Assimilation of HF radar currents in the Iroise Sea using EnKF/EnOI

Third Workshop on Remote Ocean Sensing

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Actimar, Brest, France

October 12, 2011

1. Introduction
2. Assimilation
   - EnOI in passive mode
   - EnKF
3. Statistical forecasts
4. Conclusions and perspectives

1 Introduction

2 Assimilation
- EnOI in passive mode
- EnKF

3 Statistical forecasts

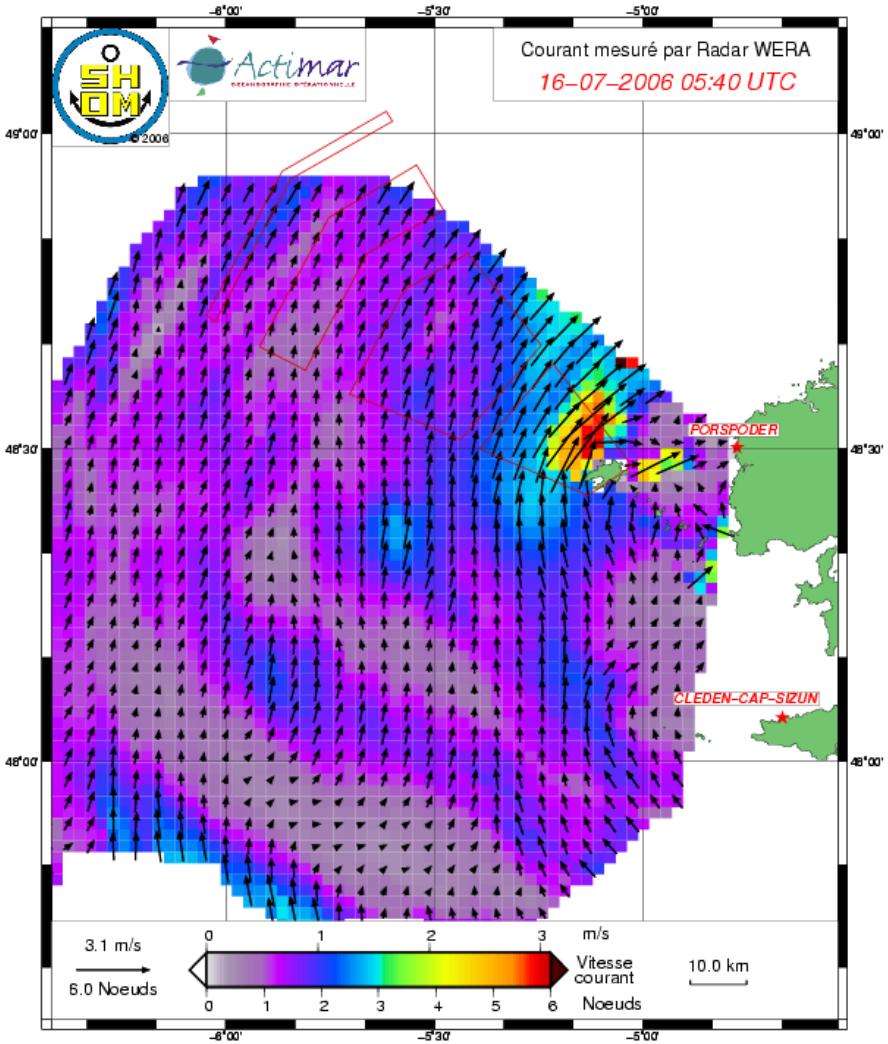
4 Conclusions and perspectives

Actimar

Brest, France

- Small private company (25).
- Interested in operational oceanography.
- This work:
  - Intersection of two “teams“: HF radar management + Ocean modelization and assimilation.
  - Very weakly funded (Stradivarius project). Be tolerant!
  - First steps toward good short term predictions of sea state (mainly currents).
- Among the potential applications: stochastic predictions of leeway trajectories.

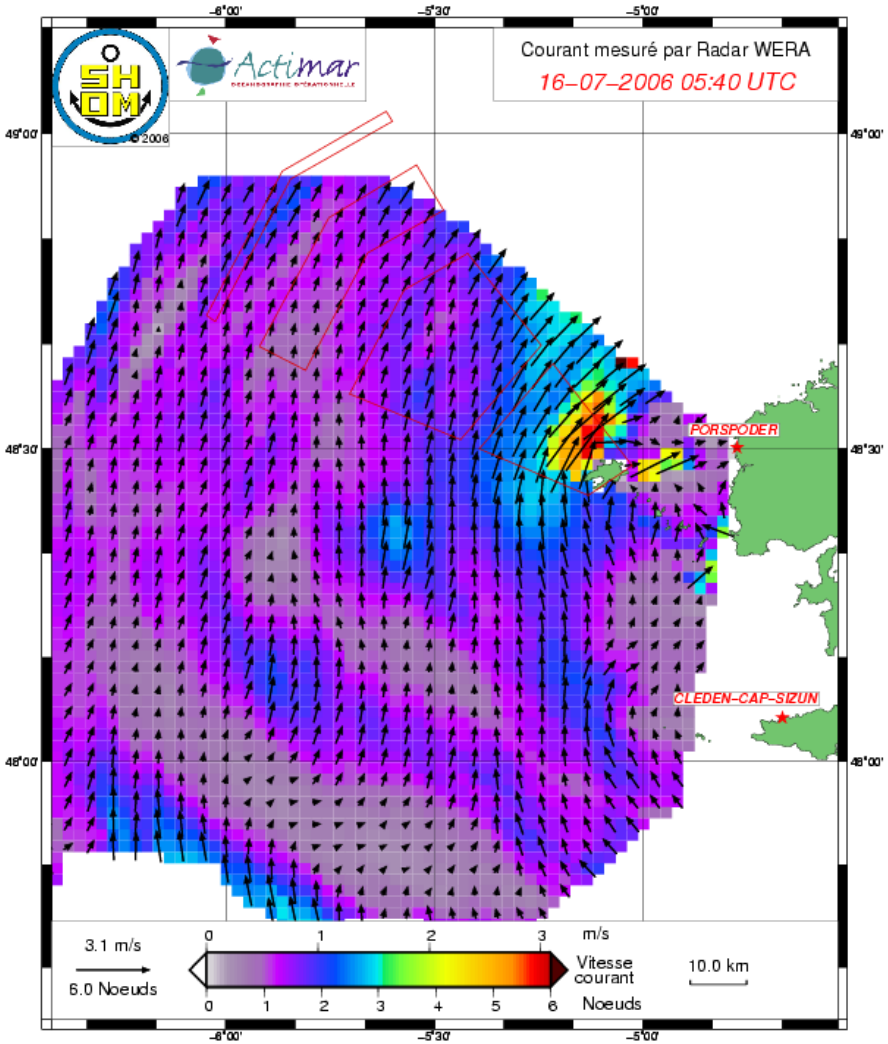
HF radars in the Iroise Sea



Emission

Reception

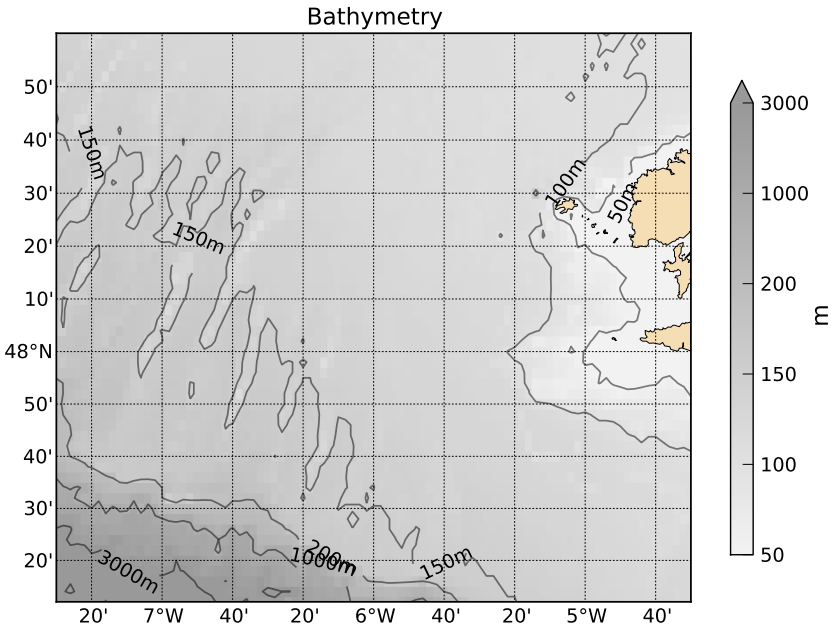
HF radars in the Iroise Sea



- Operated by Actimar for the SHOM since 2006.
- WERA 12.4 MHz.
- Reception: 16 antennas, BeamForming.
- Currents every 20 mn

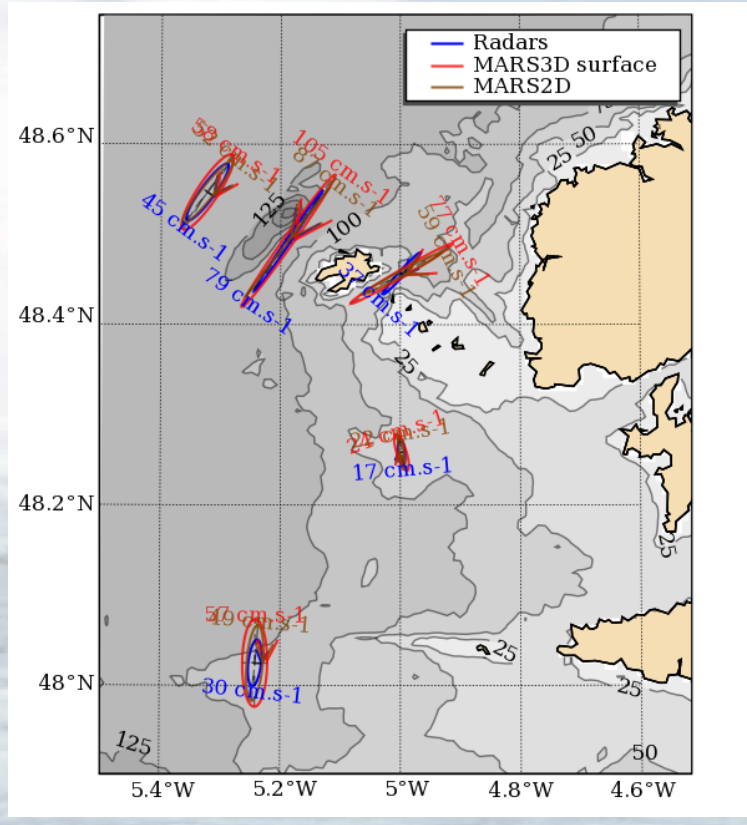
Iroise Sea

Bathymetry and currents



- On the shelf (above 200m).
- Islands.

M2 signal

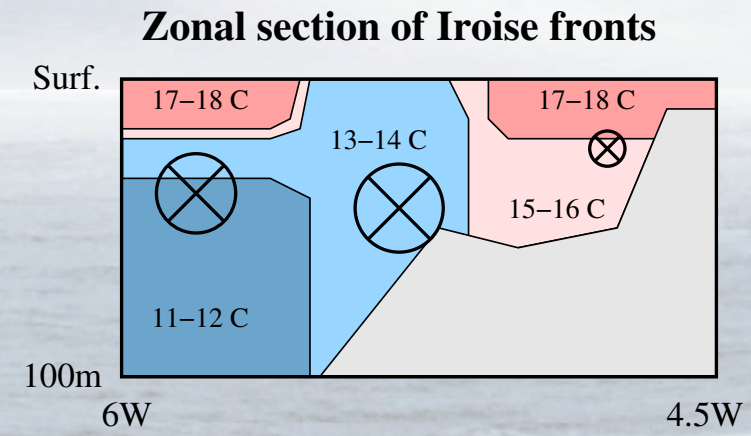


- Mainly driven by tidal currents.
- Strong atmospheric forcings and way-induced mixing may occur → effect on surface currents.
- Models overestimate tidal currents (MARS, ROMS).

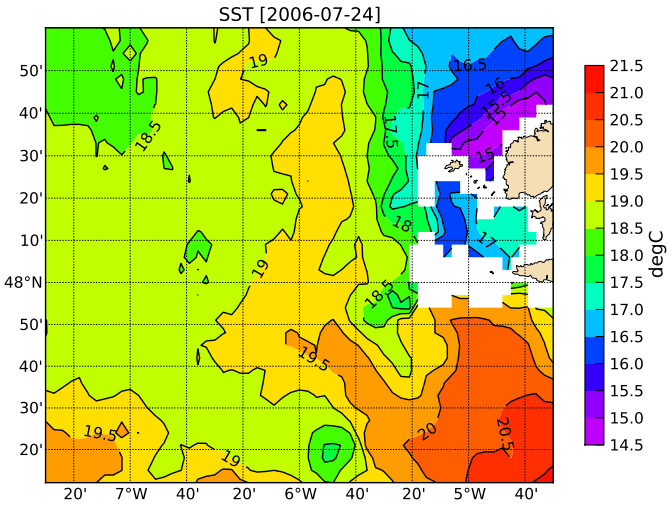
Iroise Sea

Thermodynamics (in summer)

- Vertical physics.
- Shallow areas: merge bottom and top mixing.



- Stratification for bottom depths $>$ 90m in summer.
- Frontal zones.



Among the effects on currents

- Density currents along SST fronts.
- Increased stratification impacts surface currents.

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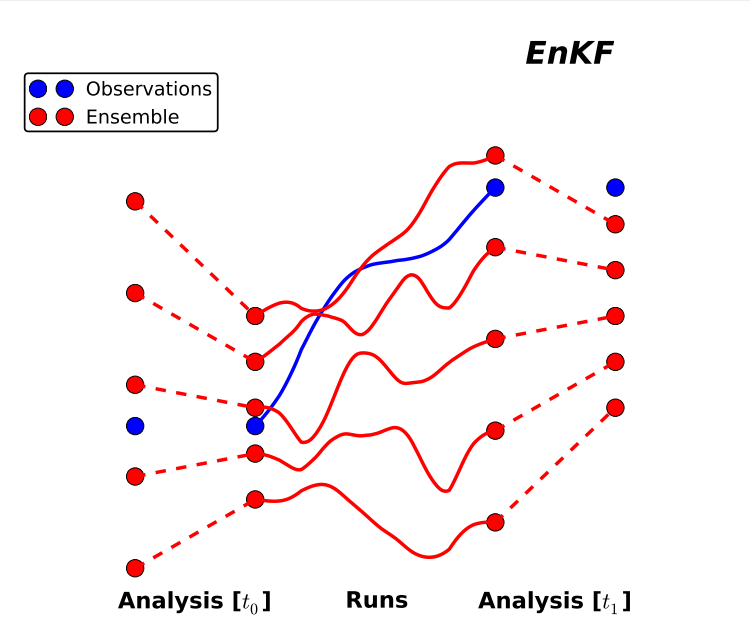
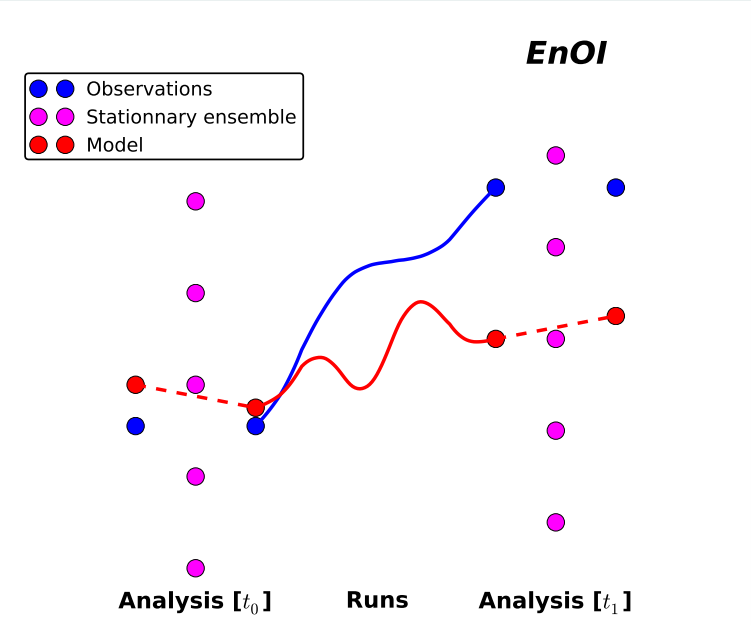
EnKF and EnOI

Ensemble Kalman Filter



- Generation of errors: model parameters, forcing, initial conditions.
- Need to run *nrens* simulations.
- Generally hard to create model errors.
- Need to not destroy model errors during analysis.

Ensemble Kalman Optimal Interpolation



- Generation of errors: large stationary undersampling, with scale a factor.
- Need to run only one simulation.
- Model errors are less realistic than with EnKF.
- No need to restart the model (in passive assimilation mode).

EnKF and EnOI

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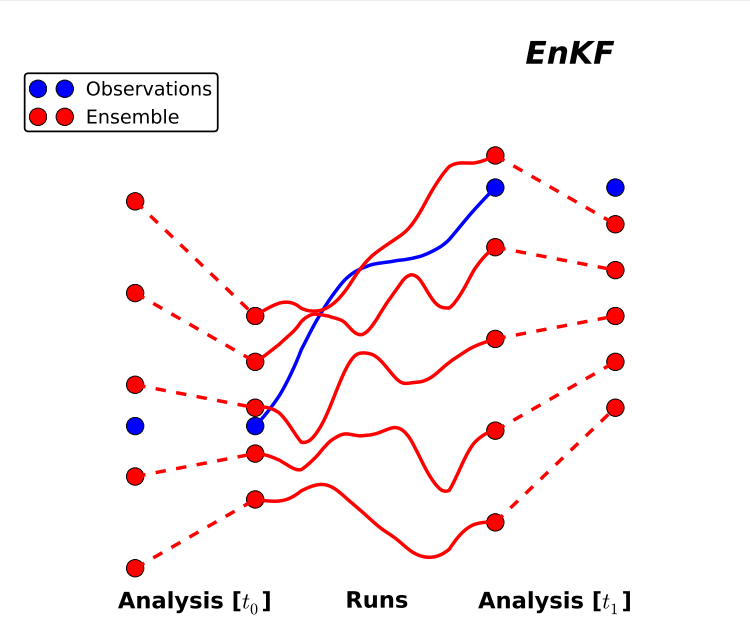

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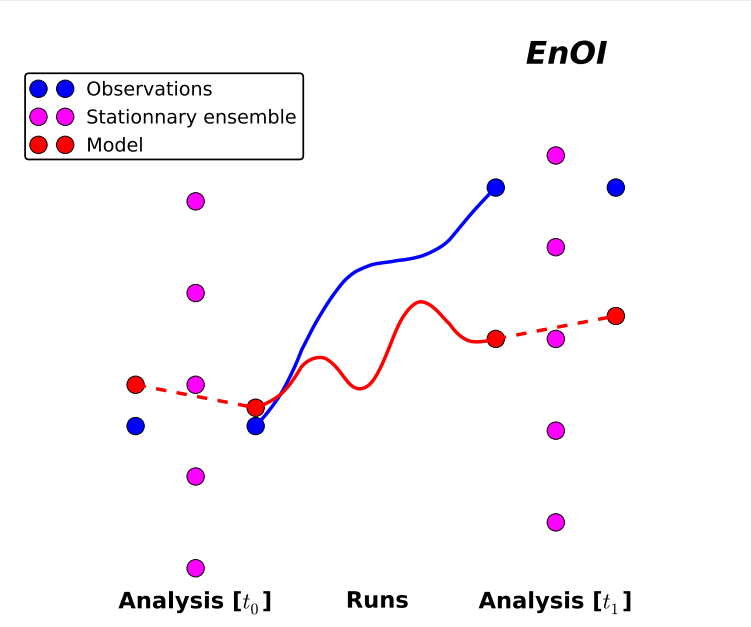

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Model

Source Preliminary tests with archived runs from PREVIMER (IFREMER, France).

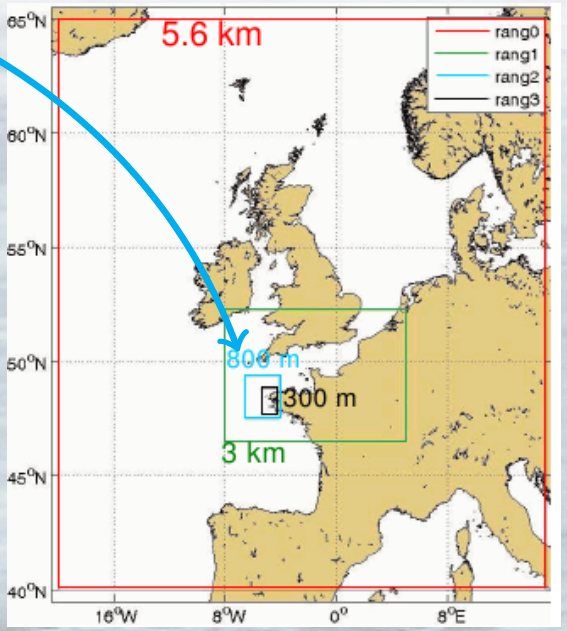
Model MARS3D, rank 2 (800m resolution).

Performances In terms of currents: generally too strong, especially near Ouessant (Ushant) and Sein islands.

Testing period August 2009.

Assimilation The model is not restarted = passive assimilation.

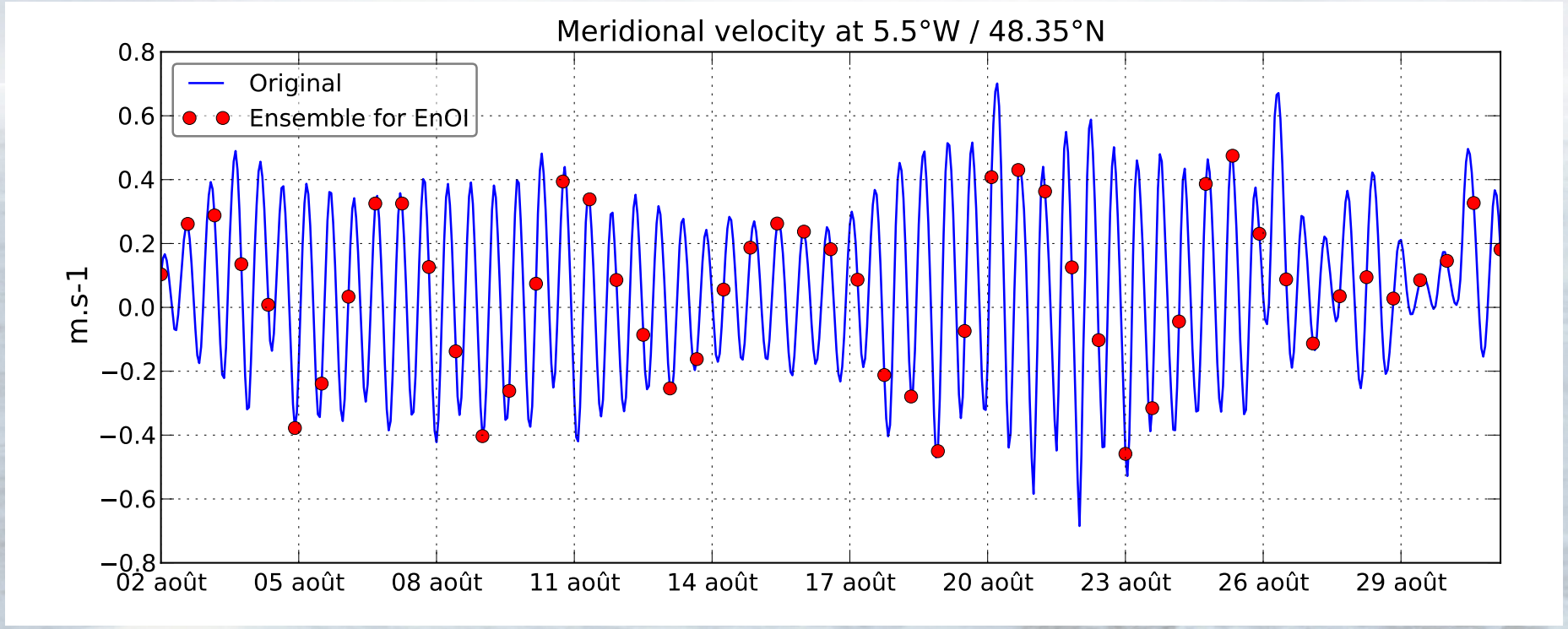
PREVIMER ranks



Errors

Model errors: generation

Ensemble for generating errors is built with en 14-hour undersampling of one month $\longrightarrow$ ensemble of 50 members.

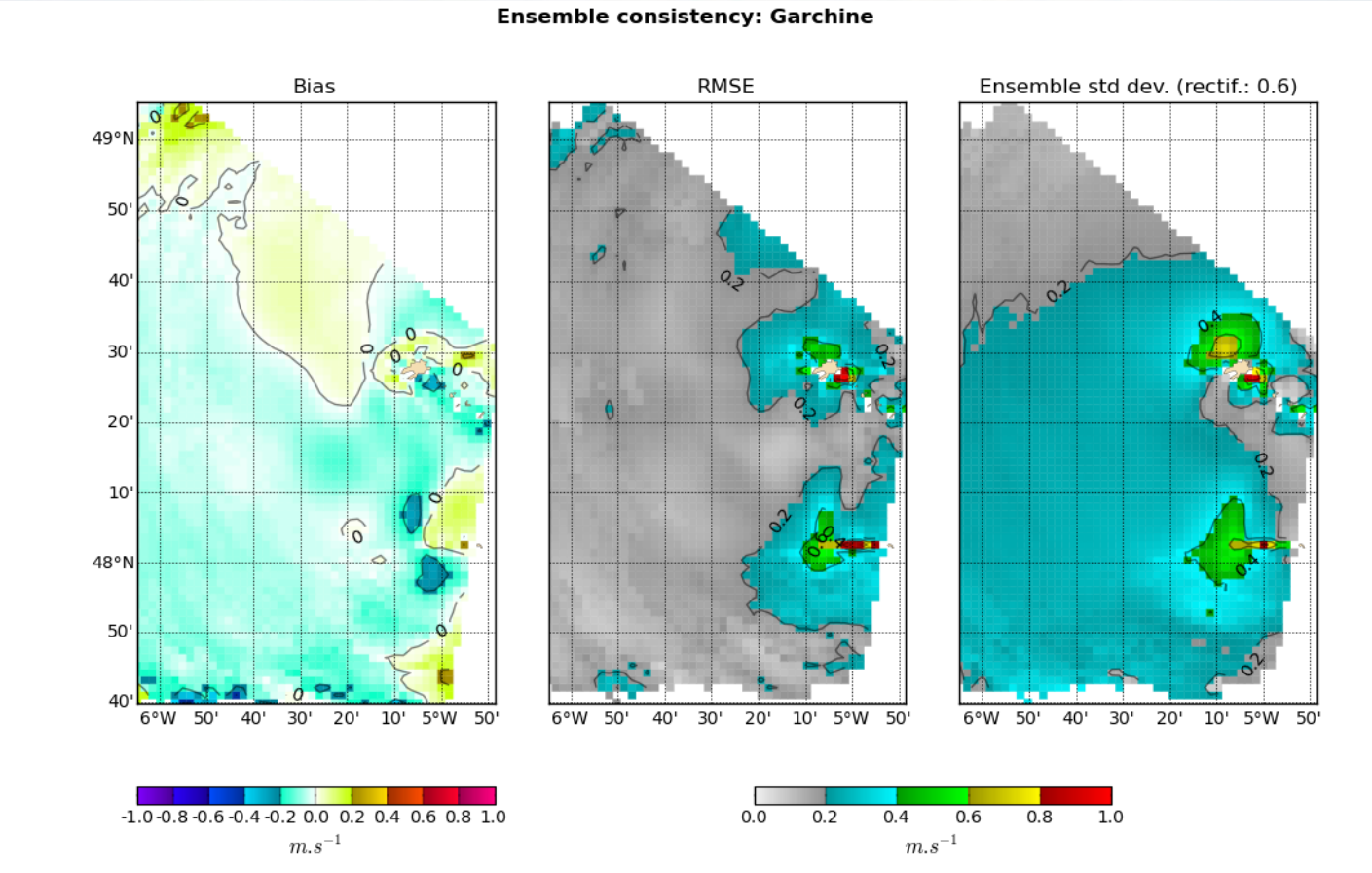


Undersampling a large period gives better results.

Errors

Model errors: consistency

Ensemble variance must be close to model errors for both radars (with a rectification factor).



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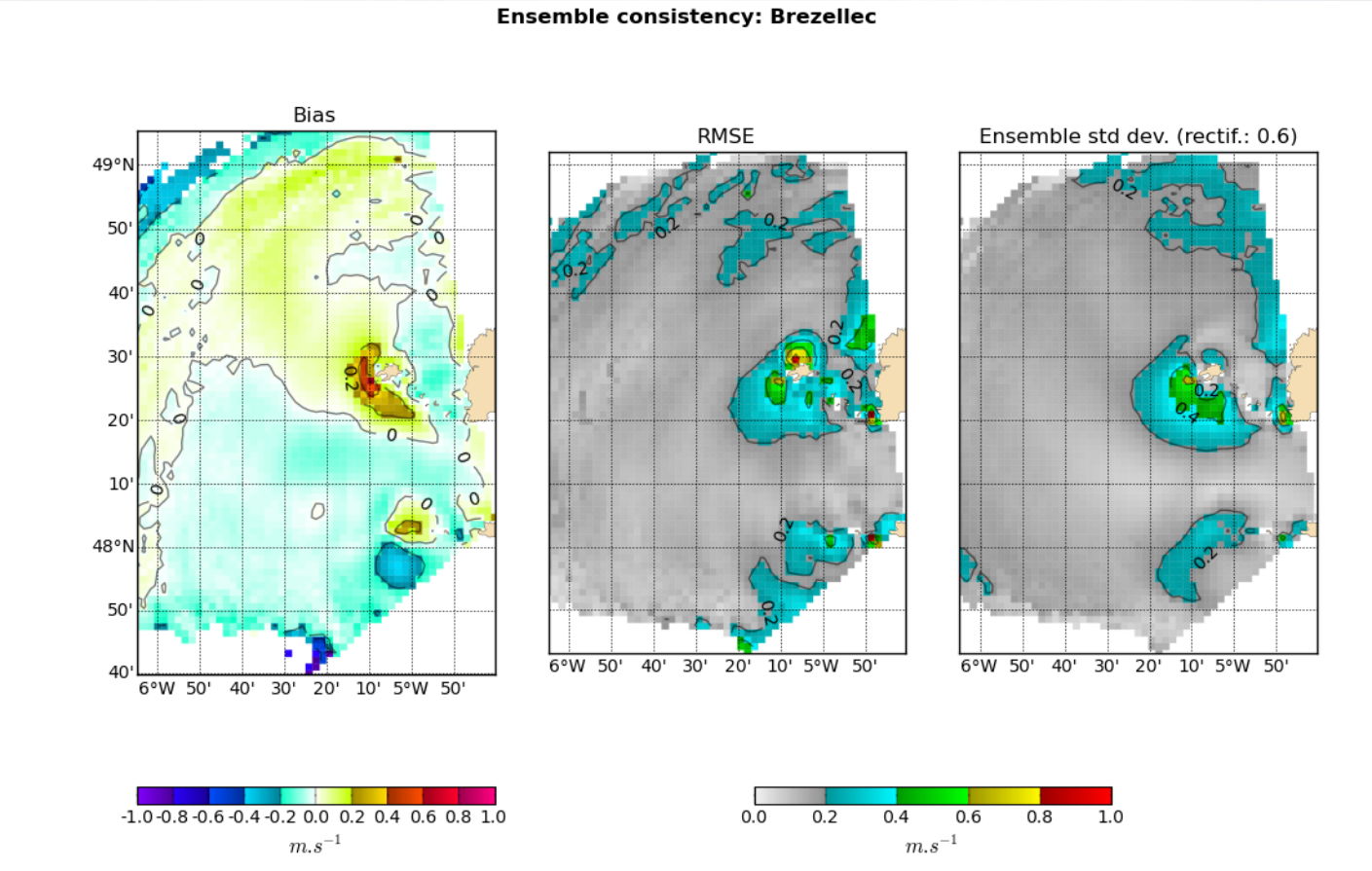

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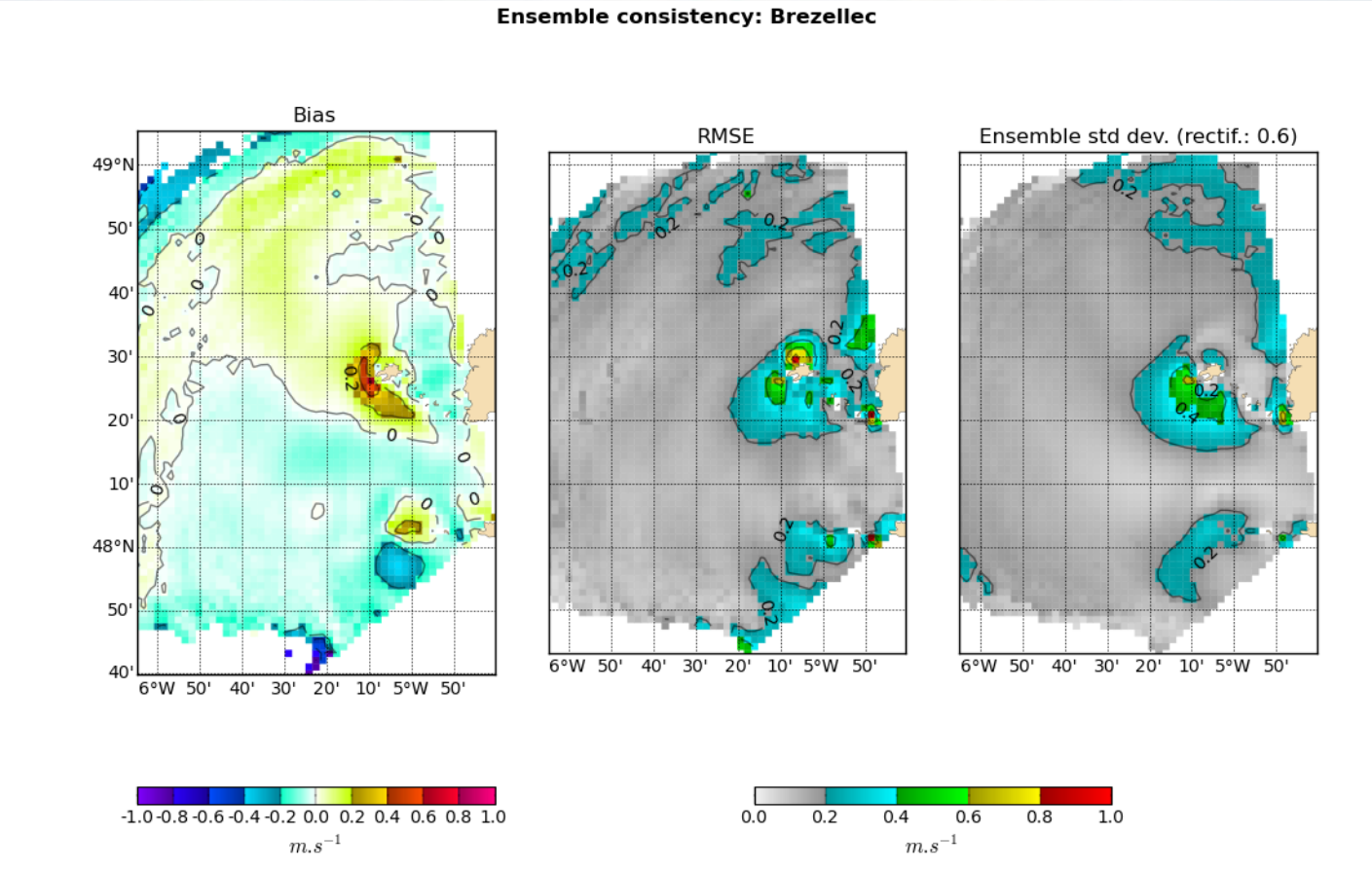


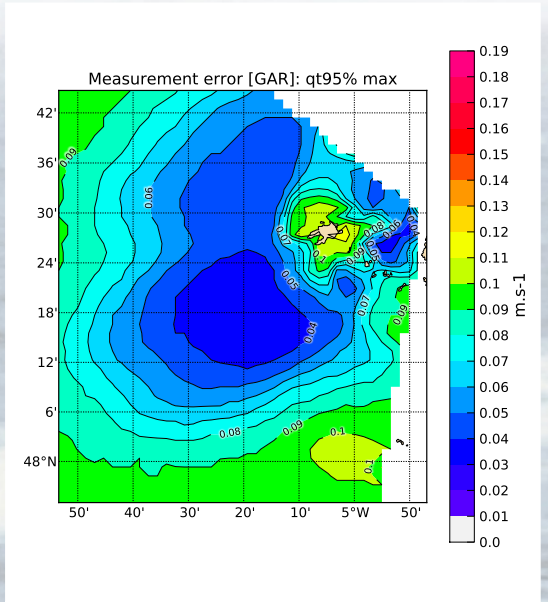
→ **Rectification factor:** 0.6

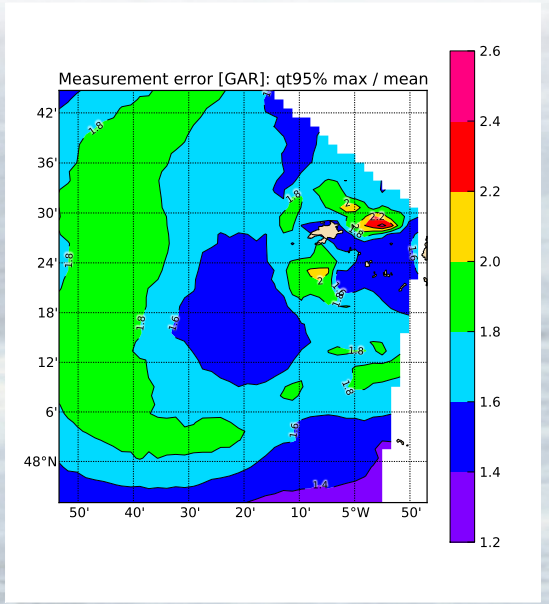
Errors

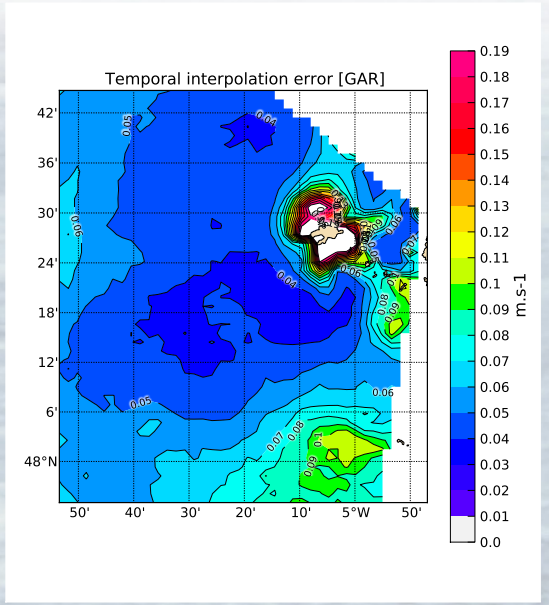
Radar errors

Only error covariances matrix is needed for EnOI ⇒ no need to generate an ensemble.
Two sources of errors for observations:

- from radar measurements → directly interpreted as standard deviation (95% quantile),
- from time ”interpolations“ to nearest hour.







Interpolation errors are weak except around islands.

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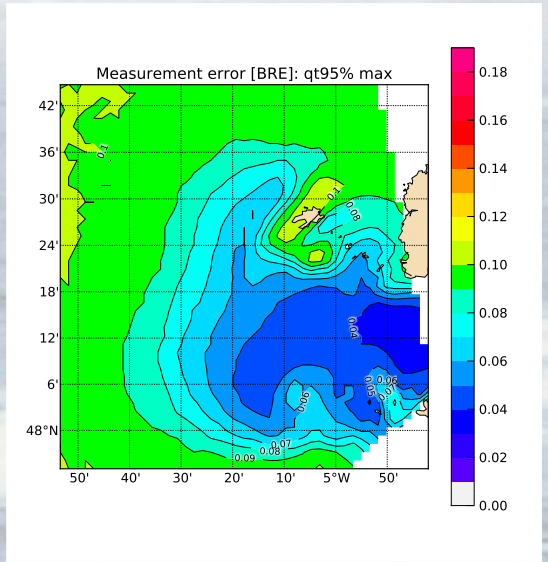
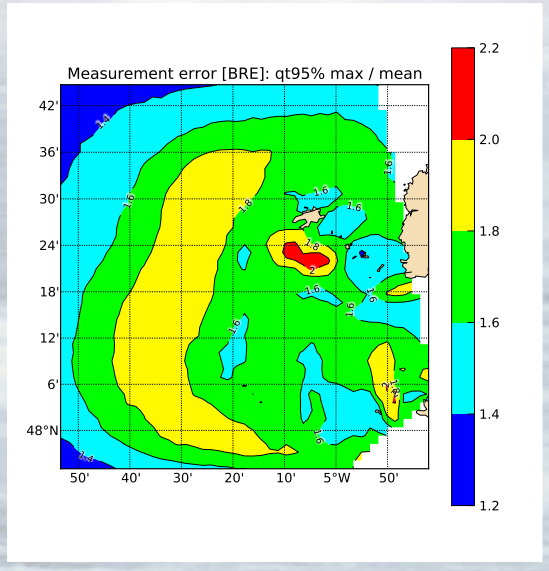
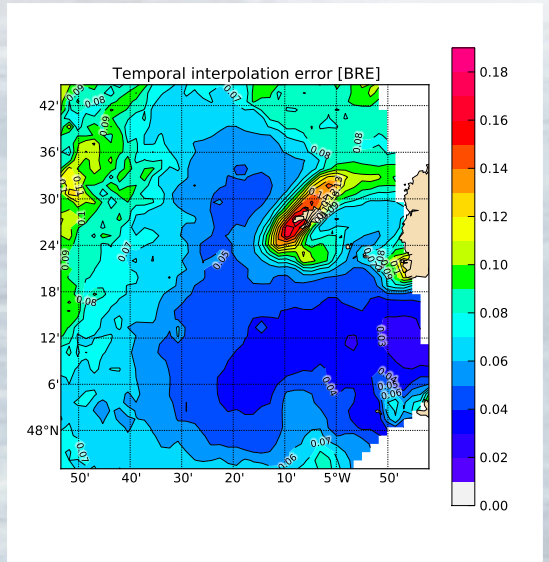






Interpolation errors are weak except around islands.

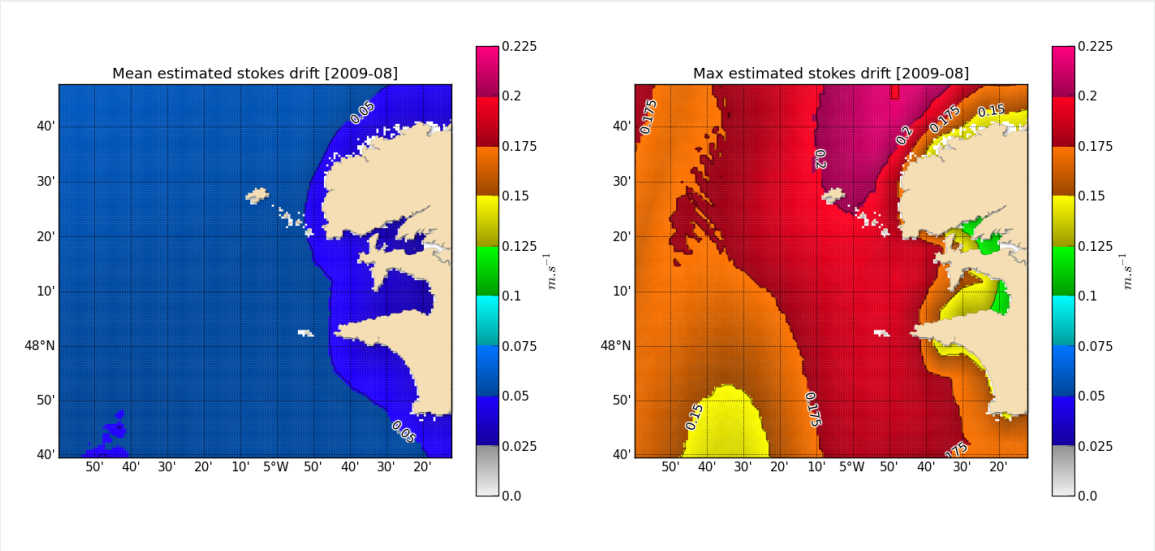
Projection onto radars (*H* operator)

In three steps:

1. Add the Stokes drift.
2. Bilinear interpolation into the radar grid.
3. Projection of components onto the radial axis.

Stokes drift

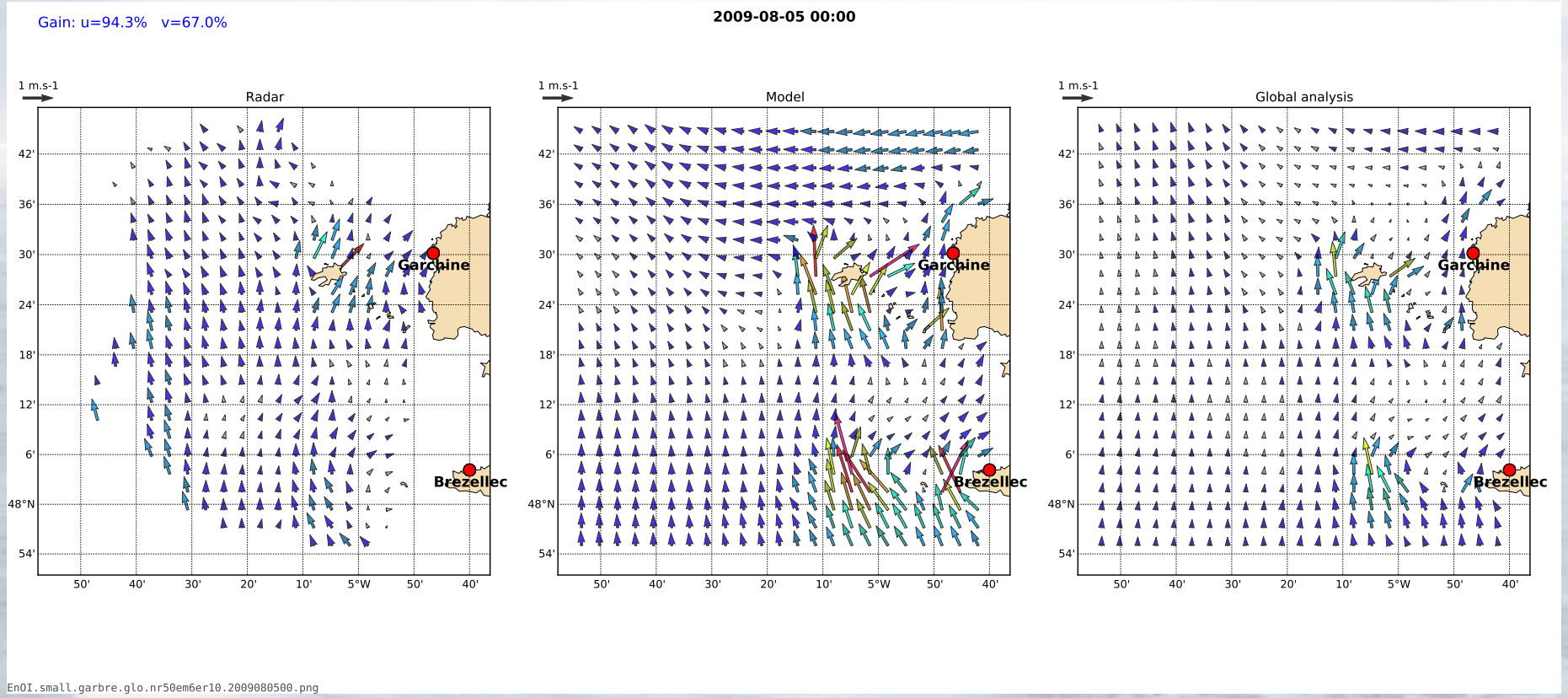
Approximation with two second order polynoms of the 10-meter wind.



Global analyses

Garchine + Brezellec

Examples of hourly analyses over 10 days.



Strong correction. Maybe too much?

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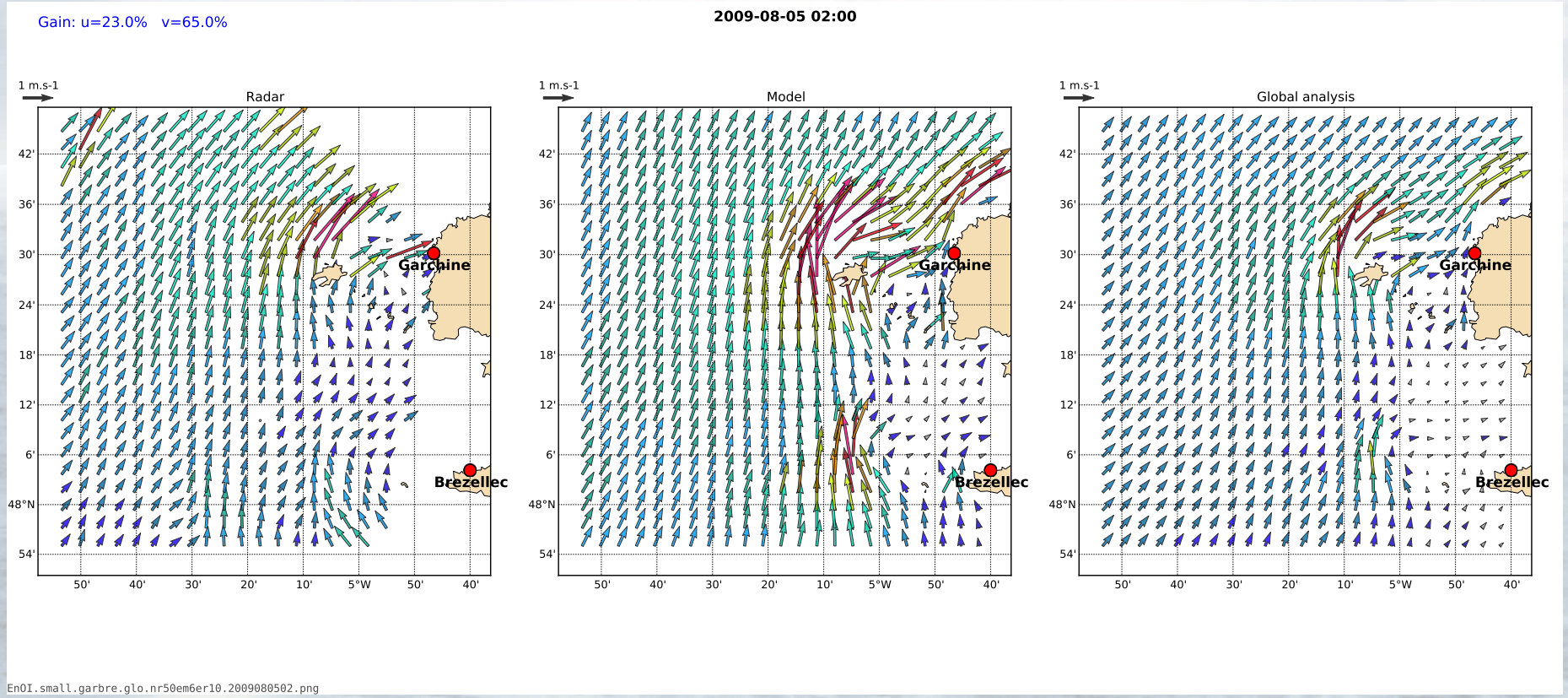

Good correction also in the center, but still not northward double jet in the south.

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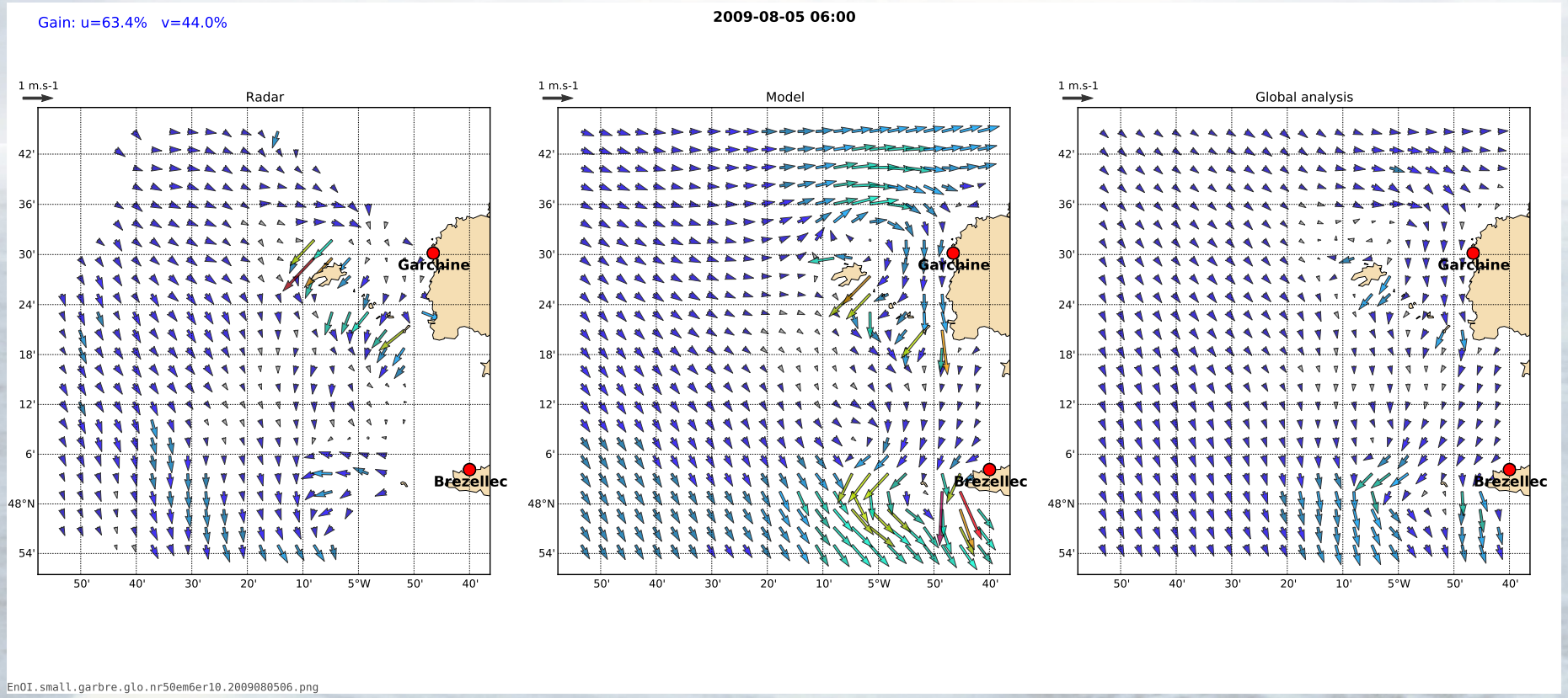

Situation of complex currents.

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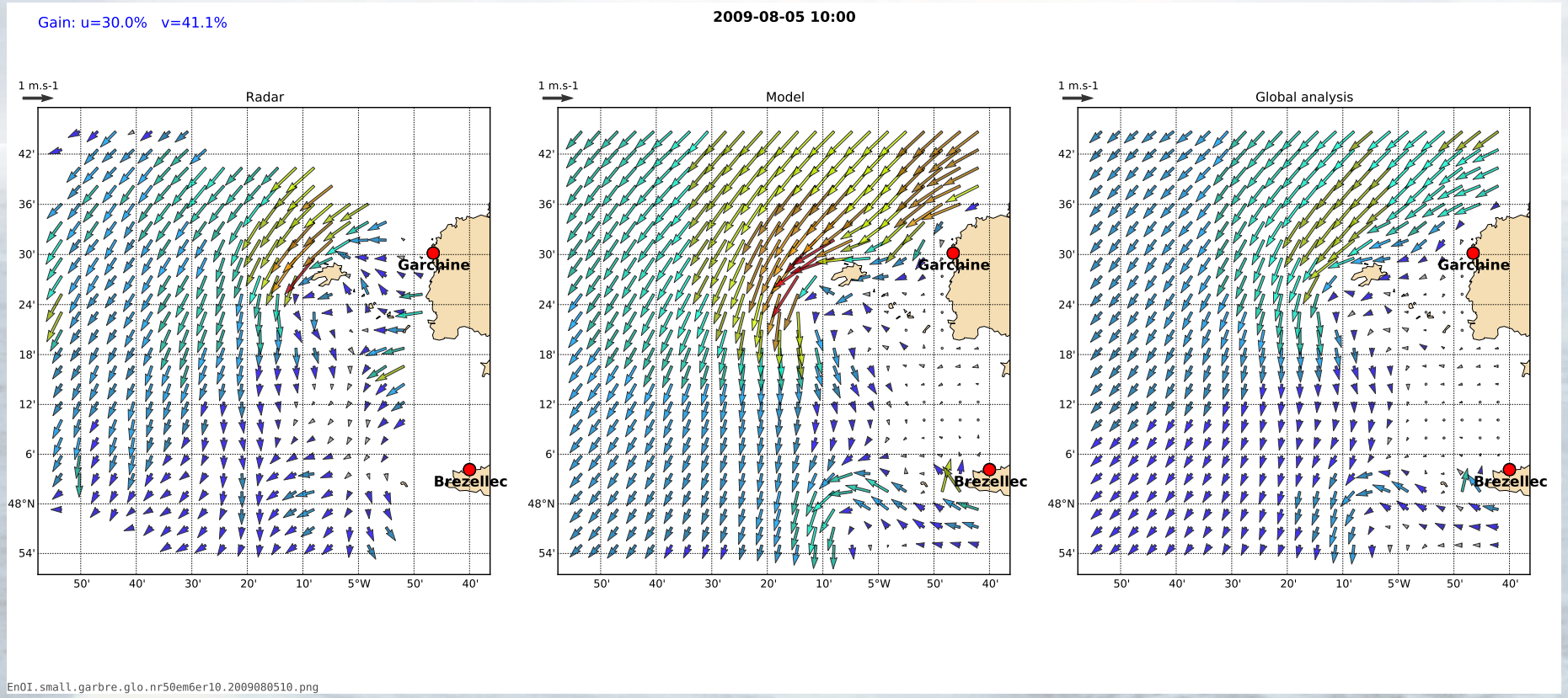

No westward jet in the east.

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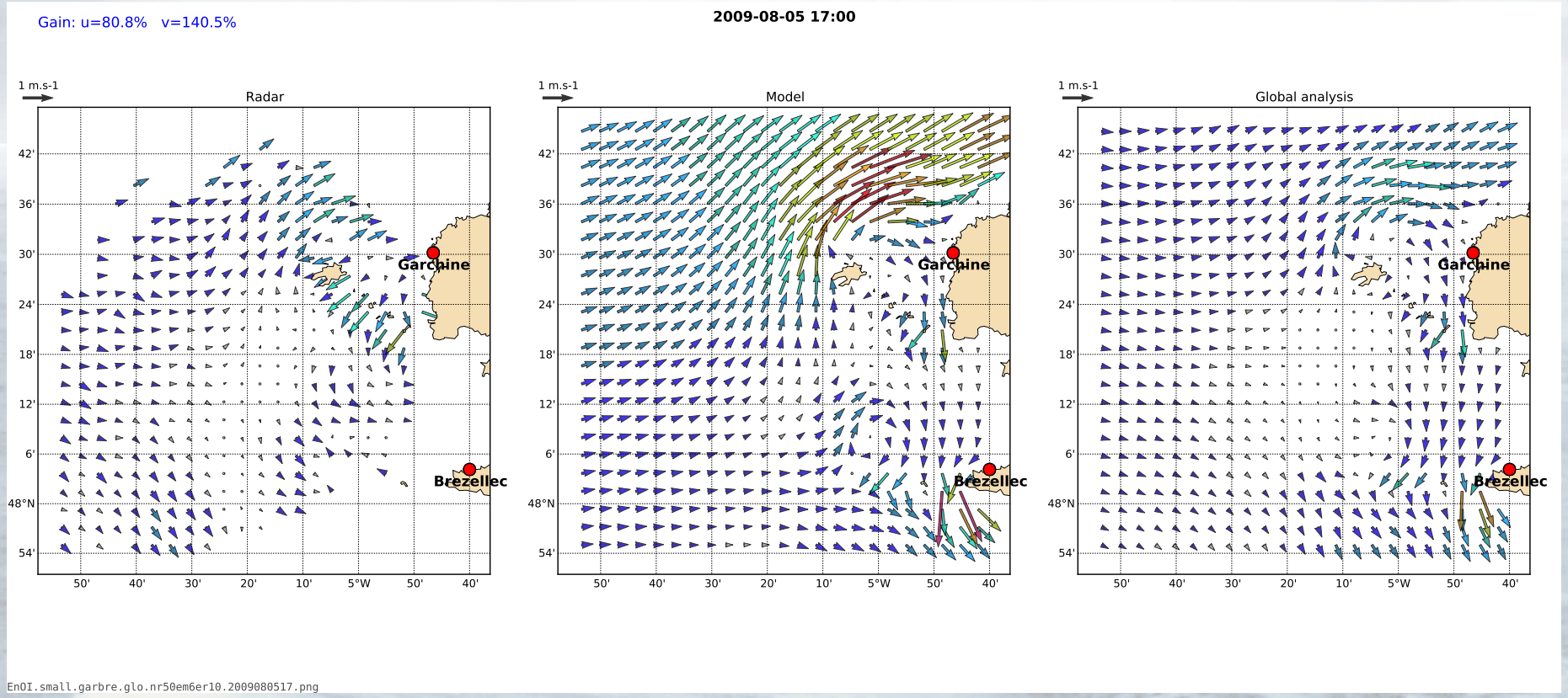


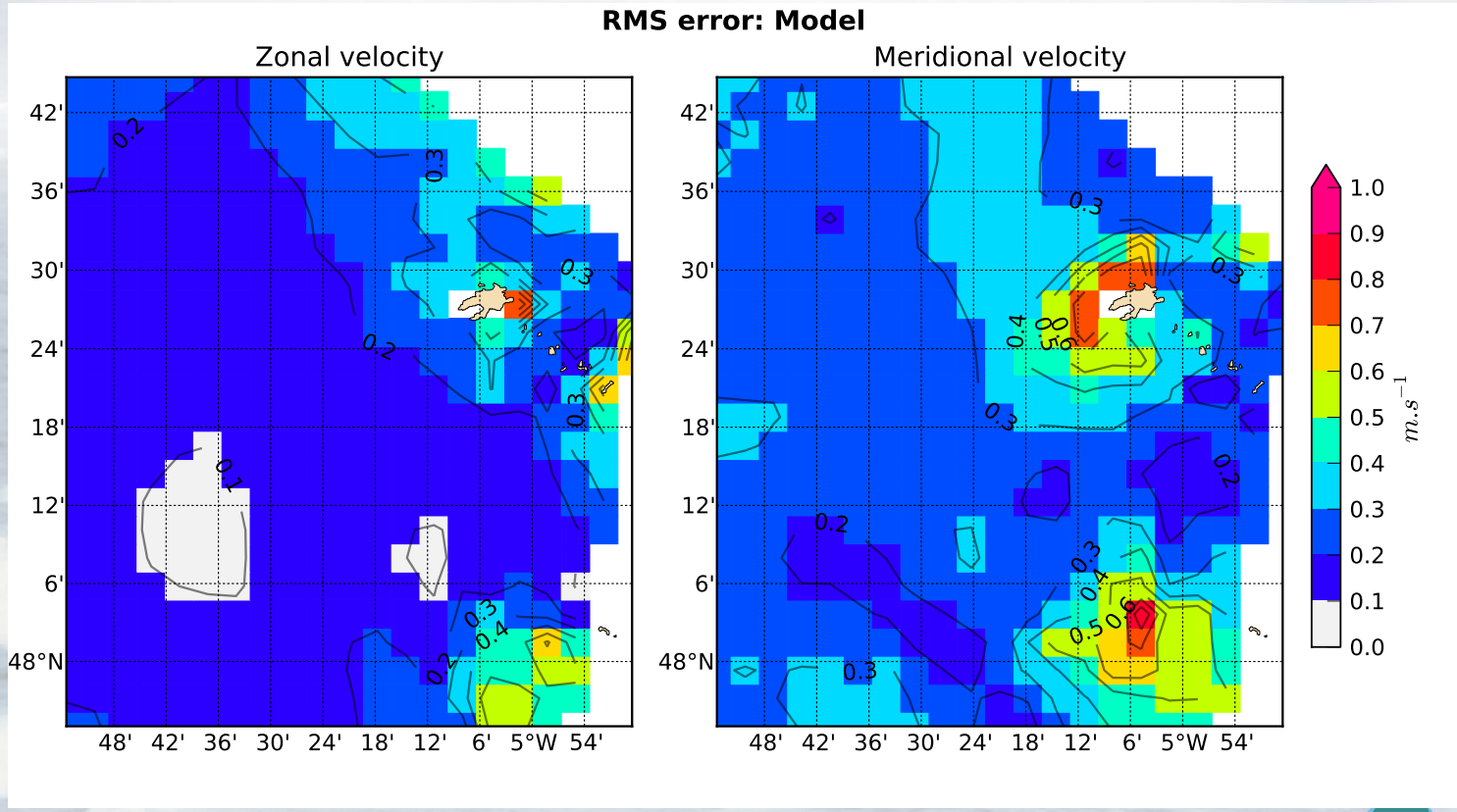
Strong correction in a complex with few data.

Global analyses

Garchine + Brezellec

Temporal statistical performances.

Gain of analysis over forecast [%] : $100\left(\frac{RMSE(forecast)}{RMSE(analysis)} - 1\right)$ ($\rightsquigarrow <$ 0 means no gain).



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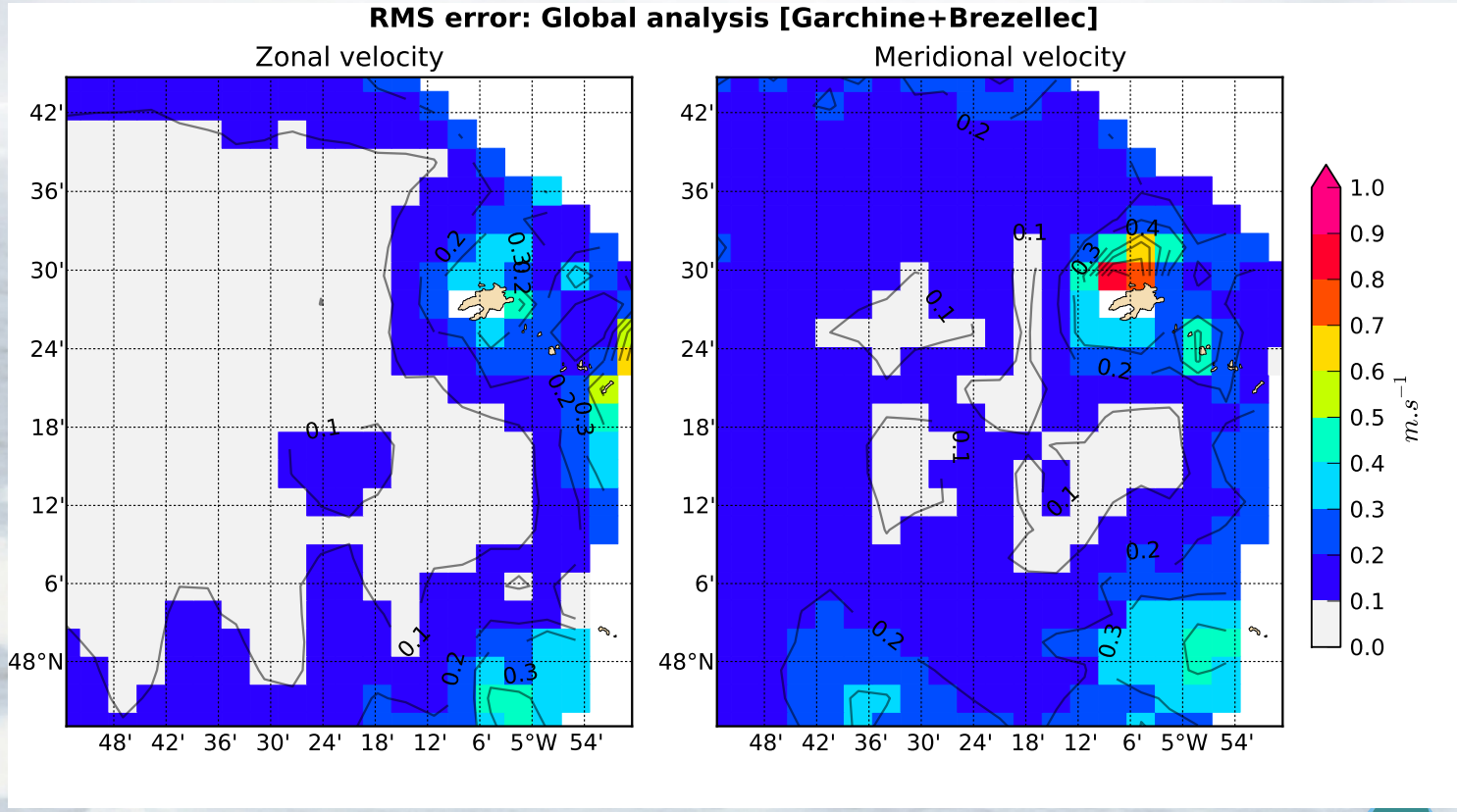

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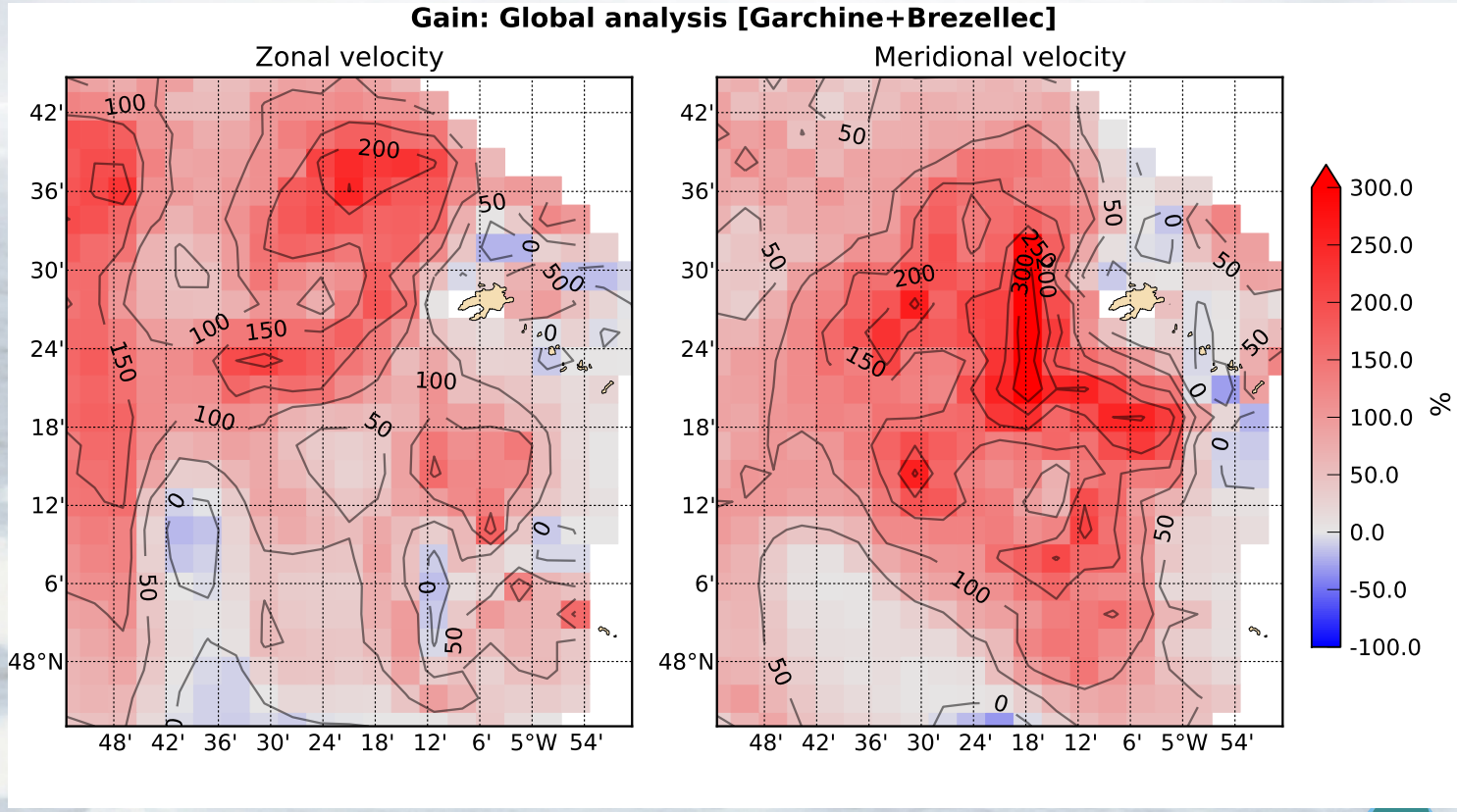


Localization

Why?

Correction of single model points with close observations.

Positive side Prevent remote corrections when no real physical relationships between errors.

Negative side

- Use less observations $\Rightarrow$ sometimes cannot correct.
- More time consuming.

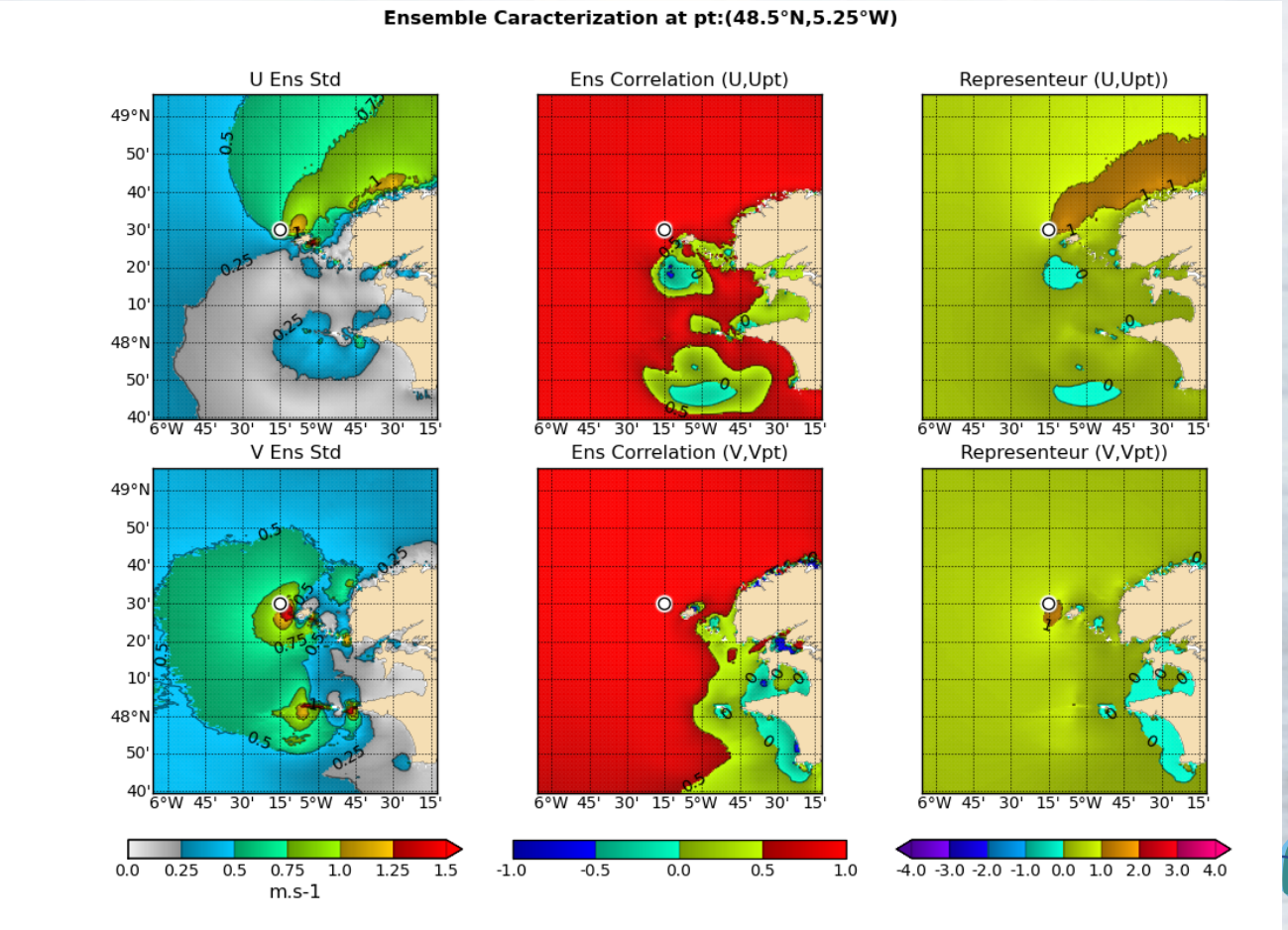
And how about the Iroise Sea ?

Localization

Iroise Sea

Strong statistical relationships due to tidal forcing, but physical relationships of model errors not clear.

Notion of representer: $\frac{COV(mod, mod_{pt})}{VAR(mod_{pt})} \rightsquigarrow$ impact over the domain of an analysis of one observation at point *pt*.



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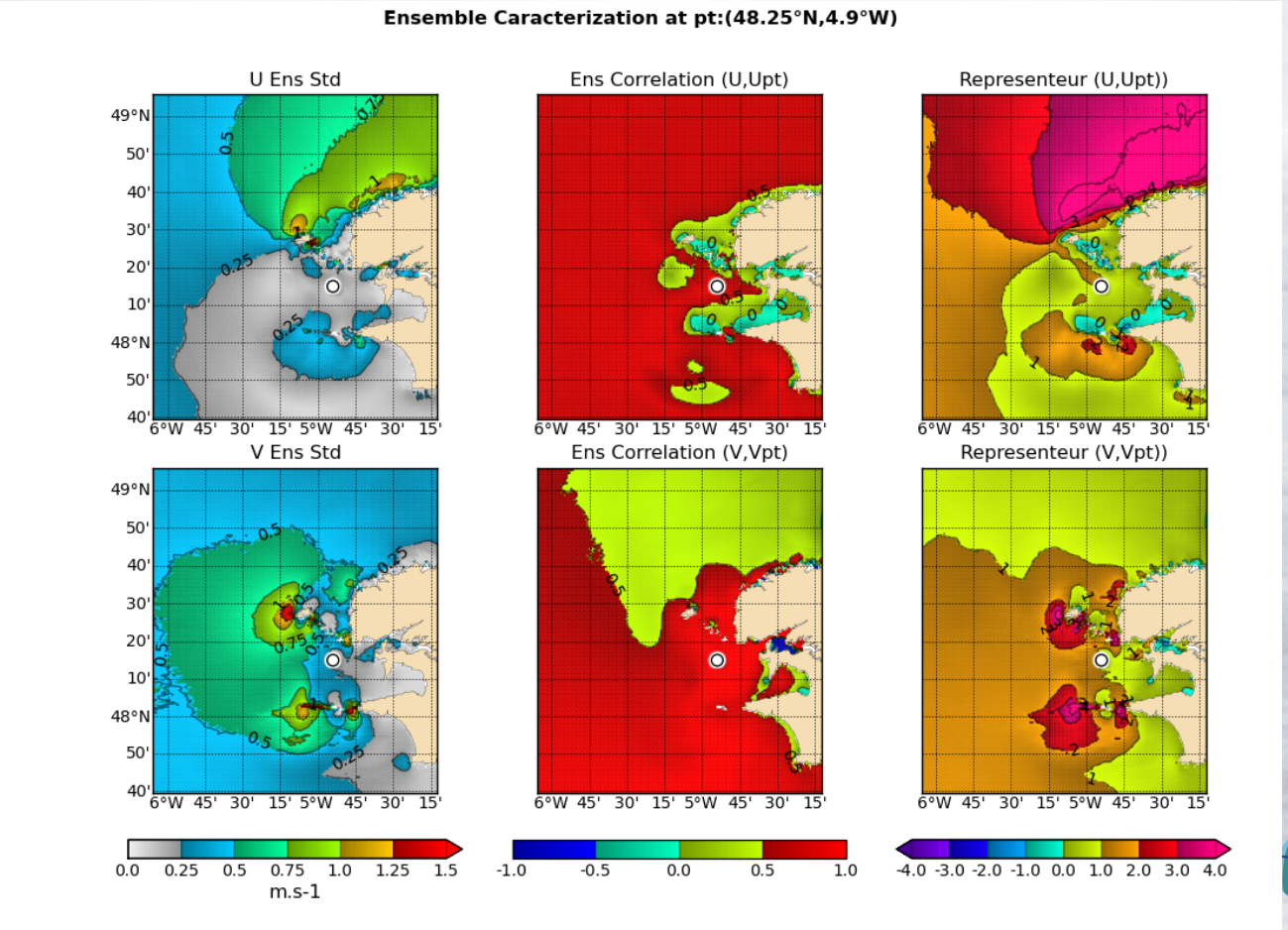
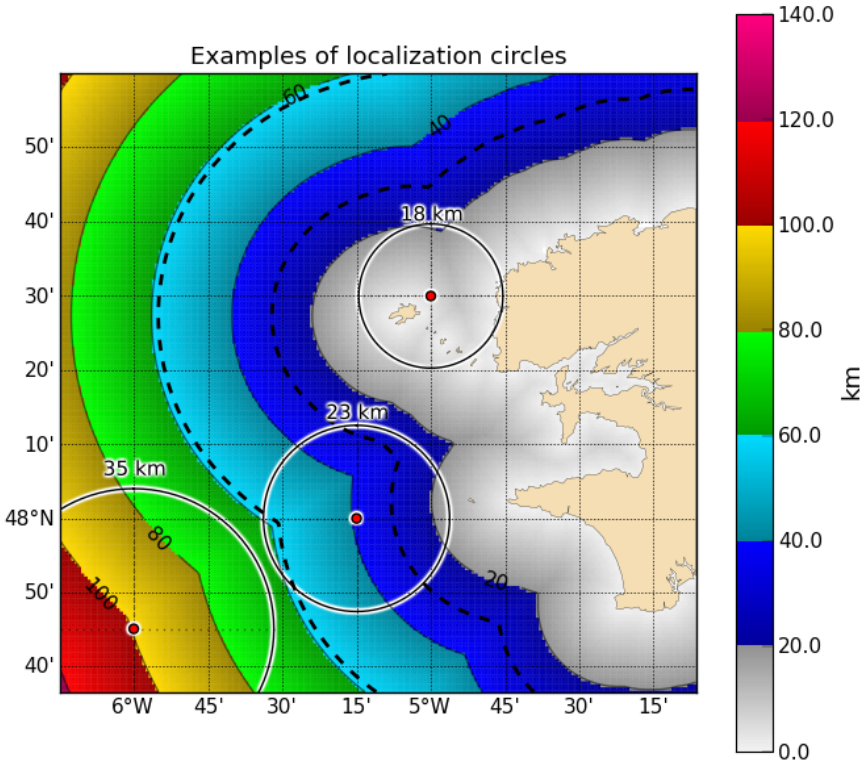
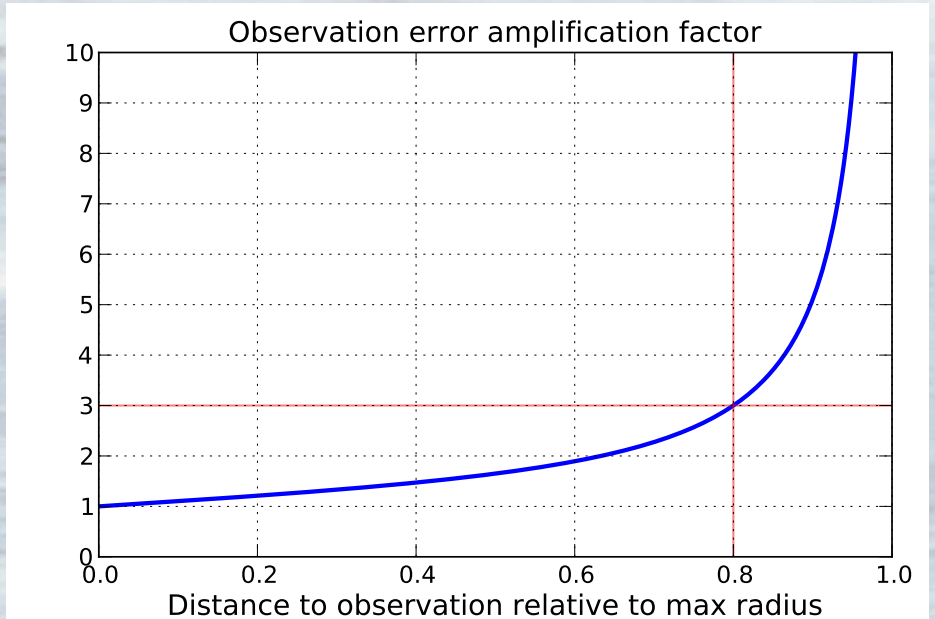


Localization

Implementation

- Radius R is a function of distance to coast D: $R_{min} < \alpha D < R_{max}$ with $0 < \alpha < 1$.
- Observation errors are amplified inside the circle of proximity with distance to center $\longrightarrow$ prevent strong discontinuities.

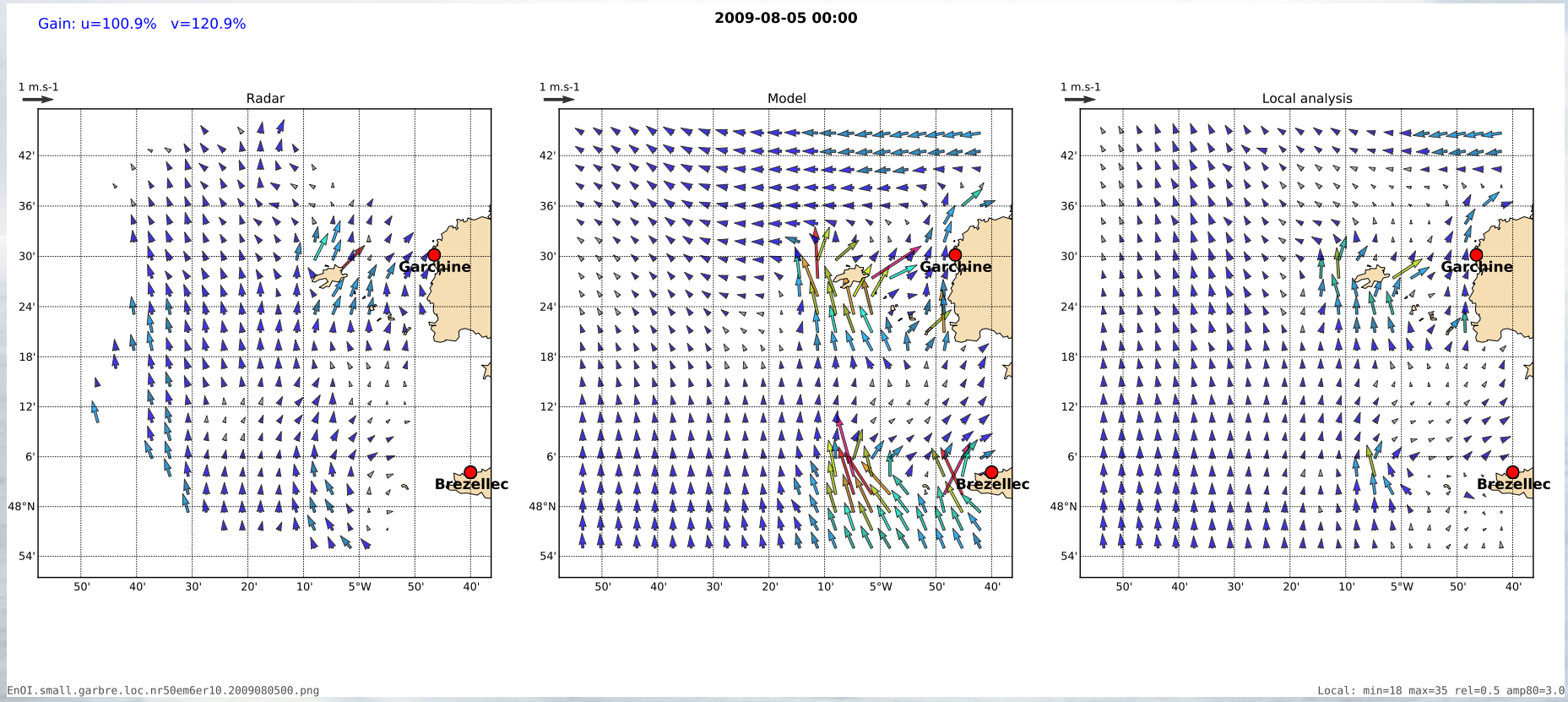




Local analyses

Garchine + Brezellec

Local analysis



- Reduced damping offshore.
- Better corrections near Sein.

Local analyses

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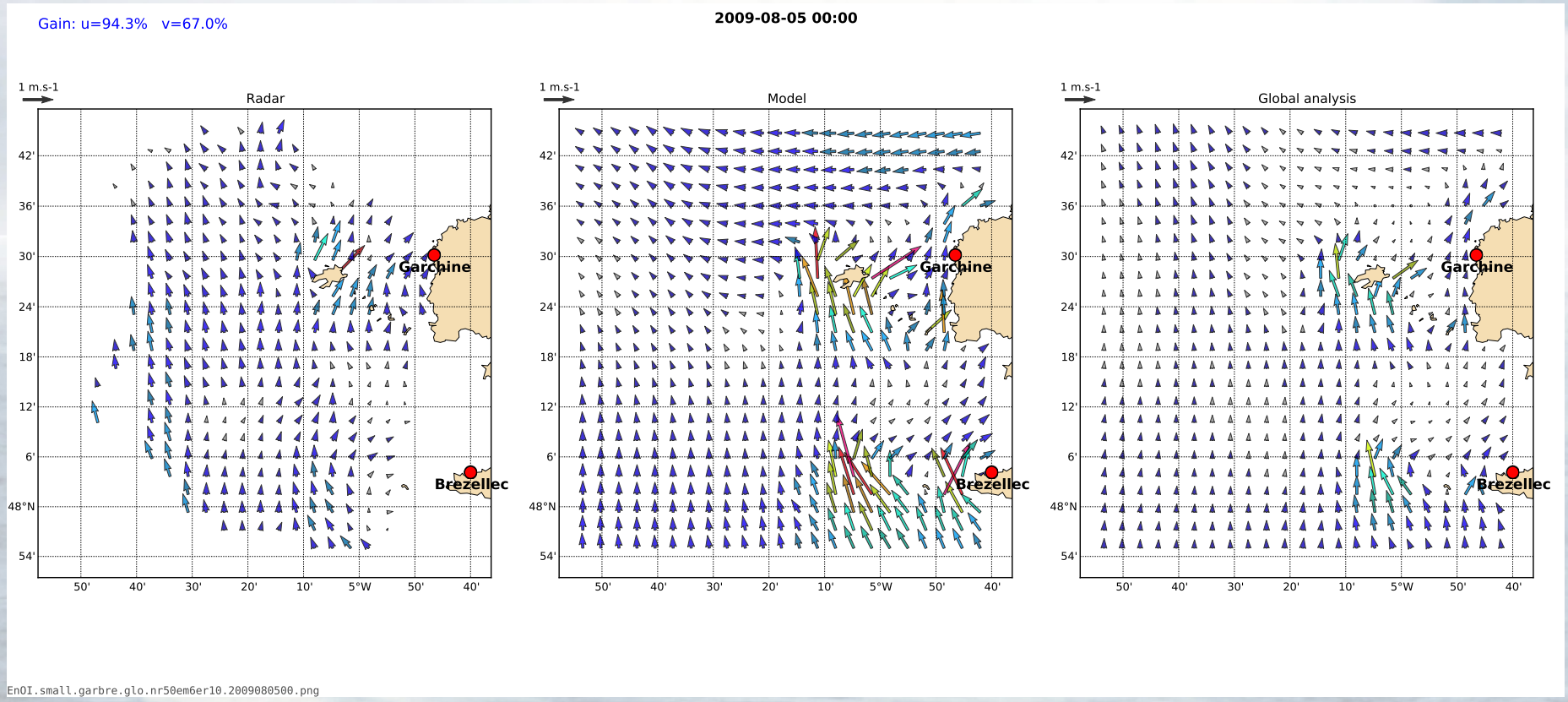
Global analysis



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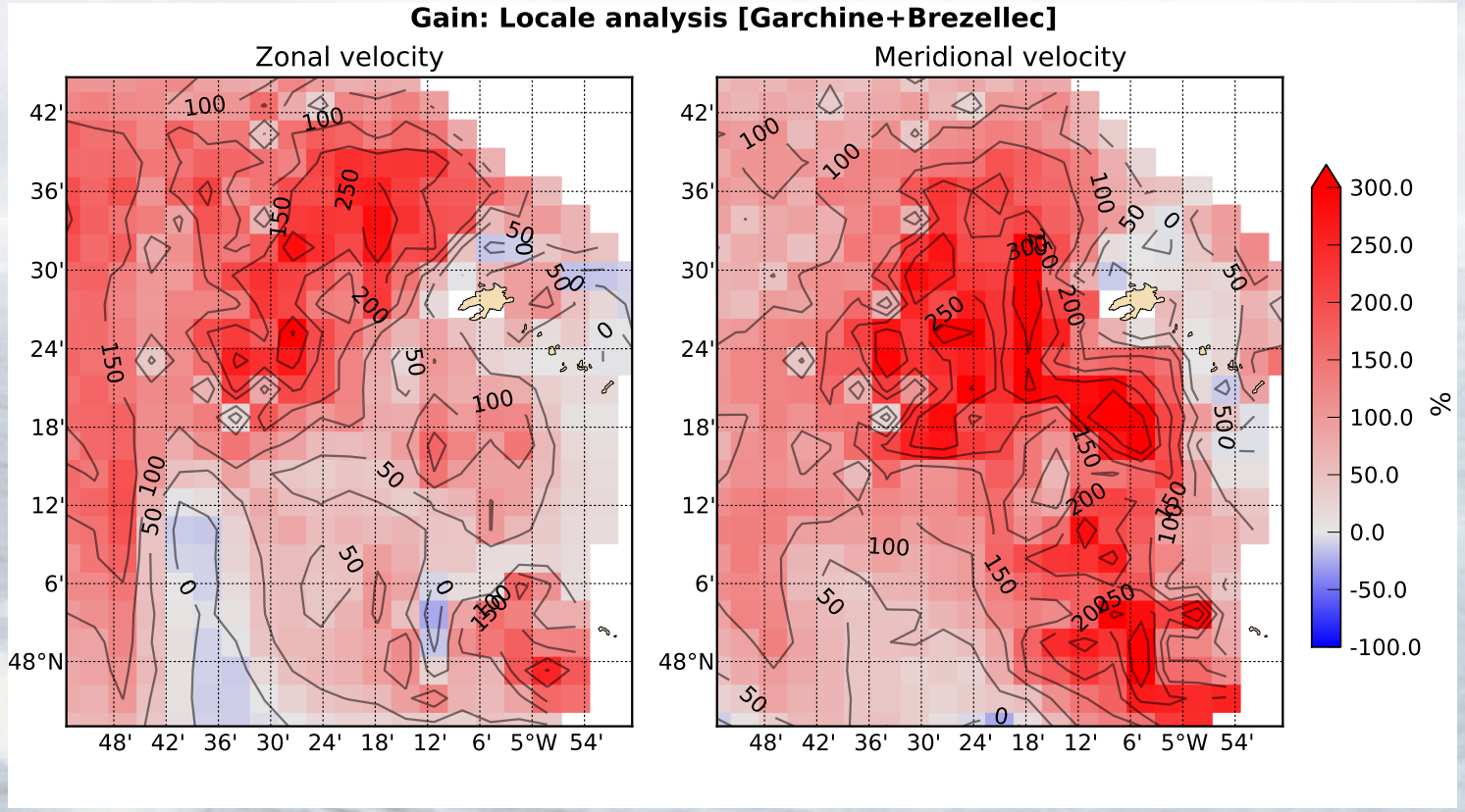

Better corrections also between the Iroise fronts (center).

Local analyses

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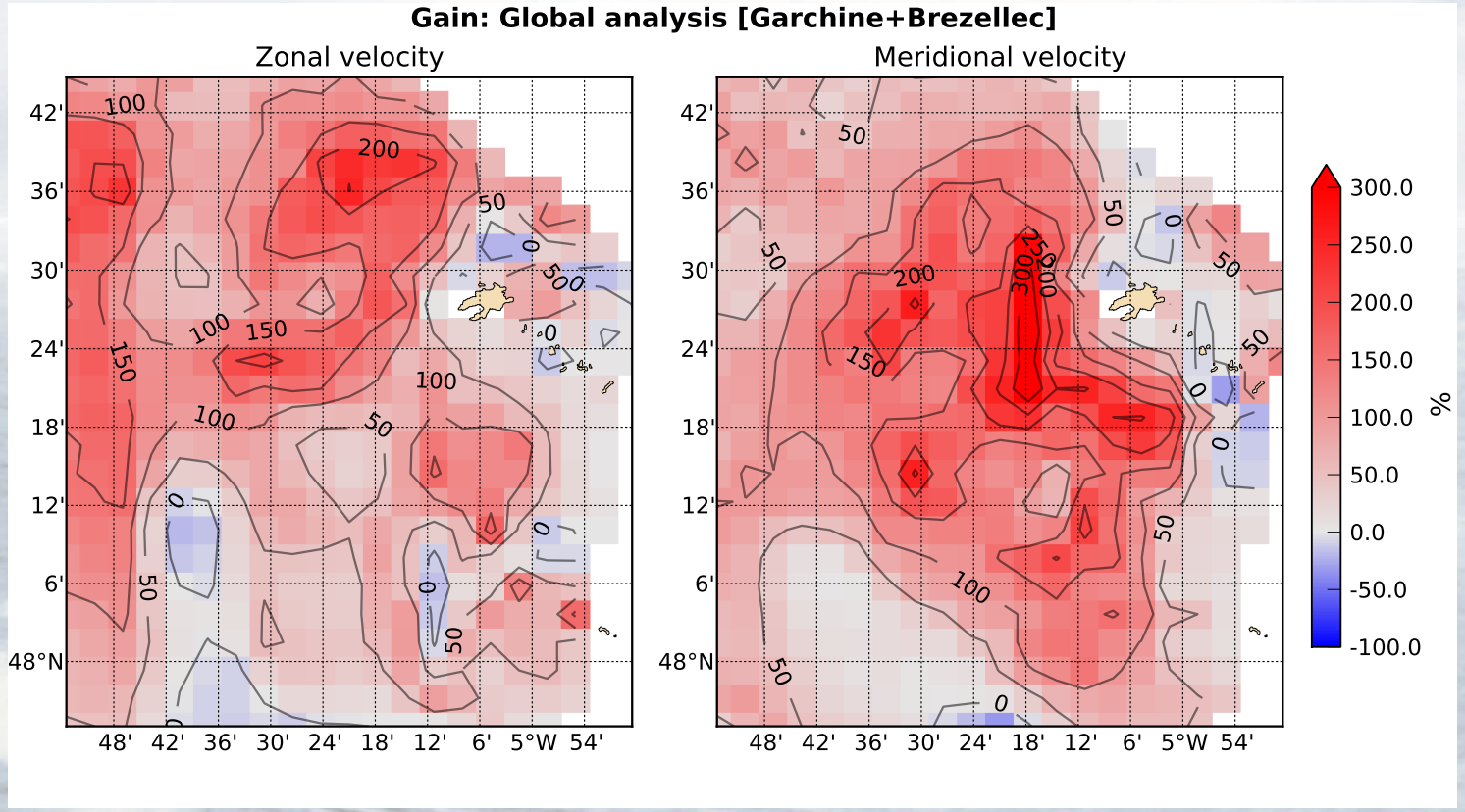

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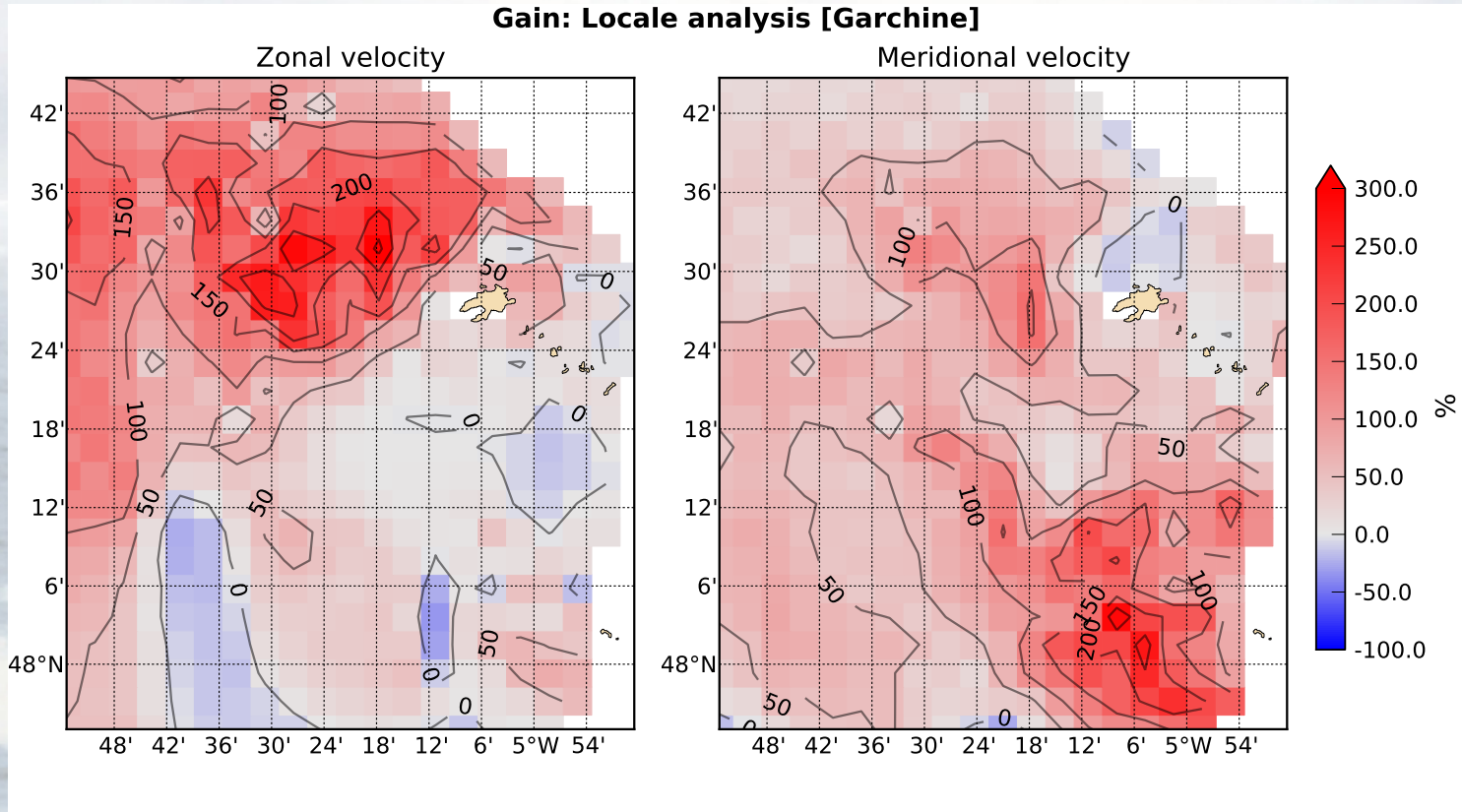
Local analyses

Garchine only

Now work with only one radar.



Garchine-only less efficient with zonal velocity in the south and meridional velocity in the north (orthogonal velocities) → efficiency of correction depends on the direction of currents, but it still good!

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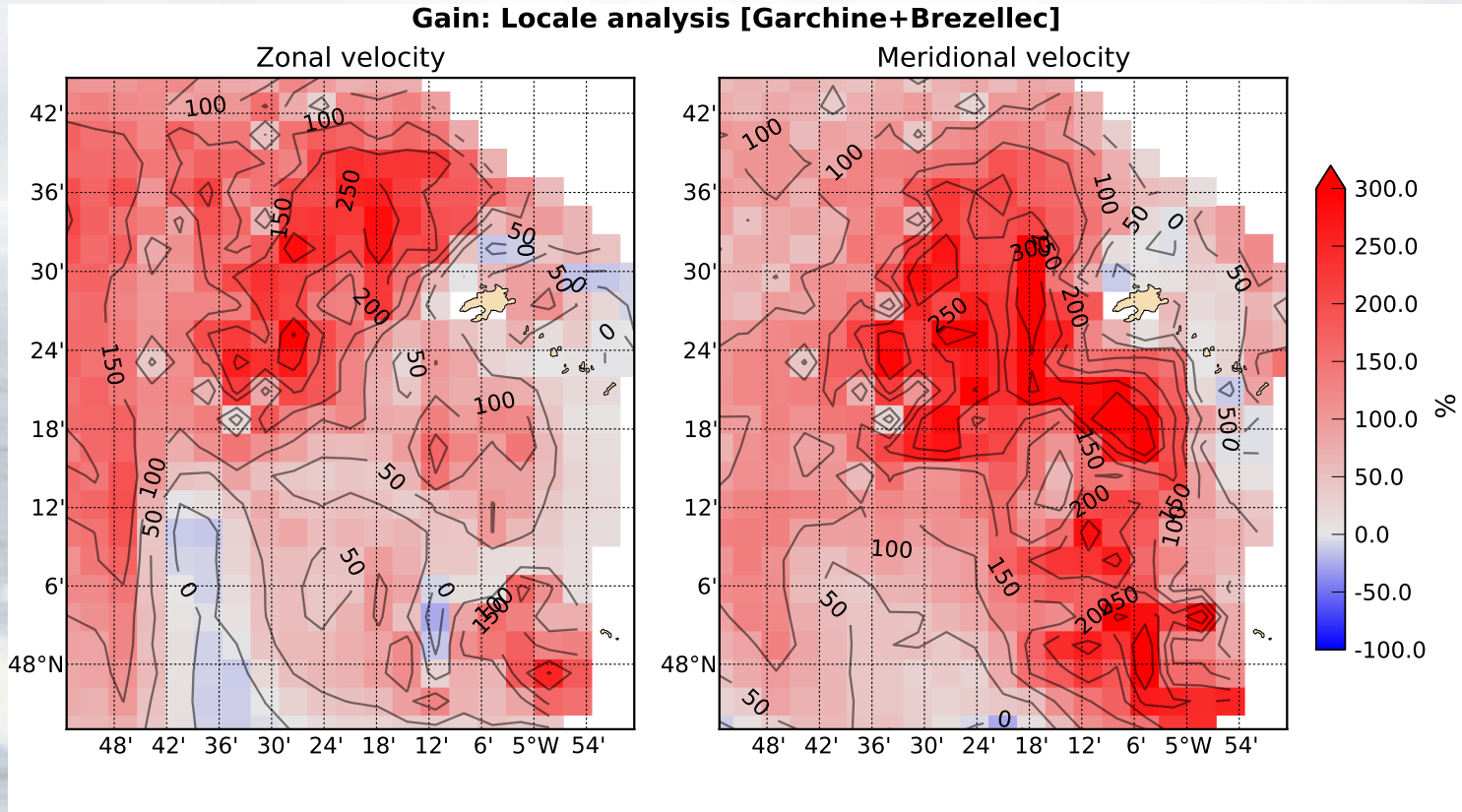

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Local analyses

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An example.

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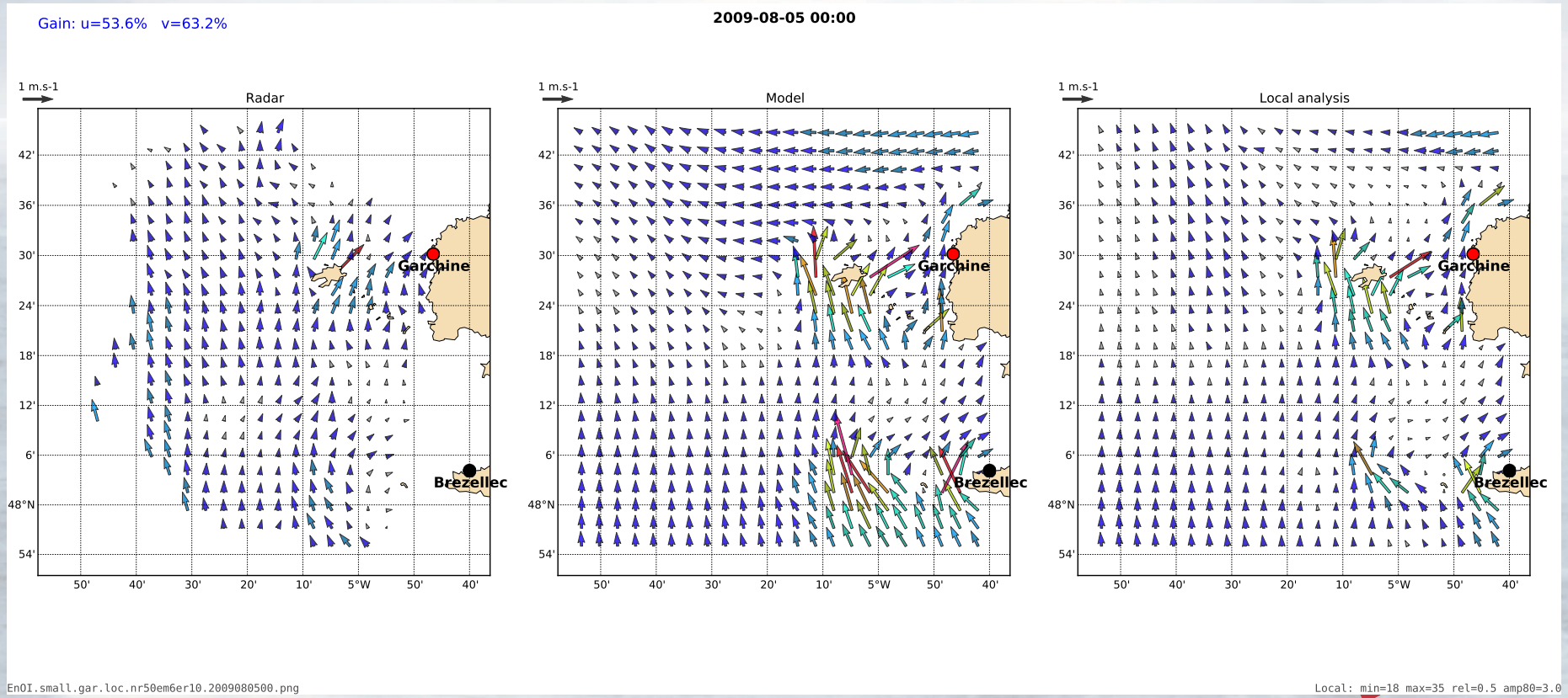

Local analyses

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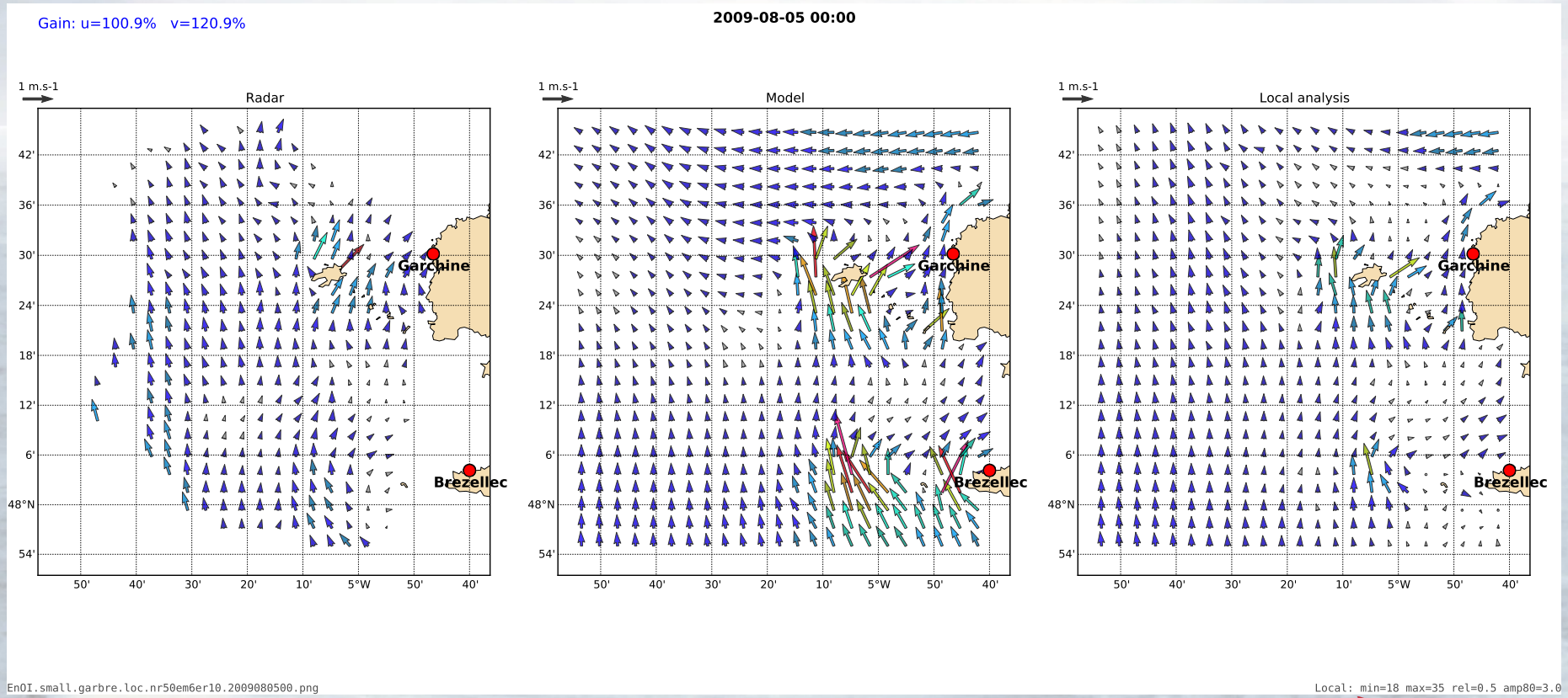
Garchine + Brezellec



All configurations

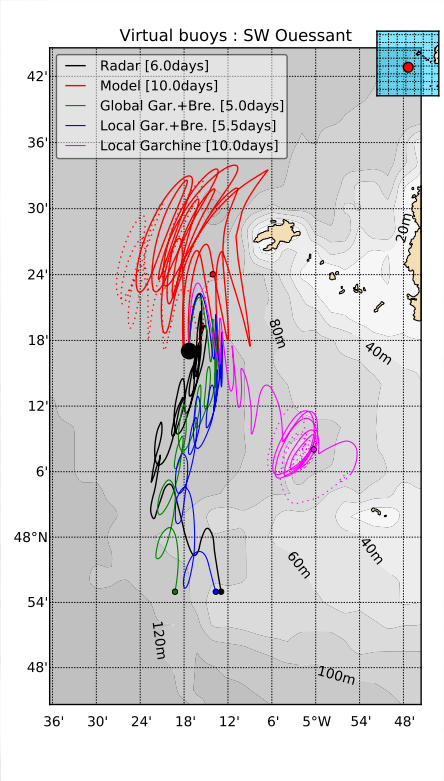
Time averages of gains:

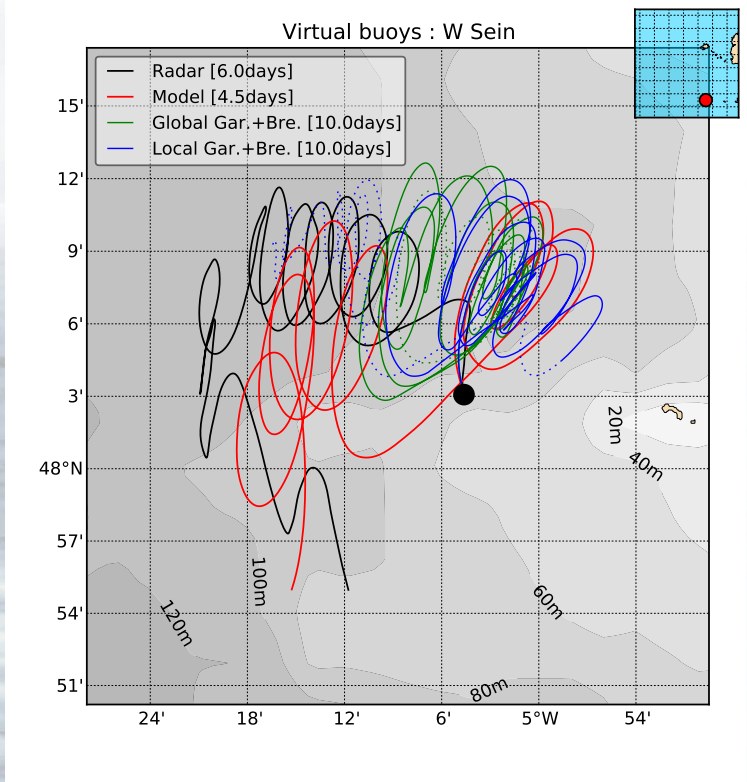
	U	V
Global 2 radars	50.1%	69.3%
Local 2 radars	62.3%	95.6%
Local Garchine	39.4%	53.2%
Local Brezellec	11.6%	37.1%

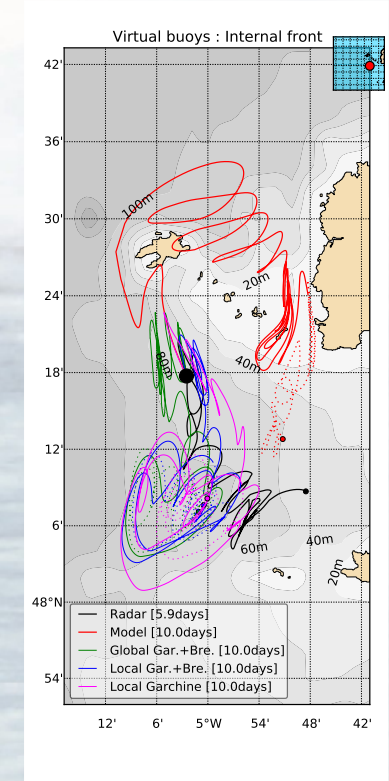
$\longrightarrow$ With these configurations and simplifications, it always helps assimilating at least one radar, from the eulerian point of view.

Lagragian point of view

- Virtual drifters using hourly currents and an integration step of 1mn.
- Radar currents slightly filled using shapiro2D+shapiro1D.







⟶ Assimilation improves lagrangian simulations.

⟶ Gain of local analyses over global analyses is not that clear.

1 Introduction

2 Assimilation
- EnOI in passive mode
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3 Statistical forecasts

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Trying EnKF

There still no results of EnKF assimilation!

What we did:

Model We set up a configuration of ROMS in the Iroise Sea (res.: 1.5km).

Ensembles Privileged solution: perturbation of the crucial parameters. We start from what we learned from the Gulf of Biscay assimilation of SST with MARS: three dominant and independent parameters. We tried:

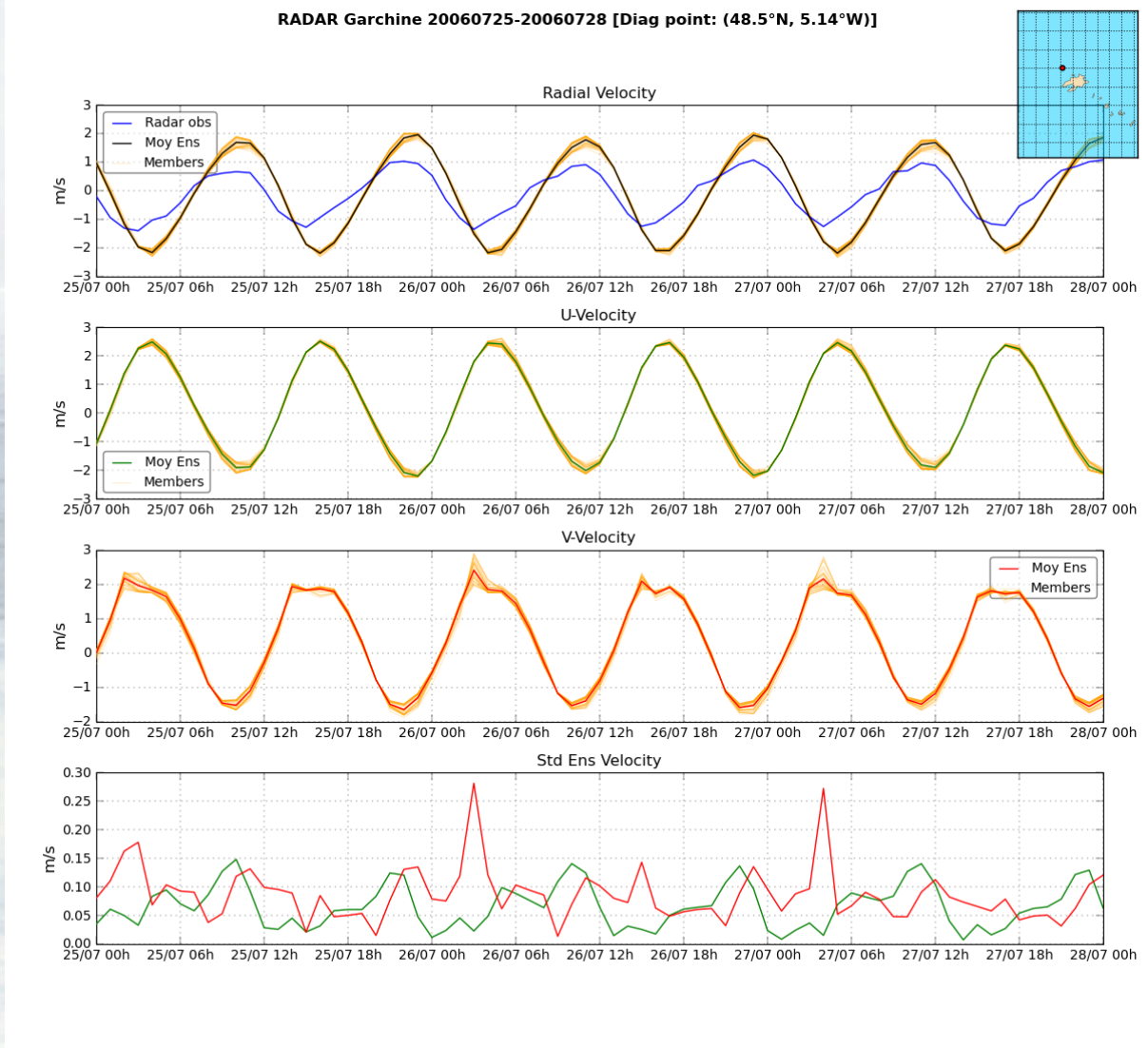
- The bottom rugosity length.
- Vertical viscosity.
- Lateral viscosity.

Runs 10 days in august 2009 (same as MARS).

Results Can't generate more than 10% of the needed variance!. Major effect of rugosity length.

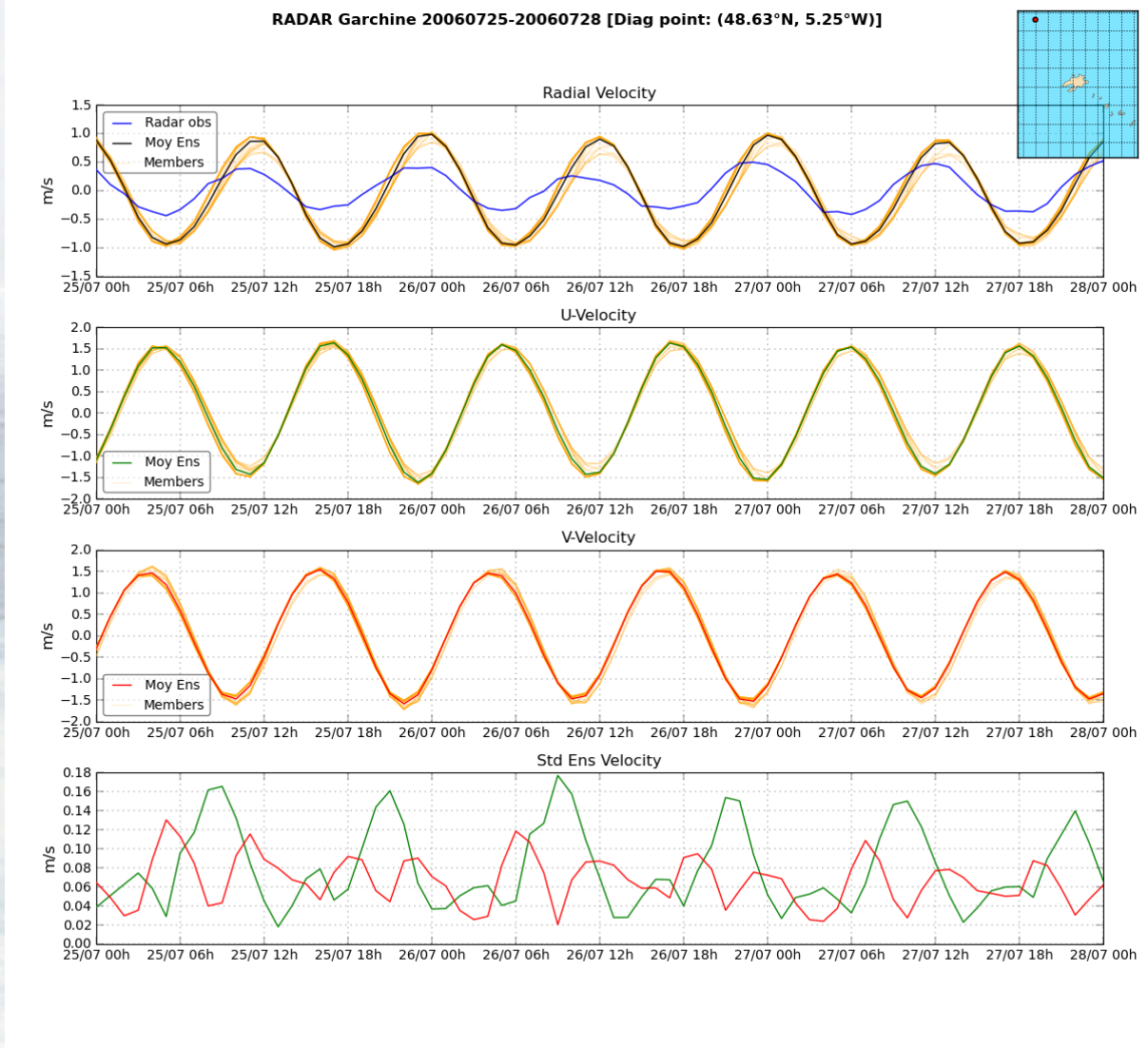
Bottom rugosity length ensemble

At single points



Bottom rugosity length ensemble

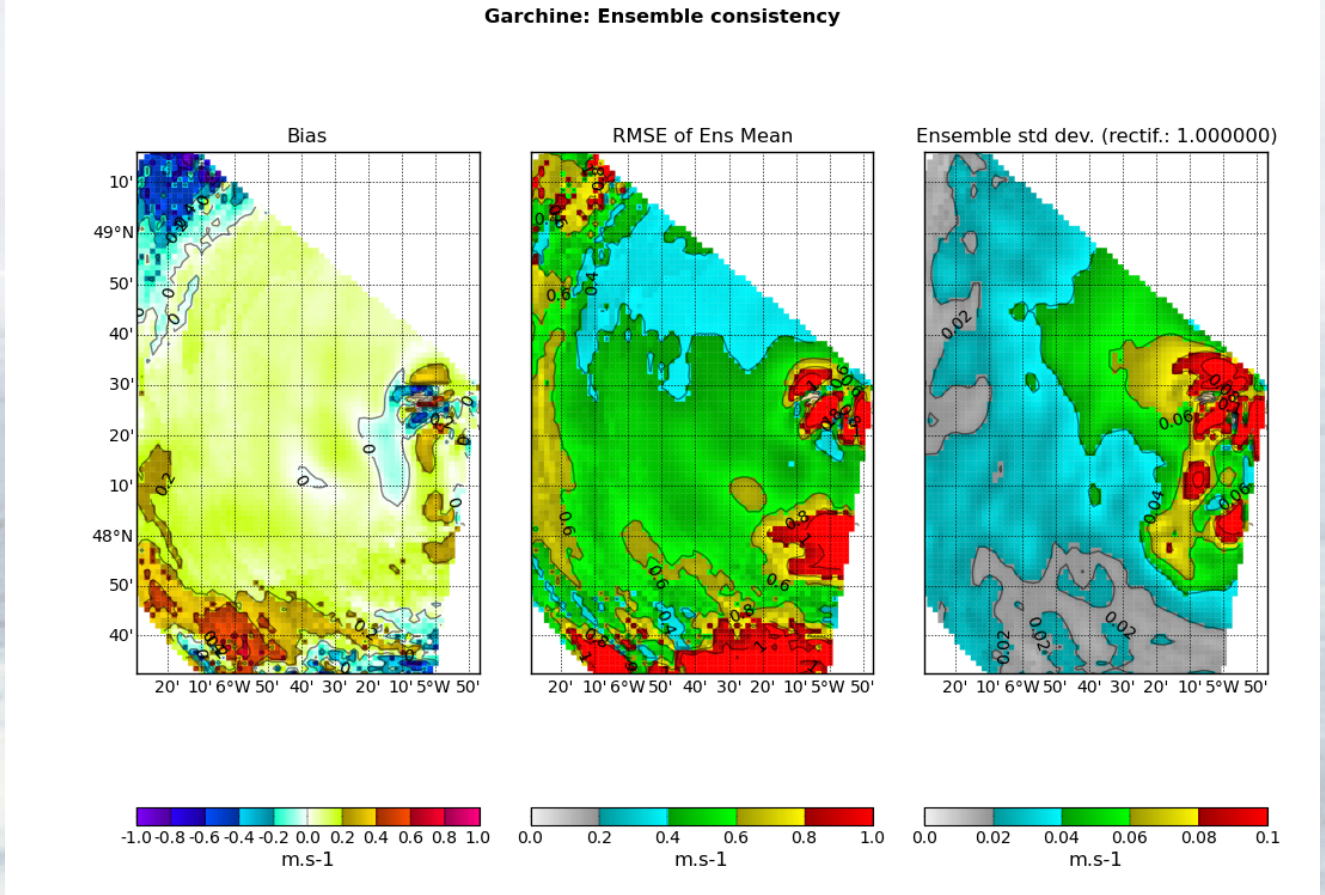
At single points



Bottom rugosity length ensemble

Consistency

Garchine

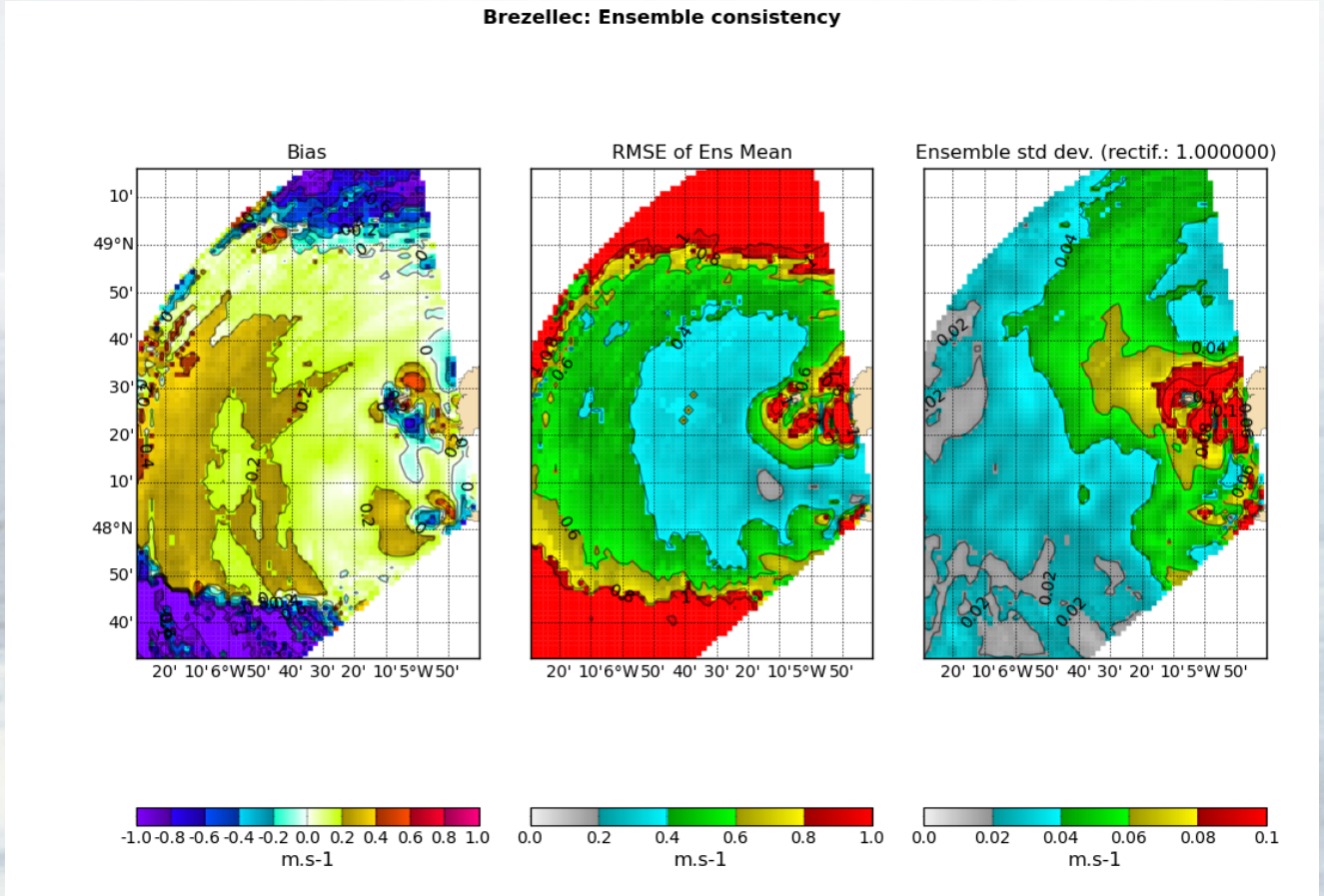


⇒ More work is needed, especially as for the amplitude.

Bottom rugosity length ensemble

Consistency

Brezellec



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1 Introduction

2 Assimilation
- EnOI in passive mode
- EnKF

3 Statistical forecasts

4 Conclusions and perspectives

Forecasting with data

Objective Perform short term predictions of currents using HF radar, and estimate typical errors.

Advantages No explicit need of setting up a Model.

Limitations

- Restriction to surface currents in a limited area.
- Depends on the predictability of the system.

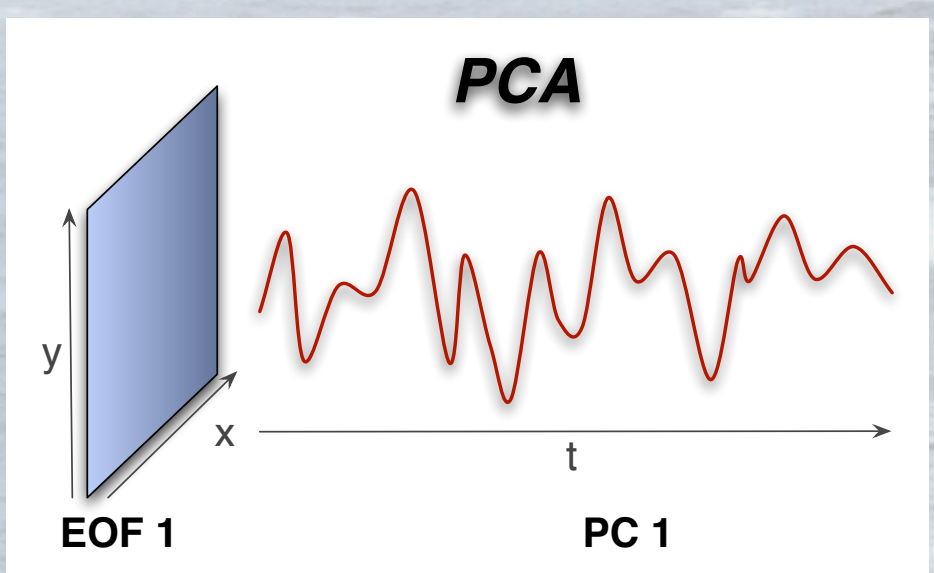
Link to assimilation? Use forecasts and errors to assimilate in the future in an operational context.

Methodology

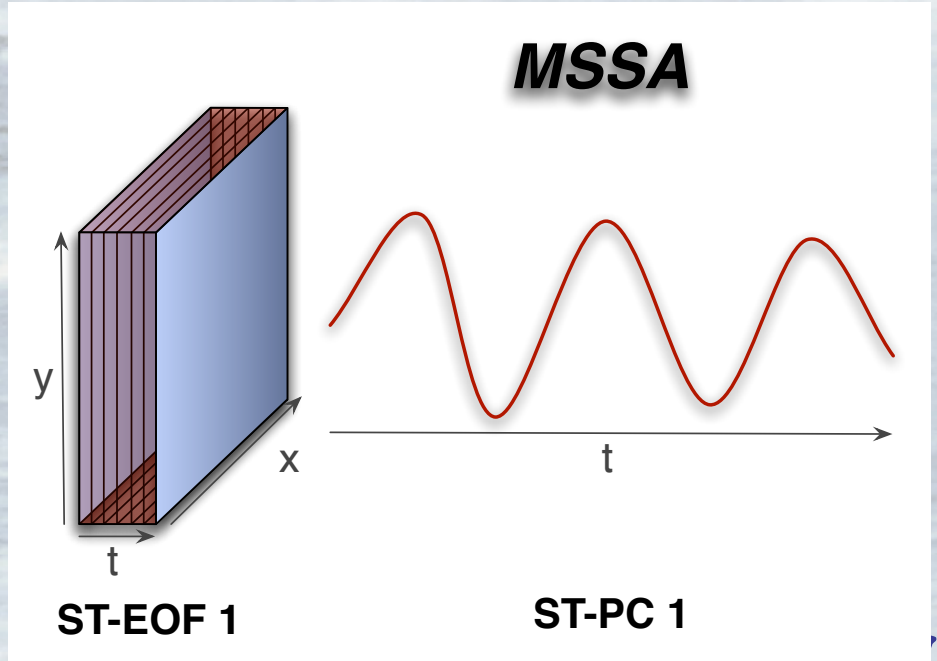
An iterative filtering loop using:

1. **PCA**: Gap filling + reduction of the degrees of freedom.
2. **MSSA**: Gap filling + forecasts. Separates white noise, oscillations, non-linear trends... Efficient on short samples.

Principal Component Analysis



Multi-Channel Singular Spectrum Analysis



Parameters: number of modes for PCA and MSSA, window of MSSA (for lag correlation)

→ not very sensitive.

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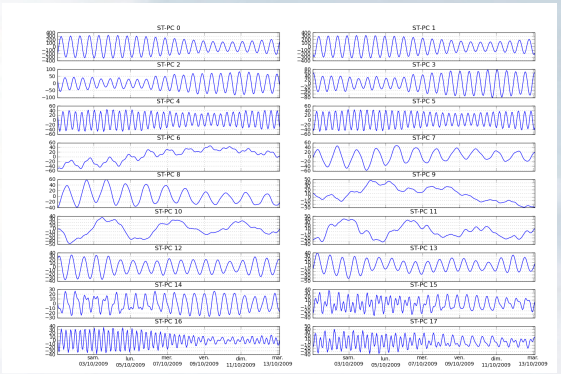

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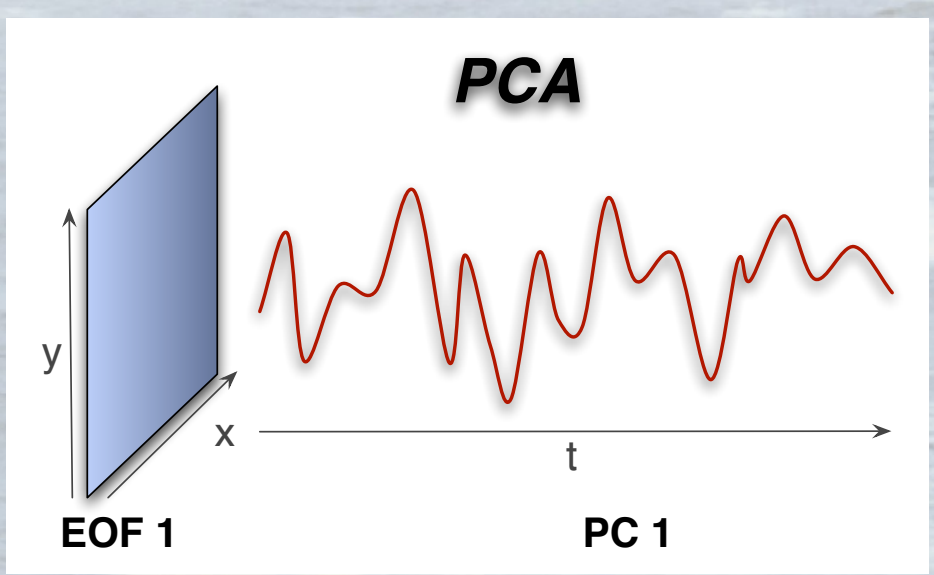
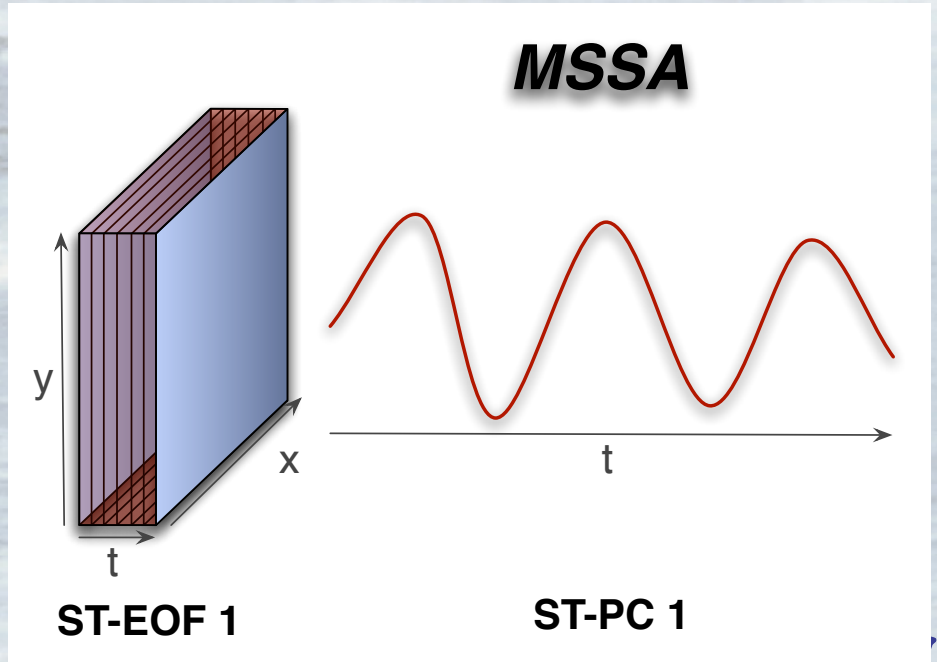


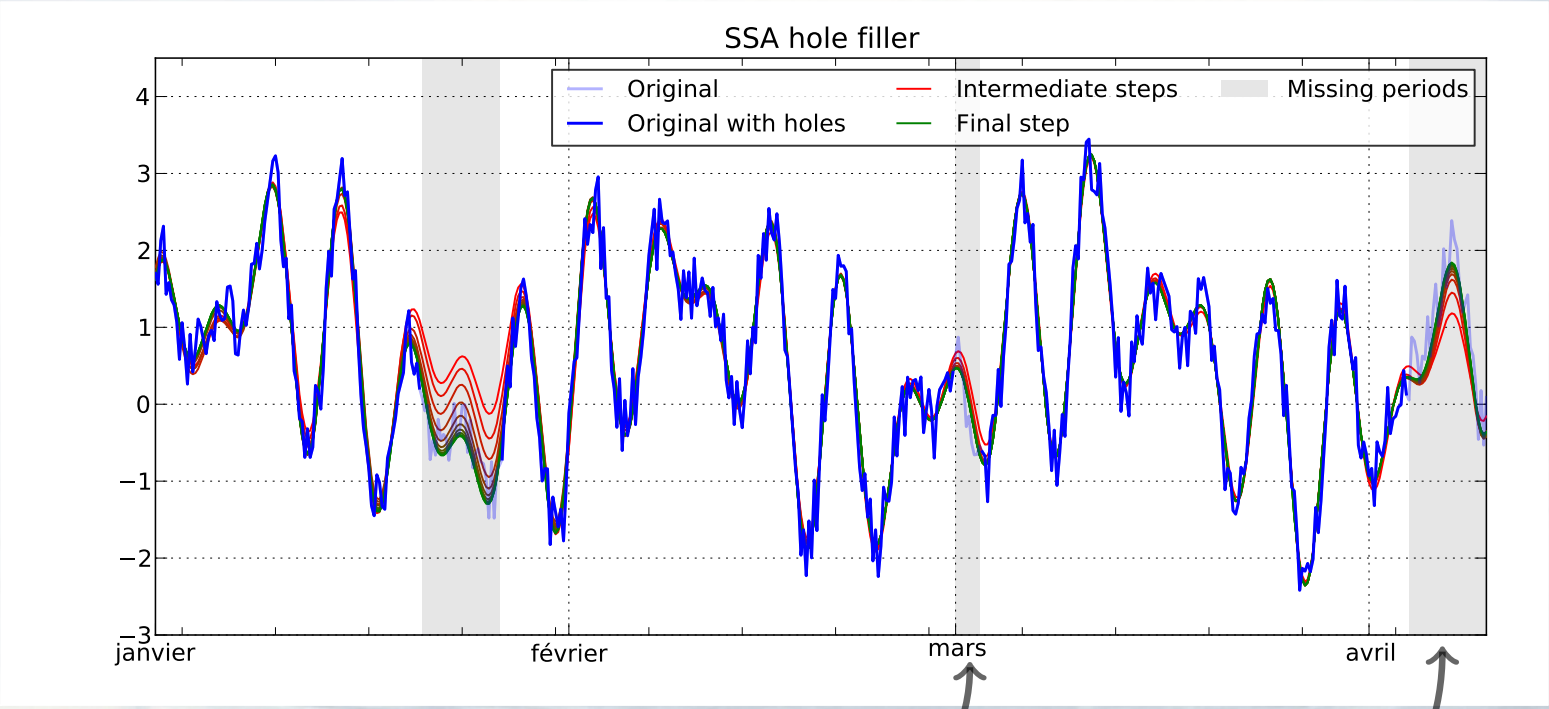


Parameters: number of modes for PCA and MSSA, window of MSSA (for lag correlation)

$\longrightarrow$ not very sensitive.

Academic example

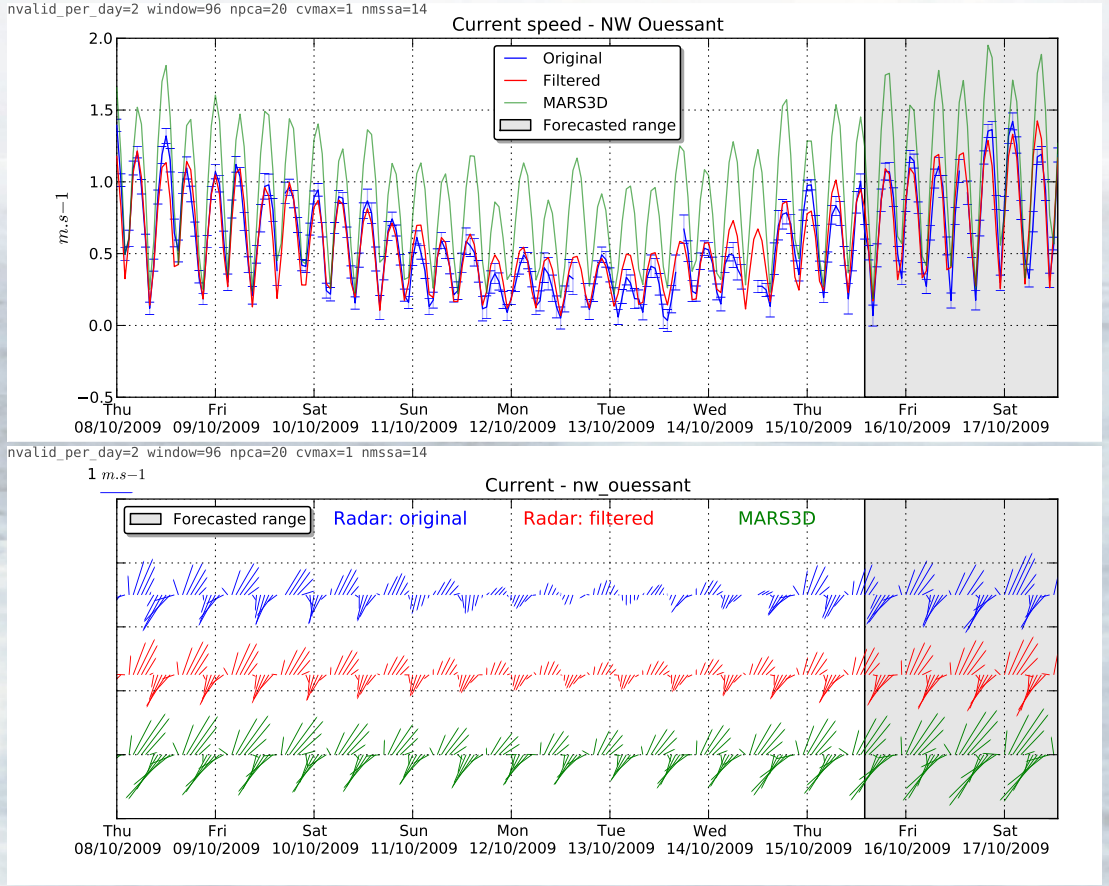
Sample: $y = sin(x) + cos(1.35x) + sin(.2x) + \varepsilon$



- Interpolation = missing values
- Extrapolation = short term forecasts

Diagnostics at single points

Sample: Two weeks of (U,V) HF radar currents (learning period – only one shown) + two days of forecasts.



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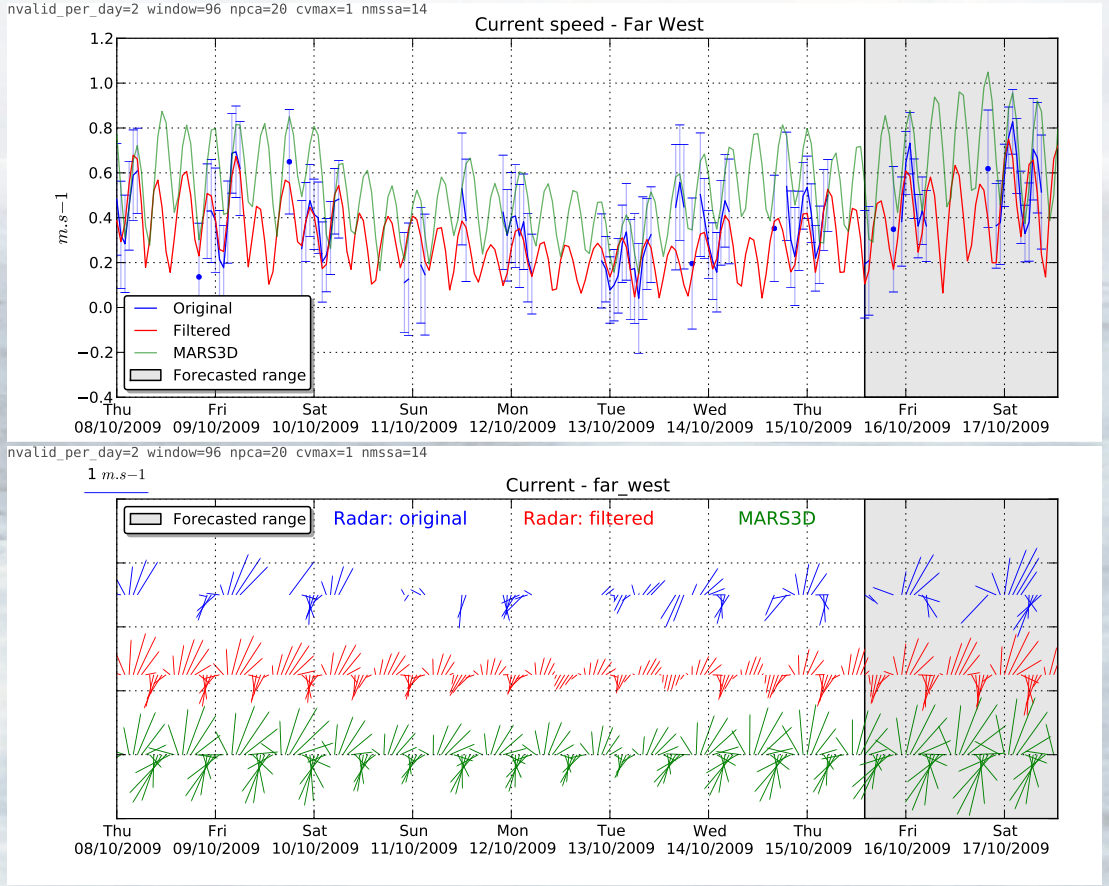
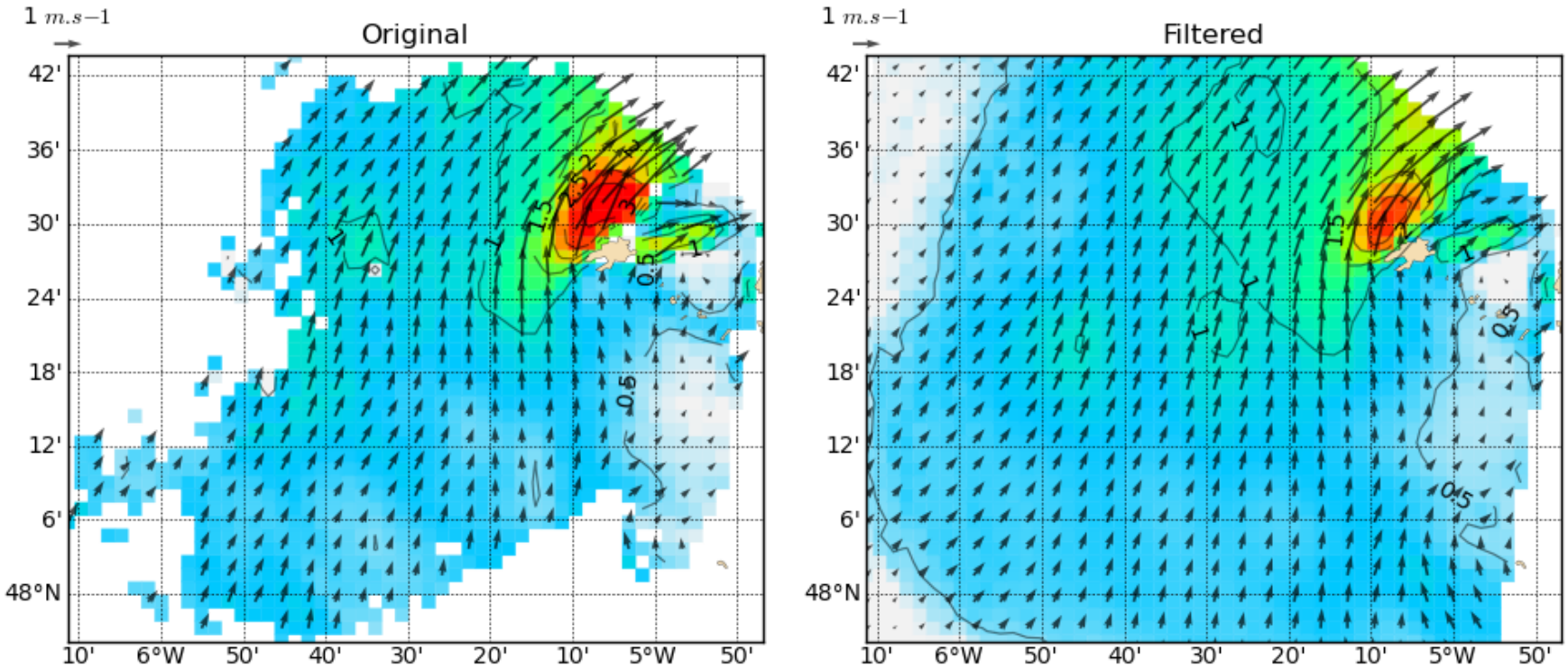


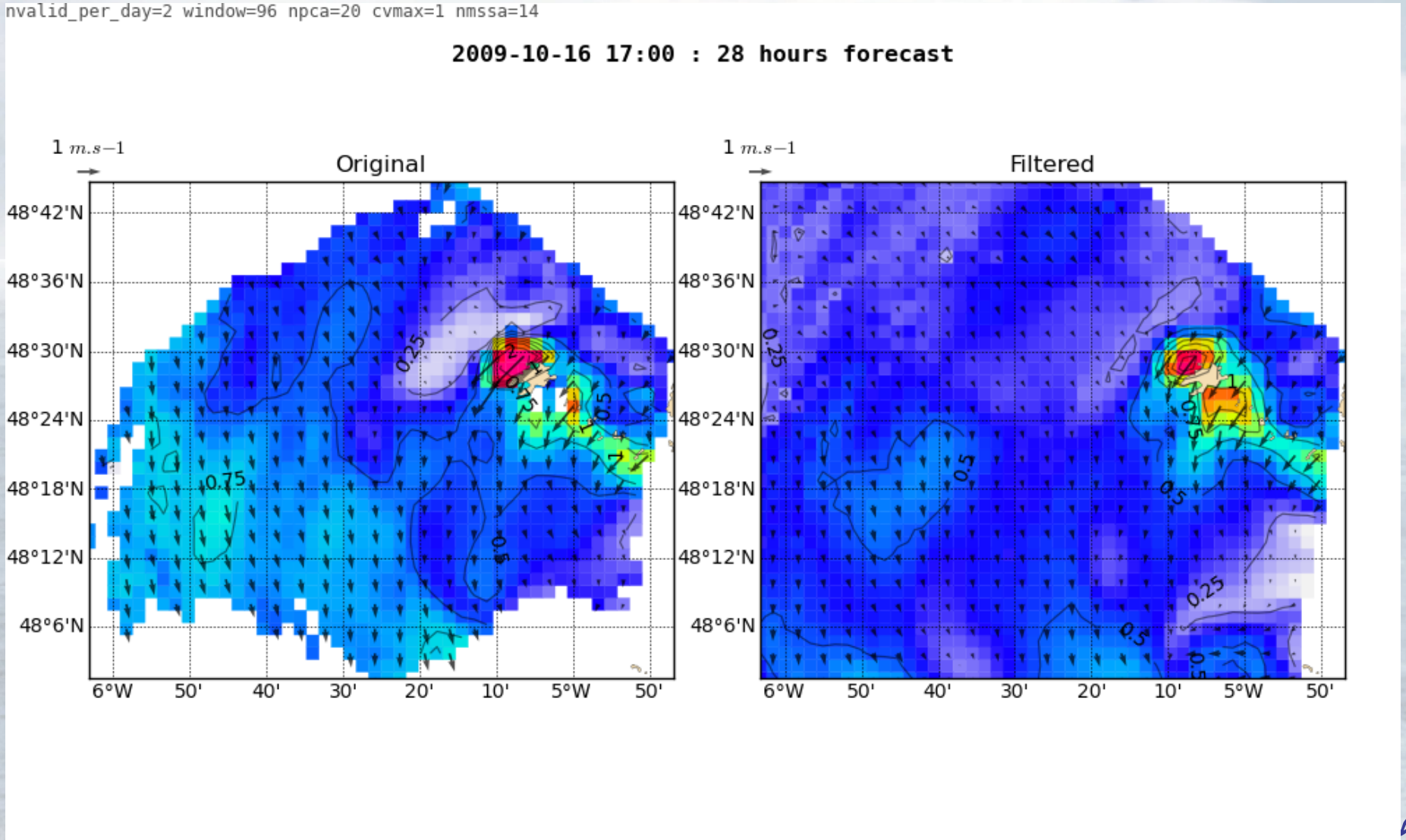
Snapshots

nvalid_per_day=2 window=96 npca=20 cvmax=1 nmssa=14

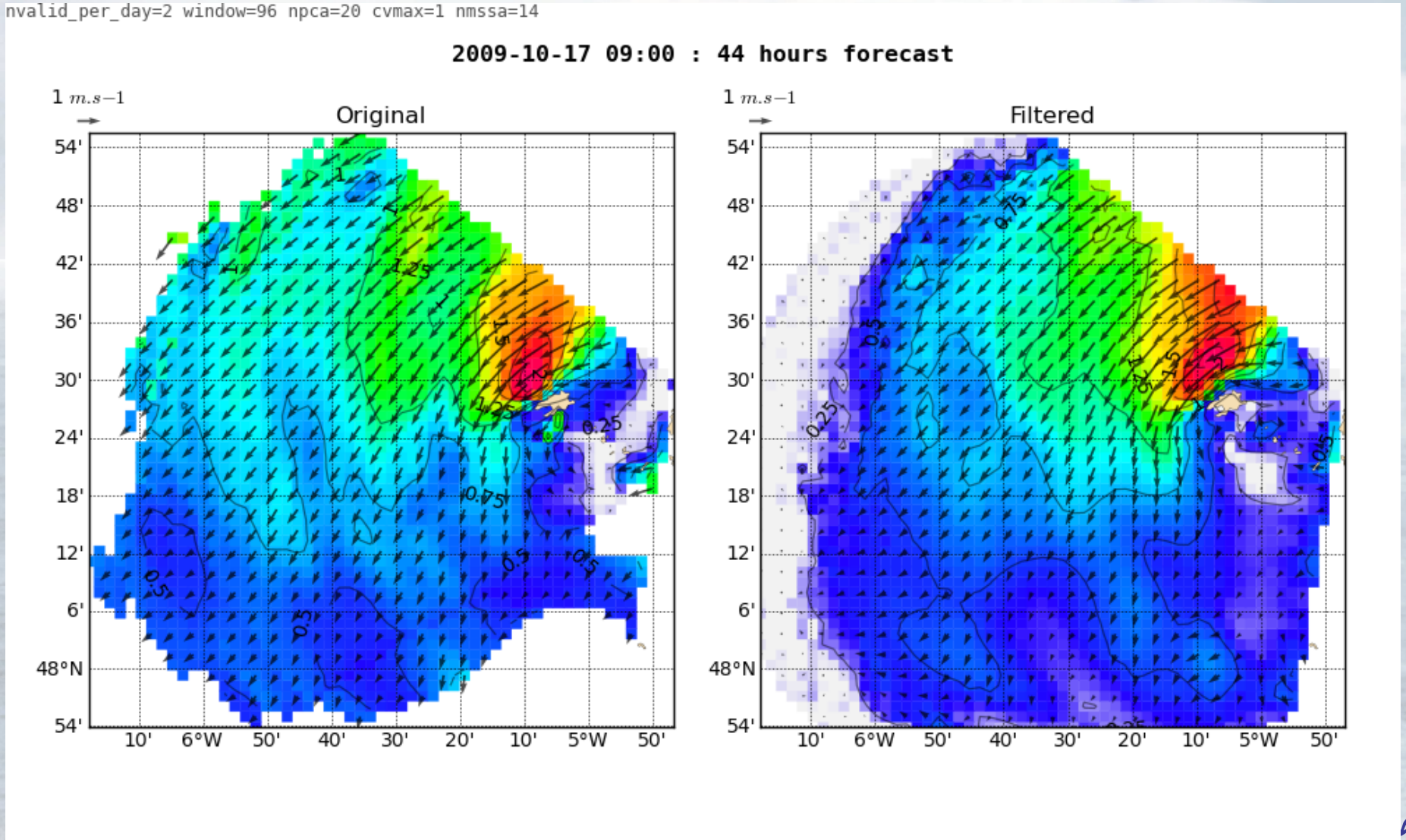
2009-10-16 13:00 : 24 hours forecast



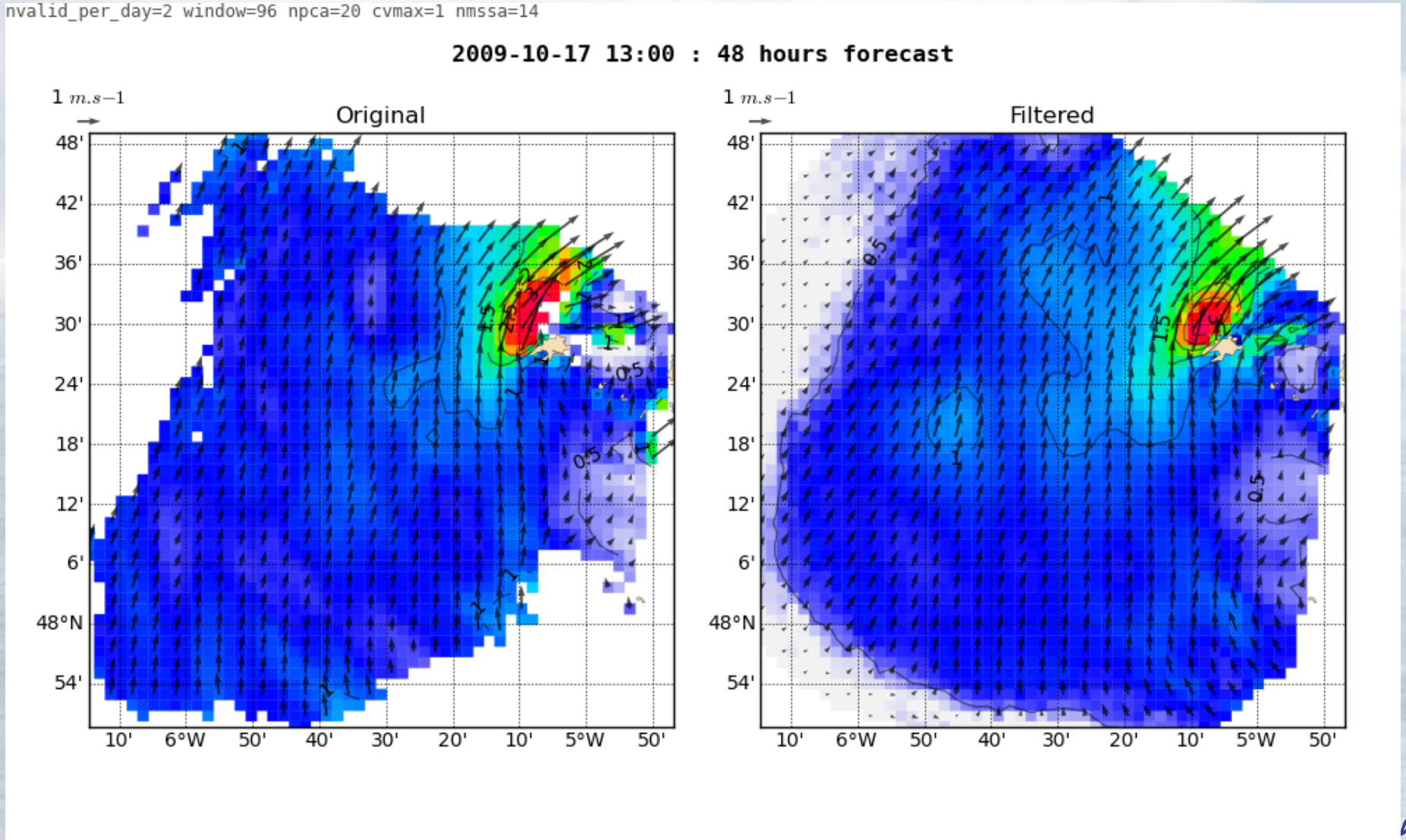
Snapshots


nvalid_per_day=2 window=96 npca=20 cvmax=1 nmssa=14
2009-10-16 17:00 : 28 hours forecast
1 m.s−1
Original
1 m.s−1
Filtered
48°42'N
48°36'N
48°30'N
48°24'N
48°18'N
48°12'N
48°6'N
6°W
50'
40'
30'
20'
10'
5°W
50'

Snapshots


nvalid_per_day=2 window=96 npca=20 cvmax=1 nmssa=14
2009-10-17 09:00 : 44 hours forecast
1 m.s−1
Original
1 m.s−1
Filtered
54'
48'
42'
36'
30'
24'
18'
12'
6'
48°N
54'
10'
6°W
50'
40'
30'
20'
10'
5°W
50'

Snapshots


nvalid_per_day=2 window=96 npca=20 cvmax=1 nmssa=14
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1 m.s−1
Original
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48'
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48°N
54'
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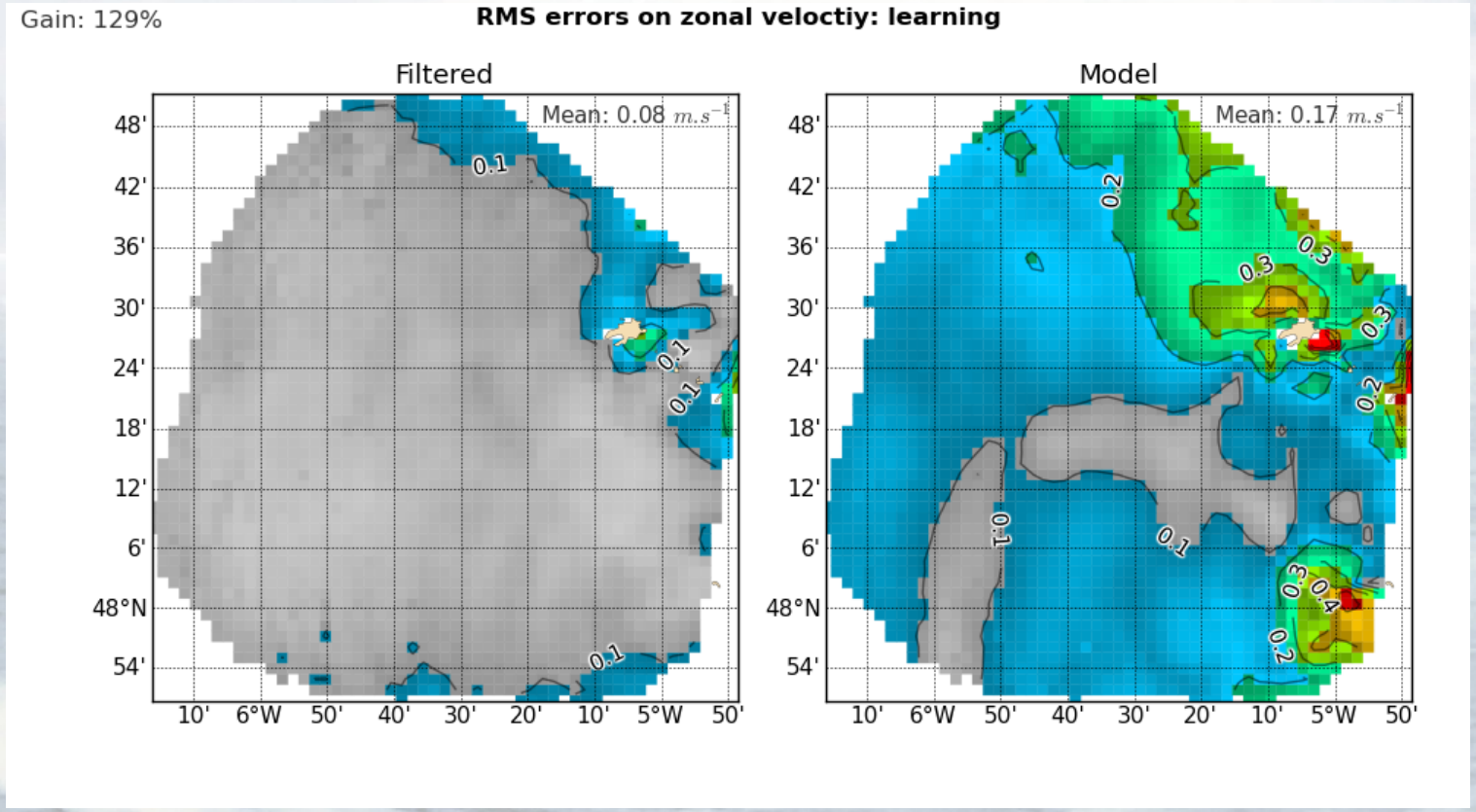
6°W
50'
40'
30'
20'
10'
5°W
50'

Temporal statistics

Learning period



- $RMSE(filtered) < RMSE(model)$ offshore ($< 0.2 m.s^{-1}$), and even lower near islands.
- Effect of radar and time interpolation errors near Ouessant.
- Large errors when very few data available: typically needs 30% of availability

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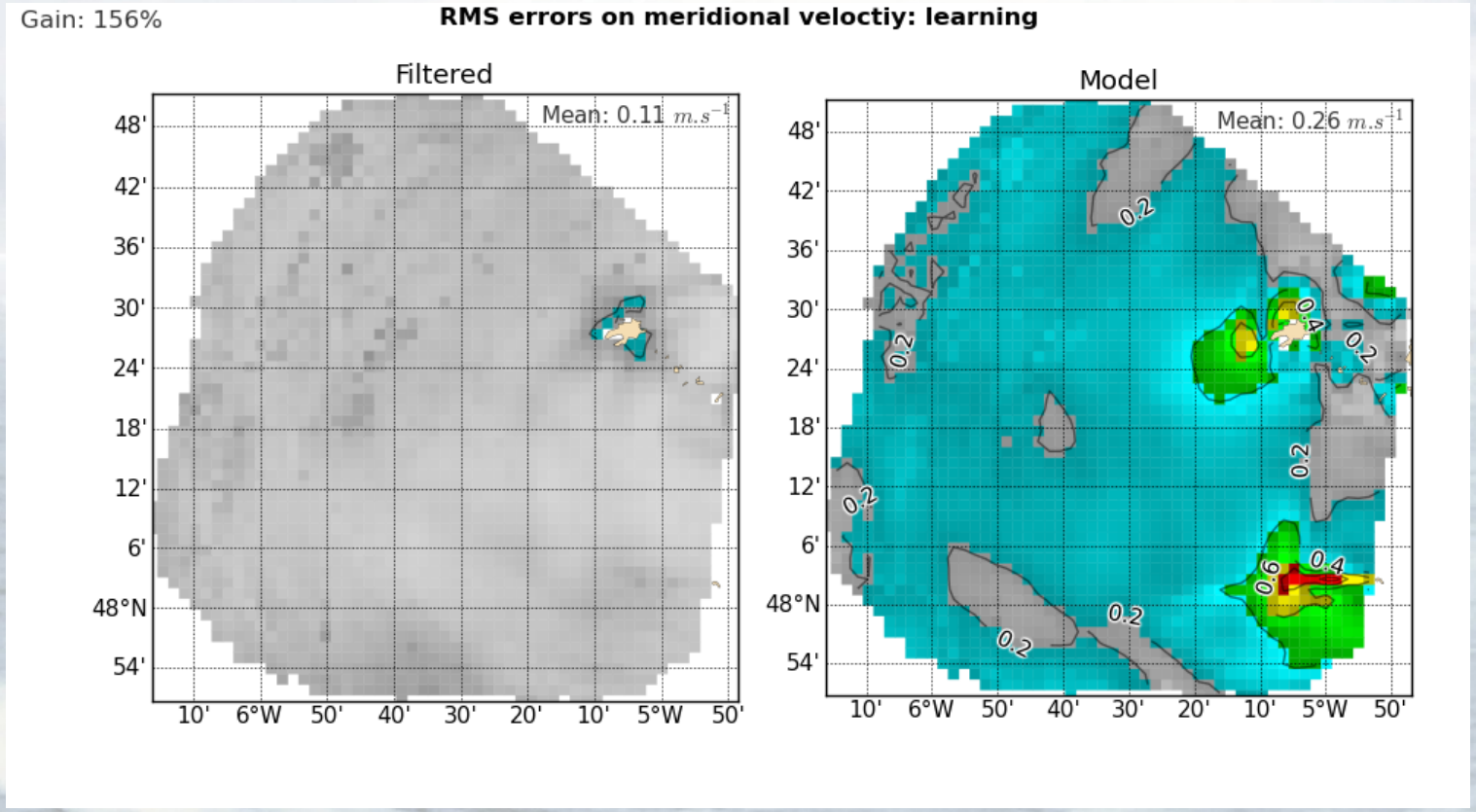

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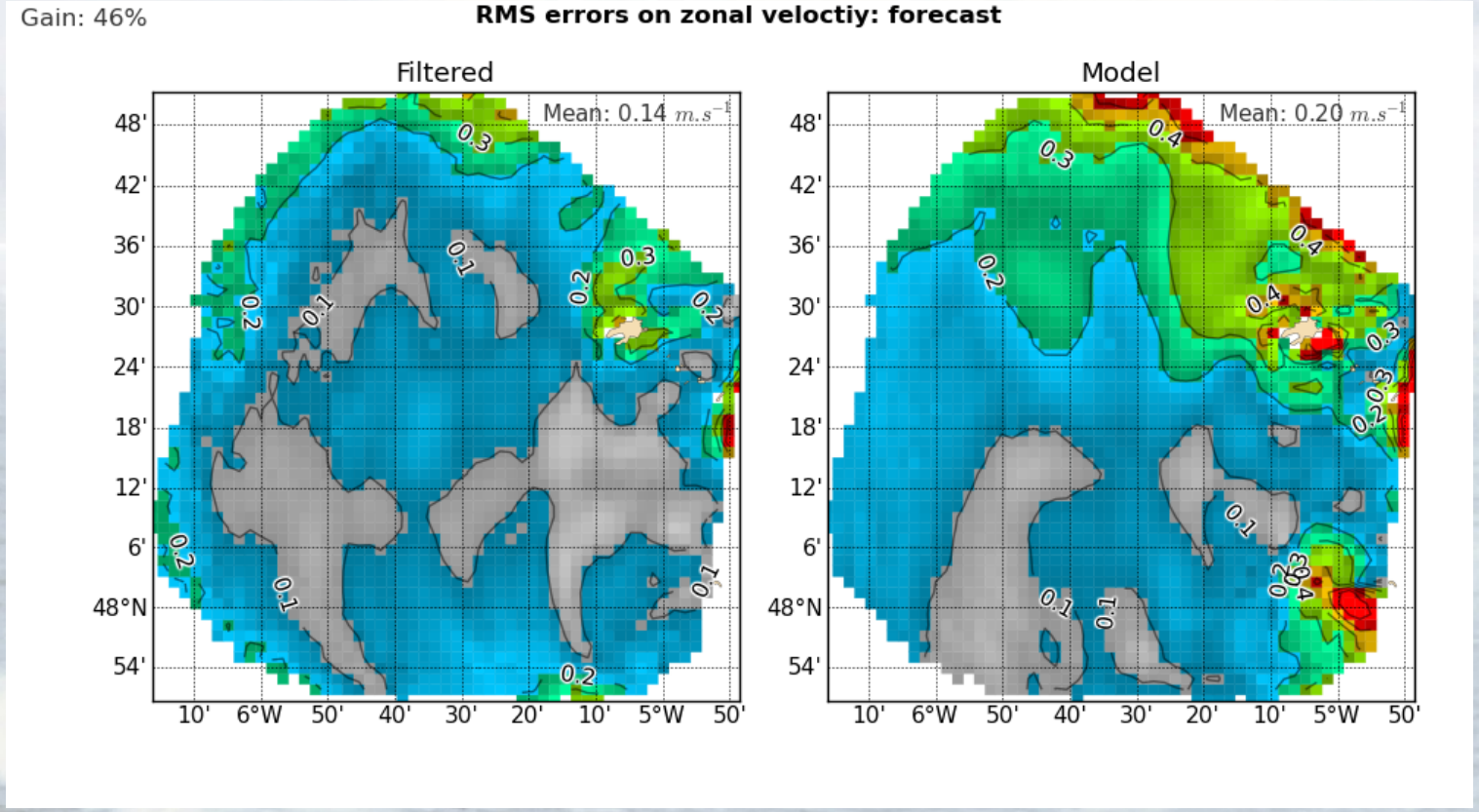
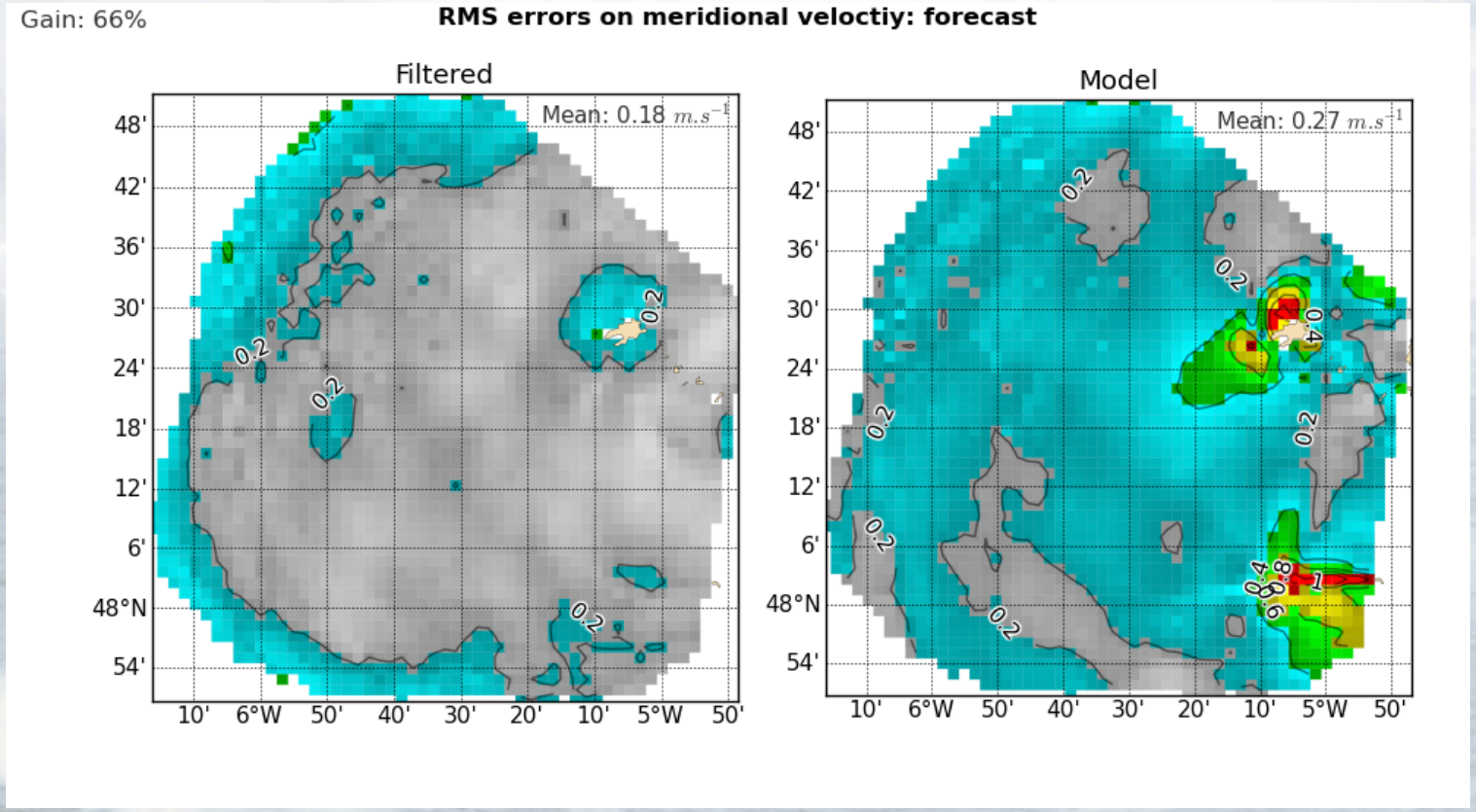


- Error increased by a factor 1.7.
- Still below model errors ⇒ potentially useful with assimilation.

Temporal statistics

Forecast period



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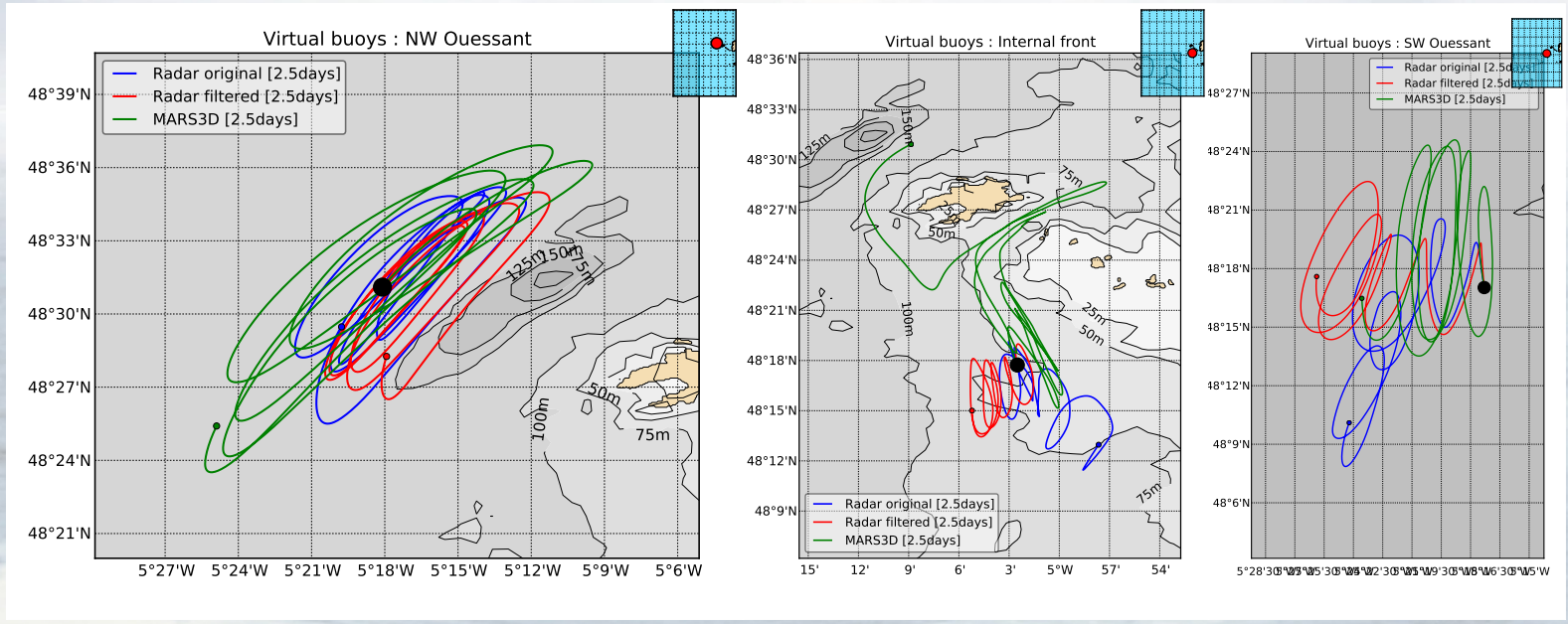
Lagrangian view

Similar approach as with EnOI evaluations, with trajectories within the **forecast period**.



Trajectories are generally best simulated with statistical forecasts than with model.

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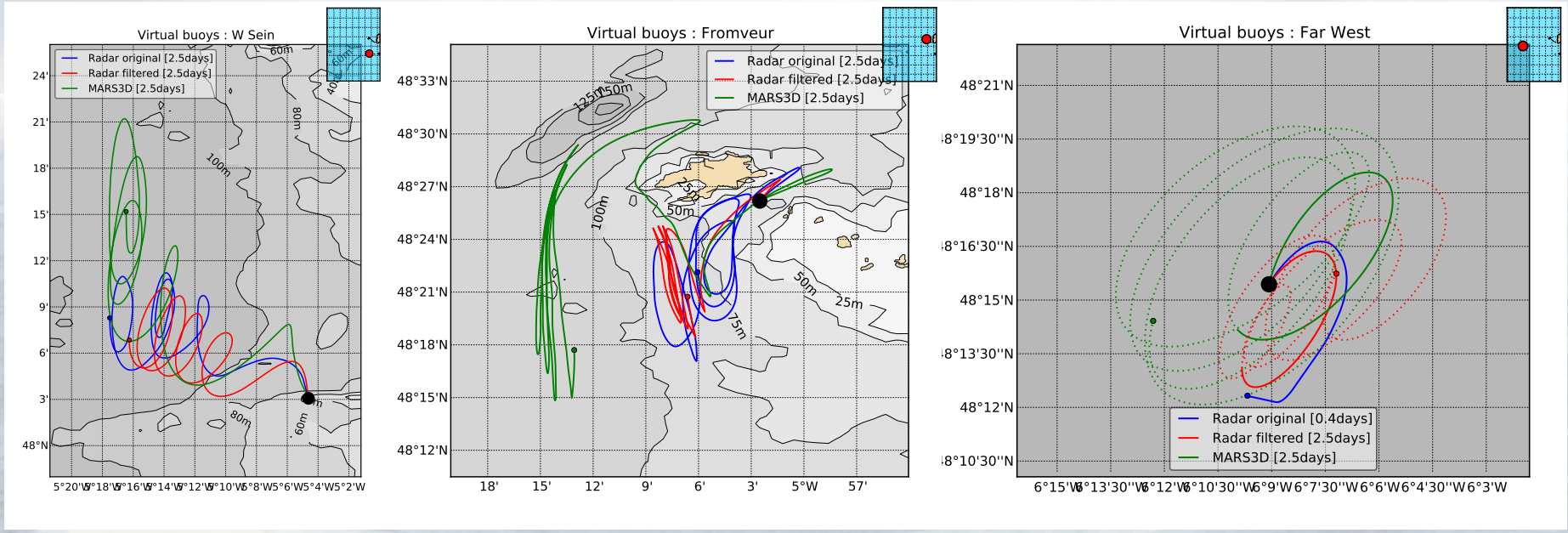

Trajectories are generally best simulated with statistical forecasts than with model.

1 Introduction

2 Assimilation
- EnOI in passive mode
- EnKF

3 Statistical forecasts

4 Conclusions and perspectives

Conclusions

Data and area Two WERA radars in the Iroise Sea. Strong tidal forcing.

EnOI assimilation Ensemble based on large undersampling of MARS3D, with Stokes drift correction → passive assimilation.

- Global analyses using both radars significantly correct surface currents.
- Localization improves analyses.
- Assimilation of a single radar is still an improvement, but depends on direction of currents.
- Similar conclusions from lagrangian point of view.

EnKF assimilation ROMS configuration. Still no analysis performed.

- Three model parameters were perturbed: rugosity length gives best results.
- Ensemble variance is strongly missing ⇒ no analysis.

Statistical forecasts Combined use of PCA and MSSA on surface currents only.

- Gap filling and 48h forecasts. Needs at least 30% of data. Not very sensitive to parameters.
- Better results with statistical forecasts than with model forecasts (eulerian and lagrangian views).

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Perspectives

Data Use data treated with direction finding algorithm (check near islands).

Validations More validations are needed:

- Eulerian and vertical: using ADCP measurements (july 2006).
- Lagrangian: stochastic trajectories compared with a real drifting trajectory (experiment in 2008).

Stokes drift Use it on the radar side to generate errors (play with wind and parameters).

EnOI Larger ensemble (spreading a year).

EnKF+ROMS More work on model parameters and forcings.

SST Assimilation of SST also to better control 2D state: with an hybrid scheme (EnOI for currents, EnKF for SST)?

Micro-tidal Extend this work to regions with weak tidal signal. We need data!

Asynchronous EnKF Scheme useful for operational forecasts.

Statistical forecasts

- Needs tests also on low tidal signals.
- Include wind forecasts?
- Merge with EnKF/EnOI assimilation (best if asynchronous).