Reconstruction of ocean velocities from the synergy between existing SSH and SST measurements

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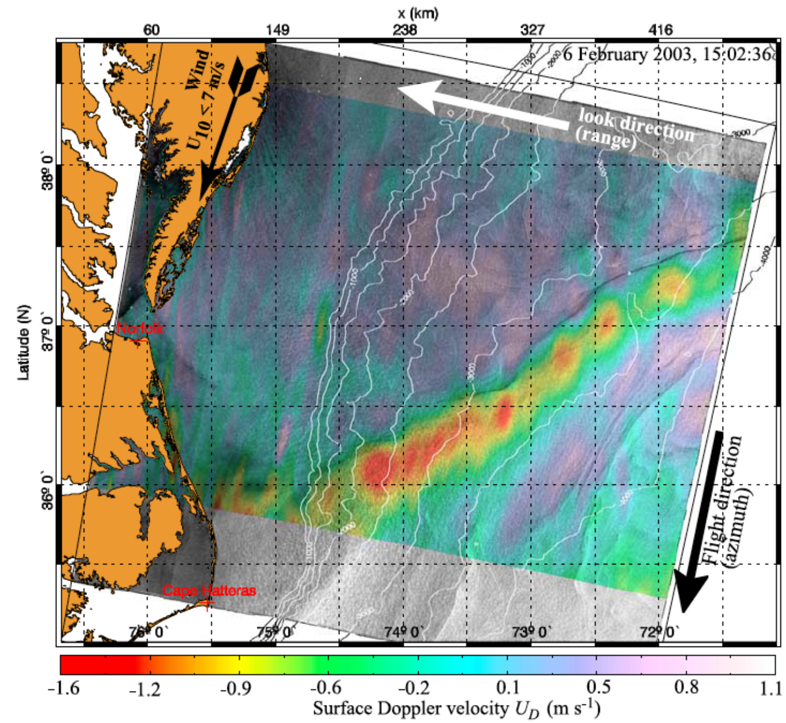
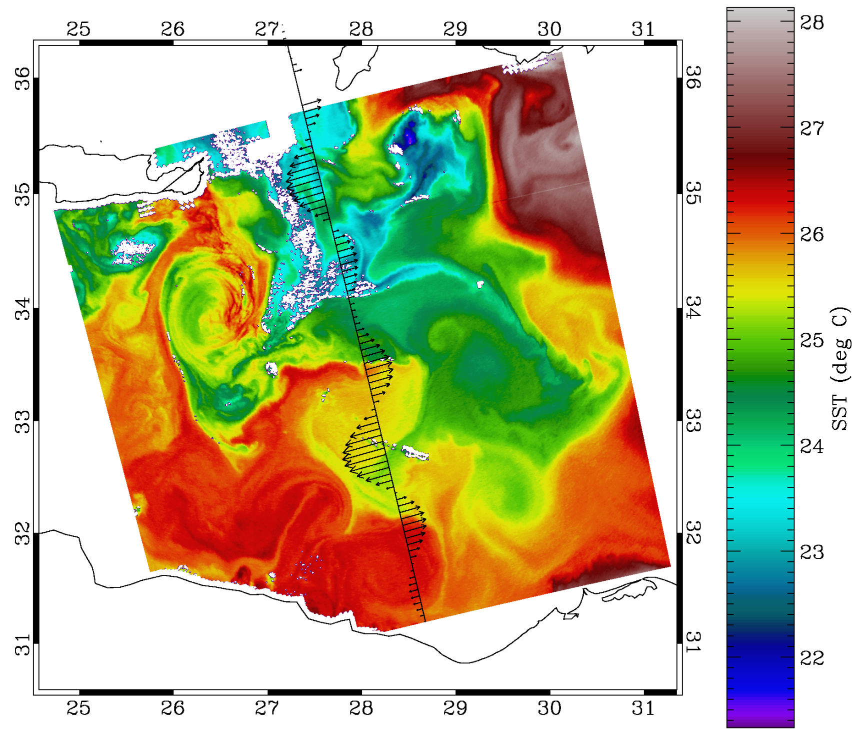
ESA DUE GlobCurrent User Consultation meeting 2012, Plouzané, France

- Radar technology has proven to be extremely useful for the estimation of ocean currents
    - Radar altimeters are key part of the Global Ocean Observing System
    - New methods have been developed to retrieve currents from SAR
- New types of radar are being developed: SWOT and Wavemil.



- Then, why should we try to reconstruct ocean velocities from SST observations?
    - Long time-series are available ⇒ important for climate studies.
    - Low cost and sustainable ⇒ based on well known technologies.
    - Existence of many dedicated instrumets ⇒ AVHRR, MODIS, AATSR, SEVIRI, AMSR, TMI, VIIRS, SLSTR
    - Complementary to existing radar measurements ⇒ synergy between SST and radar measurements can improve the retrieval of ocean velocities.

Objectives



- Current SST and SSH observations are synergetic:
    - MW/IR radiometers (SST) provide information about the location and geometry of ocean structures but it is difficult to recover velocities.
    - Altimeters (SSH) provide information about ocean velocities but it is difficult to recover the location and geometry of ocean structures.
- Objective: exploit such synergy for the retrieval of 3D ocean currents from present and past satellites to improve operational services and get insight on Earth climate

Within the eSQG approach proposed by Lapeyre and Klein (JPO 2006) SSH and SST contain the same information and both can be used to reconstruct 3D ocean dynamics (Isern-Fontanet et al. JGR 2008):

SST (T_s) | SSH (η)

$$\hat{\psi}(\vec{k}, z) = \frac{g\alpha'}{\rho_0 f_0 n_e} \frac{\hat{T}_s(\vec{k})}{k} \exp(n_0 k z) \quad (1)$$

$$\hat{\psi}(\vec{k}, z) = \frac{g}{f_0} \hat{\eta}(\vec{k}) \exp(n_0 k z) \quad (2)$$

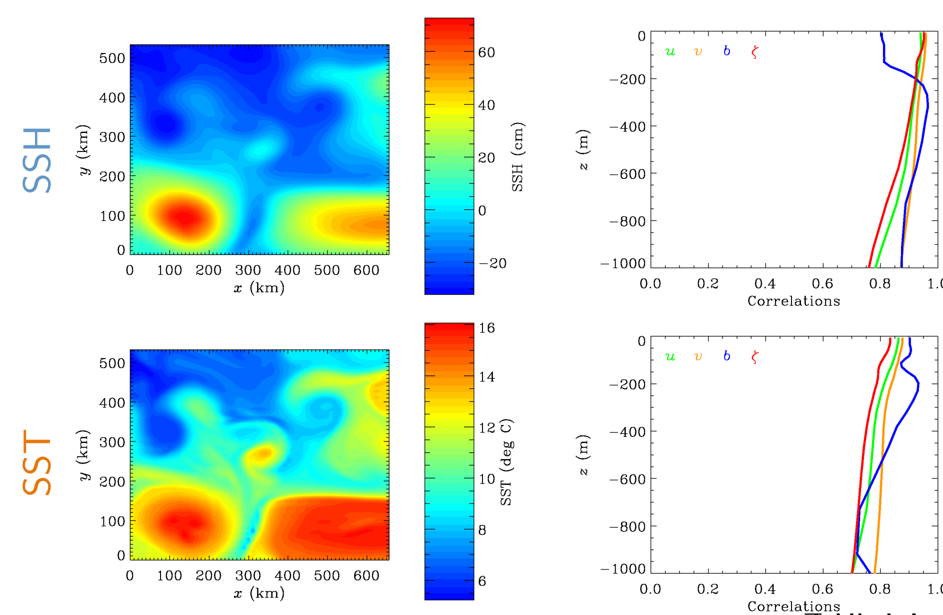
$$\hat{b}(\vec{k}, z) = -\frac{g\alpha'}{\rho_0} \hat{T}_s(\vec{k}) \exp(n_0 k z) \quad (3)$$

$$\hat{b}(\vec{k}, z) = g n_e k \hat{\eta}(\vec{k}) \exp(n_0 k z) \quad (4)$$

- Within eSQG SSH and SST are related by:

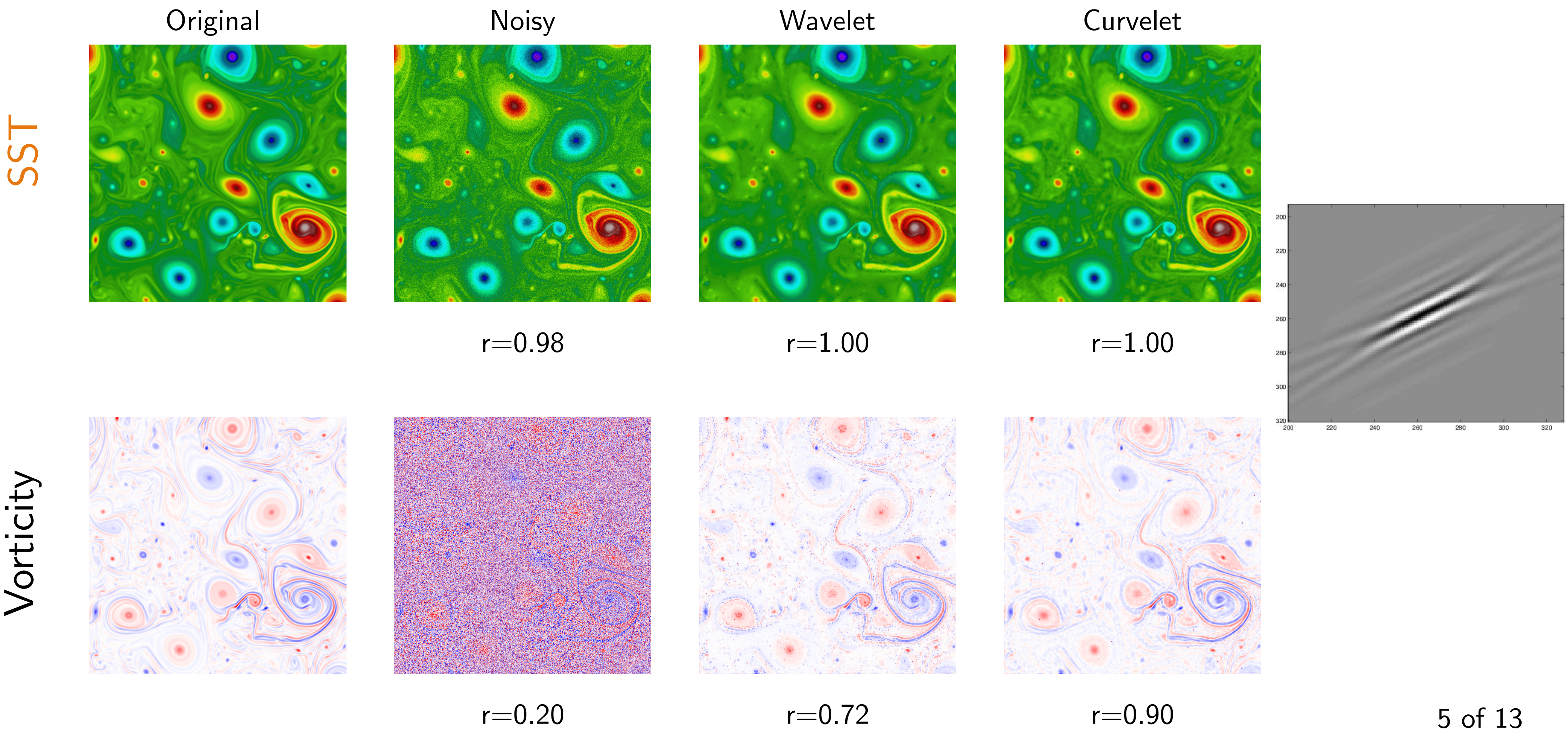
$$\hat{\eta}(\vec{k}) \propto k^{-1} \hat{T}_s(\vec{k}) \quad (5)$$

- Numerical simulations unveiled the key role of the ML in the reconstruction from SST
  - SST has to be a proxy of density anomaly below the ML $\Rightarrow$ deep ML.

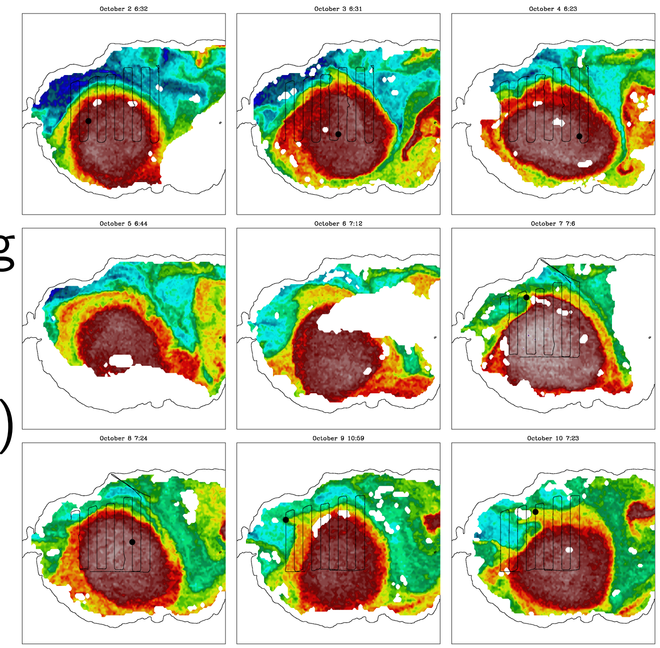


Flow reconstruction from real SST requires a careful preprocessing if high spatial resolutions are required

- We have adapted image denoising techniques used in fields such as Astronomy: wavelet and curvelet denoisng
- We tested these methods adding noise to simulated SST fields ($\sigma_{\delta T}$=0.05 K):



The eSQG approach has been validated against measurements done during the OMEGA cruise: ADCP and SeaSoar



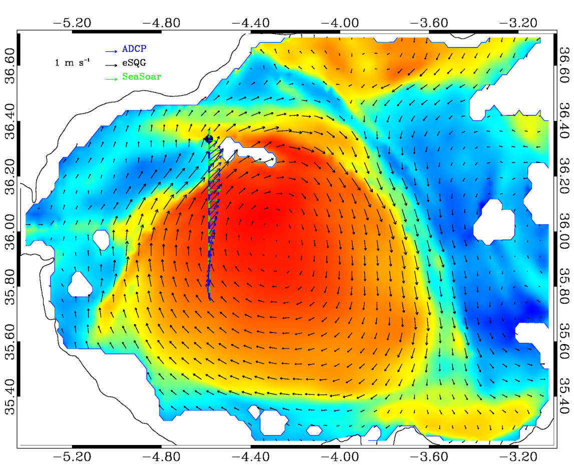
AVHRR data from MeteoFrance

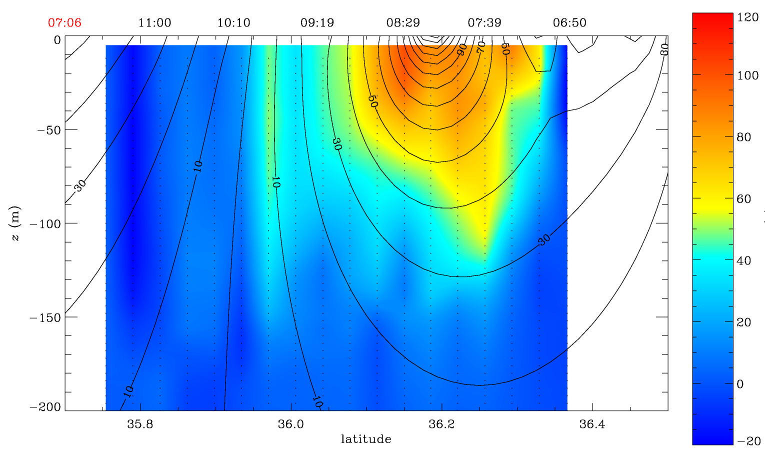
- 3D velocities have been estimated from AVHRR BT using

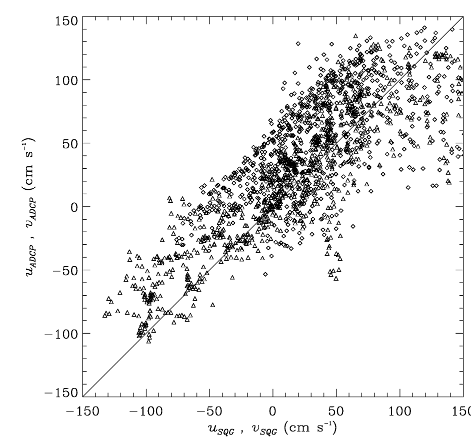
$$\hat{\psi}(\vec{k}, z) = \frac{g\alpha'}{\rho_0 f_0} \frac{\hat{T}_B(\vec{k})}{n_e k} \exp(n_0 k z) \quad (6)$$

n_e and n_0 were adjusted to observations.

- Velocities derived for each image were then interpolated in time and space to ship measurements.







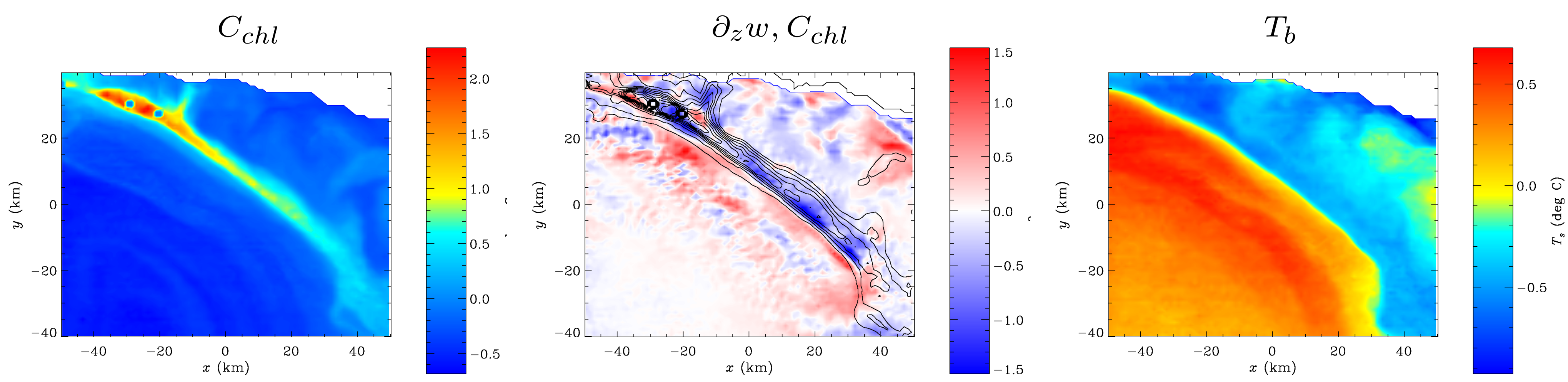
- Good correlation between in situ and satellite derived velocities: $r \sim 0.88$

Using the buoyancy equation it is possible to find an equation for vertical velocities within the eSQG approach (Lapeyre and Klein JPO 2006):

$$\hat{w}(\vec{k}, z) = \frac{1}{{n_e}^2}\left[J(\widehat{\psi_s, b_s})\exp(n_0 k z) + J(\widehat{\psi, b})\right] \tag{7}$$

where $\psi(\vec{x}, z)$ and $b(\vec{x}, z)$ are derived from SST and/or SSH.

- We have successfully tested this approach using SST and SSH from high resolution numerical simulations of forced geophysical turbulence (Klein et al. GRL 2009).
- We have used this approach to retrieve $\partial_z w$ from MODIS SST observations and we have compared them to chlorophyll patterns for very simple situations:



- We are looking for nice in situ experiments to quantitatively validate this approach!

- The eSQG approach gives good results for the reconstruction of the 3D ocean dynamics from satellite SST
- However, the reconstruction can be still improved if we exploit the synergy between SST and SSH
- As a first step, we introduce a transfer function $F_T(k)$ such that

$$\hat{\psi}_s(\vec{k}) = g f_0^{-1} F_T(k) \hat{T}_s(\vec{k}) \tag{8}$$

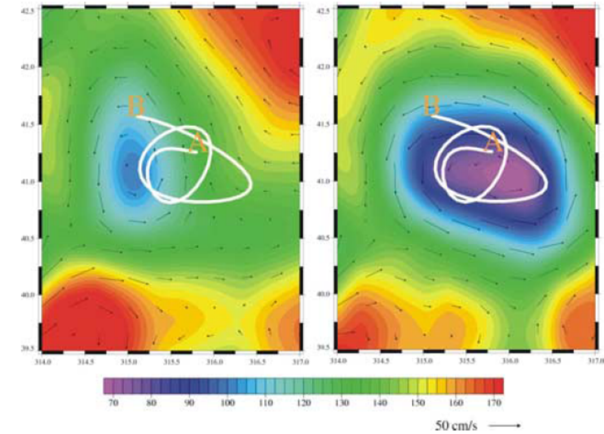
Notce that eSQG $\Rightarrow F_T(k) \propto k^{-1}$

- Our approach is to determine the transfer function $F_T(k)$ from observations

$$F_T(k) = \frac{|\hat{\eta}|(k)}{|\hat{T}_s|(k)} \tag{9}$$

Rule of thumb: take the phase from SST and the spectrum from SSH

- As in Isern-Fontanet et al. GRL 2006, we validate it using microwave SST observations and altimetric maps
  - L3 AMSR-E SST maps (REMSS)
  - 4-altimeter MADT (AVISO) for 2002-2005

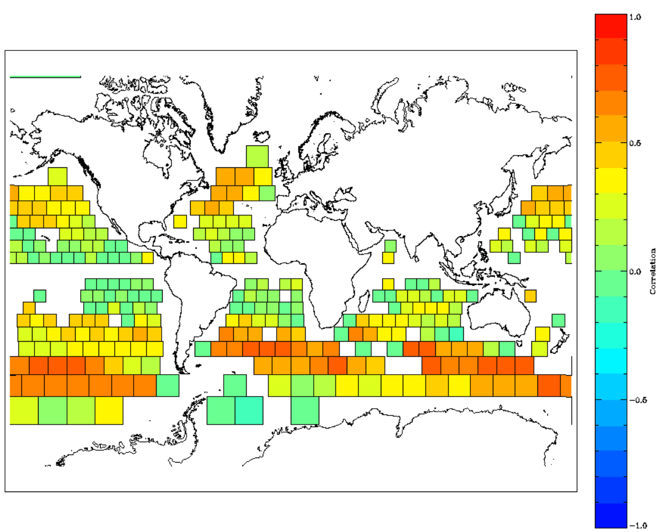


Pascual et al GRL 2006

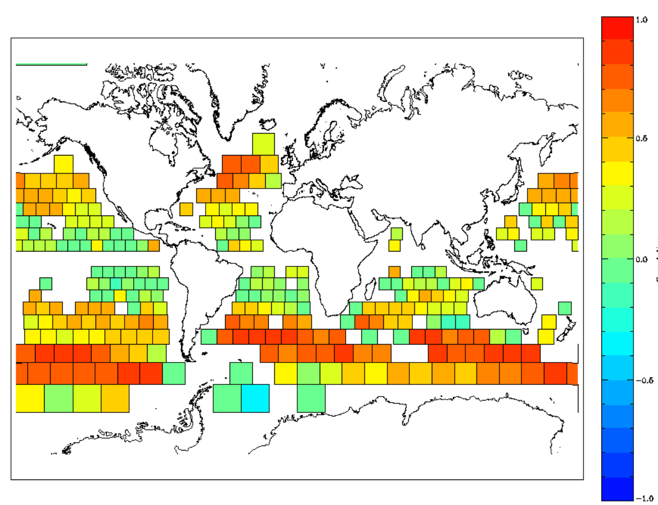
- The flow has been reconstructed from SST using 3 different transfer functions for wavelengths: 100 km $\leq \lambda \leq$400 km.

$$F_c(k) \propto 1, \qquad F_{sqg} \propto k^{-1} \quad \text{and} \quad F_T(k) = \frac{|\hat{\eta}|(k)}{|\hat{T}_s|(k)} \tag{10}$$

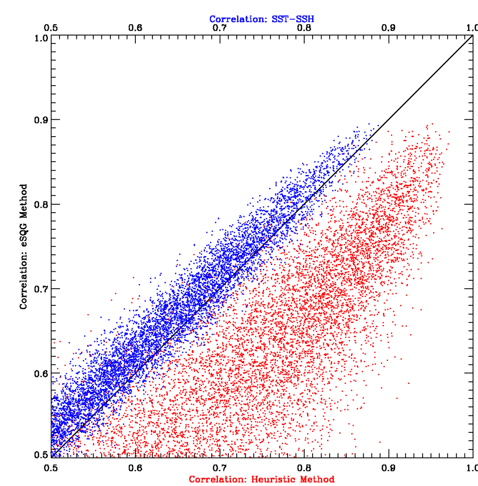
- Comparison of the correlation between the reconstructed stream-function and SSH:



eSQG

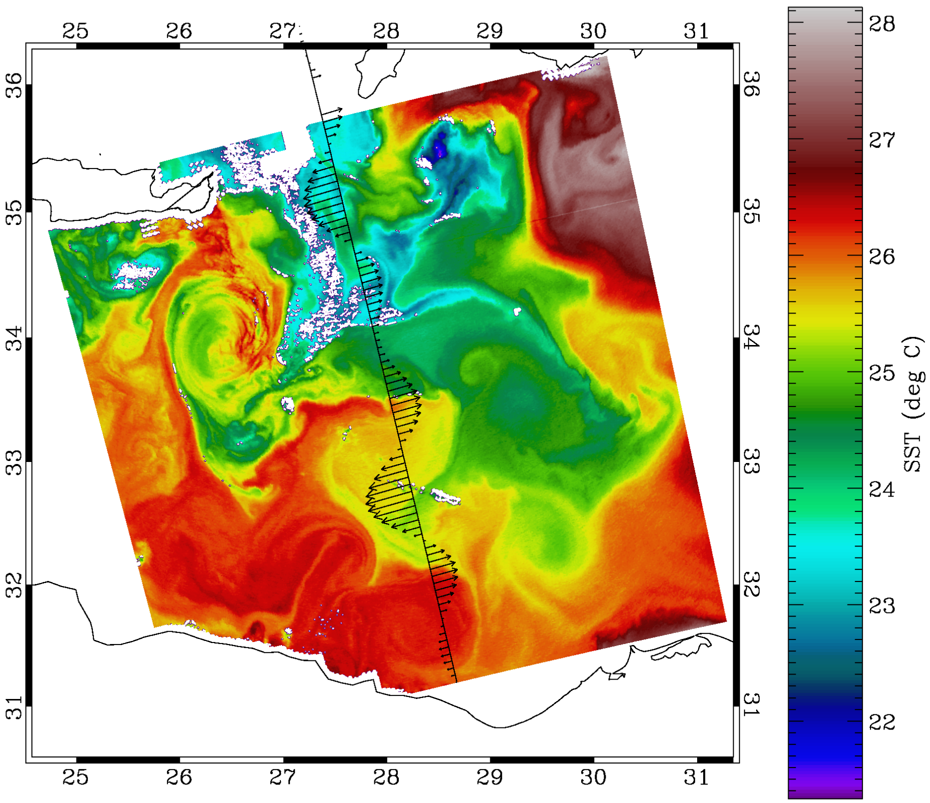


Heuristic



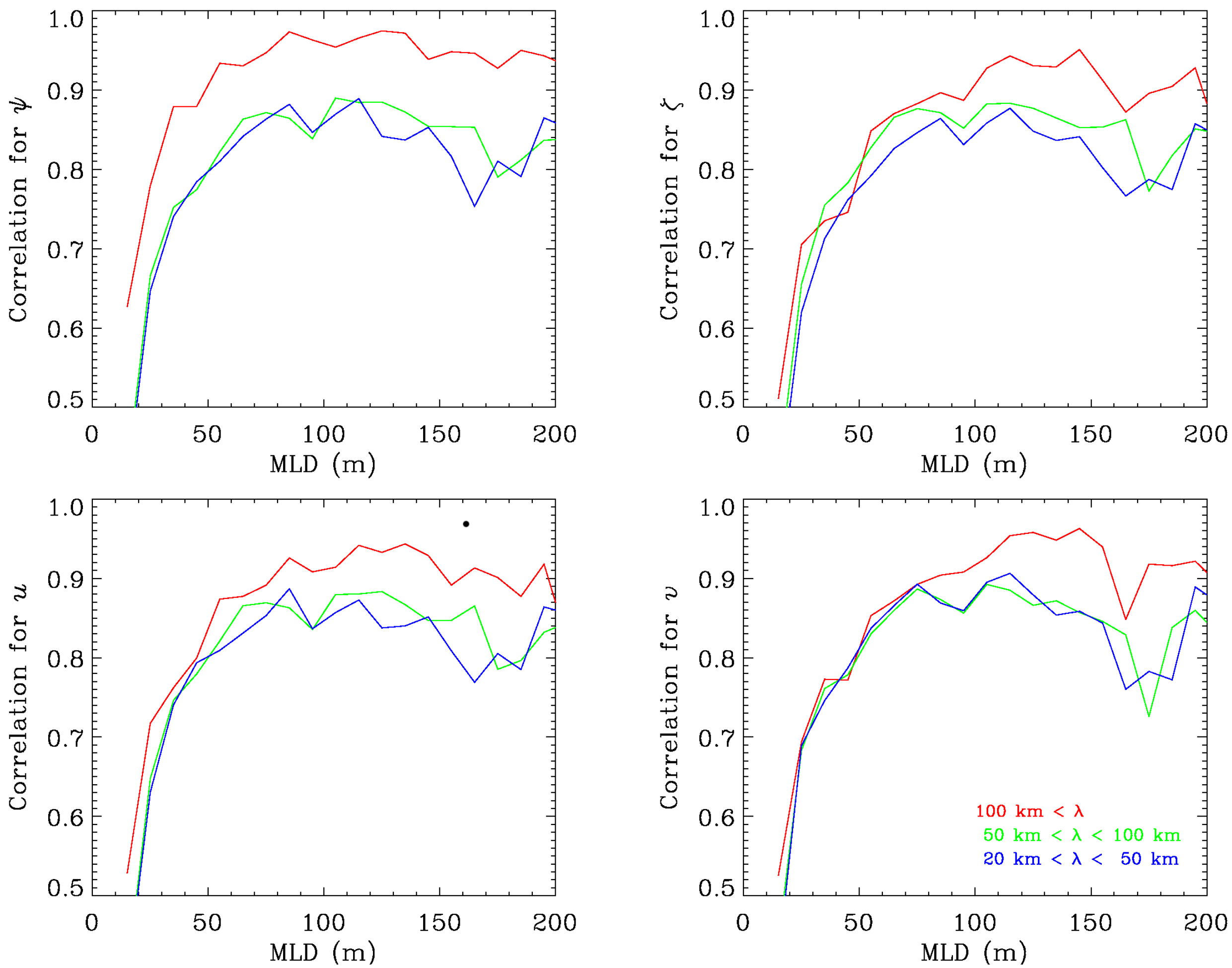
C. González-Haro PhD Thesis

Adaptation to Envisat observations



- We are currently adapting this approach to Envisat observations: one IR radiometer and one simultaneous and collocated altimeter
  - SST and BT data from AATSR for the period 2002-2011
  - We clip the stream-function derived from SST to altimetric measurements
- However, the structures present in SST/BT may have a phase shift to respect the 'true' stream-function ⇒ we need to identify when our approach can be directly applied.

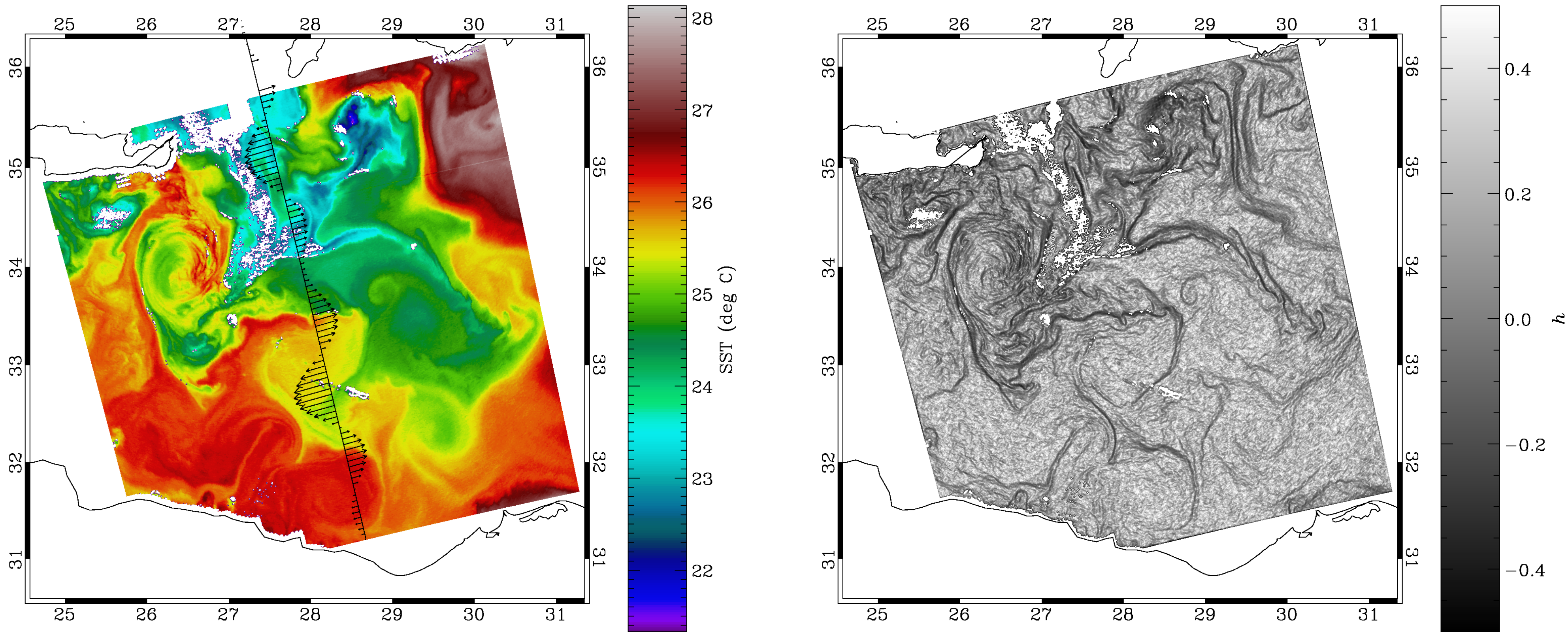
To explore the conditions under which our heuristic approach is valid we have analyzed realistic numerical simulations of the Mediterranean sea.



- Best results are obtained for MLD > 70 m.

- Complements the study done in Isern-Fontanet et al. JGR 2008.

Identification of image characteristics



- We are investigating metrics for cataloguing existing SST data
  - The objective is to quickly find images that match predefined dynamical criteria.
- Most of the effort is been done in the characterization of structures in SST images.
  - We use singularity analysis tools developed to characterize natural images.
  - In collaboration with A. Turiel (⇒ Parallel Session 5-1 at 14:15.)

Summary and conclusions

- Using the eSQG approximation, the high resolution 3D velocity field can be reconstructed from a single SST or SSH snapshot.
- The methodology required to apply this approach to real high resolution SST images is mature.
- Existing radiometers provide information about the relative position of ocean structures while existing radar altimeters provide information about the energy at each scale
  - The exploitation such synergy improves the reconstruction of velocities.
- Best reconstruction results are obtained for deep MLD.
- Requirements ⇒ improve the access to high resolution BT and SST
  - It took several months to download ATS_TOA_1P and ATS_NR_2P products!