Objective design of coastal HF Radar networks using stochastic array modes (ArM toolbox)

Chafih Skandrani (1), Pierre De Mey-Frémaux (2), Guillaume Charria (3)

(1) NOVELTIS, Toulouse, France

(2) LEGOS, Toulouse, France, pierre.de-mey@legos.obs-mip.fr

(3) LOPS, Brest, France

JOINT EUROPEAN RESEARCH INFRASTRUCTURE NETWORK FOR COASTAL OBSERVATORIES

Summary – TL;DR

We carried out an array design analysis of coastal HF radar networks with the ArM (Array Modes) method. The performances of two existing Bay of Biscay HF radar observation sites deployed on the Spanish Basque coast as well as a projected third site on the French Landes coast were evaluated.

We characterized and visualized the model error structures which are detectable by the observations and which are potentially controllable through data assimilation. We showed that adding radars improves the detection of model errors by increasing the quantity and location of observations that lead to efficient sampling of model error structures. In particular, the third projected radar site would bring additional detail at sampling zonal surface velocity errors in the model, because of its location.

Additionally, we studied the impact of correlated measurement errors on the ArM analysis. We found that our previous conclusions regarding the existing array performance and the positive impact of a third site were NOT significantly modified by such correlated noise contamination.

ArM references

Le Hénaff, M., P. De Mey et P. Marsaleix, 2009 : Assessment of observational networks with the Representer Matrix Spectra method – Application to a 3-D coastal model of the Bay of Biscay. Ocean Dynamics, 59, 3-20, DOI 10.1007/s10236-008-0144-7.

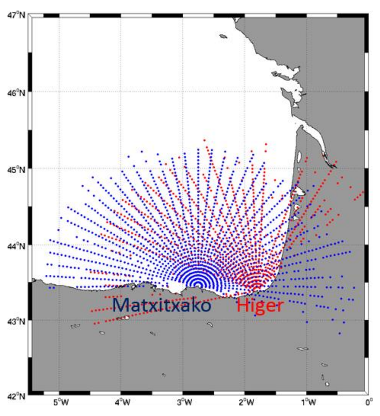
P.R. Oke, G. Larnicol, E.M. Jones, V. Kourafalou, A.K. Sperrevik, F. Carse, C.A.S. Tanajura, B. Mourre, M. Tonani, G.B. Brassington, M. Le Henaff, G.R. Halliwell Jr., R. Atlas, A.M. Moore, C.A. Edwards, M.J. Martin, A.A. Sellar, A. Alvarez, P. De Mey and M. Iskandarani, 2015: Assessing the impact of observations on ocean forecasts and reanalyses 2: Regional applications, J. Op. Oceanogr., 8:sup1, 63-79.

Lamouroux, J., G. Charria, P. De Mey, S. Raynaud, C. Heyraud, P. Craneguy, F. Dumas and M. Le Hénaff, 2016: Objective assessment of the contribution of the RECOPESCA network to the monitoring of 3D coastal ocean variables in the Bay of Biscay and the English Channel. Ocean Dynamics, 66(4), 567-588, http://dx.doi.org/10.1007/s10236-016-0938-y .

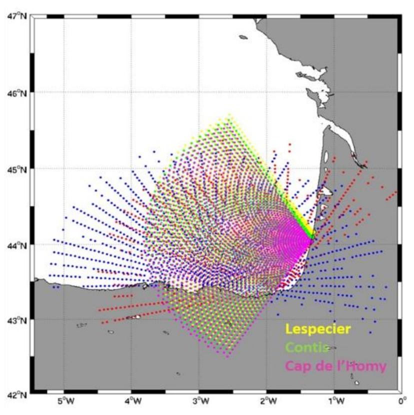
Charria, G., Lamouroux, J. and P. De Mey, 2016: Optimizing observational networks combining gliders, moored buoys and FerryBox in the Bay of Biscay and English Channel. Journal of Marine Systems, 162, 112-125, http://dx.doi.org/10.1016/j.jmarsys.2016.04.003 .

1. HF radar sites and data

We wish to objectively assess the performance of two existing Bay of Biscay HF radar observation sites deployed on the Basque coast as well as a projected third site on the Landes coast. We considered only radial velocities from the radars.



1.1. Existing sites



1.2. Existing + projected

2. ArM methodology

The ArM approach (*De Mey, 2010*) is a non-assimilative approach: it uses ensembles in response to known error sources to describe prior (model) uncertainties, and aims at quantitatively evaluating the performance of the observation network at detecting those uncertainties amidst observational noise.

In practice, ArM consists in calculating and interpreting spectra of the representer matrix, as well as modal representers, making it possible to visualize the model error structures which are detectable by the observations and, in a second step, potentially controllable through data assimilation.

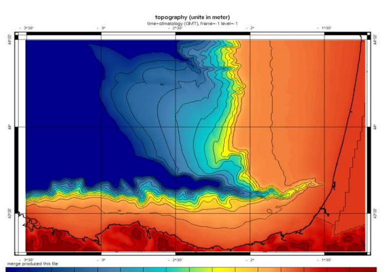
Assume we have a way of generating m prior error samples (an Ensemble). Matrix of samples (centered): $\mathbf{A}^f(n,m)$. Data space samples: $\mathbf{Y}^f(p,m) = H(\mathbf{A}^f)$.

- $\hat{\mathbf{P}}^f \overset{\text{def}}{=} \frac{1}{m-1}\mathbf{A}^f{\mathbf{A}^f}^T$ — Error Covariance Matrix, as approximated from samples
- $\mathbf{S} \overset{\text{def}}{=} \frac{1}{\sqrt{m-1}}\mathbf{R}^{-0.5}\mathbf{Y}^f$ — Scaled data-space samples (found e.g. in *Sakov et al., 2009*).
- $\hat{\boldsymbol{\sigma}}$ — Representer Matrix spectrum estimate = squares of the singular values of $\mathbf{S}$
- $\hat{\boldsymbol{\mu}}$ — Array Mode estimates = singular vectors of $\mathbf{S}$ – an orthonormal basis of $\mathbb{R}^p$ → $\hat{\boldsymbol{\mu}}$ is an orthogonal matrix
- $\hat{\boldsymbol{\rho}}_{\boldsymbol{\mu}} \overset{\text{def}}{=} \frac{1}{\sqrt{m-1}}\mathbf{A}^f\mathbf{S}^T\hat{\boldsymbol{\mu}}$ — Estimates of Modal Representers, the representers for the array modes.

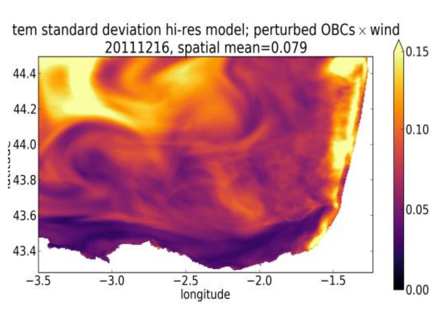
→ ArM array performance criterion: Count singular values of $\mathbf{S}$ larger than 1.

3. 500m-resolution shelf Ensemble

We used several model Ensembles for this study. In this poster, we show results obtained with a multivariate Ensemble (*Ghantous et al., 2019, submitted*) composed of 50 members from a high-resolution shelf configuration of 3D oceanic model Symphonie with 500m resolution. Both OBCs and wind were perturbed. The 500m Ensemble was downscaled from a 1/36° NEMO Ensemble (Vervatis et al., 2016).



3.1. Bathymetry



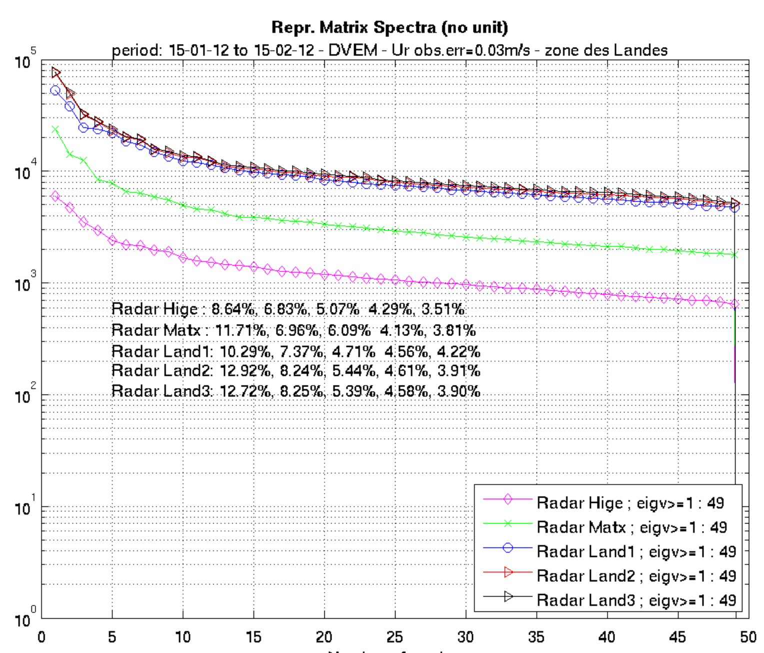
3.2. SST Ensemble stdev

4. ArM analysis

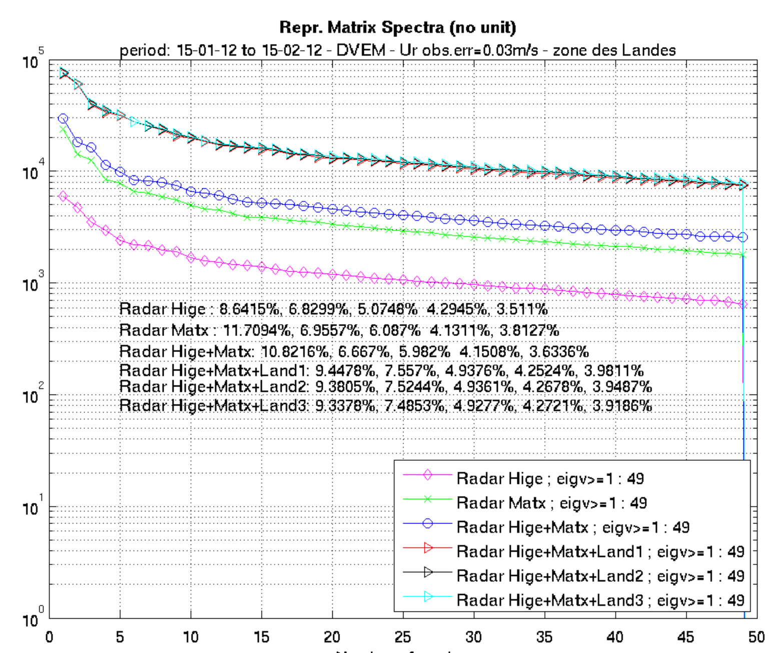
The Representer Matrix spectra below show that all 49 degrees of freedom are detectable above the observational noise floor (=1 in array mode space).

It can be also seen that adding radars improves the detection of model errors (shown in plots as eigenvalues ~7 times bigger) by increasing the quantity and location of observations that lead to efficient sampling of model error structures.

The analysis also shows that all three candidate sites appear to bring equivalent added value.



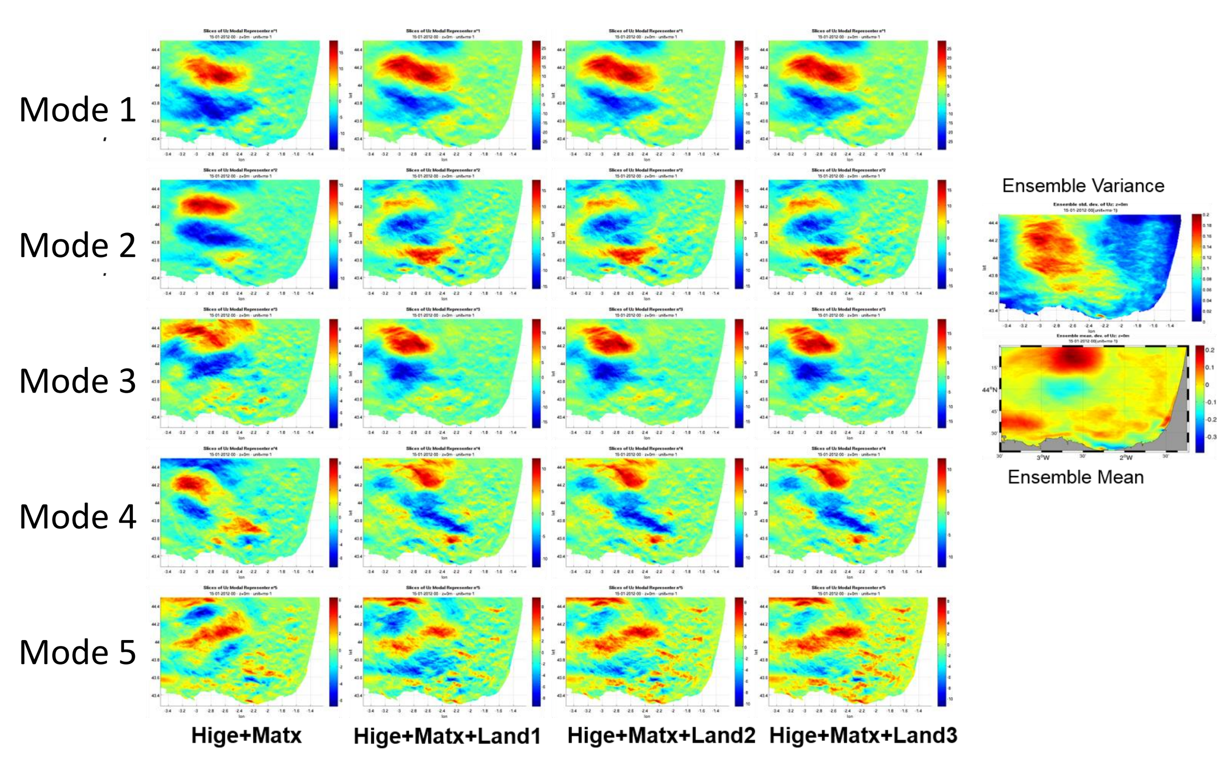
4.1. RM Spectra, individual radar sites



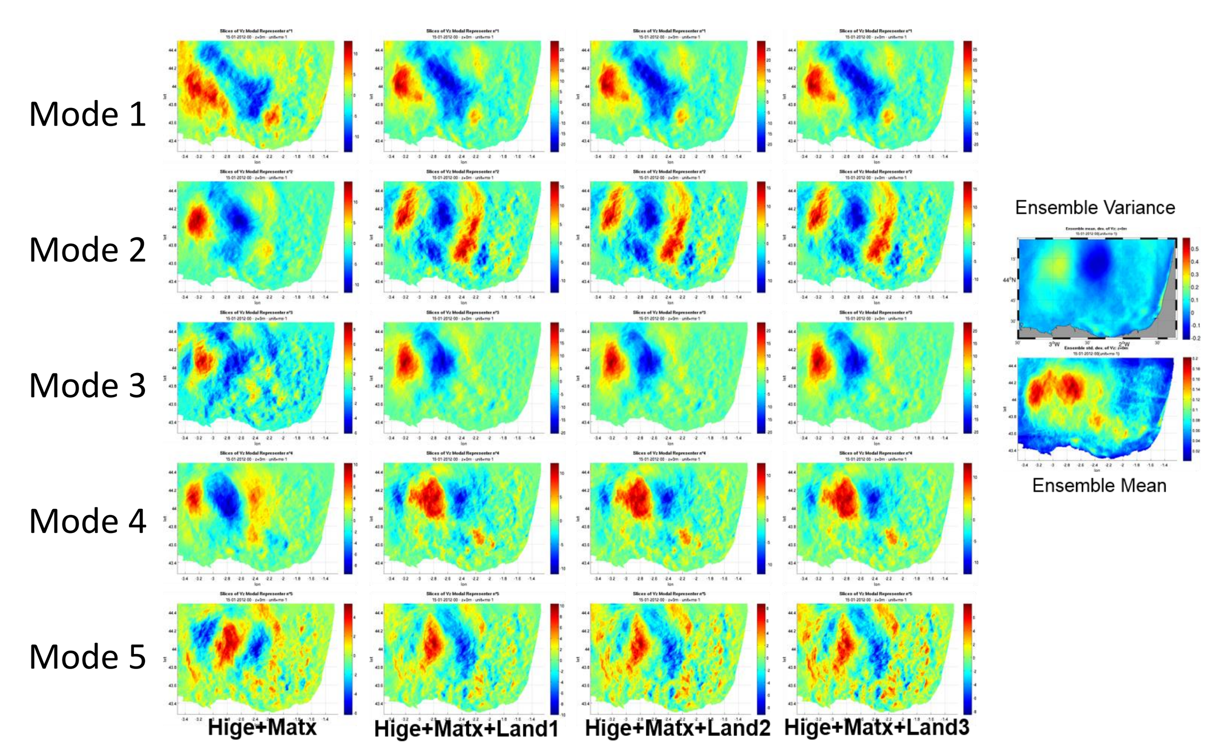
4.2. RM Spectra, radar site combinations

As can be seen for example from the mode 2 modal representers below, the third projected radar site would bring additional detail at sampling zonal surface velocity errors in the model, because of its location in the East. Meridional velocities would also be impacted south of the third site.

Former tests had used a lower-resolution Ensemble (not shown). Using higher-resolution ensembles (approximating higher-resolution model errors) as here clearly adds detail when examining the spatial structures of errors detected by the arrays (in the form of modal representers).



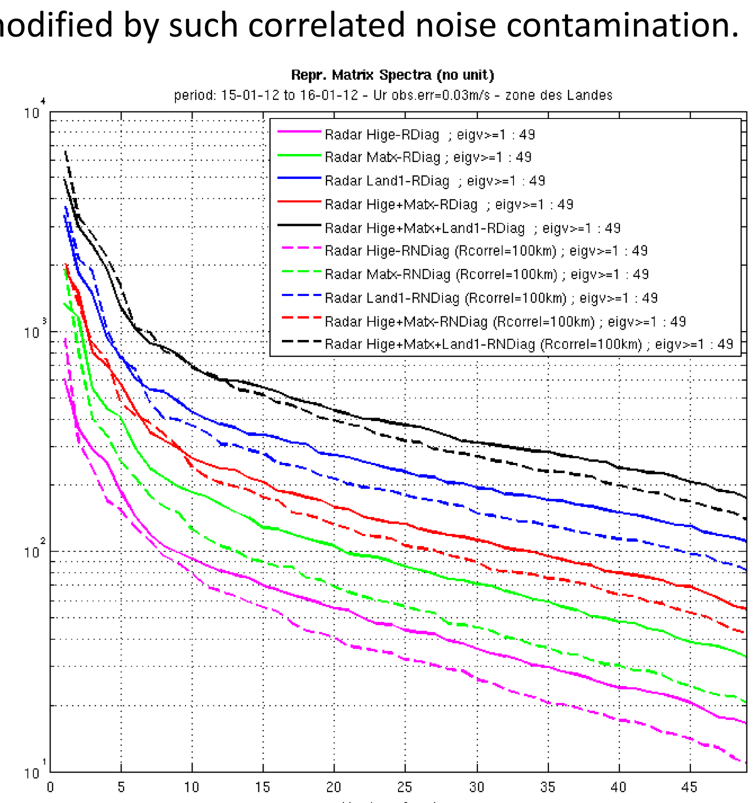
4.3. Modal Representers 1-5 for zonal surface velocity



4.4. Modal Representers 1-5 for meridional surface velocity

5. Impact of correlated HF Radar errors

We studied the impact of correlated measurement errors, e.g. via sea state which can contaminate radar-derived velocities via Stokes drift on the ArM analysis. We found that our previous conclusions regarding the existing array performance and the positive impact of a third site were not significantly modified by such correlated noise contamination.



5.1. RM Spectra, dotted = with obs err correlation

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