On the inversion of submesoscale information from SST and Ocean Color to improve larger scale dynamics deduced from altimetry

Lucile Gaultier[1], Jacques Verron[1], Jean-Michel Brankart[1] and Pierre Brasseur[1]

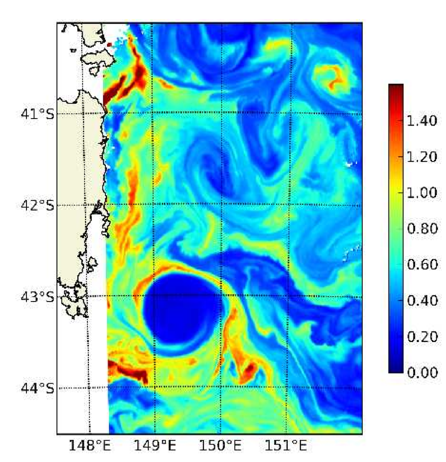
[1] *Laboratoire des Ecoulements Géophysiques et Industriels, UMR 5519, CNRS, Grenoble, France*

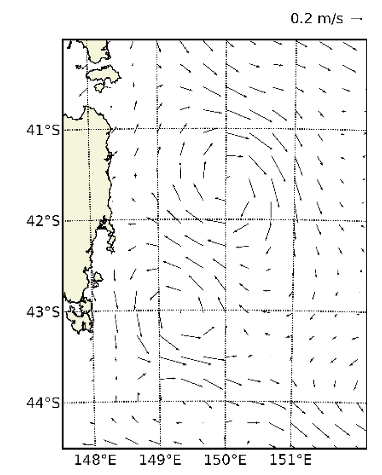
CONTEXT

➢ It is difficult to access the sub-mesoscale using altimetric satellites since they provide data along distant tracks whereas tracer sensors provide images at a resolution as low as 200 m. For example, Satellite observations of Sea Surface Temperature (SST) or Ocean Color show sub-mesoscale dynamics.

How to correct altimetric mesoscale velocity using sub-mesoscale tracer observations from space?

➢ Some studies brought to light the connection between mesoscale velocities and tracer patterns (d'Ovidio et al., 2004; Lehahn et al., 2007), but correcting mesoscale velocities using tracer images has never been done so far.

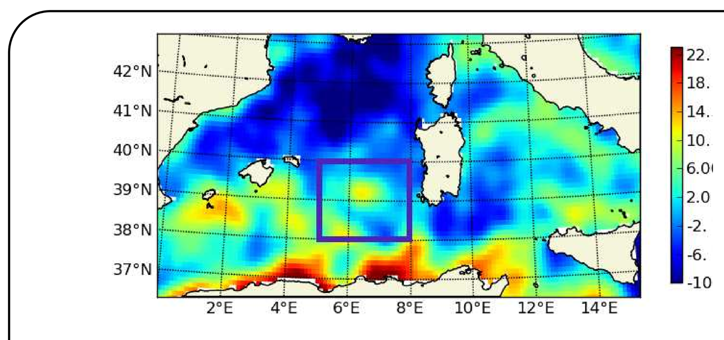




Chlorophyll, Tasmania region, December 22, 2004 — AVISO Velocity map, Tasmania region, December 22, 2004

The tracer and the velocity designate different ocean variables that are not simply linked. The Finite-Size Lyapunov Exponents (FSLE) is used as a go-between variable to enable the velocity field and the tracer image to speak together.

TEST CASE



SSH (in cm) in the Western Mediterranean Sea, first week of July, 2004. The test case is located in the purple rectangle

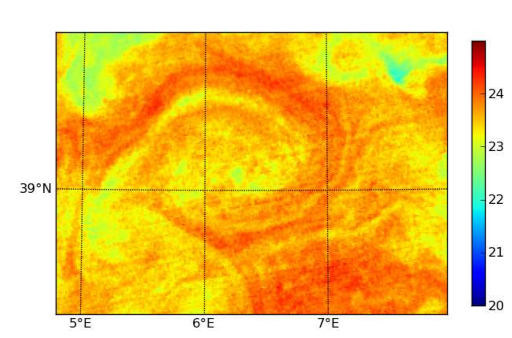
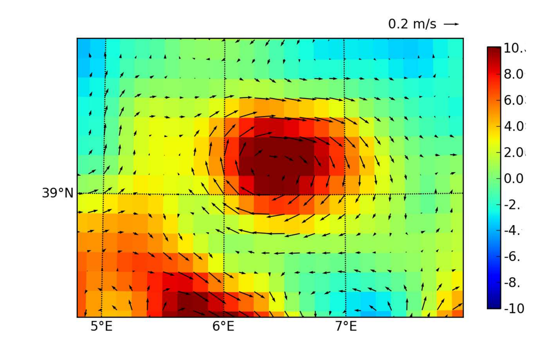
➢ Domain: [38.2°N ; 40°N] × [4.8°E ; 8°E] chosen because of:

✓ the good quality of the data set
✓ the strong filament signature

➢ Study date: July 2^{nd}, 2004

➢ Time Range to estimate the variability of the velocity: 1998-2009, 595 velocity maps

➢ Two satellite observation data sets are considered:

Tracer used as a dynamic information: high resolution SST images from MODIS sensor at 1 km resolution:	**Background velocity to be corrected**: map of velocity derived from AVISO altimetric observations at 1/8° resolution:
 SST image from MODIS sensor (in ° C) on July 2^{nd}, 2004	 Geostrophic Velocity (in m.s^{-1}) over the SSH (in cm) on the first week of July, 2004 from AVISO mapped products

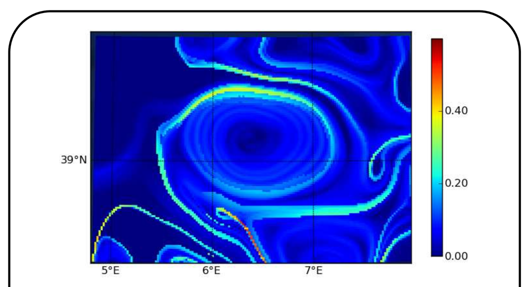
A neat eddy can be observed in both pictures. The FSLE are computed at 1/48° resolution. The SST image is filtered and coarsen at the same resolution (1/48°).

METHOD

Finite-Size Lyapunov Exponents (FSLE)

➢ FSLE measure stirring in a fluid, It is a **connection between sub-mesoscale dynamics and tracer stirring.**

➢ FSLE is the exponential rate at which two particles separate from a distance δ_0 to δ_f: $\lambda = \frac{1}{\tau}\ln\frac{\delta_f}{\delta_0}$.



FSLE (in day^{-1}) derived from the geostrophic AVISO velocity first week of July, 2004

There are similar patterns between the maximum lines of Lyapunov exponents and SST frontal structure (that is to say the norm of the gradient).

➢ **We want to find the FSLE field as close as possible to the normalized tracer gradient.** Therefore, the FSLE field and the normalized SST gradients are binarized in order to compare those two physically different variables.

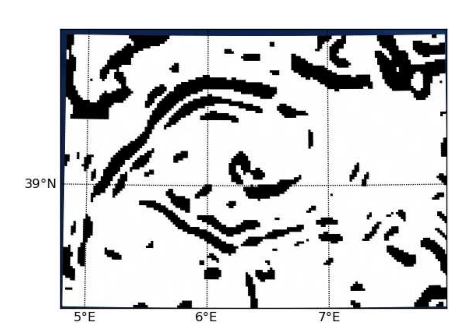
$$\hat{\lambda} = \begin{cases} 0 \ if \ \lambda < \lambda^s \\ 1 \ if \ \lambda \geq \lambda^s \end{cases}$$

The Cost Function

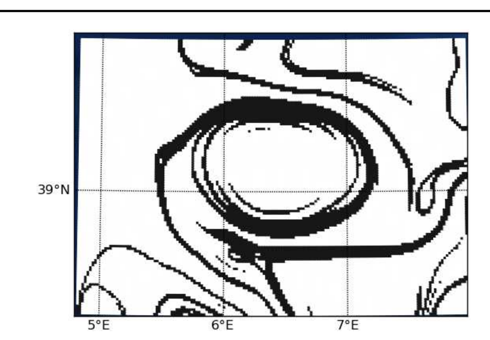
➢ **The cost function J measures the distance** between the binarized normalized gradient of SST $\hat{\lambda}_o$ and the binarized FSLE $\hat{\lambda}(\mathbf{u})$ (as a proxy of the velocity $\mathbf{u}$).

$$J(\mathbf{u}) = \mu\, ||\hat{\lambda}_o - \hat{\lambda}(\mathbf{u})||^2 + BK(\mathbf{u})$$

$BK(\mathbf{u})$ is the background term. Assuming that the error on the altimetric observation is small, the solution velocity is chosen to be close to the background AVISO velocity field. The minimum of the cost function corresponds to the velocity that is the most consistent with the tracer.



Binarization of the norm of the SST gradient on July 2^{nd}, 2004



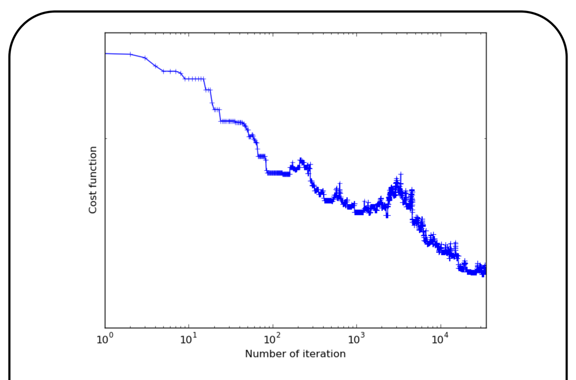
Binarization of the FSLE derived from the AVISO velocity,first week of July 2004

➢ **A velocity sub-space is created using Principal Component Analysis with an ensemble of velocities.**

Let S = $|u^{(1)}, u^{(2)}, ..., u^{(r)}|$ be the first r EOFs. The velocity errors are considered with zero mean and covariance of the ensemble of velocities S: $\delta u \sim \mathcal{N}(0, SS^T)$ so that a perturbed velocity is $\mathbf{u}_k = \bar{\mathbf{u}} + \sum_{i=0}^{r} a_k^{(i)}\mathbf{u}^{(i)}$, with a_k a perturbation vector.

Technical issues to find the optimal solution

➢ We aim at decreasing the cost function, exploring the sub-space of velocity errors previously defined. Nevertheless, **the cost function $J(u)$ is quite irregular** and many local minima can be found. To avoid being stuck in one of them, **the minimization of the cost function is performed using a Simulated Annealing.**

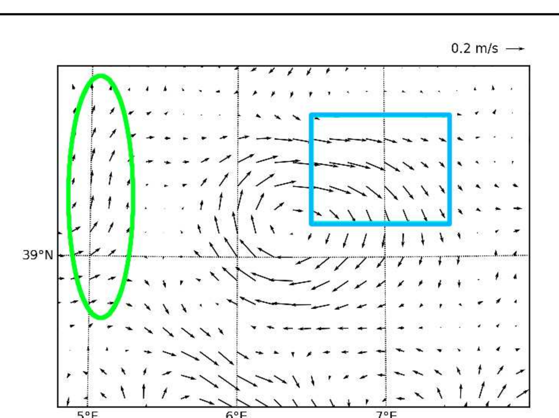


Cost function as a function of the number of iteration (log-log plot)

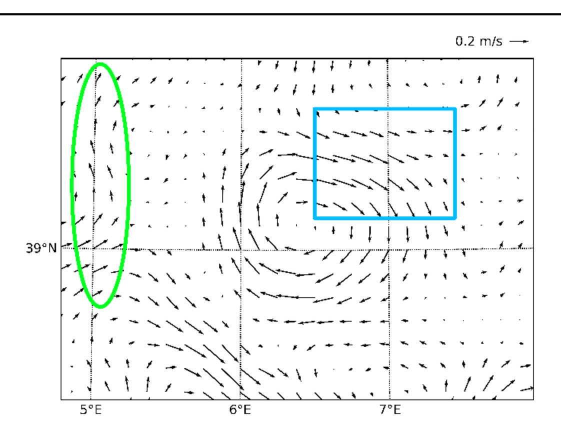
At each step, a perturbation is computed and the resulting cost function is calculated, if it is lower than the previous one, the perturbation is adopted, otherwise, the perturbation is rejected with a certain probability.

➢ As several perturbations result in similar values of the cost function, we need to find a strategy to compute accurately the final result. To do so, a Gibbs Sampler is used. In other words, all the perturbations which are potential solutions to the problem are assessed. An optimal solution is given by the velocity that has the lowest cost function among all the potential solutions. The variance of all the potential solutions indicates how reliable an optimal solution is.

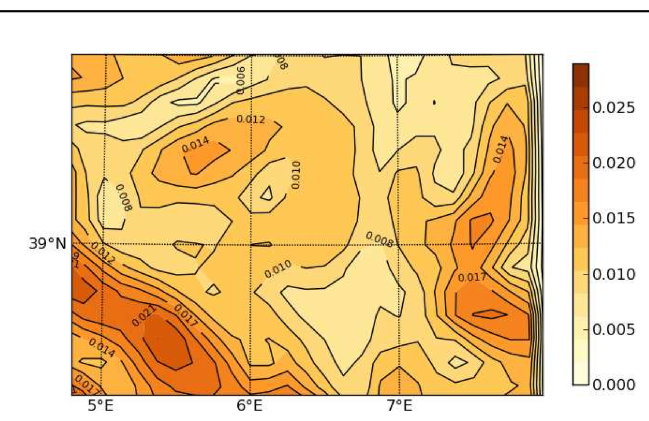
RESULTS



AVISO velocity, first week of July 2004 (m.s^{-1}).



Corrected velocity (m.s^{-1}).



Variance on the solutions to our problem (m.s^{-1}).

➢ In accordance with the implemented method, **velocity vectors are corrected so as to follow tracer frontal structures.** For instance, the North East of the eddy in the corrected velocity (blue rectangle) is much more consistent with the SST frontal structure than the North East of the eddy in the observed AVISO velocity.

➢ Nevertheless, there are some limits to this method. Indeed, in some areas (such as the West border of the image, green oval), the correction applied on the velocity is not consistent with the SST patterns. This may be due to the **over-simplicity of the algorithm of contours detection**, which is a mere binarization of the normalized SST gradient.

➢ The variance of all the possible velocities is rather small compared to the value of the velocity and the correction. It means that **the result is quite reliable**, even though the cost function is complex and seems to have several solutions.

CONCLUSION

We succeeded in correcting an altimetric mesoscale velocity field using a sub-mesoscale tracer observation from space

➢ **The corrected velocity is more consistent with the tracer field than the observed one**, and the uncertainty on this result is small. The method still needs to be improved, since some areas of the velocity field do not seem consistently corrected.

➢ We plan to use a **high resolution model to refine the method**. Indeed, knowing the true sub-mesoscale velocity, we can assess accurately how much the corrected velocity is a better match to the tracer than the mesoscale 'observed' velocity.

➢ This study opens the way for the use of very high resolution altimeter data (in the context of SWOT and SARAL projects). The strategy proposed in here enables us to handle huge amount of data in models.

References

d'Ovidio, F., Fernndez, V., Hernndez-Garca, E., Lpez, C., 2004. Mixing structures in the Mediterranean Sea from finite-size Lyapunov exponents. Geophysical Research Letters 31, 17 L17203.
Gaultier, L., Verron, J., Brankart, J., Titaud, O., Brasseur, P., submitted. On the use of submesoscale information for the control of ocean circulations. Journal of Marine Systems.
Lehahn, Y., d'Ovidio, F., Lvy, M., Heifetz, E., 2007. Stirring of the northeast Atlantic spring bloom: A Lagrangian analysis based on multisatellite data. Journal of Geophysical Research 112, C08005.
Titaud, O., Brankart, J., Verron, J., 2011. On the use of finite-time lyapunov exponents and vectors for direct assimilation of tracer images into ocean models. Tellus A.

Laboratoire des Ecoulements Géophysiques et Industriels, 1023 rue de la piscine, Domaine Universitaire, 38400 Saint Martin d'Heres, FRANCE e-mail: lucile.gaultier@hmg.inpg.fr