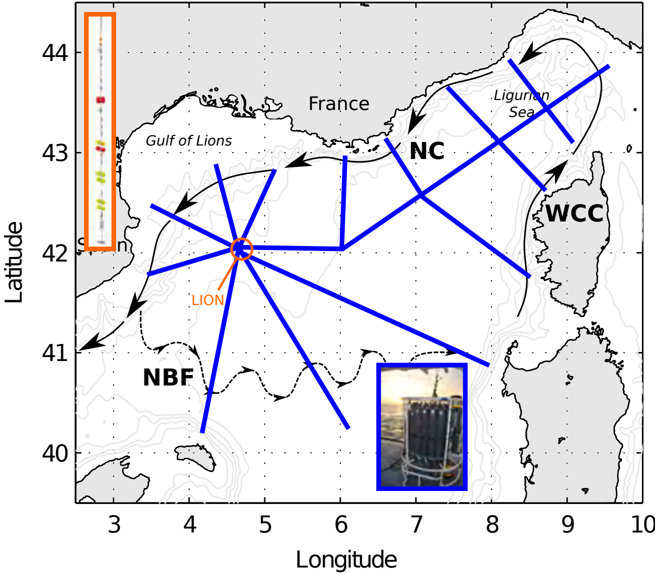

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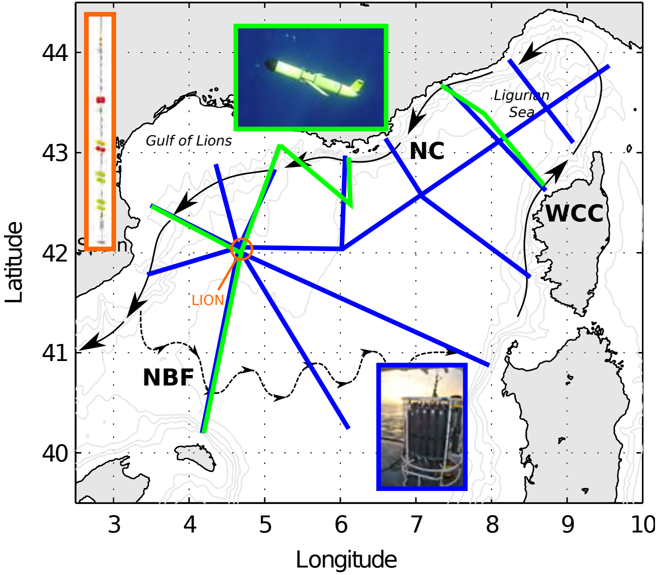

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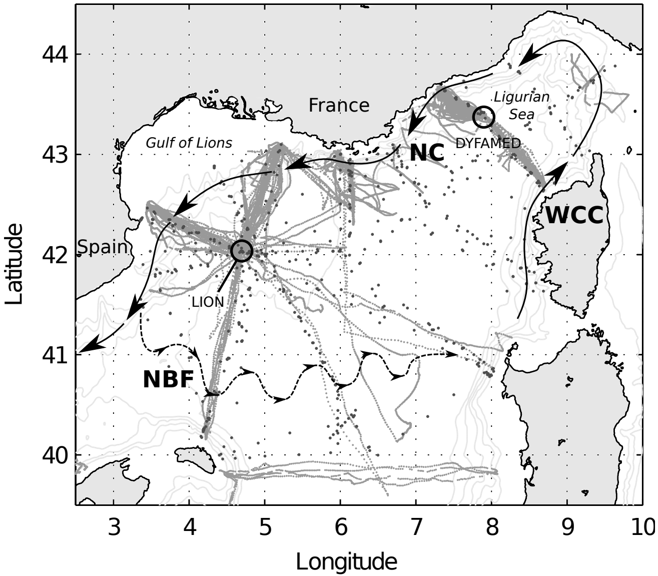

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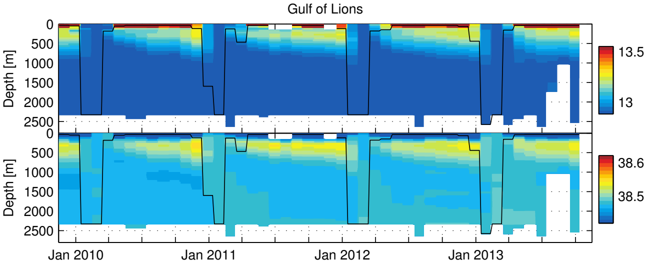
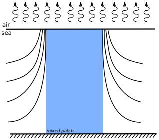
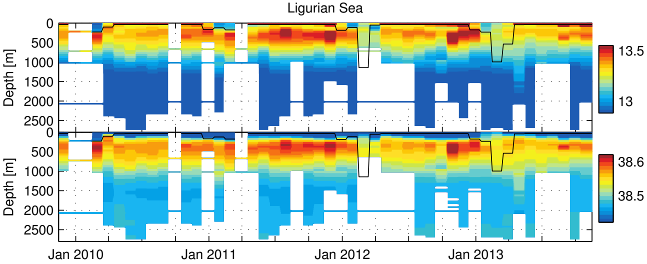
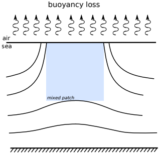


For 4 consecutive Winters, vertical mixing reached the bottom at 2400 m in the Gulf of Lions:

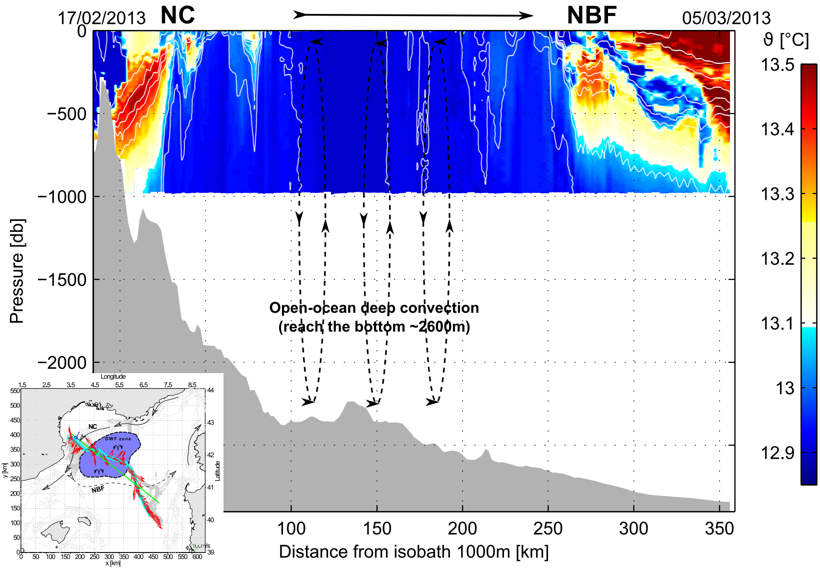




and intermediate depths (200-1000 m) in the Ligurian Sea:



Section across the DWF zone, role of submesoscale frontal exchanges



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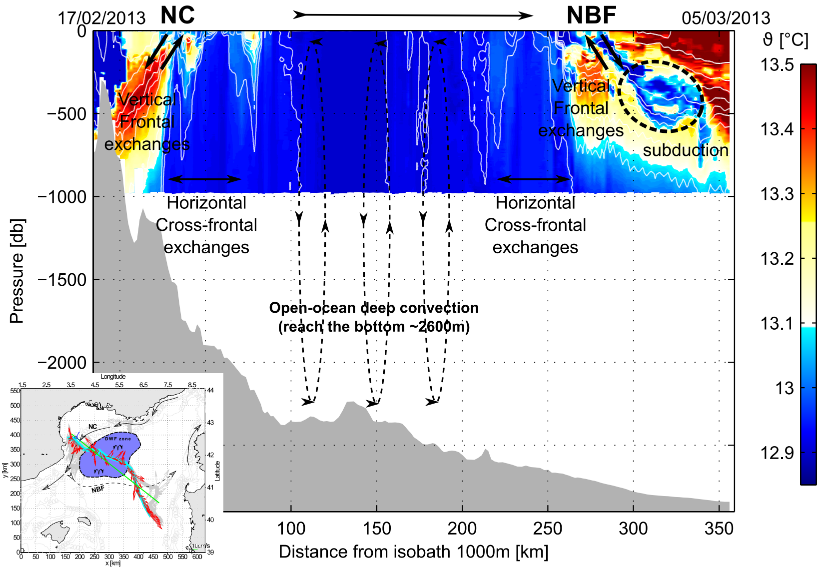


Plan

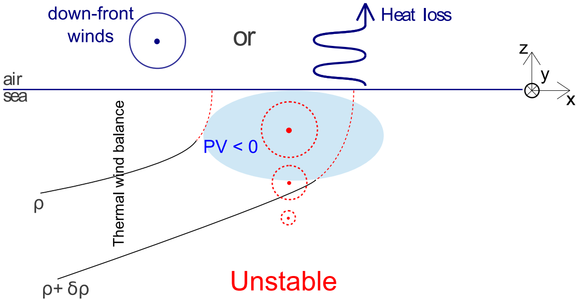
Mechanism of SI:

Definition: A fluid parcel with Potential Vorticity of opposite sign of the Coriolis parameter (<0 in the Northern Hemisphere) is unstable to along isopycnal perturbations.

In a 1D geostrophic framework, the Ertel's PV goes by:

$$q \equiv (f\hat{z} + \nabla \wedge u) \cdot \nabla \rho \propto f(f + \partial_x v)N^2 - (\partial_x b)^2 \quad \text{with } b \equiv -\frac{g\rho}{\rho_0} \tag{1}$$

Surface forcing (through buoyancy loss or down-front winds) can extract PV by weakening the stratification ($N^2 \searrow$) and enhancing density fronts ($(\partial_x b)^2 \nearrow$)



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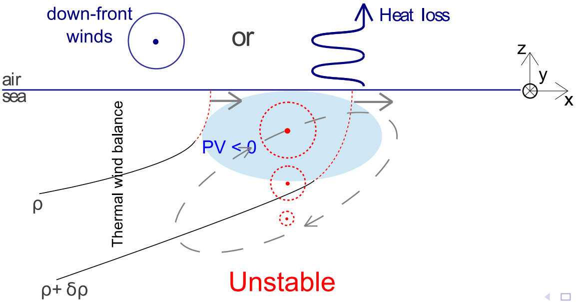

Once SI develops, fluids move along isopycnals on the vertical (x,z) plane and it tends to restratify the surface layer so that PV $\sim$ 0 ($N^2 \nearrow$ and $(\partial_x b)^2 \searrow$).

Growth time : $O(f^{-1})$

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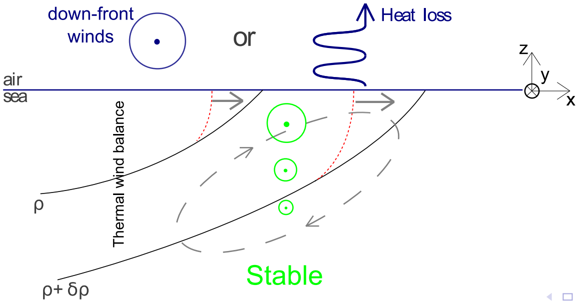

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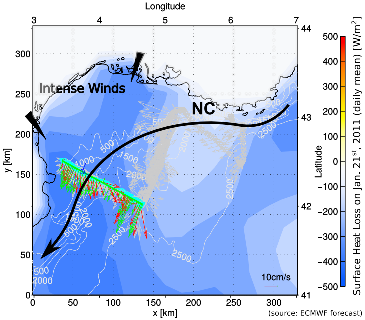
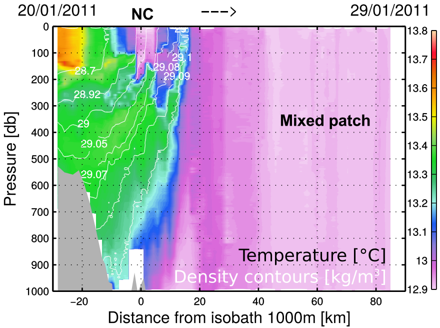
Example of a Glider section across the NC in Winter





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  $\Rightarrow$ daily mean heat loss < -500 W.m^2;
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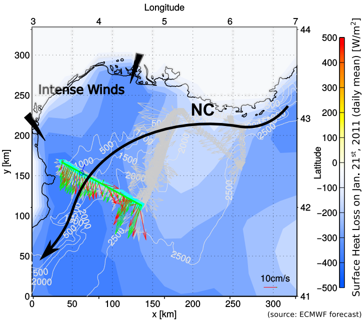

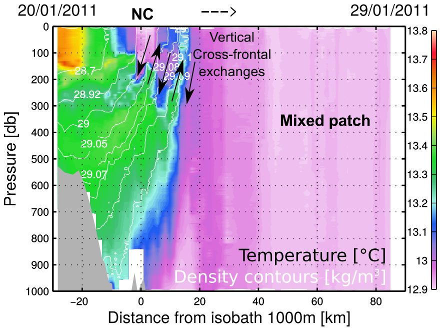

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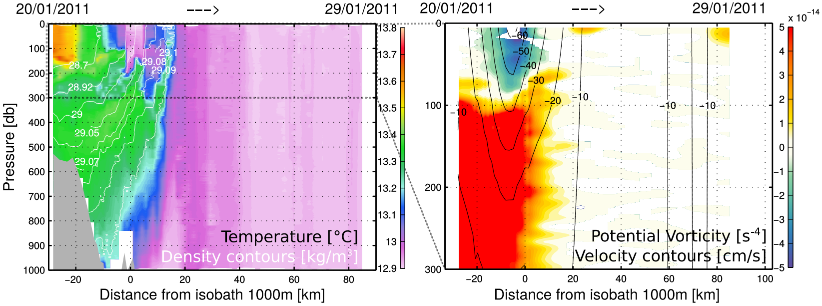
  $\Rightarrow$ daily mean heat loss < -500 W.m^2;
- bottom-reached convection (data from the mooring LION);
- The potential temperature exhibits submesoscale variability at the NC front.

Can these vertical exchanges be the result of SI?

Estimating the PV from gliders data:

- geostrophic currents perpendicular to the glider path are estimated from the integration of the vertical shear (thermal wind balance: $f\partial_z v = -\partial_x b$) from a filtered density section[1] to filter out small isopycnal oscillations due to internal waves.
- the cross-section depth-average currents (estimated by the glider navigation) are taken as a velocity reference.
- $PV = f(f + \partial_x v)N^2 - (\partial_x b)^2$ (assuming a 2D dynamics)

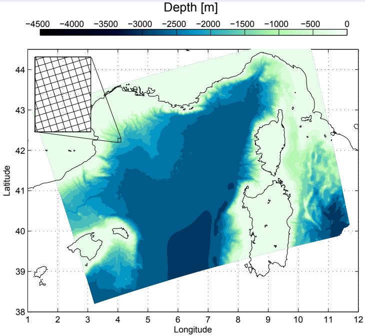


[1] gaussian running mean (σ=2km) of significant width $\sim$ 6km

Plan

The numerical model SYMPHONIE

- 3D primitive equation hydrostatic ocean model
- realistic configuration of the NWMed
- horizontal resolution of 1km, 40 σ-vertical levels
- surface forcing: ARPERA reanalysis from Sept 2010 to Dec 2011
- boundary conditions prescribed by Mercator operational model



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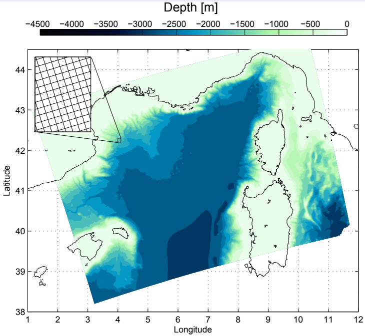
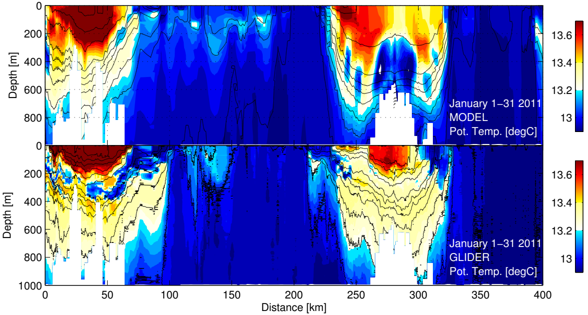
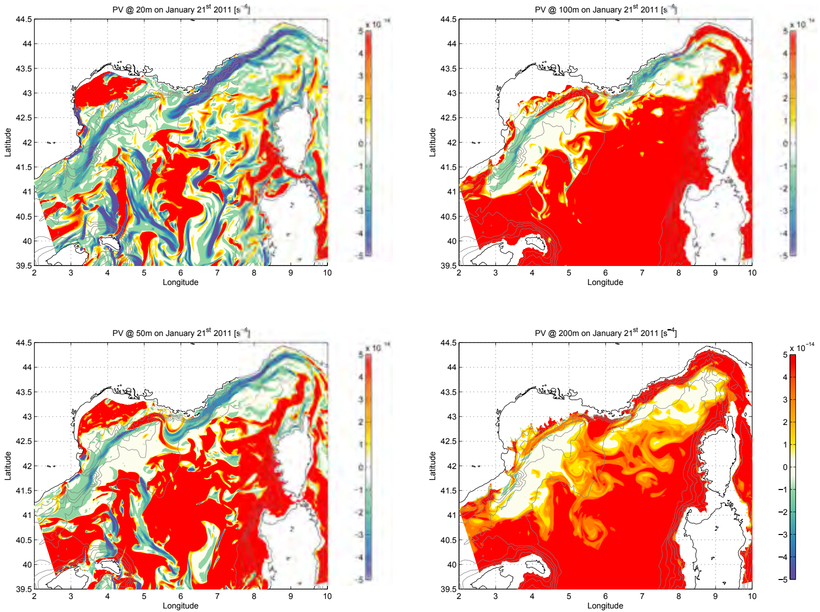




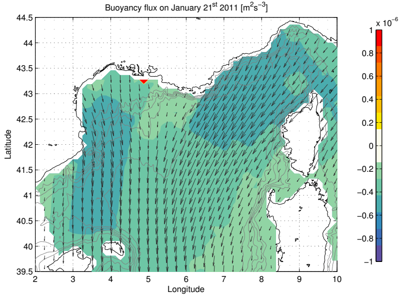
→ good representation of: deep convection and submesoscale frontal variability.

PV at different depths (20m, 50m, 100m and 200m)



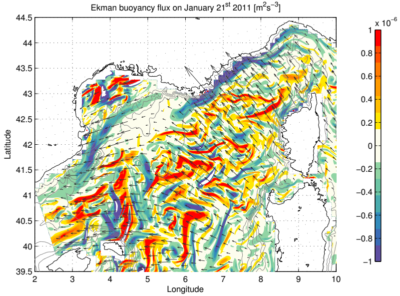
Surface buoyancy flux:

$$\mathrm{SuBF} = \frac{g}{\rho_0}\left[\frac{\alpha}{C_p}Q_{net} + \rho_0 \beta S(E-P)\right]$$



Ekman buoyancy flux:

$$\mathrm{EkBF} = \left[\frac{\hat{z}\wedge\tau}{\rho_0(f+\zeta)}\right]\cdot\nabla b$$



Down-front winds
$\Rightarrow$ dense waters onto lighter ones
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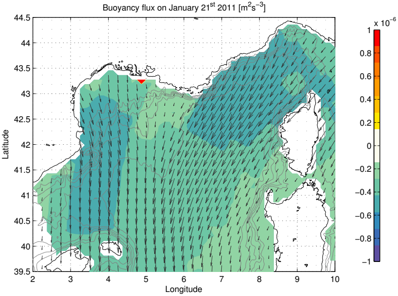

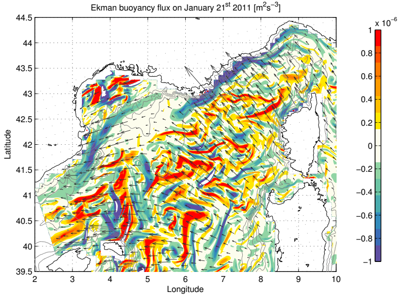

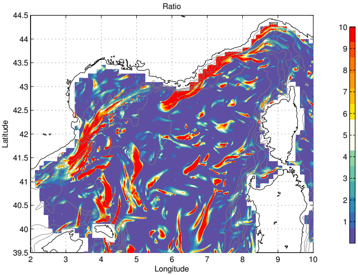

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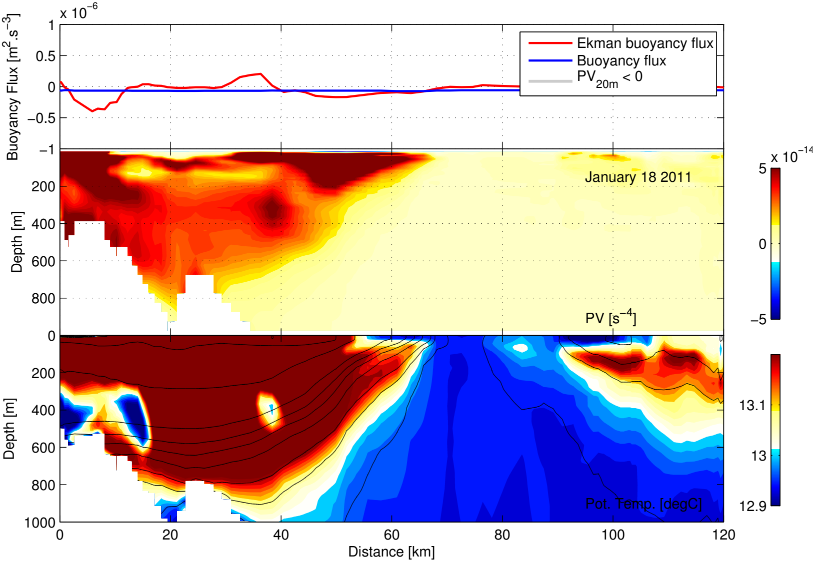
ratio: $\frac{H}{\delta_{ek}} \frac{\mathrm{EkBF}}{\mathrm{SuBF}}$ [Thomas, JPO 2005]

Effect on PV when MLD $\uparrow$

Ekman buoyancy flux $\gg$ Buoyancy flux

Development of frontal vertical motions



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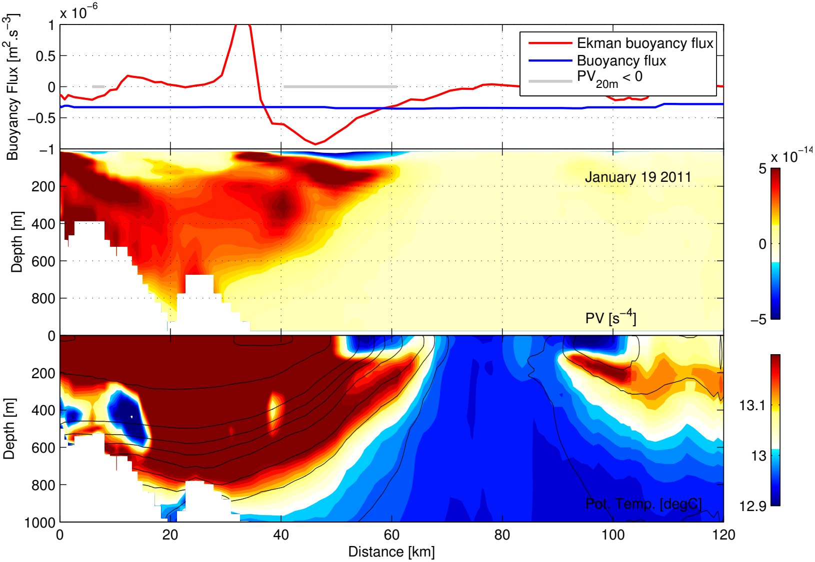

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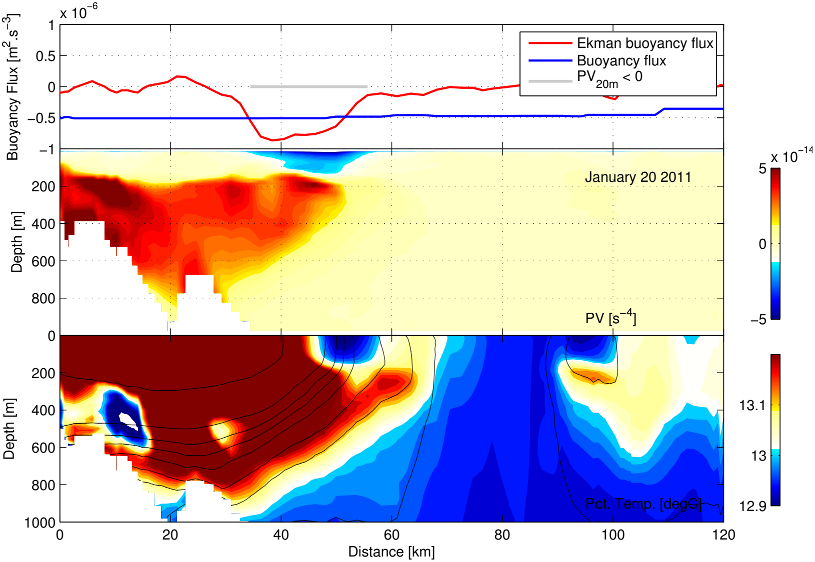

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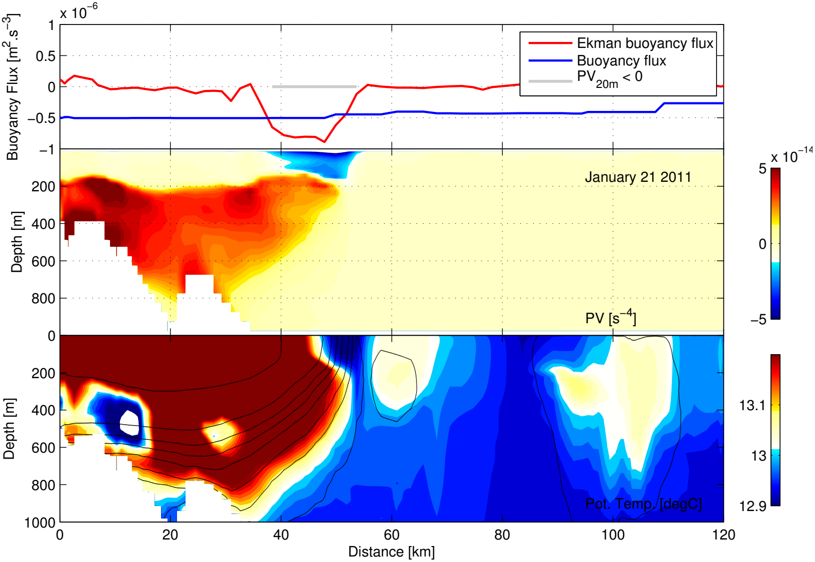

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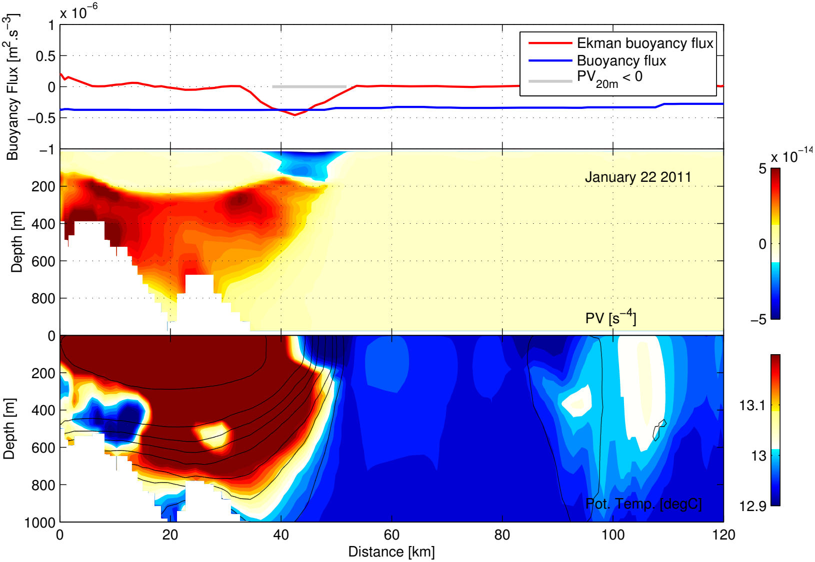

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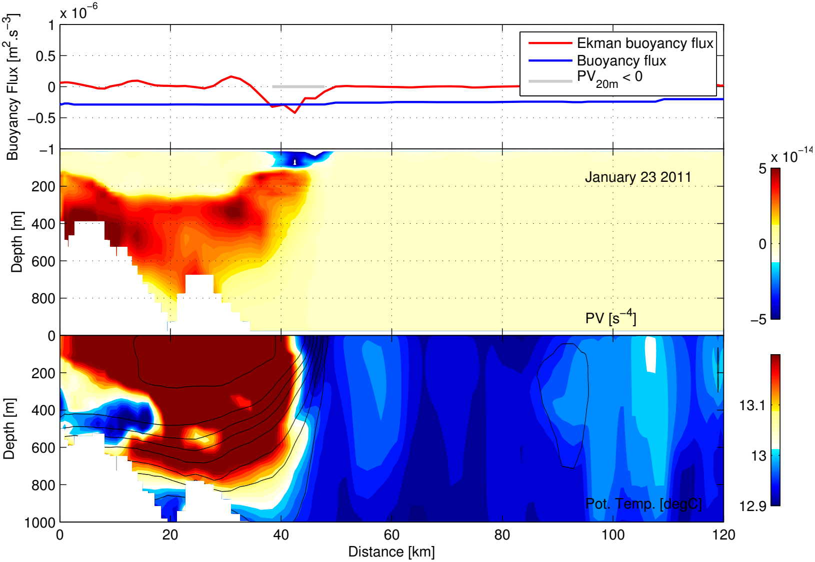

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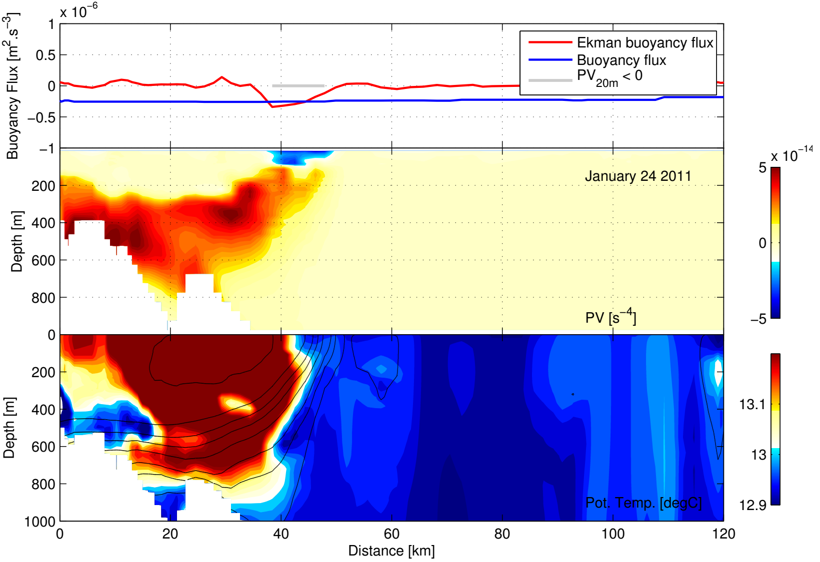

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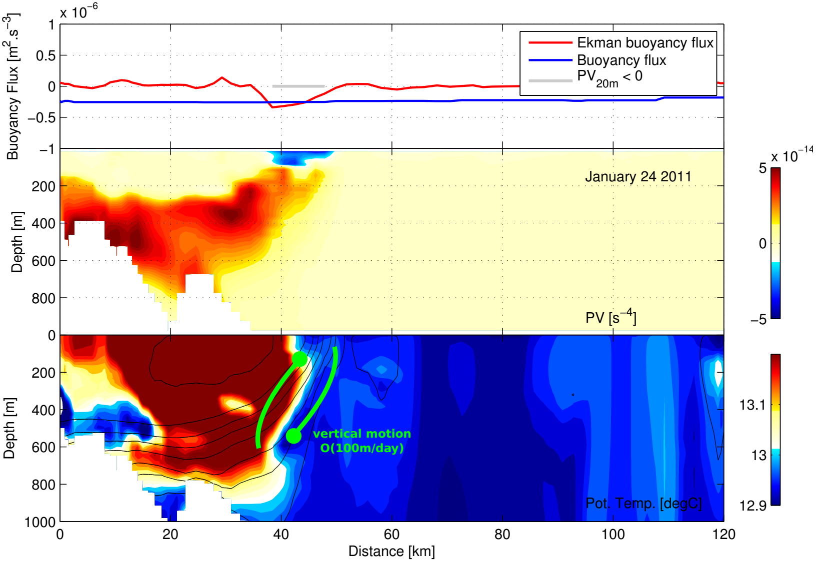
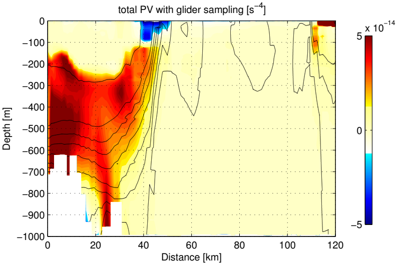
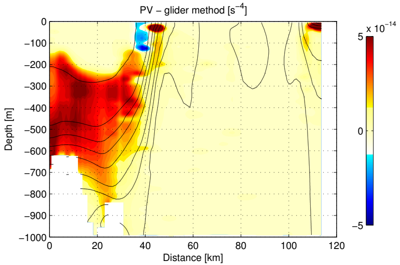


PV estimates by the glider method from model output





total PV (sampled like a glider)

PV estimated using the glider method

⇒ Good general agreement on the PV.
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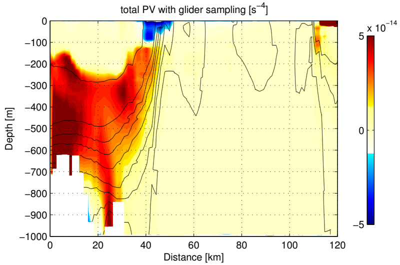

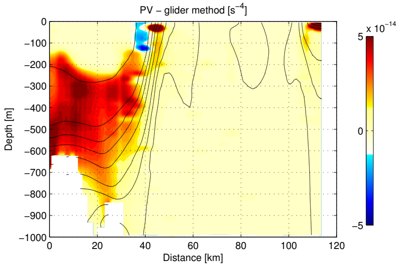

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Work in progress:

- detailed analysis of the PV conservation equation:

$$\partial_t q = -\nabla \cdot (qU + \nabla b \times F - (f\hat{k} + \nabla \times U) D_t b) \qquad (2)$$

- closer look at vertical velocities at the front and quantify the impact of submesoscale dynamics on NC heat/salt transport

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Conclusion

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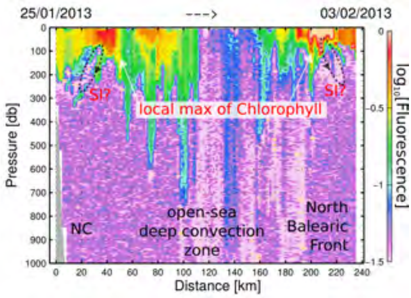

[North-South Chlorophyll section from glider Campe during ASICSMED deployment in Winter 2013.]

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- Vertical velocities at front can be 0(100m/day) $\rightarrow$ consequence on phyto growth? [Taylor and Ferrari, GRL 2011]

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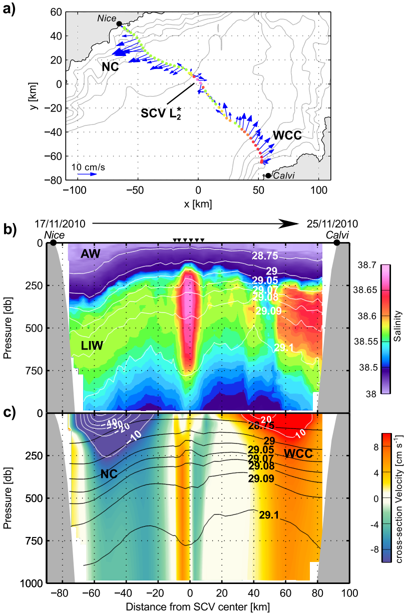
Observation of outstanding LIW SCVs in the Ligurian Sea:



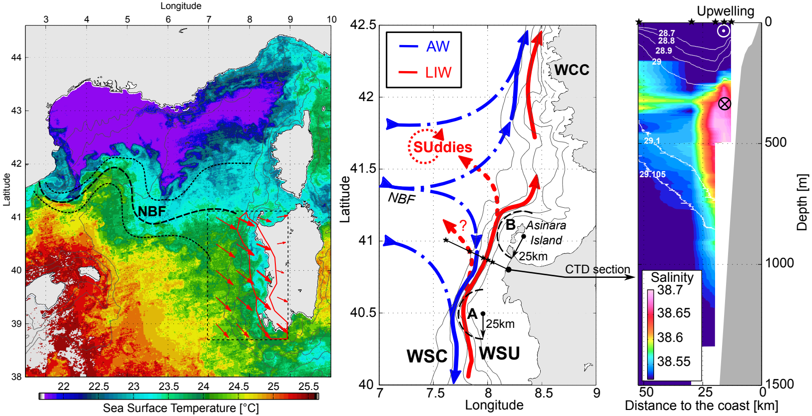
Bosse et al (2015): Spreading of LIW by SCVs in the NW Mediterranean as observed with gliders, Journal of Geophysical Research

Over about 40 Nice-Calvi section, gliders observed 5 SCVs:

- depth-intensified velocities (anticyclonic SCVs, McWilliams [1985]);
- core of very well marked LIW (S $\sim$ 38.7 (+0.1) and T $\sim$ 13.8°C (+0.4°C)
- small radius ($\sim$ 5km)
- (Ro $\sim$ 0.3 and Bu $\sim$ 0.3-1.3);
- peak velocity ($\sim$ 8cm/s) at intermediate depths ($\sim$ 400m).
- life-time > 6 months.

Process of formation: (D'Asaro [1988])

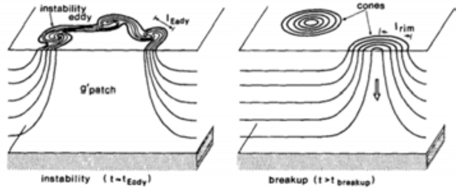
Non-conservative processes within the bottom boundary layer
+ flow detachment (curvature small enough at NW headland).



The formation of these SCVs seems to be closely linked to the circulation of AW at the surface (upwelling with southward surface flow = necessary condition).

The breakup of the mixed patch into vortical structures

Bosse et al (in prep): Multi-platform observation of submesoscale vortices formed by deep vertical mixing in the northwestern Mediterranean Sea



Cyclonic cones ↑
From Send and Marshall, *JPO* [1995]

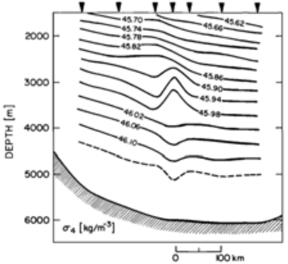


Fig. 6. A potential density cross section along 46°S latitude. The arrowheads at the top mark CTD station locations, and the center of the South Atlantic abyssal SCV is at 53.5°W longitude (A. L. Gordon and C. L. Greengrove, unpublished manuscript, 1985).

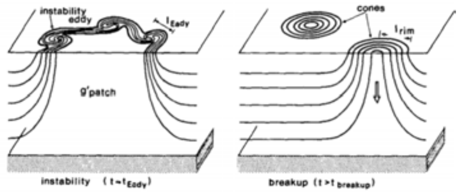
Anticyclonic SCVs
From McWilliams, *Rev. Geophys.* [1985] →

Motivation:

▷ Characterize these vortices from observations
And discuss their role for...
▷ ... the spreading of convected waters?
▷ ... the preconditioning of the ocean to vertical mixing?

The breakup of the mixed patch into vortical structures

Bosse et al (in prep): Multi-platform observation of submesoscale vortices formed by deep vertical mixing in the northwestern Mediterranean Sea



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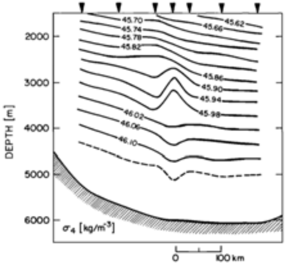

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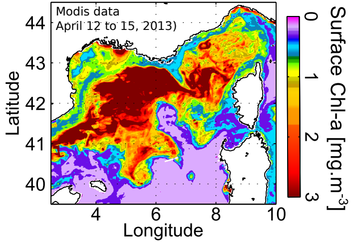
From McWilliams, *Rev. Geophys.* [1985] →



Motivation:

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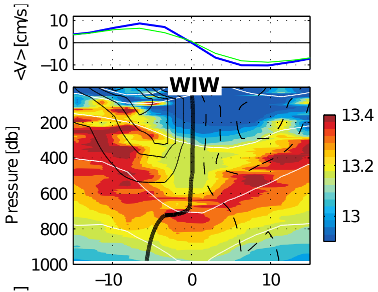
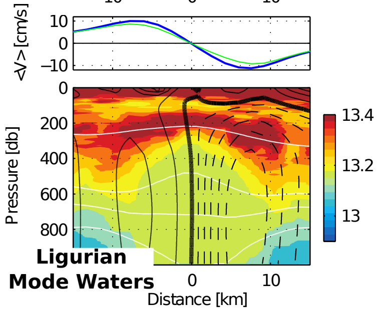
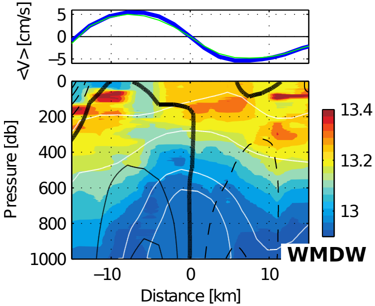
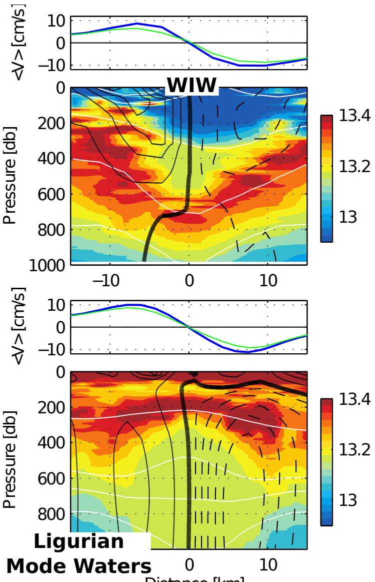
▷ ... the preconditioning of the ocean to vertical mixing?
▷ (... the biogeochemical cycles?)

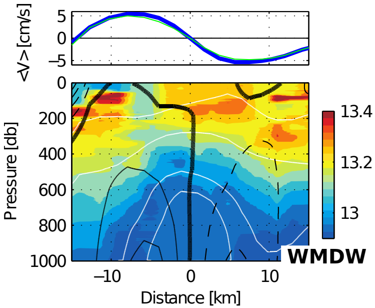






19 anticyclones in total:

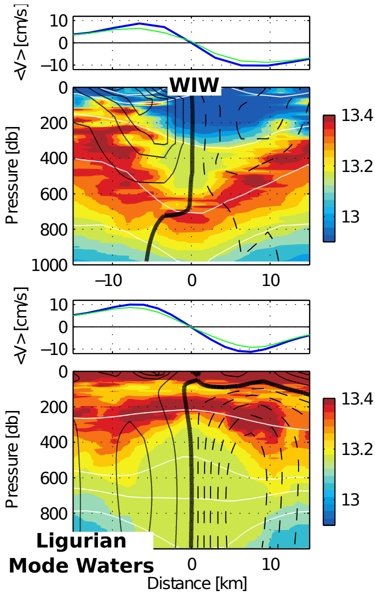


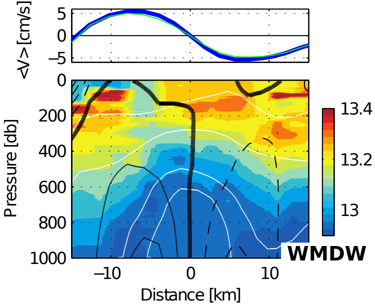


19 anticyclones in total:

type	WIW	Mode	nWMDW
# eddies	4	5	9
R [km]	5.3	6.9	7.8
V [cm/s]	17.9	13.0	$>$ 11.8
Ro $\equiv$ 2V/fRr	-0.65	-0.38	$<$-0.32
H	500	$>$800	$>$1500
N/f	2.6	3.6	2.7
Bu $\equiv [NH/fR]^2$	2.6	$>$0.22	$>$0.23

SCVs formed by Deep mixing





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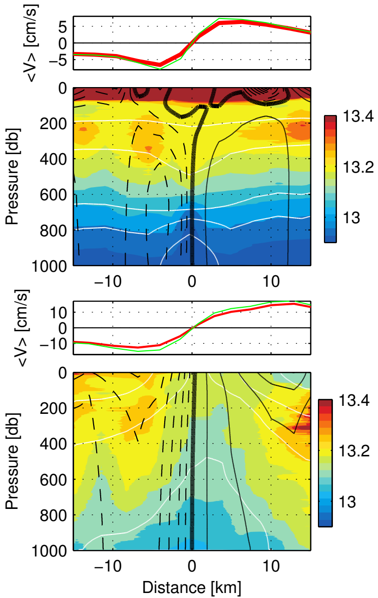
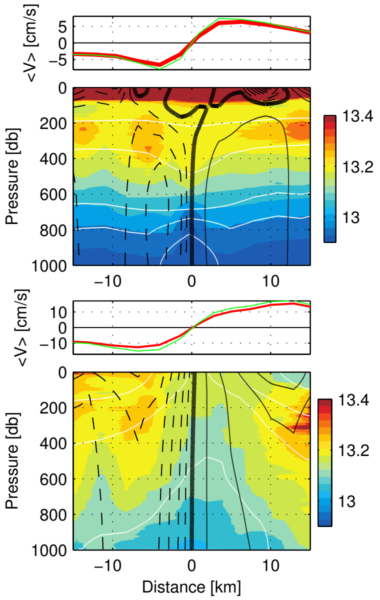
Ro = 0(1) $\Rightarrow$ non-linear eddies
Bu = 0(1) $\Rightarrow$ R = O(deformation radius)
Observed all year long $\Rightarrow$ lifetime 0(1 year)

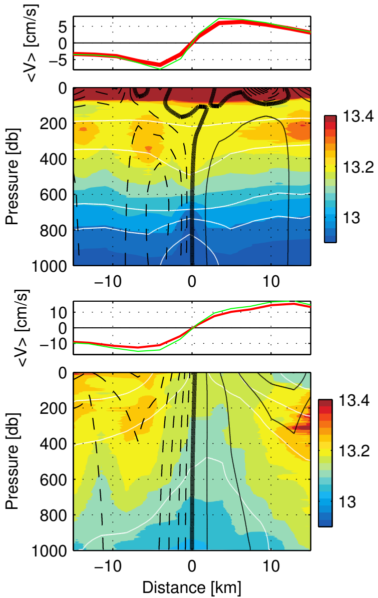


25 cyclones in total:



25 cyclones in total:

type	depth-int.	surface-int.
# eddies	14	11
R [km]	6.1	8.0
V [cm/s]	8.8	16.1
Ro	+0.32	+0.39
H	500–1800	200
N/f	4.1	29
Bu	0.37	0.75



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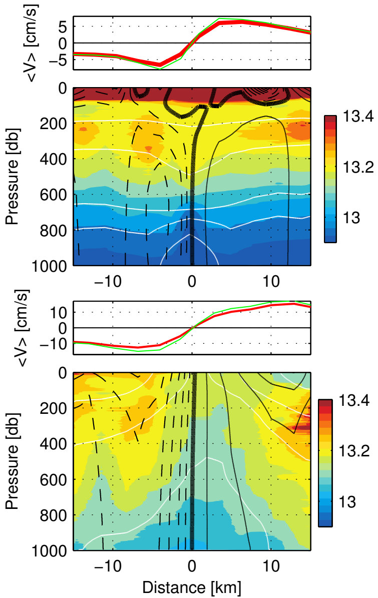

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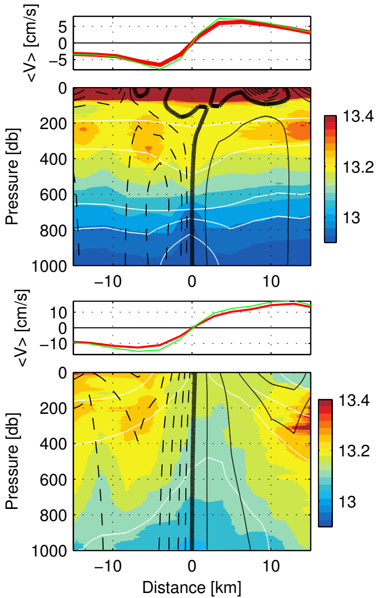
▷ Cyclones are found to be numerous and also long-lived (at least for few months)

▷ Surface-intensified cyclones have a significant barotropic component: 0(5-10 cm/s) @ 1000 m

▷ Peculiar density structure of depth-intensified cyclones characterized by a pinching of isopycnals at depths
→ Formation process to be investigated...

▷ Some of them results from dense waters cascading from the Gulf of Lions shelf



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Thank you for your attention!