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Two-dimensional surface currents from the combination of MSG and Jason observations

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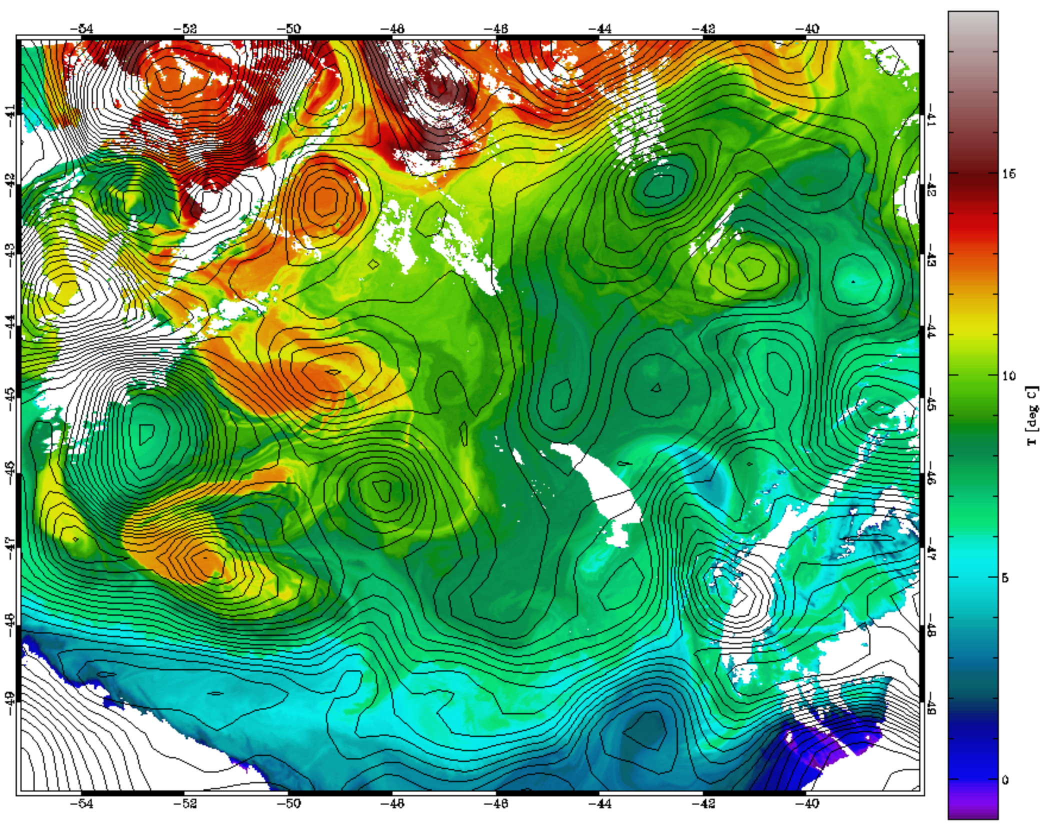
CSIC Consejo Superior de Investigaciones Científicas

ComFuturo Ciencia, Juventud y Talento

- A key problem in oceanography is the estimation of high resolution ocean currents
- However:
  - Sampling geometry and noise of present altimeters constrains the spatial scales that can be recovered to scales larger than $\mathcal{O}(100\ \mathrm{km}) \Rightarrow$ altimetric gap
  - Sampling geometry can also introduce errors in the location of ocean currents



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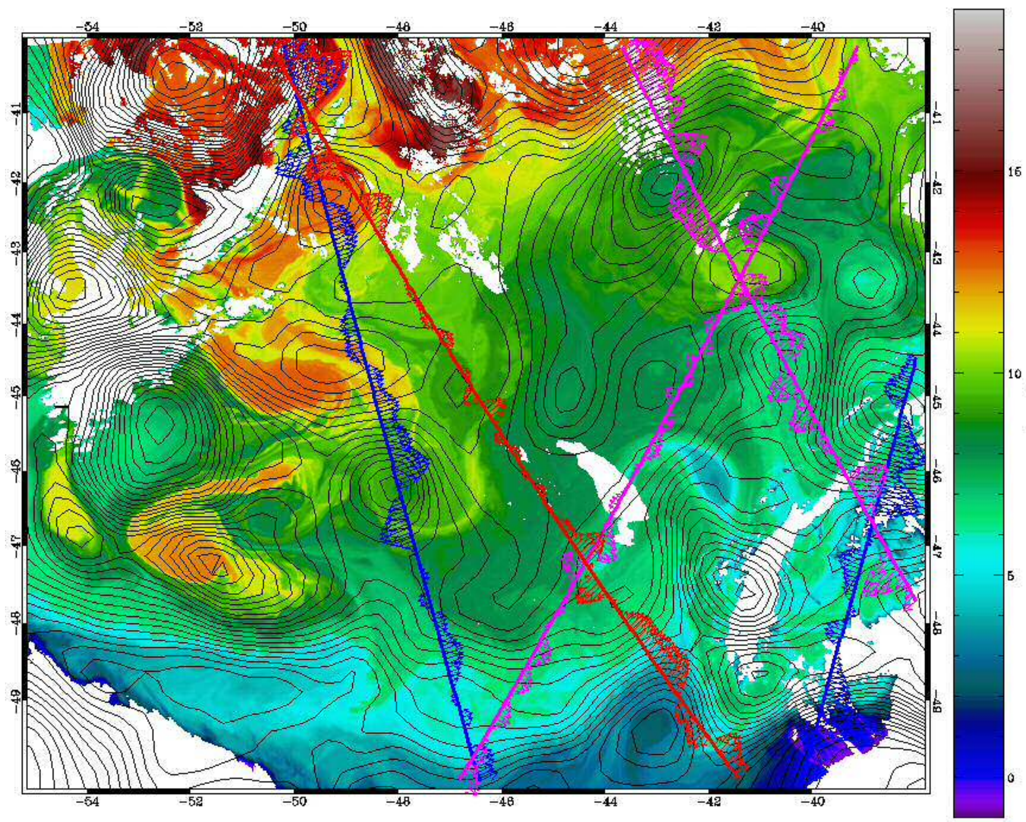
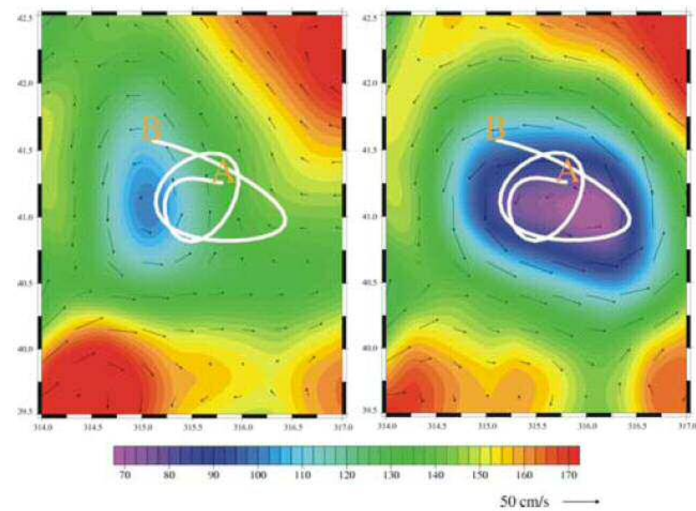
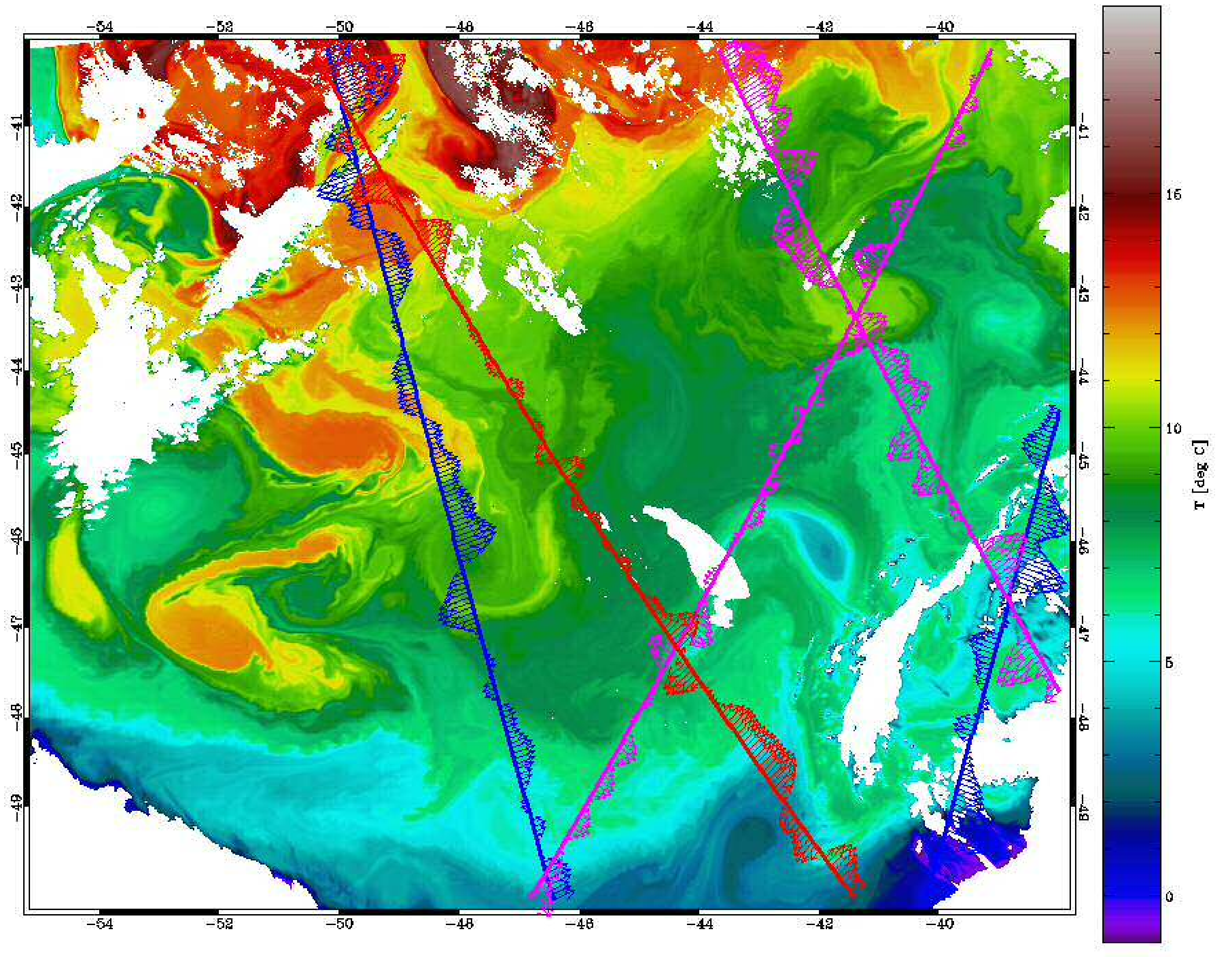




Pascual et al. GRL 2006

Need to exploit the synergy between sensors



- IR & MW (SST): have wide FOV allowing for a good estimation of current patterns but it is difficult to recover current intensities.
- Radar altimeters (SSH): provide measurement at nadir strongly limiting the observation of current patterns but they provide good estimations of current intensities.

- For a non-divergent flow it is possible to define a stream-function, such that

$$\vec{v}(\vec{x}) = \vec{e}_z \times \nabla \psi_s(\vec{x}) \tag{1}$$

- The reconstruction of surface currents from SST ($T_s(\vec{x})$) can be formulated in terms of a transfer function

$$\hat{\psi}_s(\vec{k}) = C F_n(\vec{k}) e^{-i\Delta\theta(\vec{k})} \hat{T}_s(\vec{k}) \tag{2}$$

- The transfer function and phase shift can be theoretically derived from GFD
  - Surface Quasi-Geostrophic (SQG) equations predicts that

$$\Delta\theta(\vec{k}) = 0 \qquad F_n(\vec{k}) \propto k^{-1} \tag{3}$$

  - Many other solutions can be found imposing different stratifications.
  - They have in common that $\Delta\theta(\vec{k}) = 0$ and $F_n(\vec{k})$ depends only on k.

(Isern-Fontanet et al. JPO 2014)

- Altimeters provide a direct measurements of the geostrophic stream function

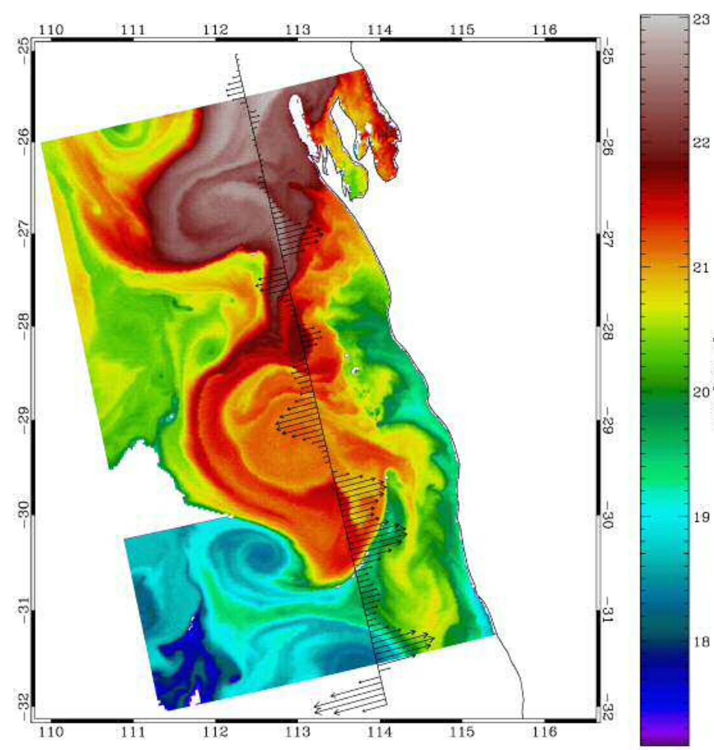
$$\psi_s(\vec{x}) = \frac{g}{f_0}\eta(\vec{x}) \tag{4}$$

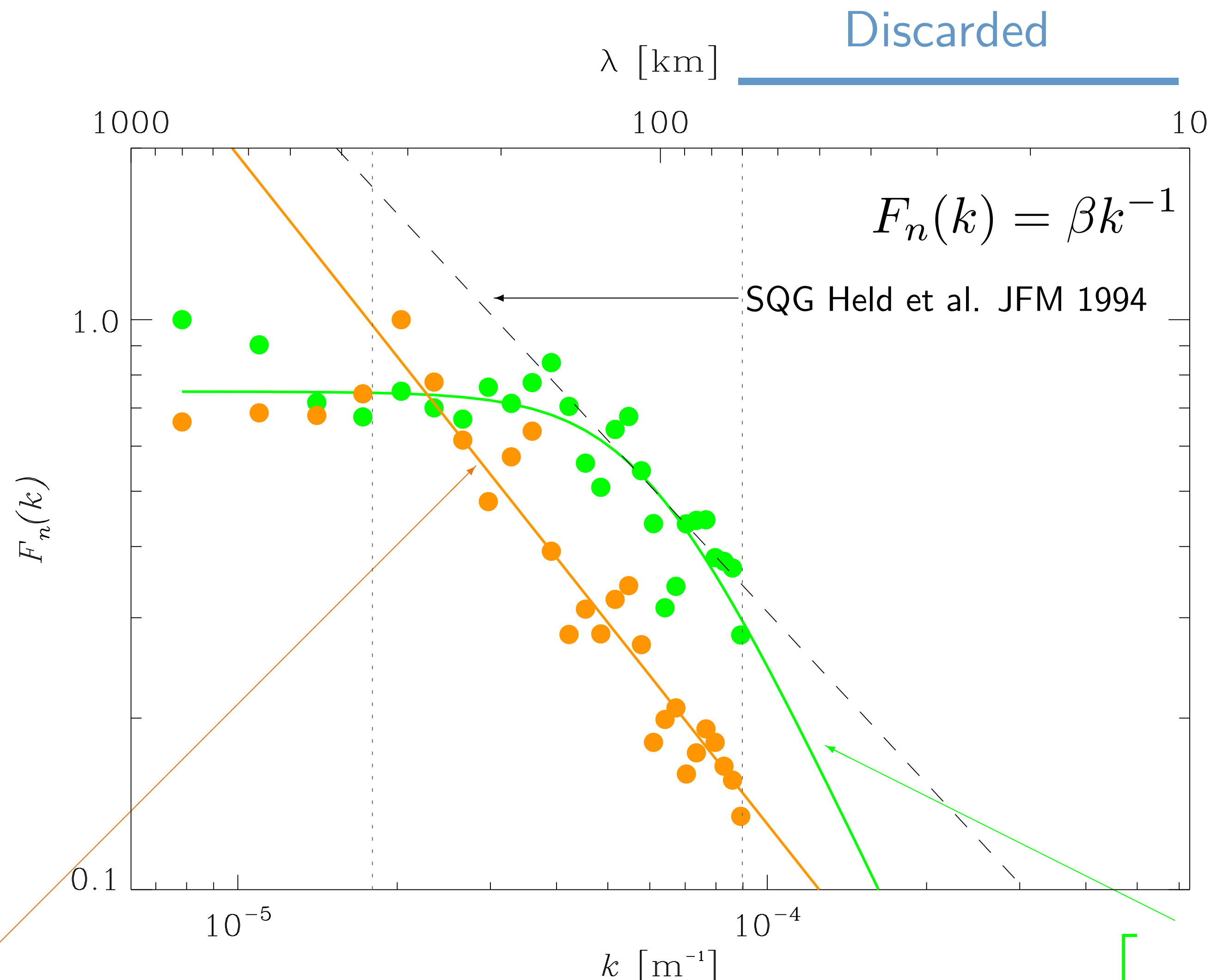
- The amplitude of the transfer function can be estimated from SSH and SST observations

$$CF_n(k) \approx \frac{g}{f_0}\frac{\langle|\hat{\eta}|\rangle_k}{\langle|\hat{T}_s|\rangle_k} \tag{5}$$

(Isern-Fontanet et al. JPO 2014)

- Transfer functions have been estimated from Envisat data
  - Applied to Envisat data (RA and AATSR) for the period 2002-2010
  - Regional analysis: West Australian coast, Mediterranean Sea





$$F_n(k) = \beta k^{-\alpha}$$

Pierrehumbert et al. CS & F 1994

$$F_n(k) = \left[1 + \left(\frac{k}{k_c}\right)^{2\alpha}\right]^{-\frac{1}{2}}$$

Isern-Fontanet et al. JPO 2014

- Along-track SSH are used to fix the energy level
- Along-track SSH are used to select the best transfer function

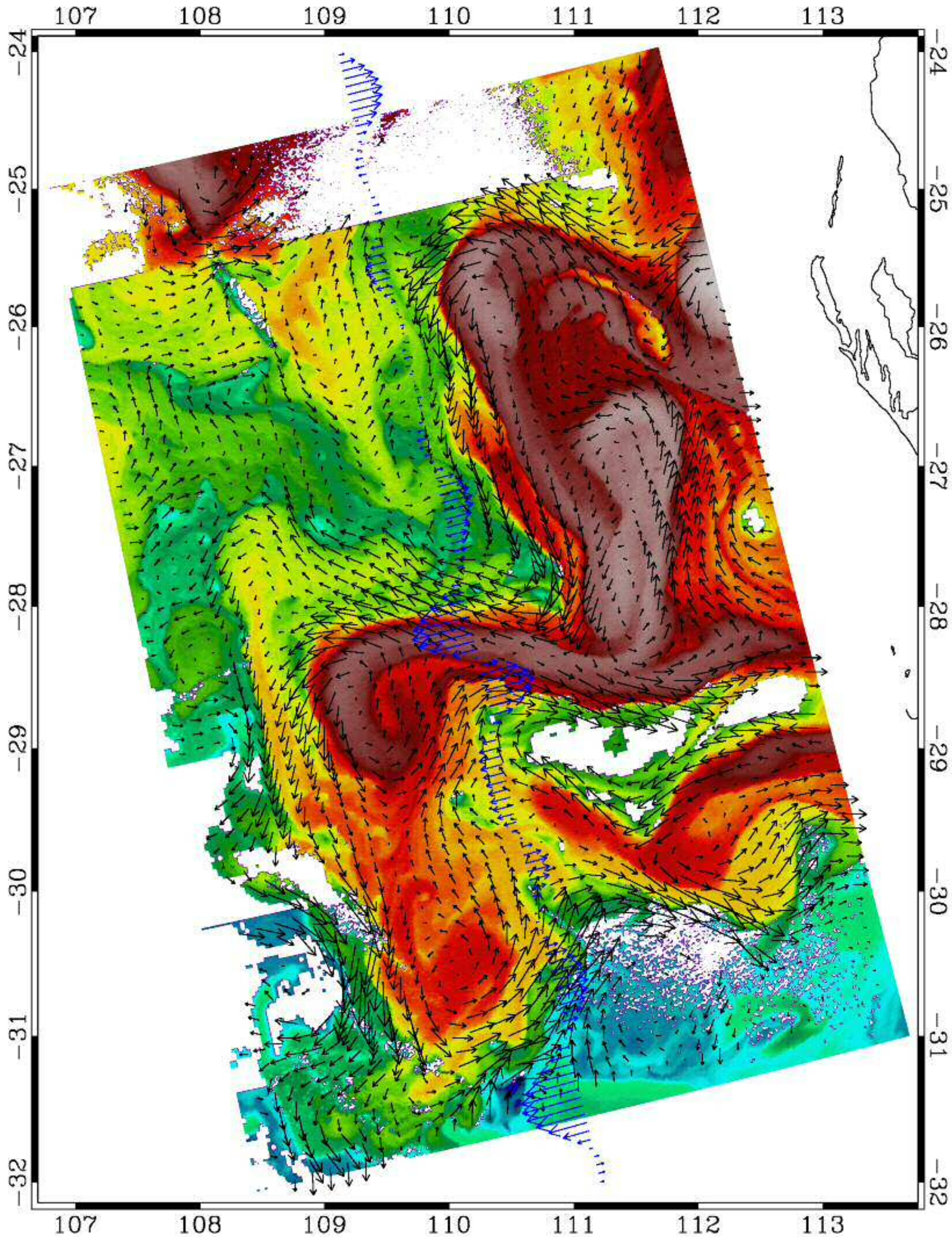
$$F_n(k) = \left[1 + \left(\frac{k}{k_c}\right)^{2\alpha}\right]^{-\frac{1}{2}}$$

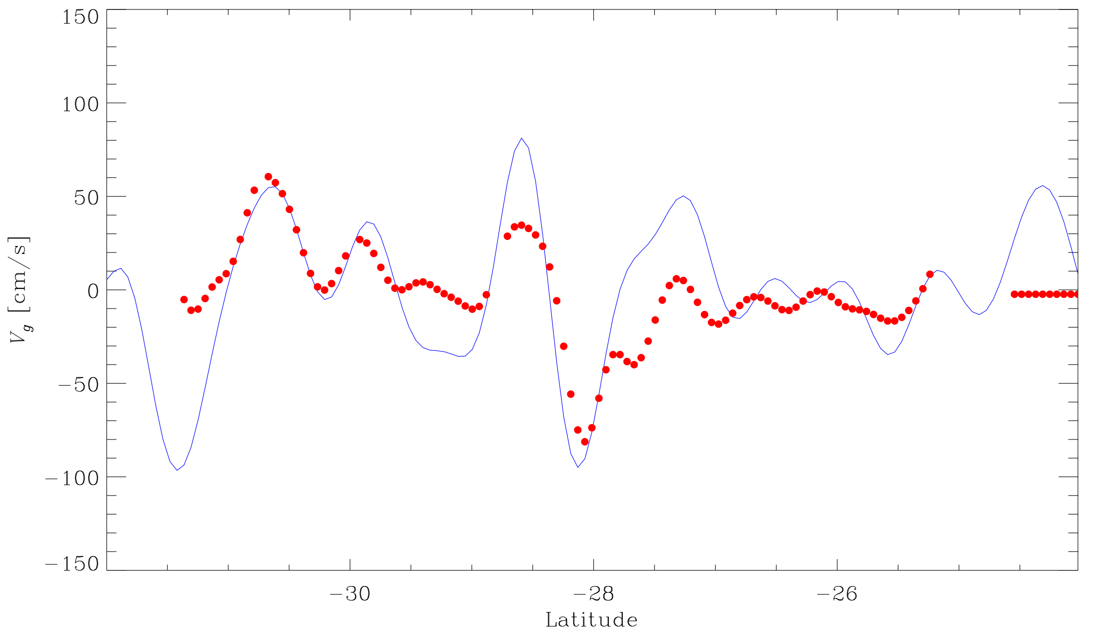
- Along-track SSH are used to set transfer function parameters

$\alpha = 2$, $\lambda_c = 200$ km

- Along-track SSH are used to asses the quality of the velocity reconstruction

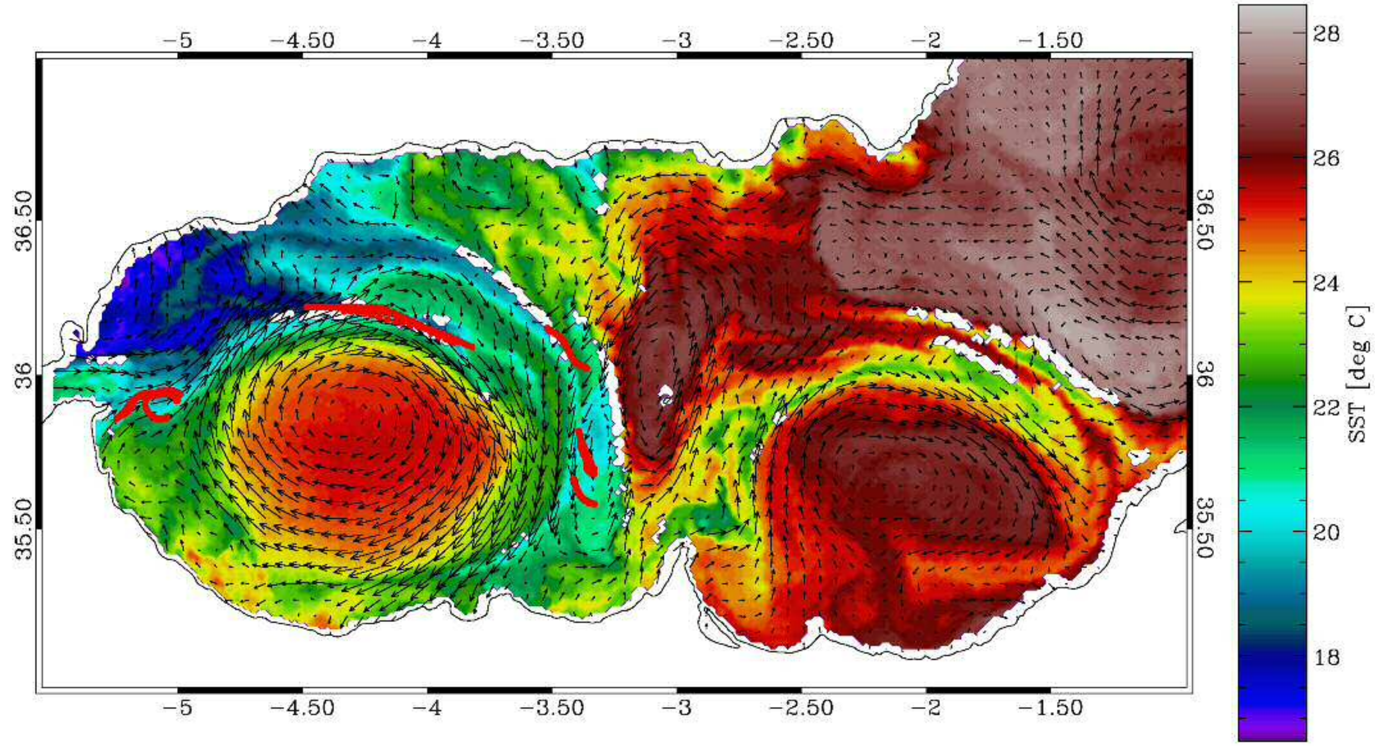
Correlaton	0.71
RMSE	35.14 cm/s





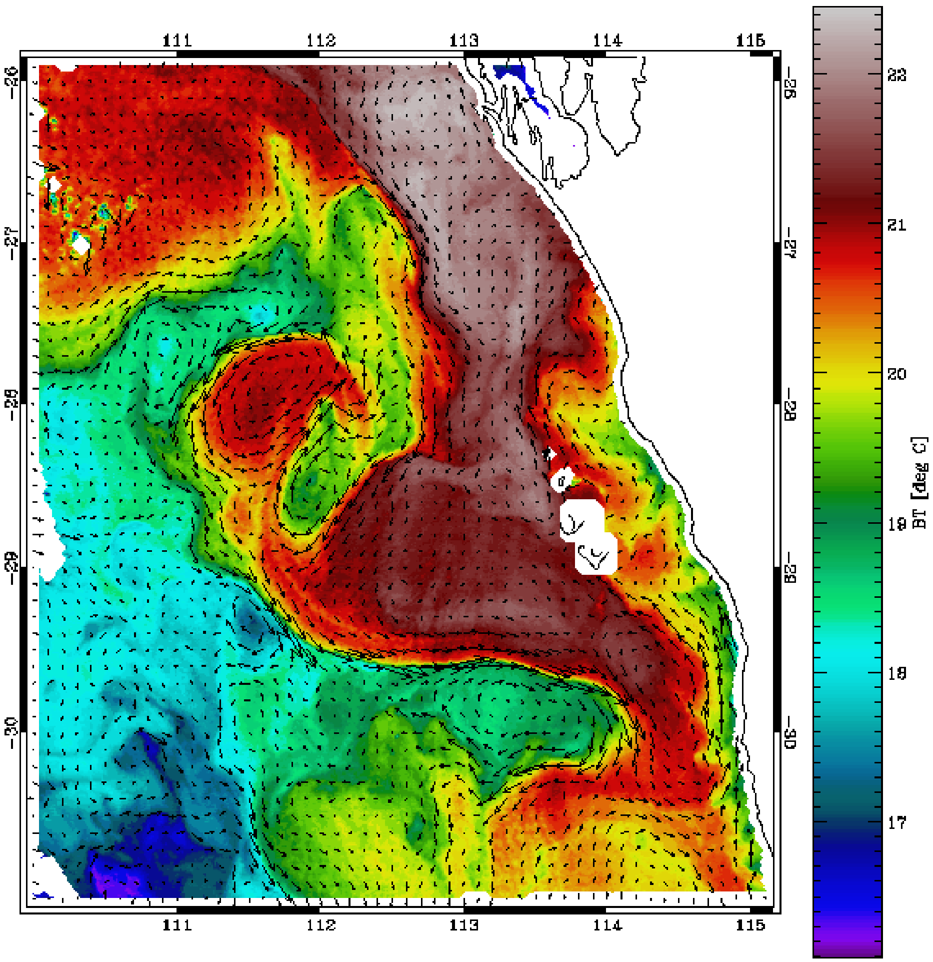
- We assume that $\Delta\theta(\vec{k}) = 0$
  - This is not always true
    (e.g. González-Haro and Isern-Fontanet et al. JGR 2014)
  - Furthermore, usually $\Delta\theta(\vec{k}) \neq 0$
    (e.g. Isern-Fontanet et al. JGR 2008, Isern-Fontanet et al. JPO 2014)

- Phase shift has many origins: Mixed Layer dynamics, interior PV, salinity distribution...
- We have implemented phase corrections due to salinity distribution for the Mediterranean Sea
  - Origin: change of sign of SST anomaly of incoming fresh Atlantic waters.
  - Approach: Wavelet-based image segmentation and correction

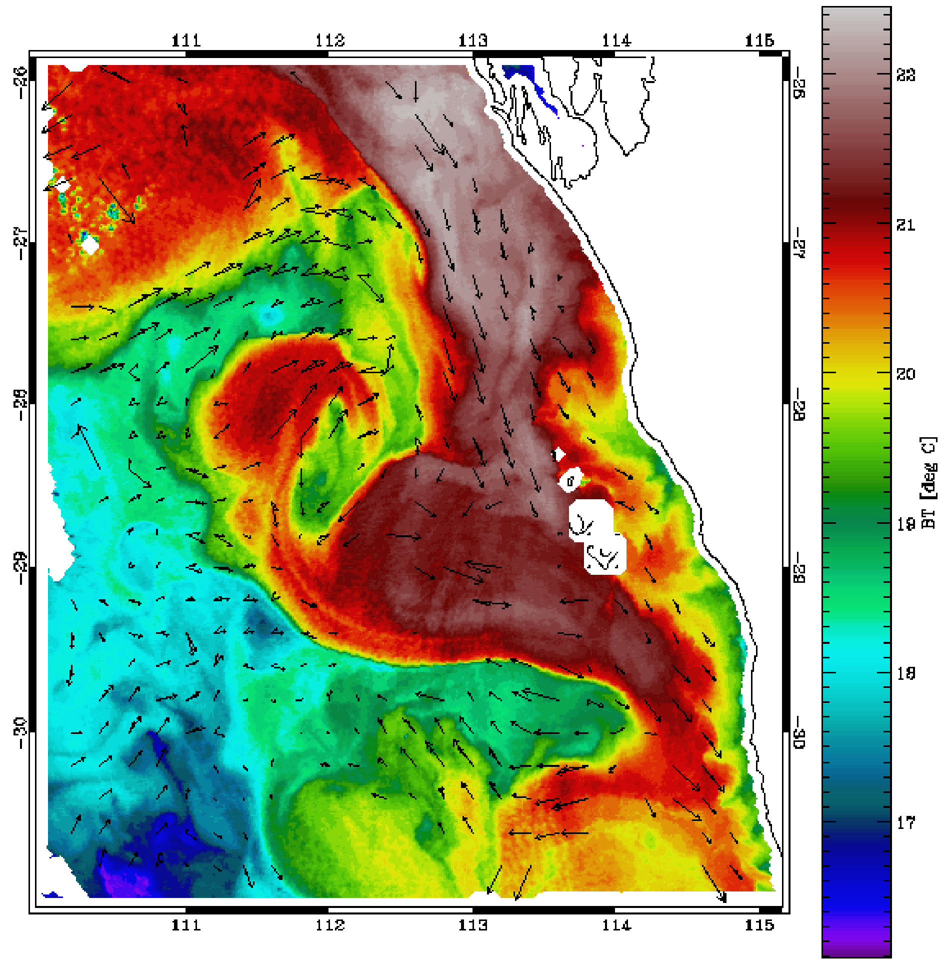


- SATVELS is a software created by Almodis Solutions S.L. to diagnose high resolution currents from SST alone or exploiting the synergy between SST and SSH.
  - Includes some standard image processing algorithms (denoise, segementations,...)
  - Includes most of the theoretical as well as optimized empirical transfer functions
  - Fine processing of SSH observations, including SAR mode altimtery
  - Preliminary phase correction algorithms
- A new version is under development
  - Move to FORTRAN08 (current version is IDL)
  - Version 2.0 ready before the launch of Sentinel-3
  - Improve and and add new phase correction algorithms (version 2.1)

Our approach



MCC

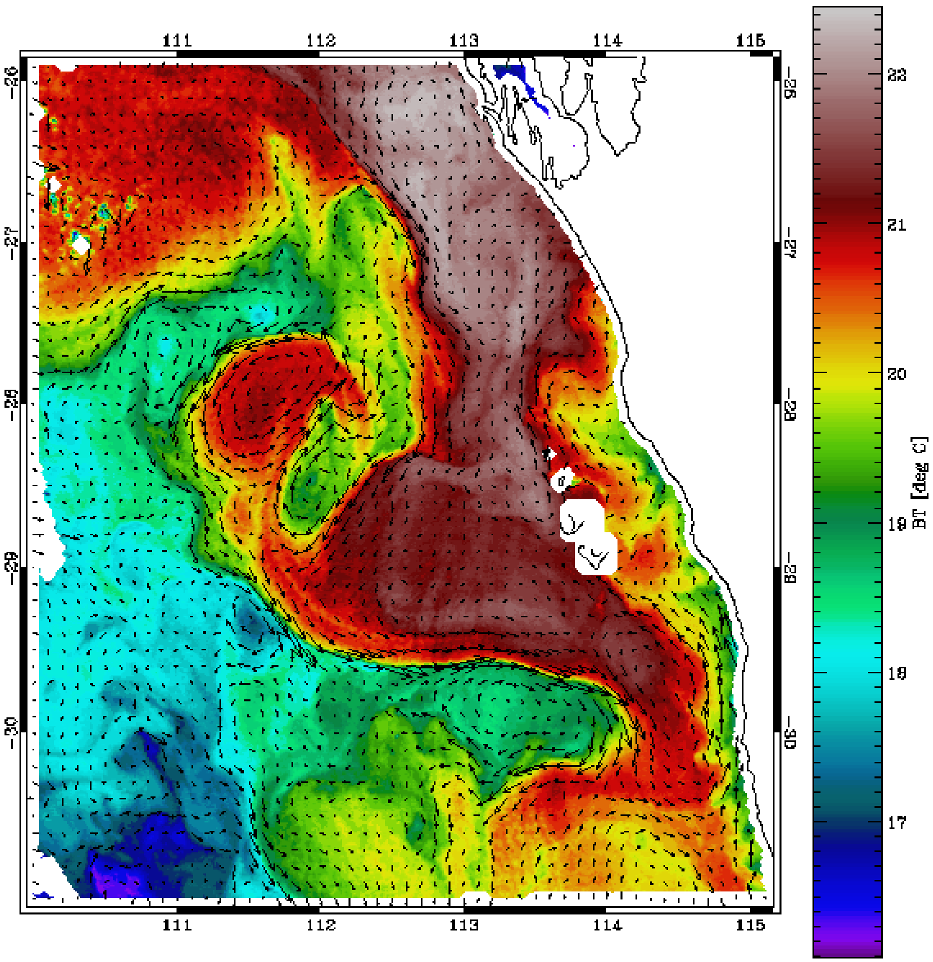


MCC: I. Barton personal communication

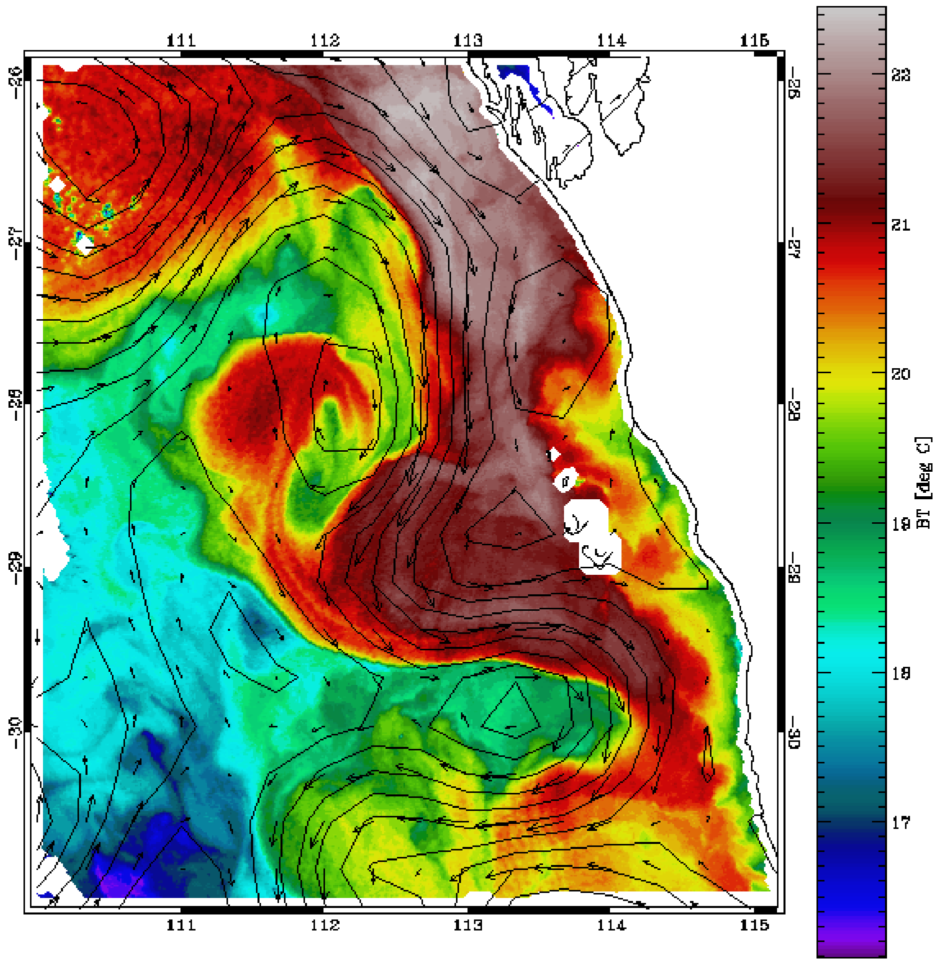
SST: CSIRO

SATVELS: Comparison to altimetric maps

Our approach

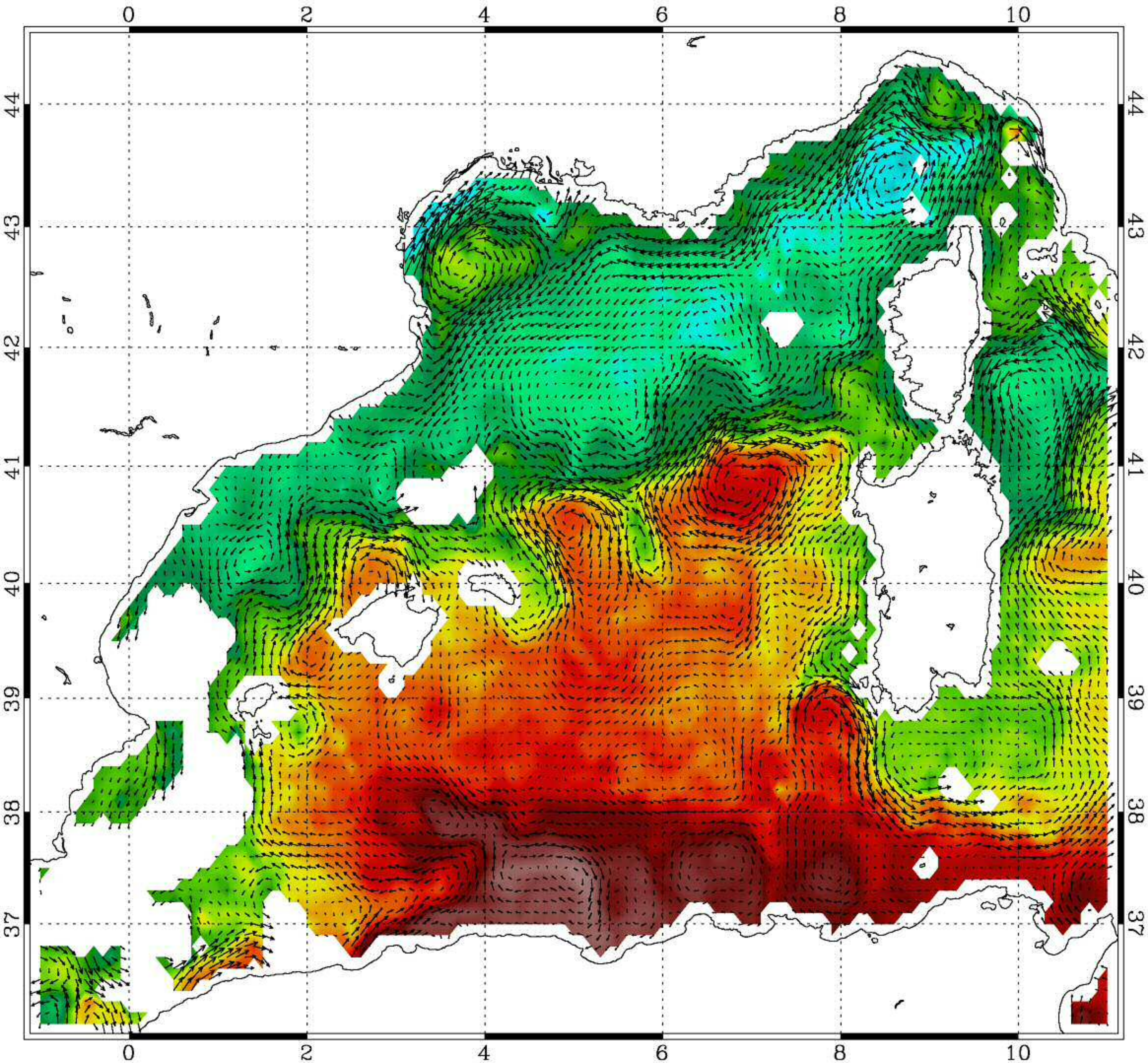


Altimetry



MADT: AVISO Altimetry

SST: CSIRO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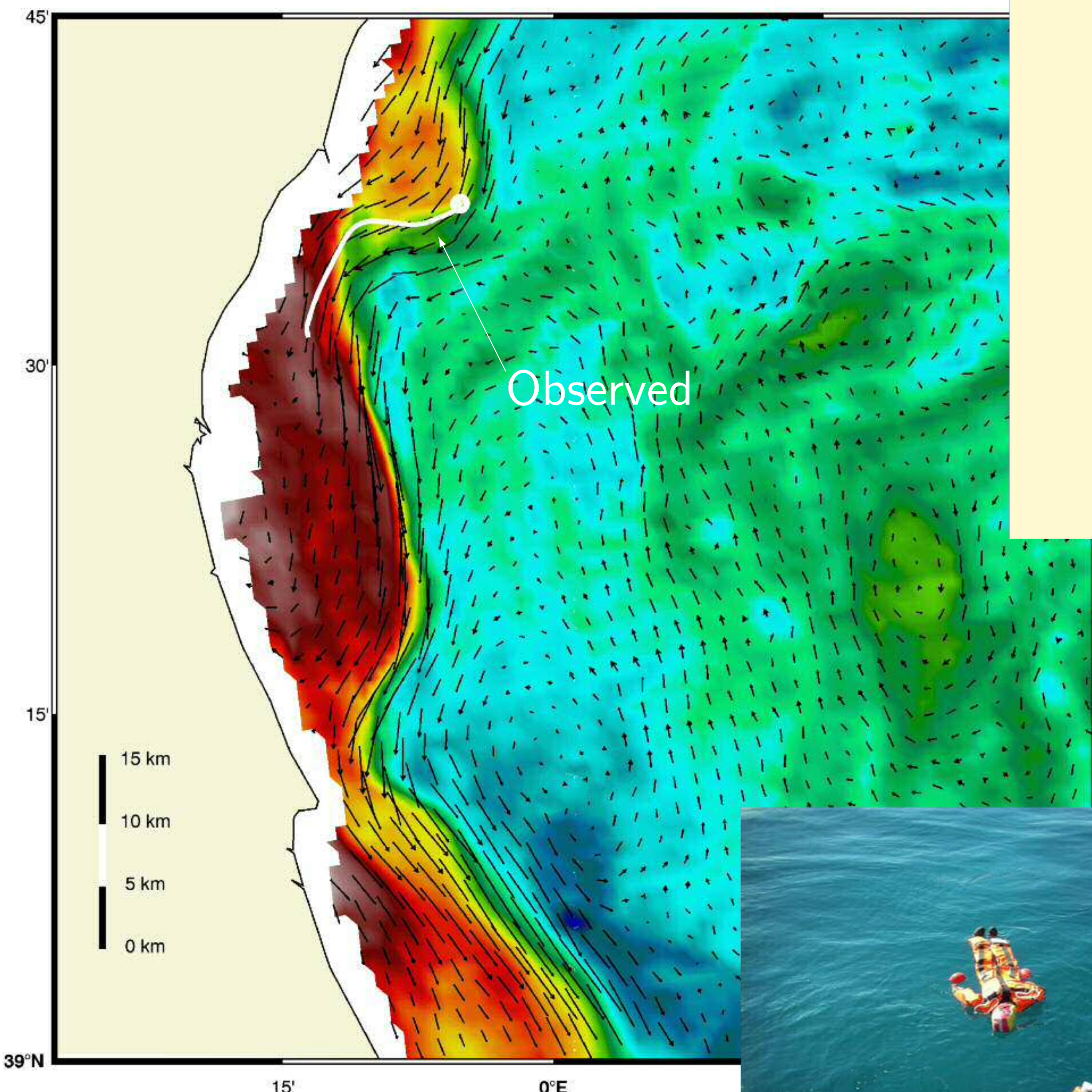
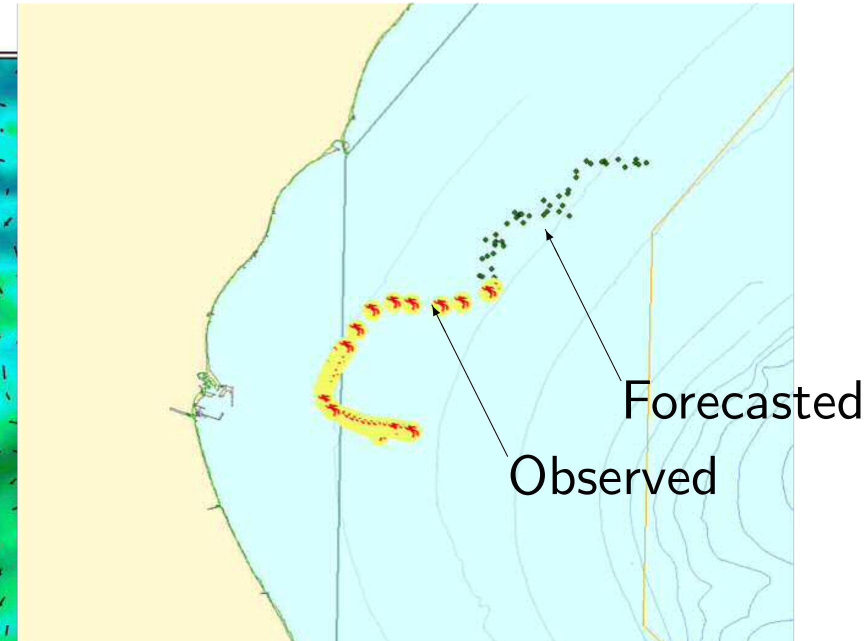
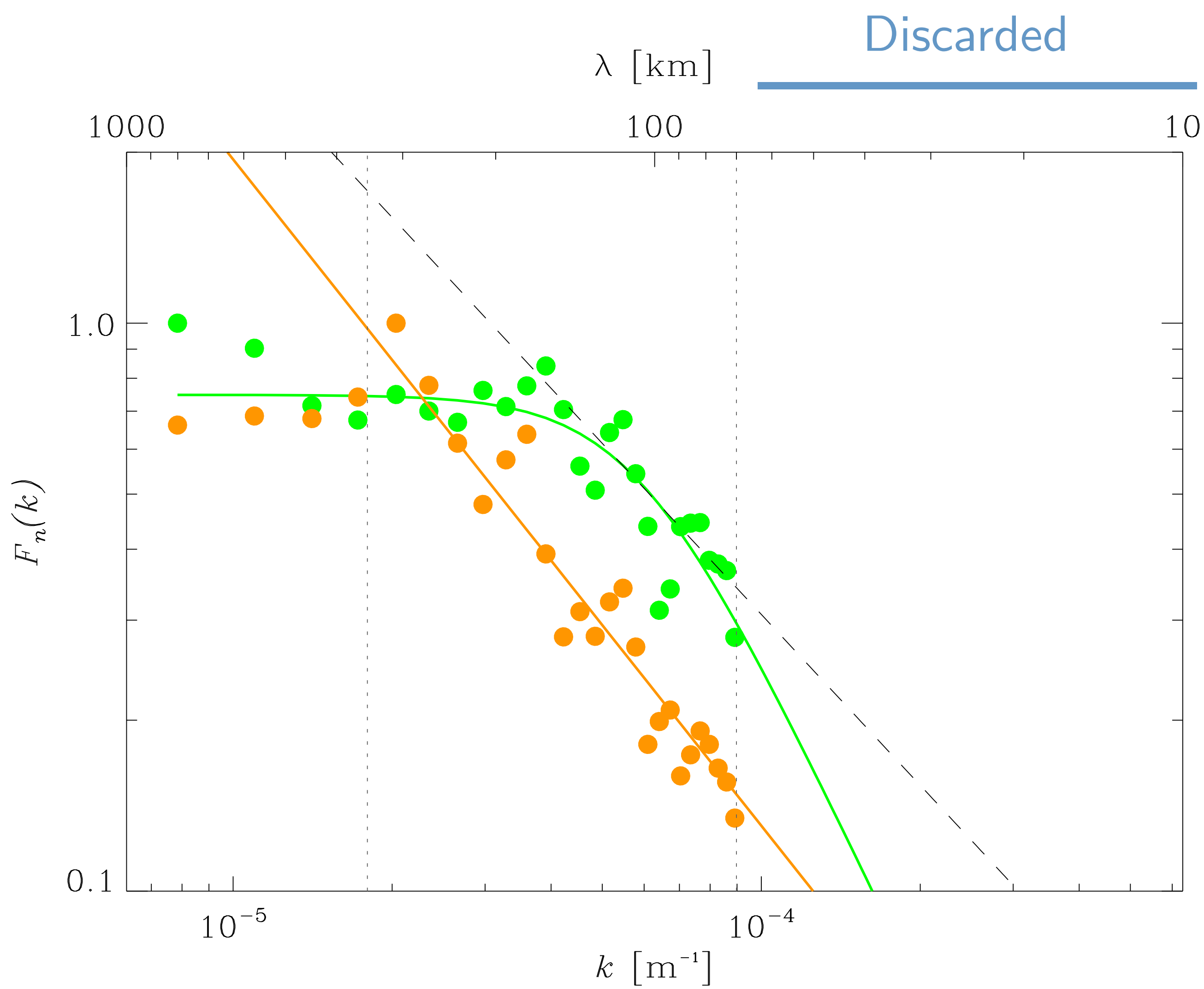
SATVELS: Search and Rescue







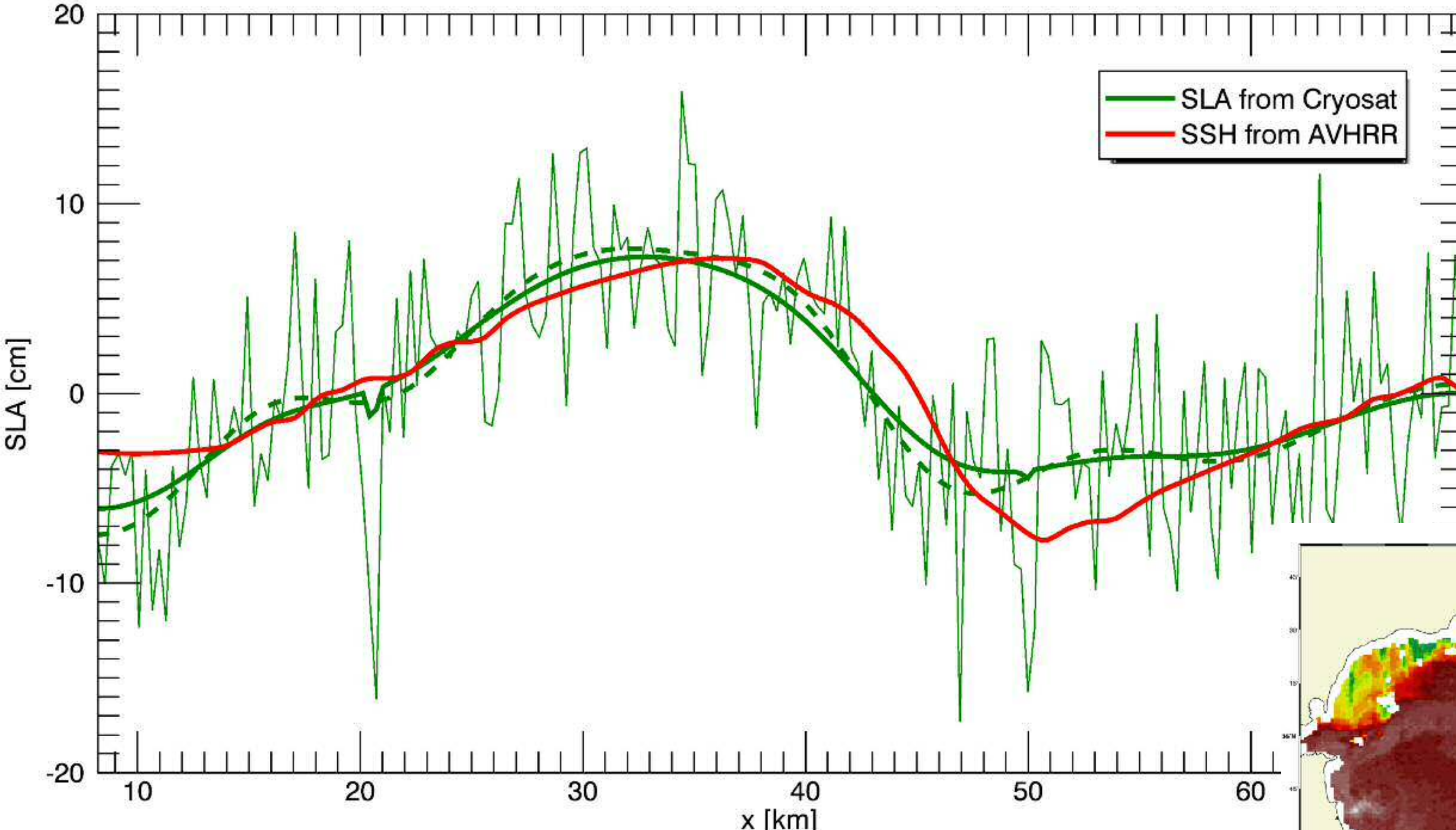
- At short scales the transfer function was extrapolated as $F_n(k) \sim k^{-\alpha}$
- We want to explore scales below 60 km

- The capability to observe structures along-track is strongly limited by the presence of noise.
  - A major contribution to noise are ocean waves
  - Signal-to-noise ratio (SNR) is not homogenous
- A classical low-pass filter with a fixed cut-off wavelength may not be adequate to remove noise
  - May remove small scales with large SNR
  - Does not attempt to correct large scales with low SNR
- Denoising using wavelets

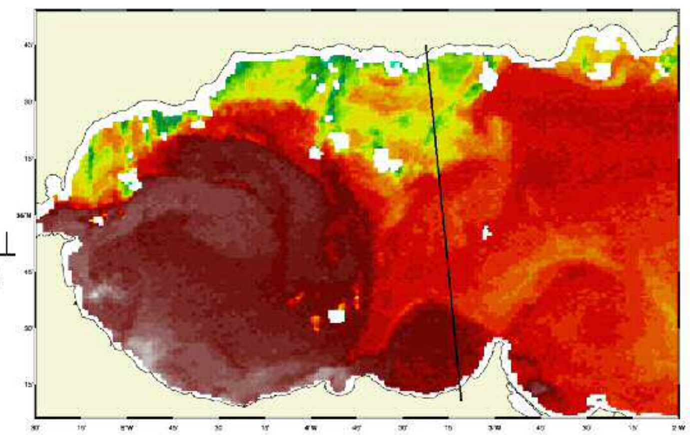
$$\eta(x) = \sum_i w_i \phi_i(x) \qquad \Rightarrow \qquad \tilde{\eta}(x) = \sum_i w_i^* \phi_i(x) \tag{6}$$

(e.g. Isern-Fontanet and Hascoët JGR 2014)

Application to CryoSat: a coastal eddy



Correlations	
Raw	0.64
Filtered	0.91
Denoised	0.93



- Wavelet coefficients are modified based on the derived SWH and waveform fitting
- High correlation with SSH derived from SST observations
- Results encourage us to extend this approach to conventional altimetry: Jason-1/2

- The synergy between SSH and SST measurements can be exploited to improve the reconstruction of surface ocean currents
  - SST is used to recover the topology of the flow
  - SSH is used to recover the energy of the flow at different scales
  - The comparison of both allows to asses the quality of the reconstruction
- Several configurations have been explored
  - Mono-satellite configuration: one IR radiometer (AATSR) and one altimeter on the same platform $\rightarrow$ ERS*, Envisat, Sentinel-3
  - Geostationary configuration: one geostationary IR radiometer (SEVIRI) and simultaneous altimeters $\rightarrow$ MSG, Jason*
- Our approach has the potential to retrieve coastal structures of the order 5-10 km
- We are developing an adaptative approach to process SSH measurements to keep the shortest possible wavelength