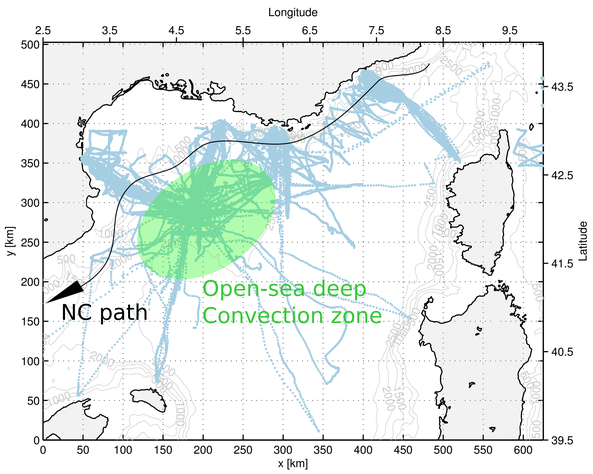
Survey of submesoscale structures at the margin of the Northern Current in the North Western Mediterranean Sea using Gliders: observations and diagnostics

Anthony Bosse[(1)], Pierre Testor[(1)], Laurent Mortier[(2)], Laurent Beguery[(3)], Karim Bernardet[(3)], Vincent Taillandier[(4)], Fabrizio d'Ortenzio[(4)], Louis Prieur[(4)], Laurent Coppola[(4)], and François Bourrin[(5)]
corresponding author email: bosse@locean-ipsl.upmc.fr
[(1)]CNRS-Université Pierre et Marie Curie, LOCEAN/IPSL, Paris, France; [(2)] ENSTA-ParisTech, Palaiseau, France; [(3)] CNRS-DT INSU, La Seyne sur Mer, France; [(4)] CNRS-Université Pierre et Marie Curie, LOV, Villefranche-sur-mer, France; [(5)] CNRS-Université de Perpignan, CEFREM, Perpignan, France

Introduction, gliders obs in the NW Med Sea

Since 2007, > **50 000** profiles were collected (23 846 profiles to 200m and 31 539 profiles to 1000m), in the framework of European and national projects (and in particular in the framework of MOOSE - northwestern Mediterranean Observatory, INSU, France: http://www.moose-network.fr/ since 2010):



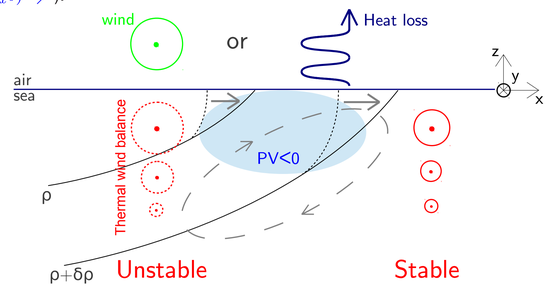
- Northern Current (NC) path follows the front between the fresh and warm Atlantic Waters (AW) and the modifed AW found offshore;
- Coast/open-sea contrasts are enhanced in Winter through intense **surface buoyancy loss** → frontal processes;
- The dataset exhibits many cases of **subsurface T/S variance at submesoscale** (mostly in winter, but also in stratified conditions).

Mechanism 1: Symmetric Instability (SI)

Definition: A fluid parcel with **Potential Vorticity of opposite sign of** f is unstable to along isopycnal perturbations ([1]).
In the 1D case, the Ertel PV goes by:

$$\mathbf{q} \equiv (f\hat{z} + \nabla\vec{u}) \cdot \nabla\rho \propto f(f + \partial_x v)N^2 - (\partial_x b)^2 \text{ where } b \equiv -g\rho/\rho_0 \quad (1)$$

Surface forcing (through heat loss and/or Ekman transport by down-front winds) can extract PV by weakening the stratification ($N^2 \searrow$) and/or intensifying front ($(\partial_x b)^2 \nearrow$).

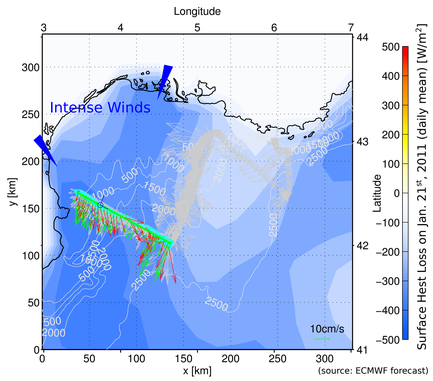


Once the instability develops, overturning cells tend to restratify the fluid ($N^2 \nearrow$ **and** $(\partial_x b)^2 \searrow$) so that **PV** > 0.

Mechanism 2: effect of Mesoscale Stirring

- [2] revealed the importance of the stirring of large scale T/S gradient by the mesoscale turbulence in the generation of subsurface T/S variance at small scale (downward energy cascade);
- **Diagnostic**: the T/S variance should be aligned with f/N **slopes**.

Example 1: Deployment MooseT02-02 in January 2011



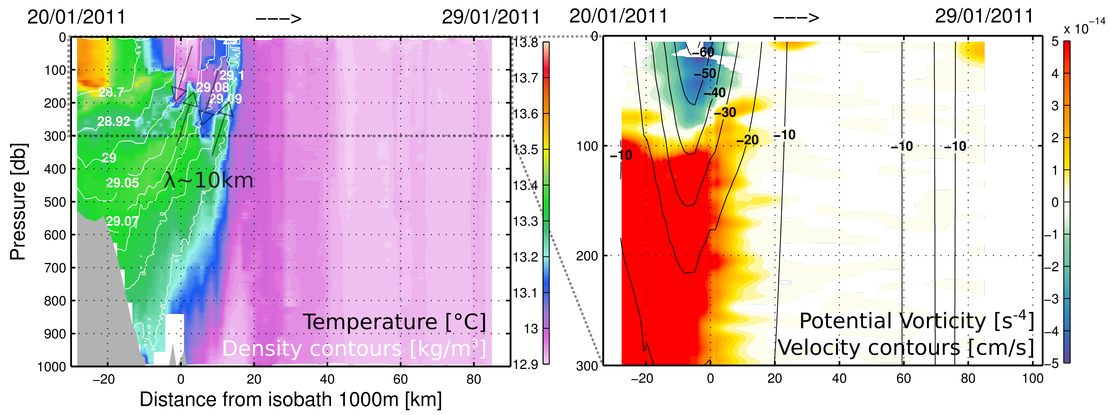
Deployment during a intense Mistral/Tramontane wind event (surface heat loss peaks at values < -500**W.m**$^{-2}$) → Temperature section exhibits strong variability at subsurface.

Methodology of the PV calculation:

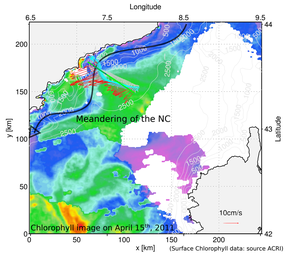
- projection of the profiles onto a **section perpendicular to the NC path** (→ loss of accuracy offshore, but better representation of the frontal region);
- geostrophic currents computed from **integrated vertical shear** (given by filtered[a] density section through thermal wind balance $f\partial_z v = -\partial_x b$) and by taking the **cross-section component of the dive-averaging velocity estimation** made by the glider;
- PV is taken as the geostrophic PV of a 1D-flow given by (1).

Conclusion: the presence of **PV<0** patches on a lot of sections of winter deployments (not only this one) carried out during **intense buoyancy loss** makes think that **SI maintained by surface heat loss** is likely occuring and might be responsible for the observed T/S variance.

[a]by application of a gaussian running mean of 5km width, thus filtering isopycnal variation due to internal waves (internal deformation radius is small in the region: 5-10km)

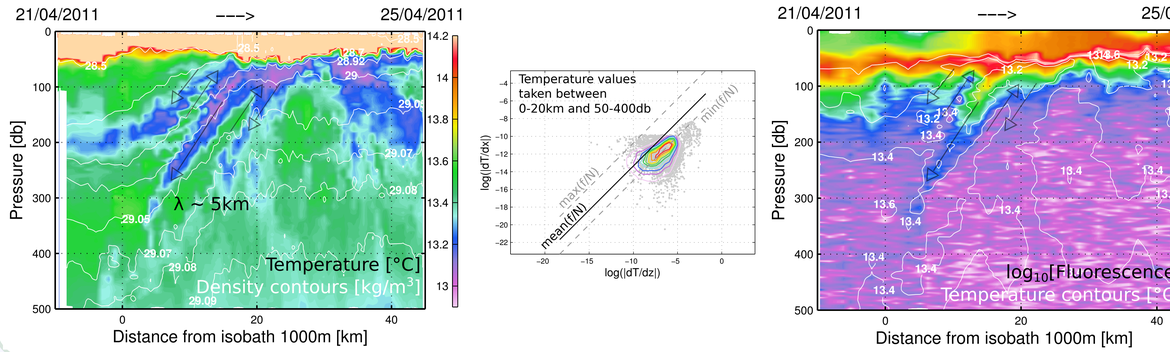


Example 2: Deployment Suna in April 2011



Deployment in Spring while surface heat flux were much lower than in case 1, but still strong **T/S variability** found at subsurface between Winter Intermediate Waters (WIW) and Levantine Intermediate Waters (LIW) flowing with the NC.
Surface Chlorophyll images show evidences of **meandering of the NC and mesoscale eddies**, which might enhance the geostrophic turbulence and thus the stirring of the T/S field.

Conclusion: the alignment of the **T/S isolines with** f/N **slopes** suggests an importance of the **stirring**. However the cholorophyll section also exhibits **downward tongues**, signs of vertical velocities which could have been caused by **other mechanisms** since the large scale Chlorophyll horizontal gradient is not likely to be initially the same as the T/S gradient. Moreover a brief episode of down-front wind happenedcould have triggered SI, but the PV diagnostic in that case is not clear (PV is <0 but only in a surface boundary layer with $N^2 < 0$).



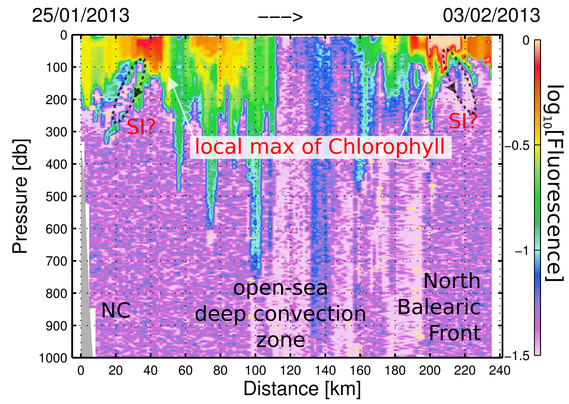
Other Mechanisms:

Others mechanisms could be at play and are known to be able to generate such strucures:

- **Frontogenesis** is a major source of vertical velocities → hard to quantifiy in our cases because of a lack in horizontal informations;
- **Double diffusion** can also drive interleaving layers of different T/S properties. These processes have been associated as a major process of the slow mixing of the Meddies which are long lived vortices (lifetime up to several years) wandering across the Atlantic Ocean → the time scale involved does not match that of observations + the development of such structures is inhibited by baroclinicity;

Perspectives:

- to quantify the **error** made by the sampling of the glider in the PV computation → ongoing collaboration with P. Damien, C. Estournel and P. Marsaleix at the Laboratoire d'Aérologie (Toulouse): use of the SYMPHONIE regional model run at very high resolution (∼1km horizontal resolution) and ;
- the ASICSMED/HyMEX/MerMex glider fleet experiment in 2013 (up to 5 gliders into the water during the winter) + DEWEX cruises will enable to monitor the presence over the time of < 0 PV at several places (margin of the NC, and of the North-Balearic front) and better characterize the phenomena occurring during strong winter-time conditions;
- to assess the role of these physical processes on vertical velocities and the **phytoplankton** (triggering local blooms in winter trough restratification by SI [3]).



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

References

[1] Hoskins, B.J. (1974): The role of potential vorticity in symmetric stability and instability, Quarterly Journal of the Royal Meteorological Society, 100(425):480-482

[2] Smith, K.S. and R. Ferrari (2009): The Production and Dissipation of Compensated Thermohaline Variance by Mesoscale Stirring, Journal of Physical Oceanography, 39:2477-2501

[3] Taylor, J.R. and R. Ferrari (2011): Ocean fronts trigger high latitude phytoplankton blooms, Geophysical Research Letters, vol. 38, L23601, doi:10.1029/2011GL049312 39:2477-2501