

Summary:

The interface between the continental shelf and the deep ocean is a place of high mesoscale activity, such as slope current variability, vortices and filaments. These processes play a major role in water mass exchange, transport of nutrients, and interact with large scale currents. Unfortunately, they have short space scale and are thus difficult to observe continuously –especially by current altimeters–, therefore to predict. It is a major issue for future altimetric missions, as well as in situ networks, to be able to observe such dynamics.

In this study, we set up a 3D coastal ocean model on the Bay of Biscay during summer 2004. We focus on the variability of mesoscale features. Two ensembles of runs are performed, the first by perturbing the wind stress field, the second by shifting the depths of isopycnals in the initial conditions. In each case, the ensemble variability is assumed to be a good proxy for the model state error associated to uncertainties in the perturbed parameter considered (winds or initial conditions).

Thanks to ensemble statistics, it is possible to assess an observation network with the idea that a “good” network is a network that controls model state error. This ability is tested by studying the eigenvalues and the associated eigenvectors of the scaled representer matrix. This method is referred to as RMS, for Representer Matrix Spectra. It is here tested with two types of experiments: the first compares two altimetric scenarios, the second two *in situ* networks configurations.

This method appears to be a promising tool for visualizing which model error modes the observation network can detect, and has potential for discriminating between observing networks based on the number and nature of degrees of freedom of model error captured.

1. Observational network assessment: Representer Matrix Spectra method (RMS) (Le Hénaff et al., 2008)

- Ensemble statistics to characterize the model error covariance P^g (Evensen, 1994):

$$P^f = E[\epsilon^g \epsilon^{gT}] \approx (\mathbf{x}_i^g - \mathbf{x}_i^g)(\mathbf{x}_i^g - \mathbf{x}_i^g)^T$$

where ϵ^g is the model error, \mathbf{x}_i^g is the model state of the member i of the ensemble

- Study of the scaled representer matrix χ (Jorda, 2005, after Bennett, 1985):

$$\chi = R^{-1/2} H P^g H^T R^{-1/2}$$

where :

- R is the observation error covariance matrix
- H is the projection matrix from the model space to the observation space
- Focus on the spectrum of χ :
 - if $\lambda_i \ll 1$, the observation error is too high for the network to properly detect and constrain the associated model error mode
 - if $\lambda_i > 1$ or $\lambda_i \approx 1$, the network is able to observe the model error and thus to correct the model trajectory through a data assimilation step
 - Eigenvectors provide a qualitative analysis tool

Symphonie Model (Marsaleix et al., 2008):

- 3D model, primitive equations (horizontal resolution 3km)
- free surface
- generalized sigma coordinates (45 levels)
- boundary conditions : Psy2v1 Mercator model (1/12th deg.)
- surface forcing : Aladin Météo-France model (10km, 3h)
- no tides
- period of study : July and August 2004
- 2 day output

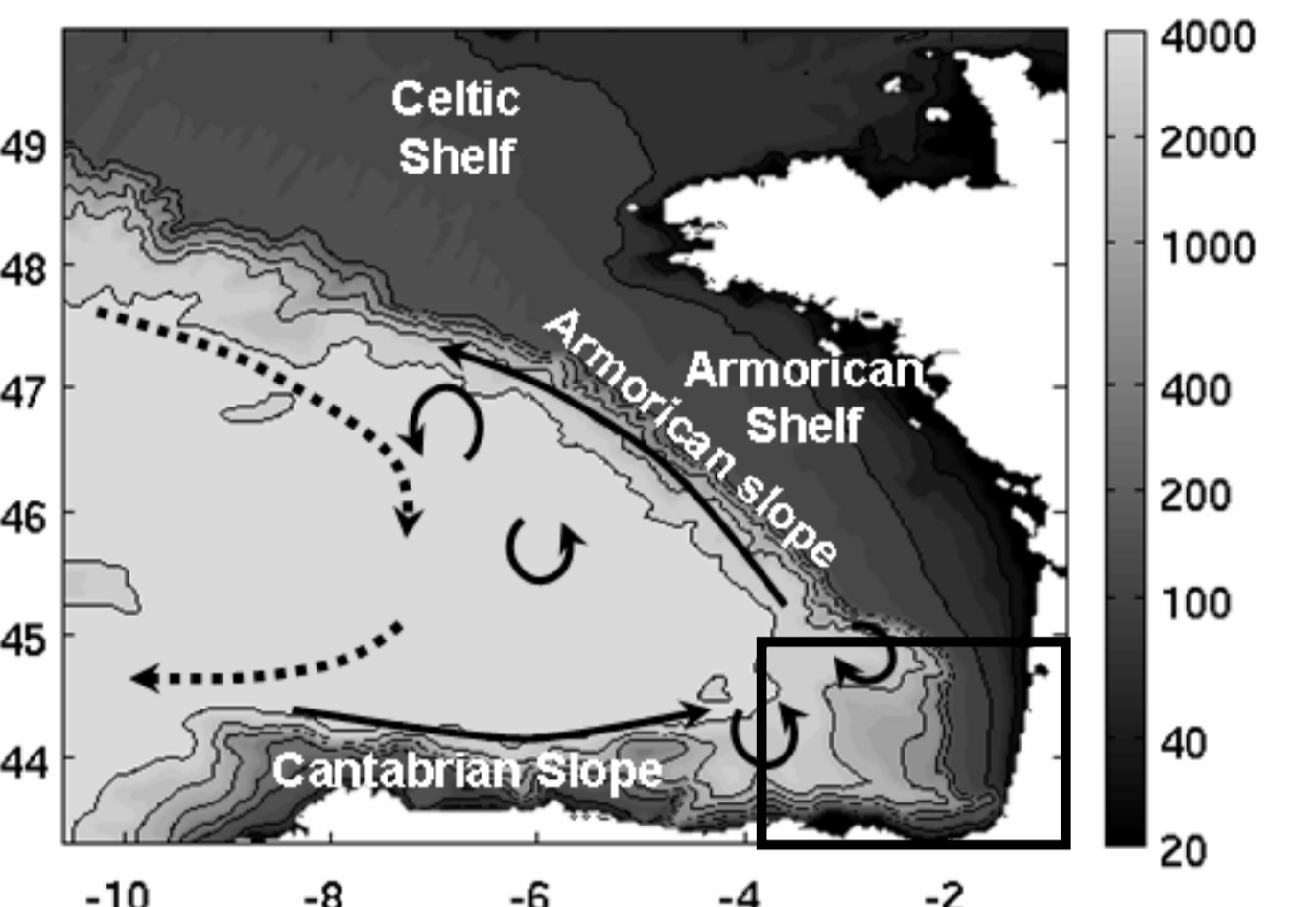


Fig. 1: Study zone with bathymetry (m) and main dynamics (continuous arrow: slope current, dotted arrow: general circulation, circular arrow: eddy). Black square: Landes Plateau zone, see Part 3.

Sources of model errors:

- Ensemble 1** : Uncertainties on the wind : random realistic perturbations of the wind along the dominant EOFs modes of the reference wind field during the study period
- Ensemble 2** : Uncertainties in the initial conditions : random displacements of isopycnal depths, with space scales close to those of mesoscale

2. Altimetry experiments: test of two altimetric network scenarios thanks to the RMS technique

Two experiments:

- Exp A: “classical” Jason 1 nadir altimetry measurements over the zone in the 10 day period Jul 27 – Aug 5, with a measurement error of 3.9 cm rms
- Exp B: Wide Swath altimeter type measurements on the same period, with an increasing error from the nadir (3.9 cm rms) to the far end of the swath (5.3 cm rms)

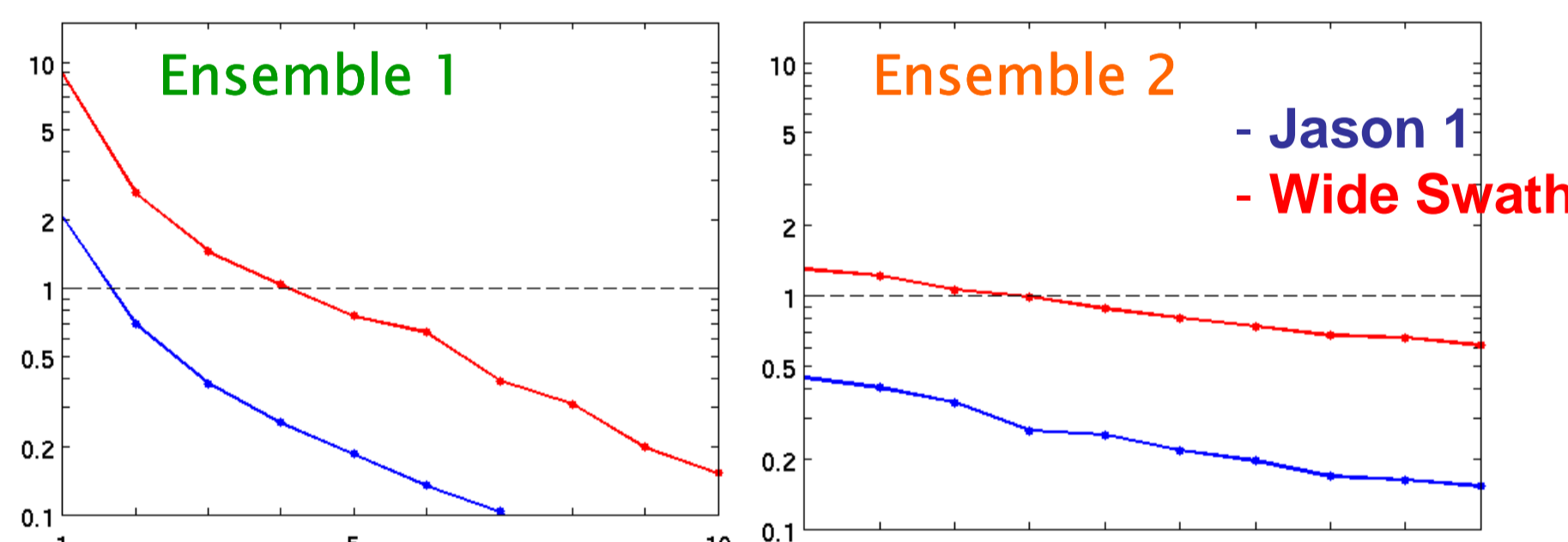
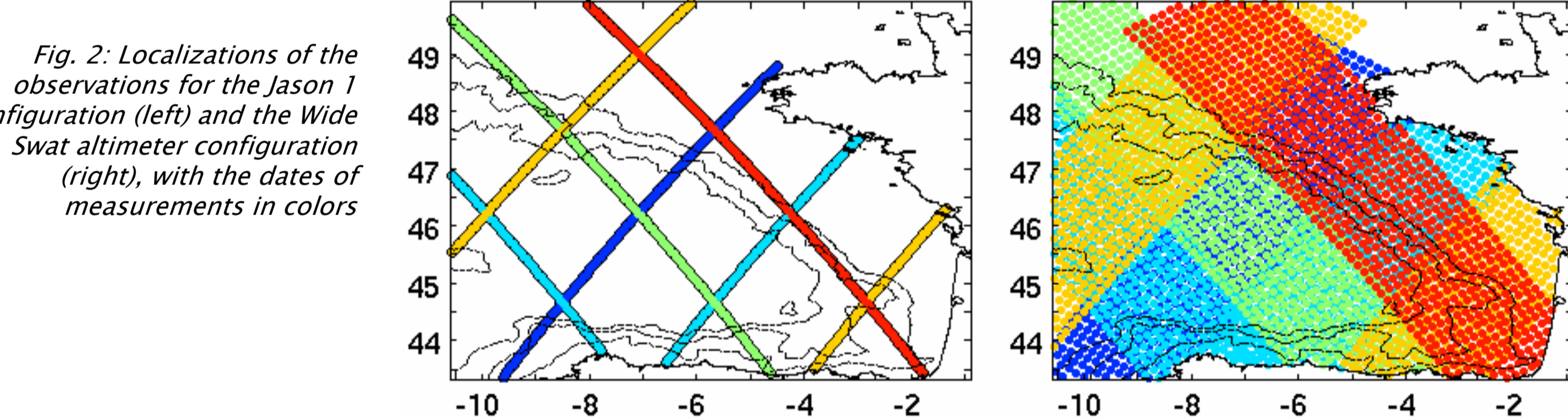
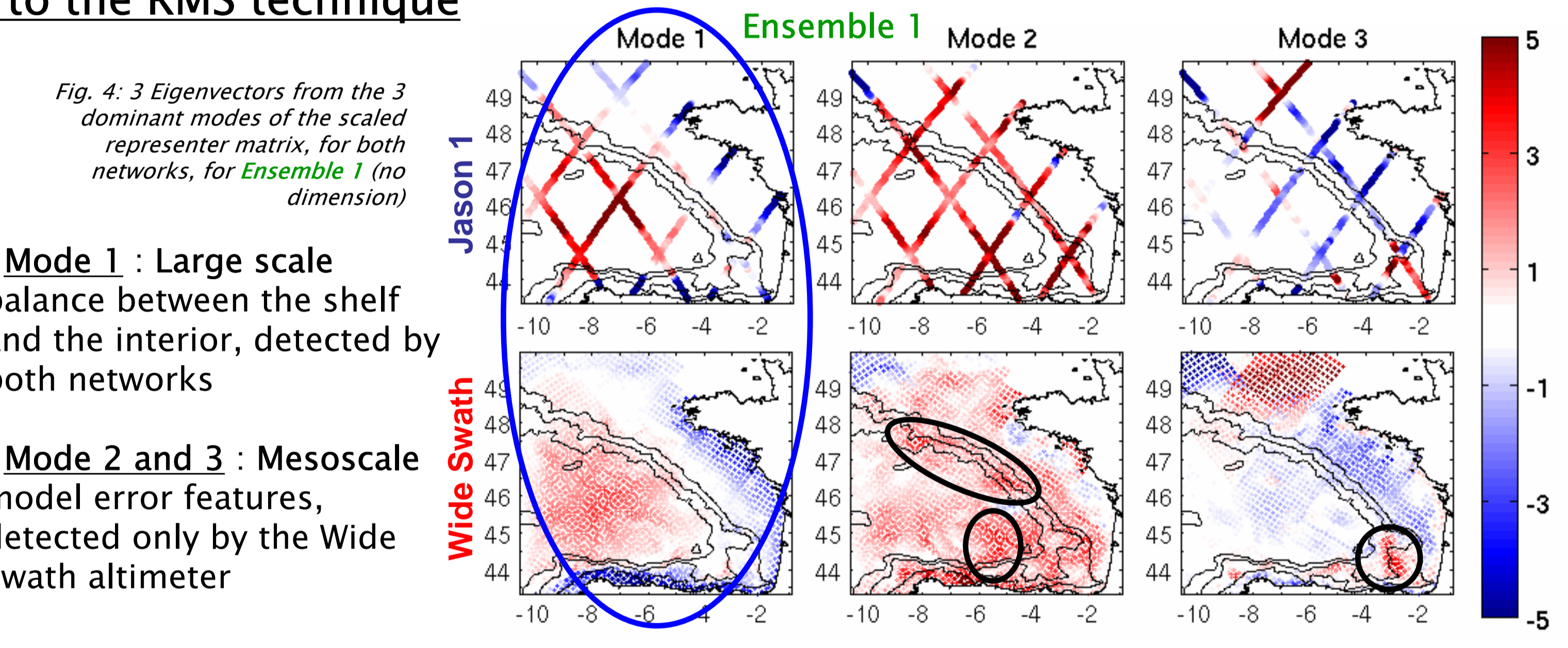


Fig. 3: Spectra of eigenvalues of the scaled representer matrices, for Ensemble 1 (left) and Ensemble 2 (right), for both experiments (colors). The reference spectrum of the Identity matrix (equal to 1) is in dashed line.

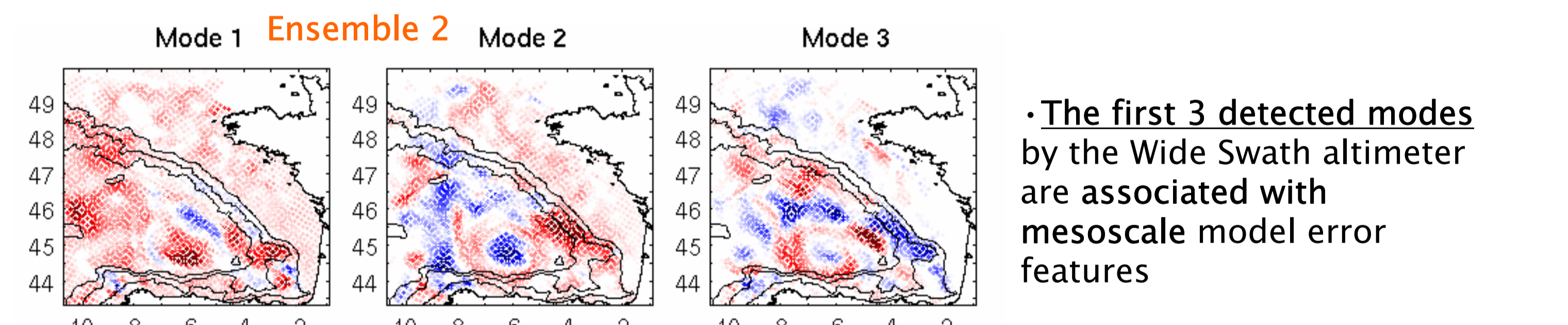
- Ensemble 1** : Jason 1 has 1 detected mode, the Wide Swath altimeter 4
- Ensemble 2** : Jason 1 has no detected mode, the Wide Swath altimeter 3

For both ensembles, the Wide Swath altimeter has more detected modes than the nadir altimeter

What is the physical meaning of the detected modes?



- Mode 1** : Large scale balance between the shelf and the interior, detected by both networks
- Mode 2 and 3** : Mesoscale model error features, detected only by the Wide Swath altimeter



- The first 3 detected modes by the Wide Swath altimeter are associated with mesoscale model error features

Both ensembles illustrate the ability of the Wide Swath altimeter to detect model error associated to coastal mesoscale dynamics

3. In situ measurement network deployment strategy : test of various scenarios on the Landes Plateau

Two experiments:

- Exp C: vertical temperature measurements on August 15, 0.2°C rms observation error
- Exp D: same as Exp C, with added measurements of currents on the central line, with an error of 1 cm/s rms

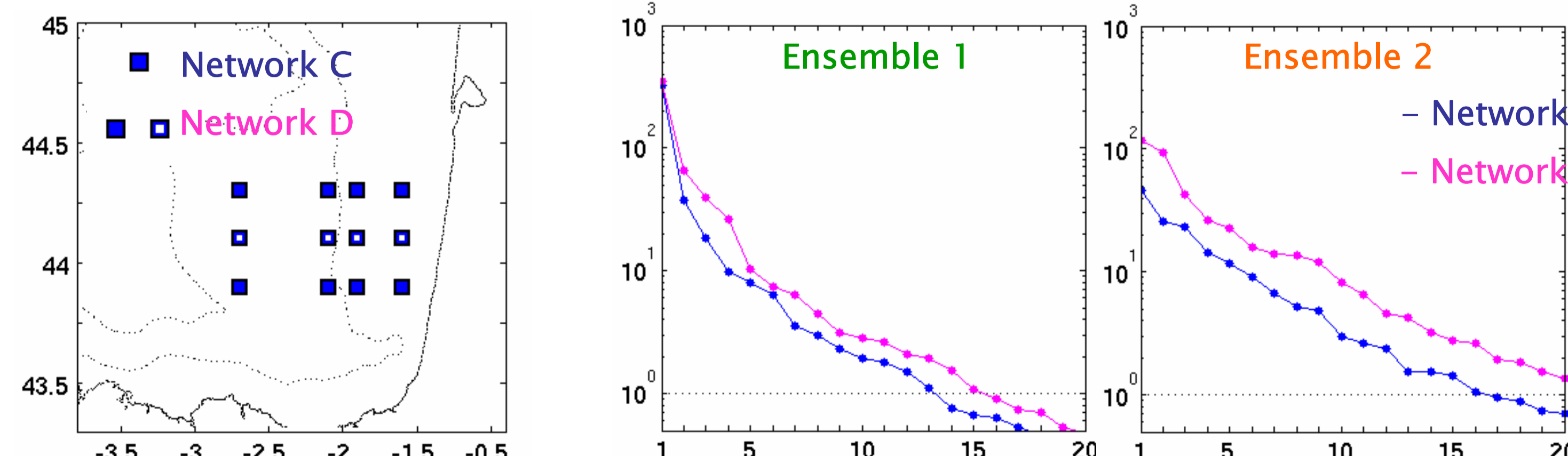
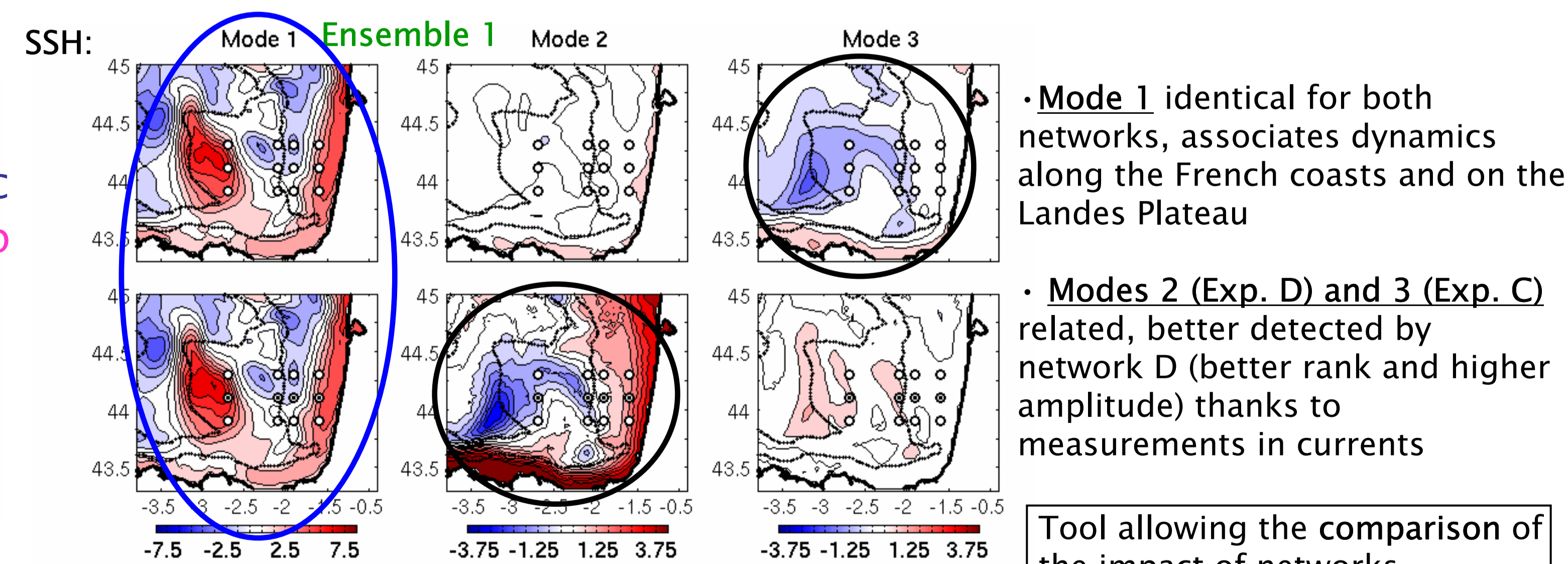


Fig. 6: Localizations of the observations for both experiments

Fig. 7: Spectra of eigenvalues of the scaled representer matrices, for Ensemble 1 (left) and Ensemble 2 (right), for both experiments (colors).

For both ensembles, Network D measures more of the model error modes. What is the physical meaning of the detected modes?

Qualitative analysis tool: study of the modal representer matrix $\rho_\mu = P^g H^T R^{-1/2} \mu^i$, (μ^i : eigenvectors of χ): impact of one detected mode in the model space.



- Mode 1** identical for both networks, associates dynamics along the French coasts and on the Landes Plateau
- Modes 2 (Exp. D) and 3 (Exp. C)** related, better detected by network D (better rank and higher amplitude) thanks to measurements in currents

Tool allowing the comparison of the impact of networks measuring different variables

Bibliography:

- Bennett, A. F., 1985: Array Design by Inverse Methods, *Progress in Oceanography*, 15, 129–151.
- Evensen, G. (1994), Sequential data assimilation with a nonlinear quasi-geostrophic model using Monte Carlo methods to forecast error statistics, *J. Geophys. Res.*, 99(C5), 10,143–10,162.
- Le Hénaff M., De Mey P., and P. Marsaleix, 2008: Assessment of observational networks with the Representer Matrix Spectra method – Application to a 3D coastal model of the Bay of Biscay, *Ocean Dynamics*, accepted.
- Jorda, G., 2005. Towards Data Assimilation in the Catalan Continental Shelf, PhD thesis, Université Paul Sabatier, Toulouse
- Marsaleix P., Auclair F., Floor J. W., Herrmann M. J., Estournel C., Piraud I., Ulses C., 2008: Energy conservation issues in sigma-coordinate free-surface ocean models. *Ocean Modelling*, 20, 61–89

Perspectives:

- Promising method for assessing an observational network
- Test other types of networks, for example Lagrangian ARGO drifters
- Currently performing classical OSSEs experiments with EnKF to compare the conclusions from both approaches
- Test the dependency of the method on the model error regime

Acknowledgements:

All these heavy calculations have been run on a cluster of 15 PCs at the POC in Toulouse: thanks to the computer engineers of the team. This study started during my PhD thesis funded by DGA, and takes place the ECOOP EU/DGXII project. It is carried out in the framework of the MICSS OSTST proposal.