A few perspectives for mapping Ocean surface current from future spaceborne doppler observations

Clément Ubelmann, Marie-Hélène Rio, Gérald Dibarboure, Fabrice Ardhuin, Lucile Gaultier

Outline

- **Combining altimetry and surface current: a challenging inversion problem and first results in OSSEs (SciSoc+CNES)**

- **Ongoing work to deal with Inertial Oscillations (CNES)**

- **Ongoing work in the Tropics (SKIM-PE, SciSoc)**

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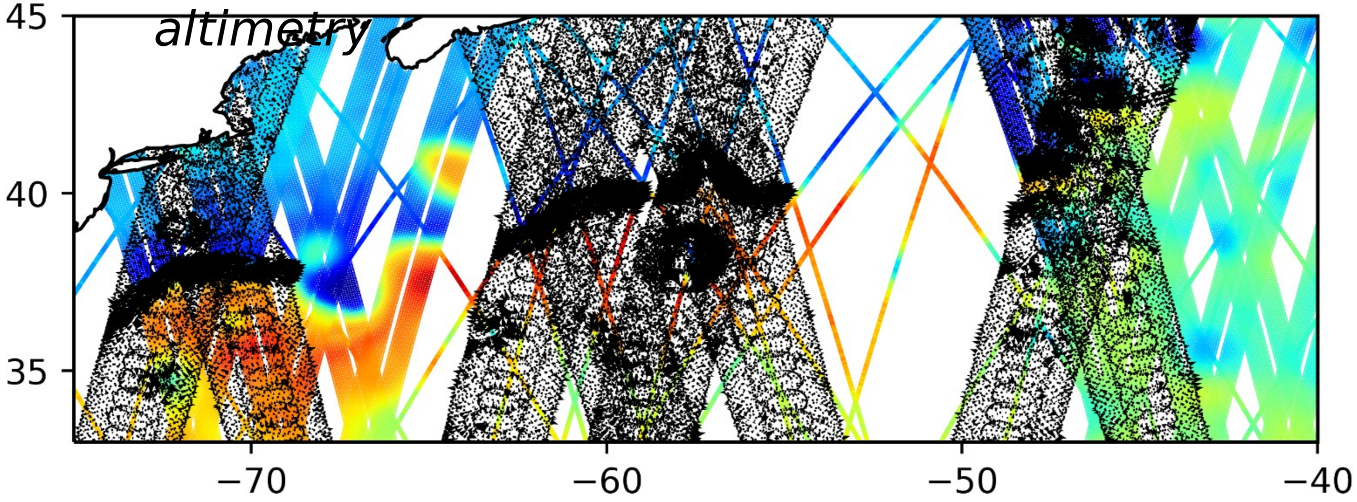
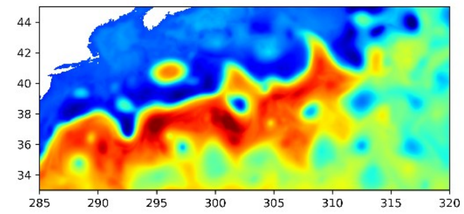
Future coexistence of altimetry and spaceborne surface current?

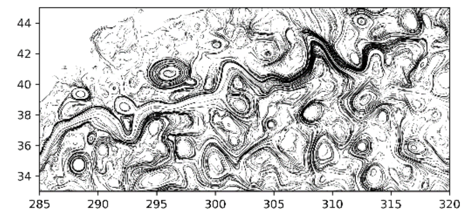
3 days worth of nadir + SWOT + SKIM current altimetry



How to use a synergy to reconstruct maps of the Ocean surface circulation?

?





Ways to leverage the synergy

- **Data assimilation**
  Synergy between a model and different sets of observation
  Should be the ultimate use of data. But complex.

- More simple **data-oriented analysis** still perform well for surface fields(e.g. Aviso/CMEMS maps for surface topography)

  It is interesting to test the combination topography+surface current with this approach: here multivariate optimal analysis

The challenge of surface current high frequencies

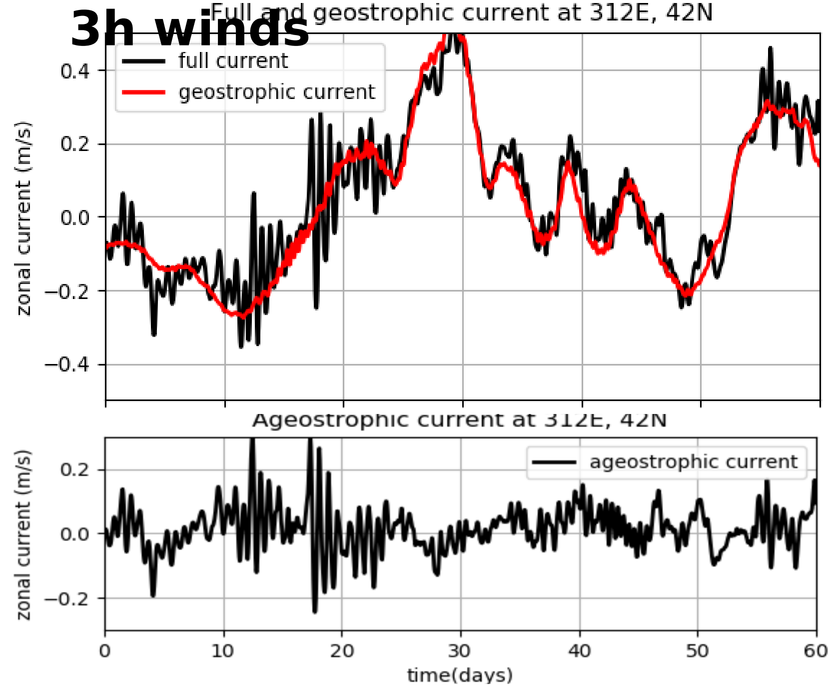
Beyond geostrophy:

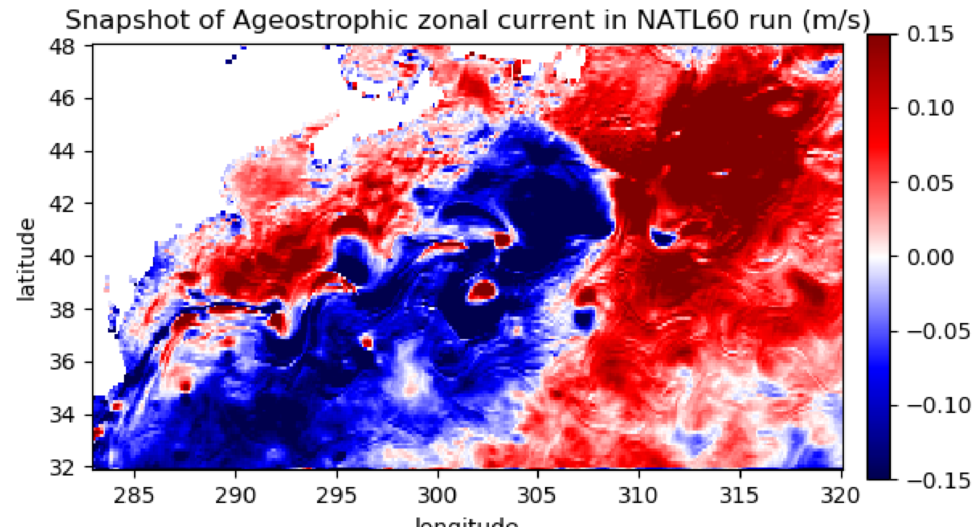
• The ageostrophic current contains Inertial Oscillations (IO), Ekman, tidal (barotropic and internal), submesoscales…

• At first order, IO seem to dominate, here with O(10cm/s) in NATL60 run (NEMO)
a challenge to de-aliase with limited observation repeats

• But patterns are quite large in the simulation and should be distinct to mesoscale eddies

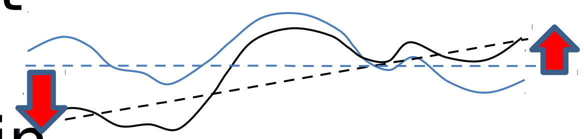
From NEMO/NATL60 simulations, 3h winds





How to handle ageostrophy in the mapping method?

→Altimetry profiles and surface current would have an obvious mismatch if we stick to the geostrophic relation in the covariance functions of analysis



→We chose to define additionnal covariance functions to handle ageostrophy:

- A low-frequency component to be resolved
- A high-frequency component in the error matrix

The Covariance functions

		Physical components:				
		Resolved state		In error matrix	Not considered yet	
		Geostrophy (rotational only)	'slow' ageostrophy	Inertial Oscillations	Internal tides	Barotropic tides
Variable nature:	SSH	Standard model used in Aviso	0	0	From altimetry spectrum	From models
	Current	Derived standard model used in Aviso	low-pass in time cov. functions	low-pass in space, high-pass in time cov. functions	Momentum and continuity eq., e.g. Zaron et al.	From models
	Cross SSH/ Current	Partially derived standard model used in Aviso	0	0	Momentum and continuity eq., e.g. Zaron et al.	Derived from models

The multivariate mapping algorithm

- State vector **x**: [SSH, current]
- Standard OI formula : $\mathbf{x_a} = \mathbf{BH^T(HBH^T + R)^{-1}y}$

Estimate (grid,obs) signal cov (obs,obs) signal cov (obs,obs) error cov SLA and radial current obs

Main issue: prohibitive cost (α n^3) if we extend time window to include the wide range of signals proposed on previous slide

- We propose a variational approach involving the minimization:

$$J = \boldsymbol{\eta}^T \mathbf{Q}^{-1} \boldsymbol{\eta} + (\mathbf{y} - \mathbf{G}\boldsymbol{\eta}) \mathbf{R}^{-1} (\mathbf{y} - \mathbf{G}\boldsymbol{\eta})^T$$

State in param space

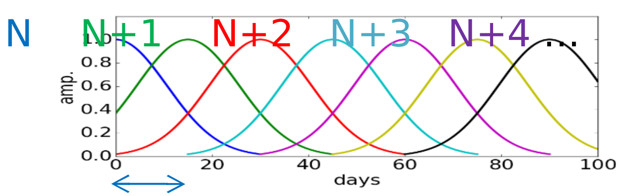
Prescribed variance of the components

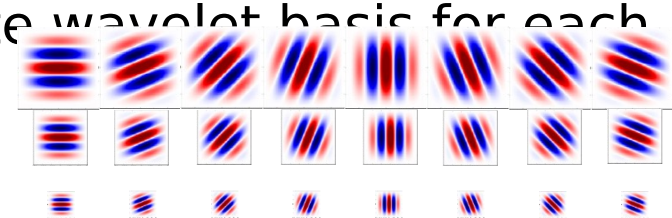
basis of components for distinct dynamics

Benefits: We can extend the inversion window (cost α n) in time and space

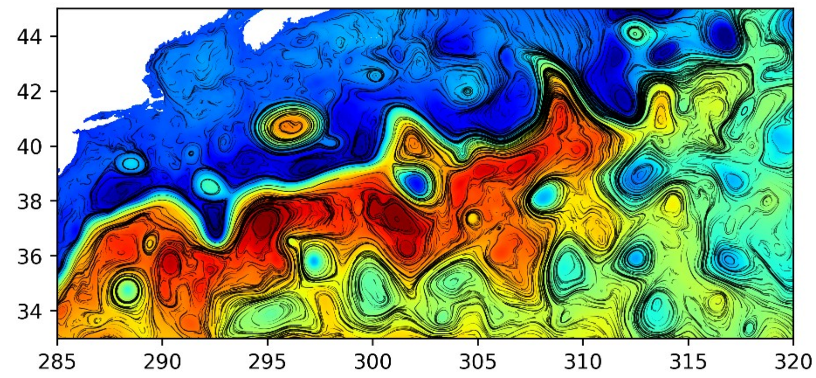
✓ Equivalence with OI (provided GQG^T matches the right covariance model)

ate wavelet basis for each physical



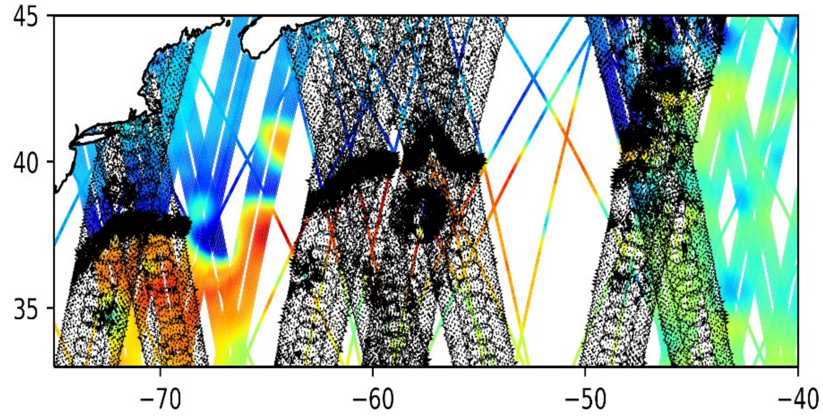


The OSSEs

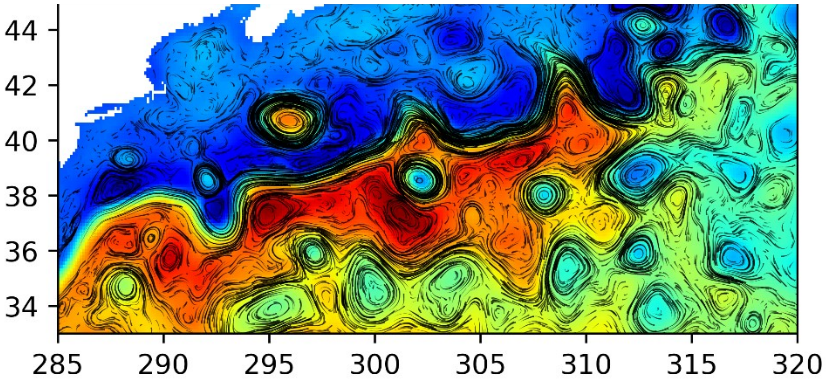


Focus in mid-latitude where altimetry is already usefull for current

Reference (‘truth’):
Hourly outputs from NATL60 simulations.
(forced with 3-hour ERAinterim winds)



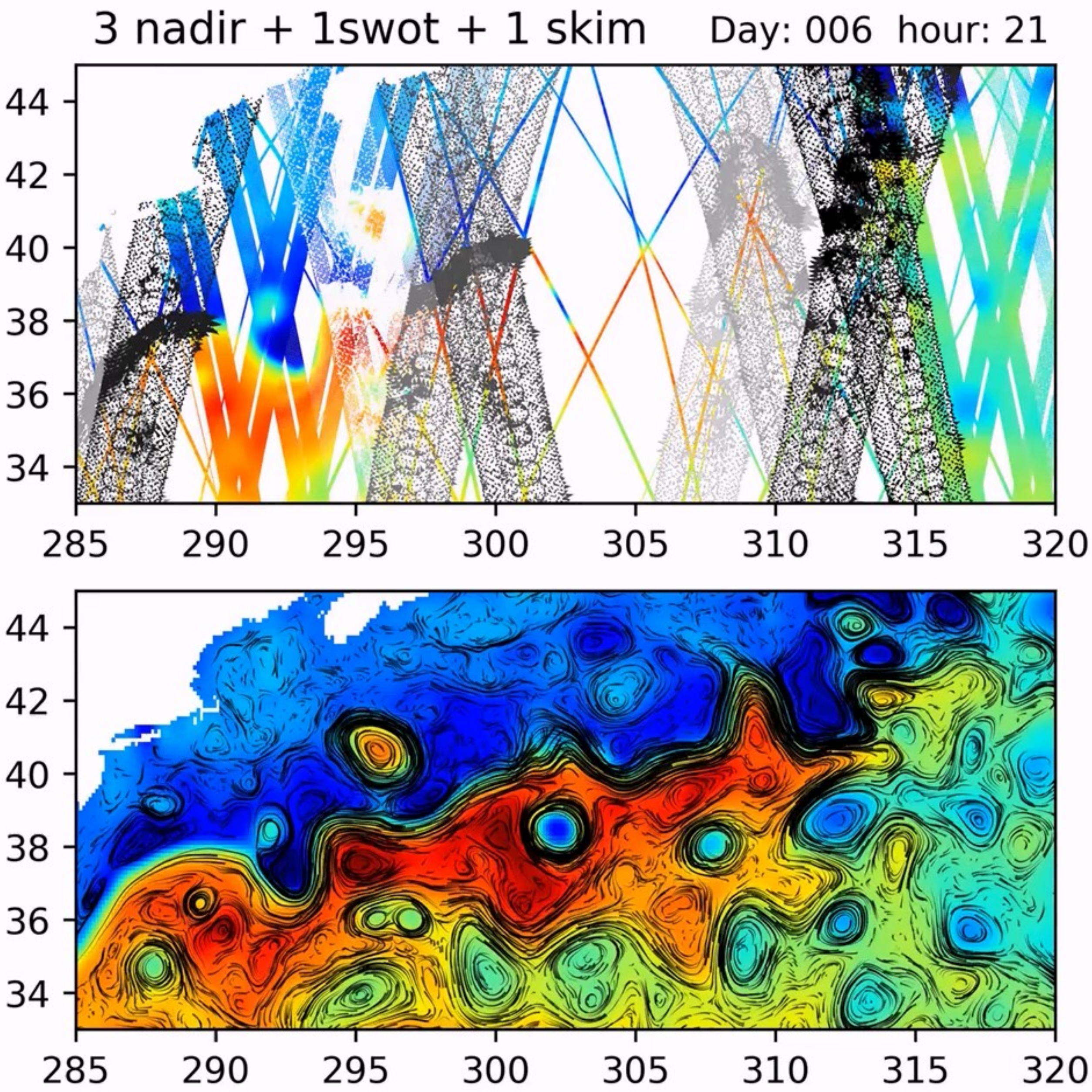
Generation of synthetic observations using the swot/nadir simulator and the skimulator* (sampling+errors*)



Reconstruction of the state vector (current + topography)

Comparison with truth

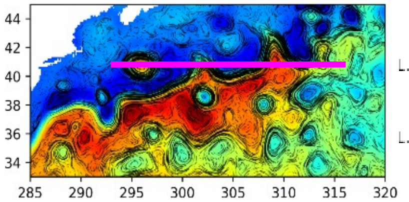
***see backup slides**

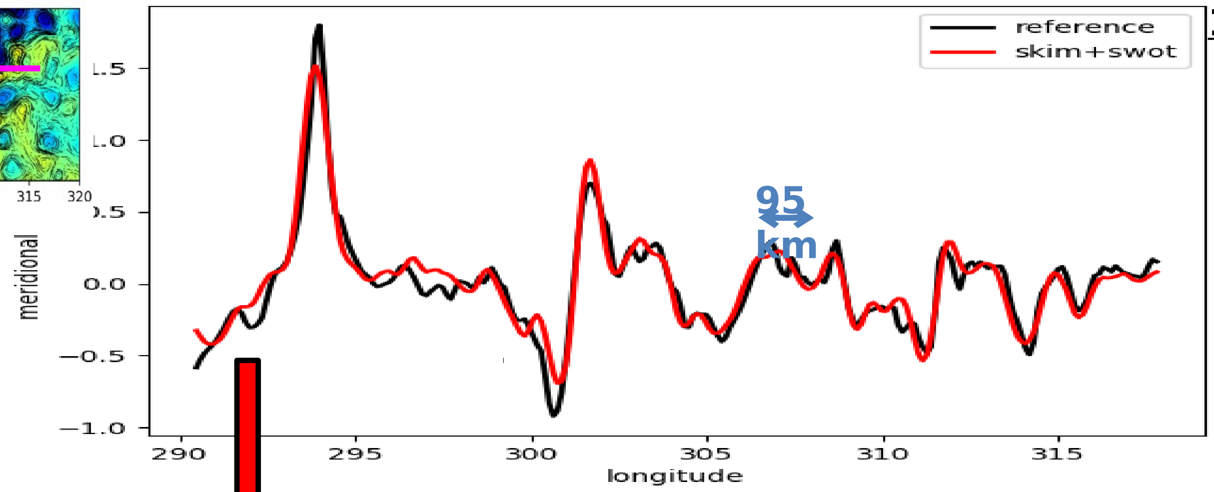


3 nadir + 1swot + 1 skim
Day: 006 hour: 21
44
42
40
38
36
34
285
290
295
300
305
310
315
320

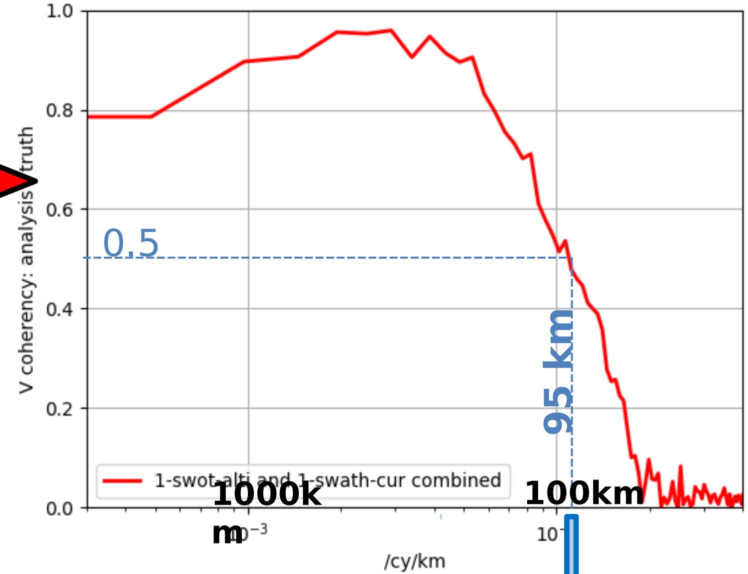
Cross-spectral analyses to assess resolving capabilities

1-day averag



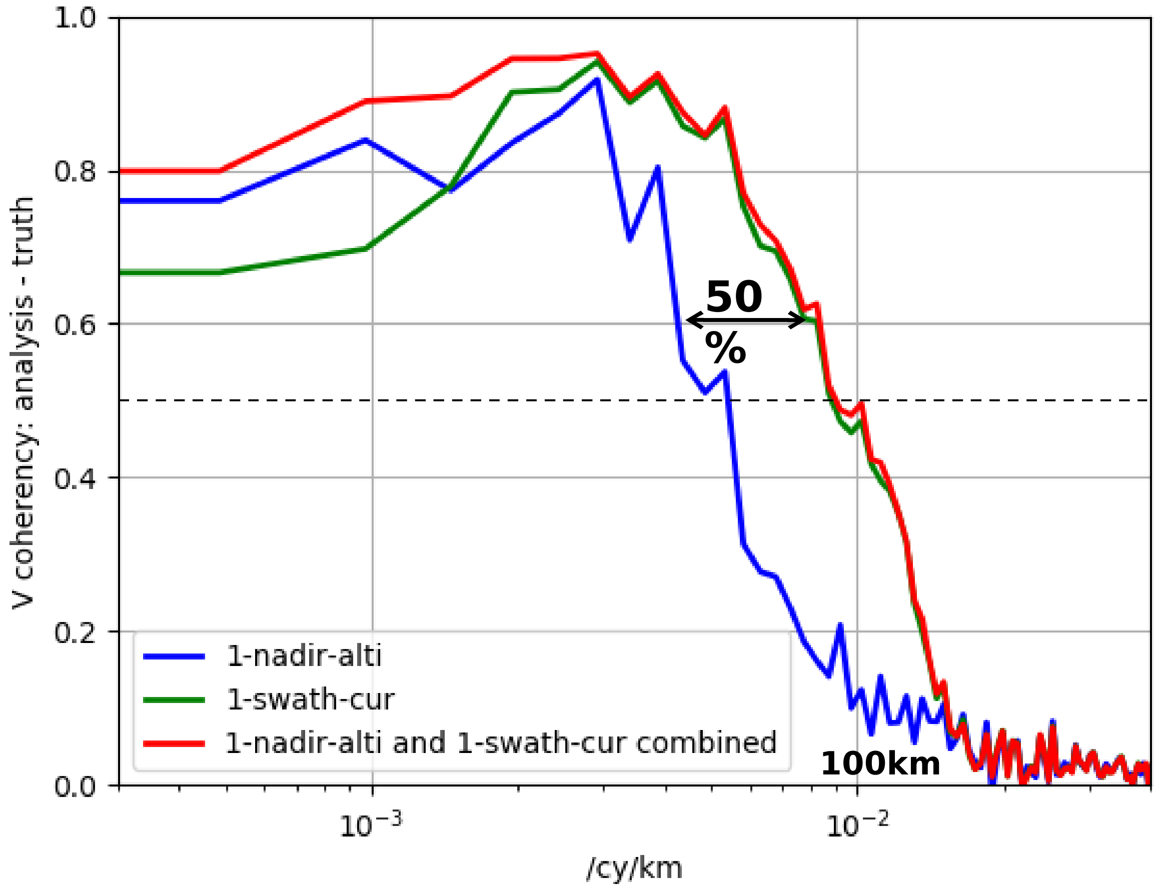


Cross-spectrum: coherency

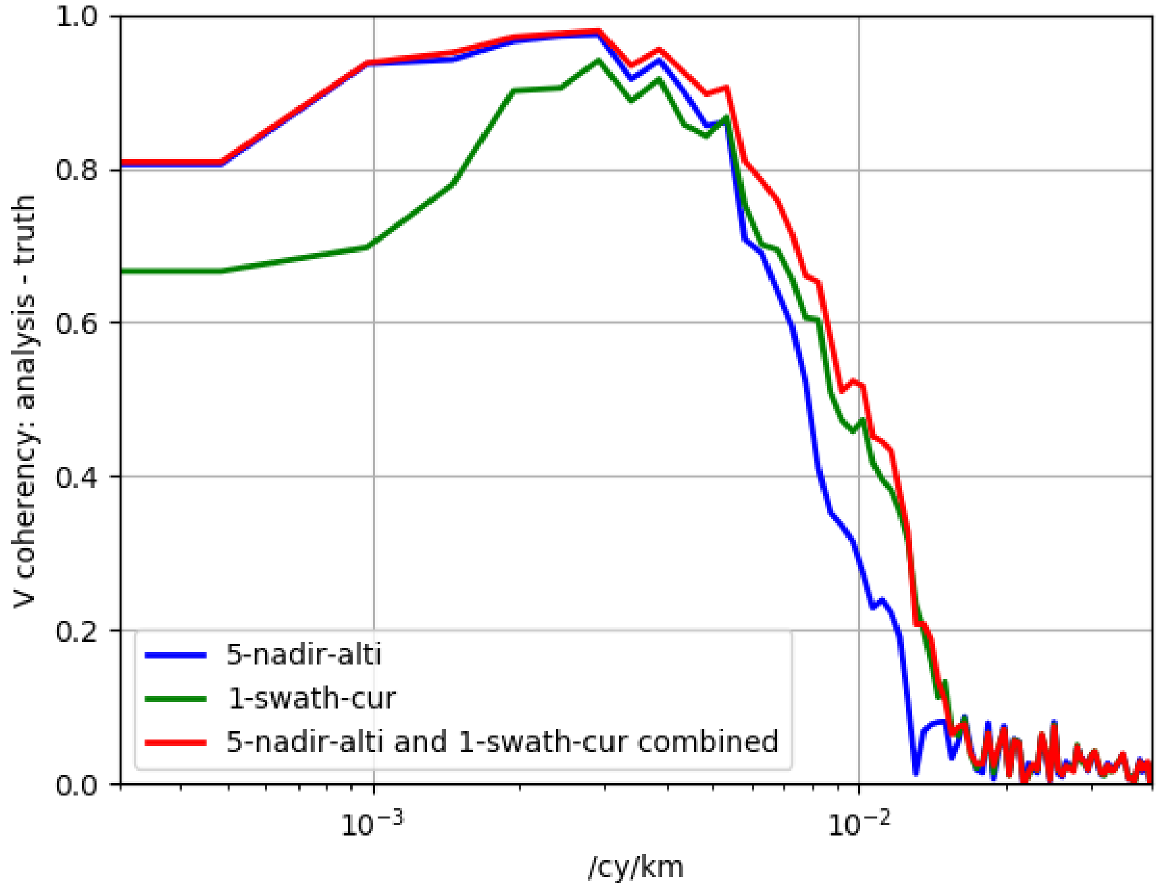


Effective resolution

Performances from cross-spectral analysis

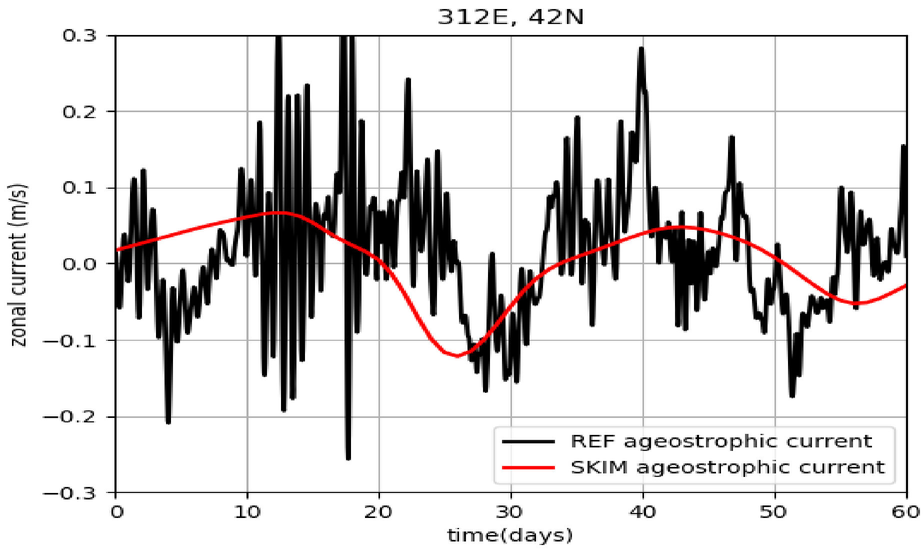


Performances from cross-spectral analysis



- Large scale current is more accurate from altimetry
- Short scale is more accuracte from doppler current
- The combination allows the best at each scale

Attempts to capture ageostrophy



- High-frequencies (inertial oscillations) do not mess up the analysis
- Work in progress to improve that:

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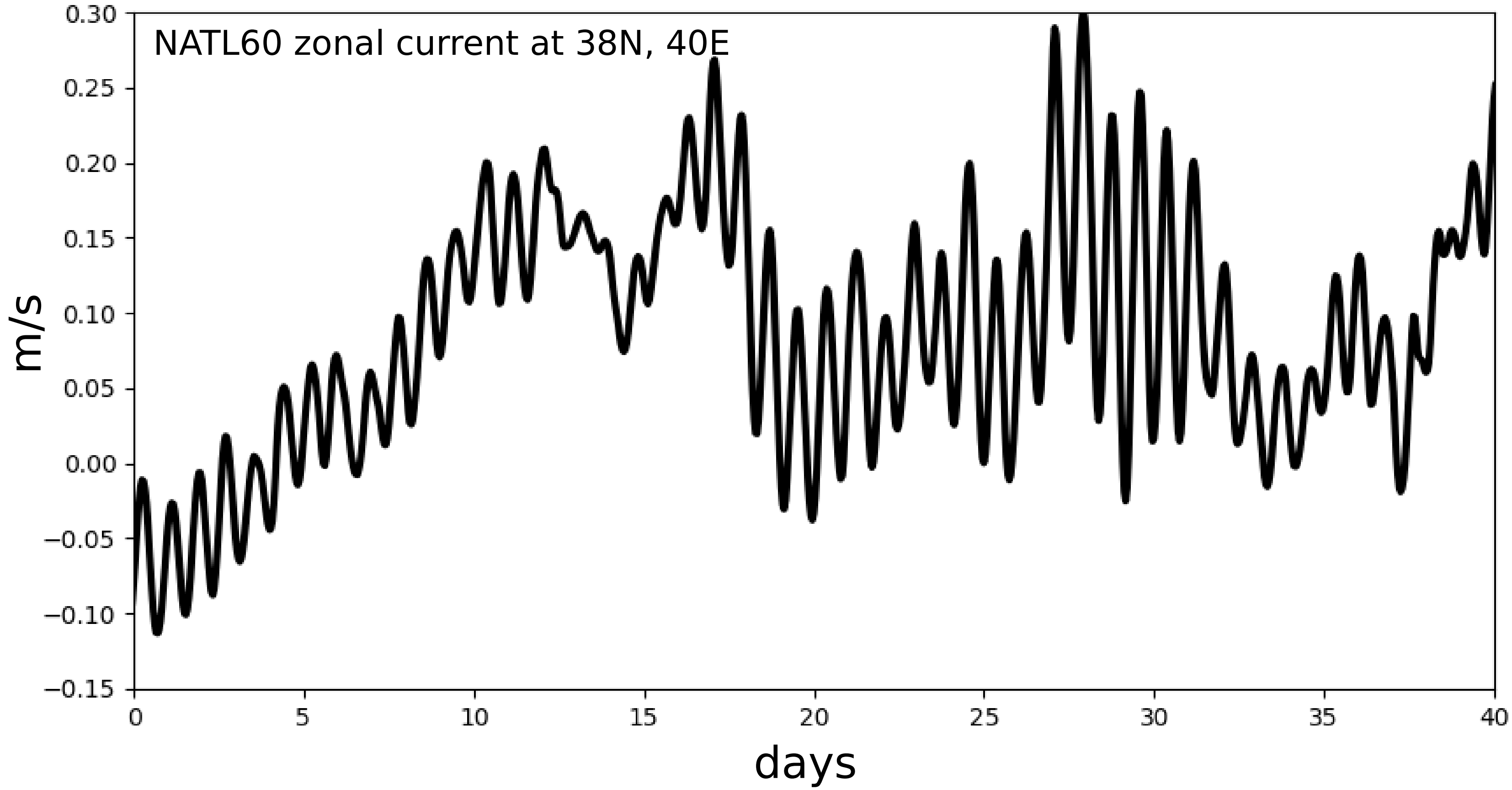
Specific OI scheme for IO : quick idealized experiment



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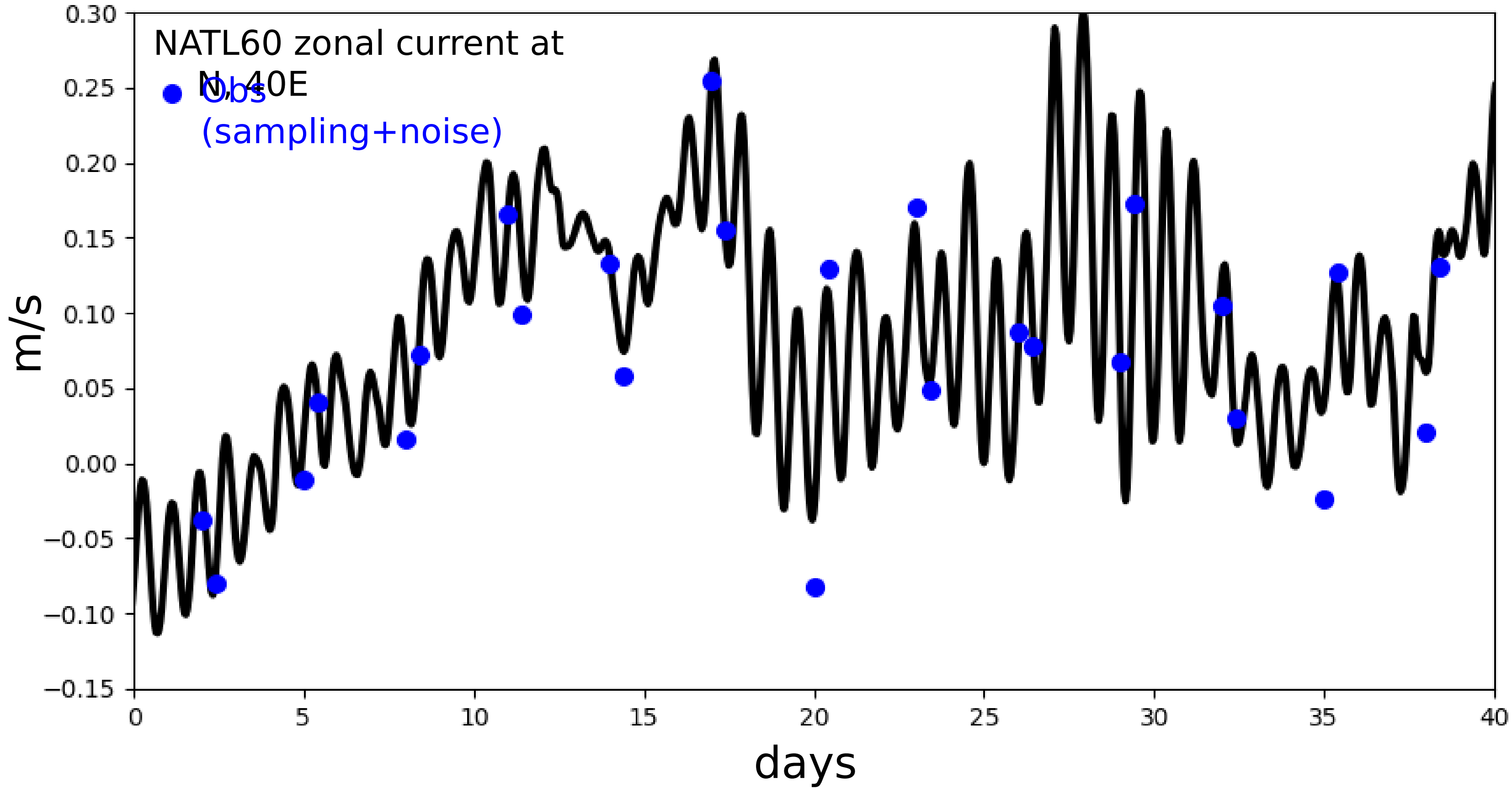


Specific OI scheme for IO

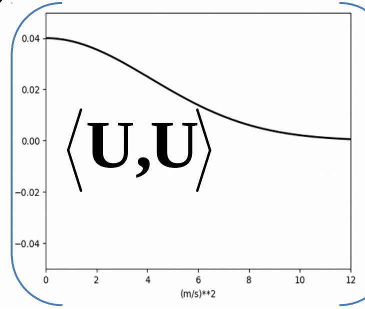
$$\begin{pmatrix} Ua \\ \vdots \\ Va \\ \vdots \end{pmatrix} = \mathbf{BH}^{T}(\mathbf{HBH}^{T} + \mathbf{R})^{-1} \begin{pmatrix} Uobs \\ \vdots \\ Vobs \\ \vdots \end{pmatrix}$$

- $\mathbf{H}$: Obs operator
- $\mathbf{B}$: Signal cov.
- $\mathbf{R}$: Error cov

Standard time decorrelation function for mesoscales:

$$\langle \mathbf{U},\mathbf{U} \rangle, \langle \mathbf{V},\mathbf{V} \rangle = \sigma_{LF}^{2} \exp\left(- \frac{\delta t^{2}}{\tau_{IO}^{2}} \right)$$

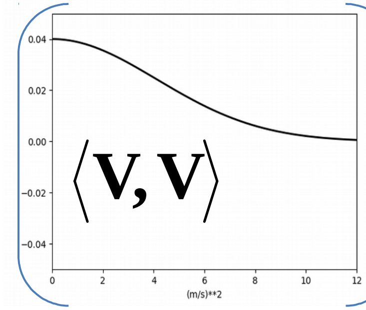
$\mathbf{B} =$



$\langle \mathbf{U},\mathbf{U} \rangle$

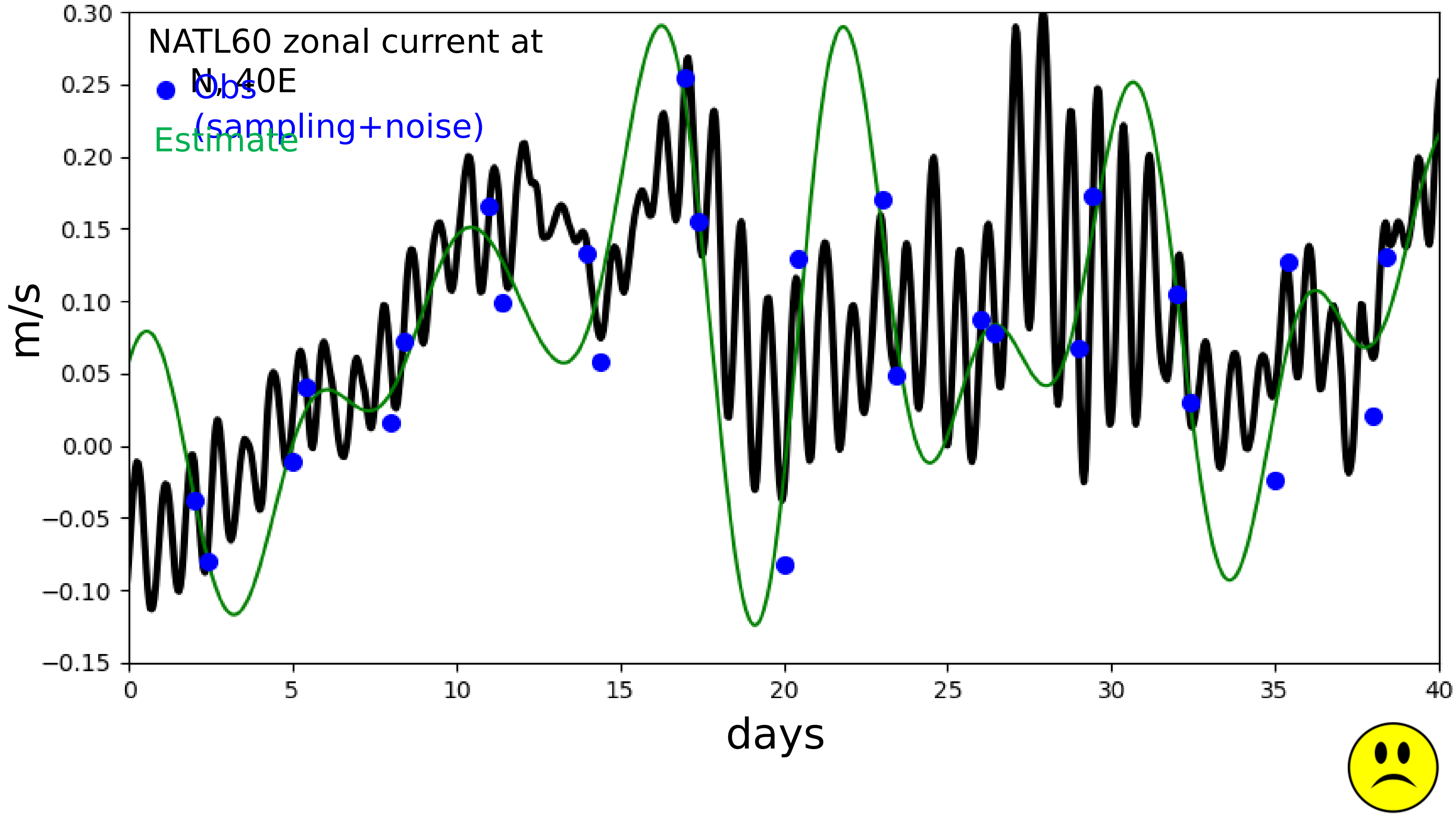
$\langle \mathbf{V},\mathbf{U} \rangle = 0$

$\langle \mathbf{U},\mathbf{V} \rangle = 0$



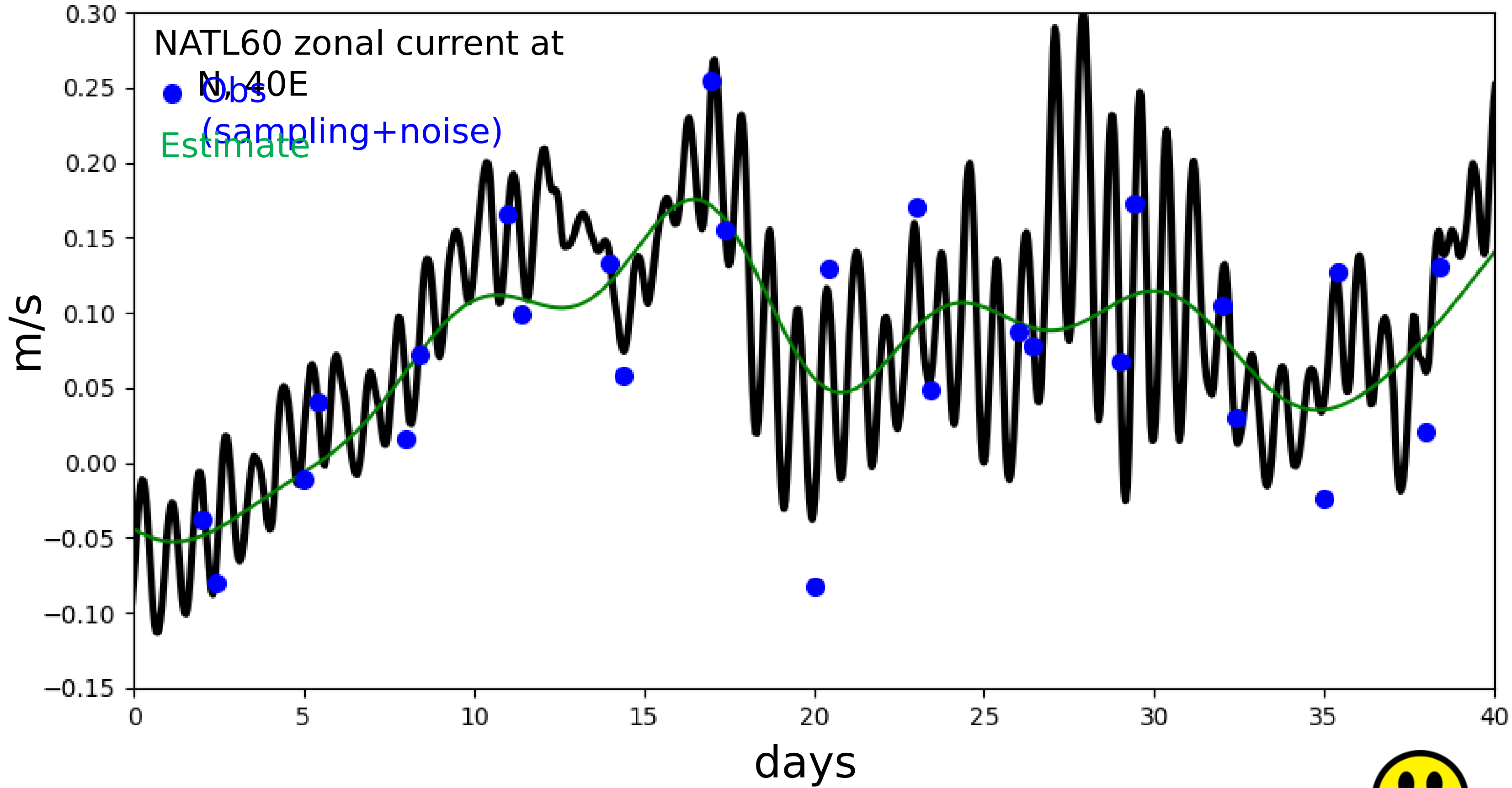
$\langle \mathbf{V},\mathbf{V} \rangle$

Specific OI scheme for IO : quick idealized experiment



Terrible aliasing

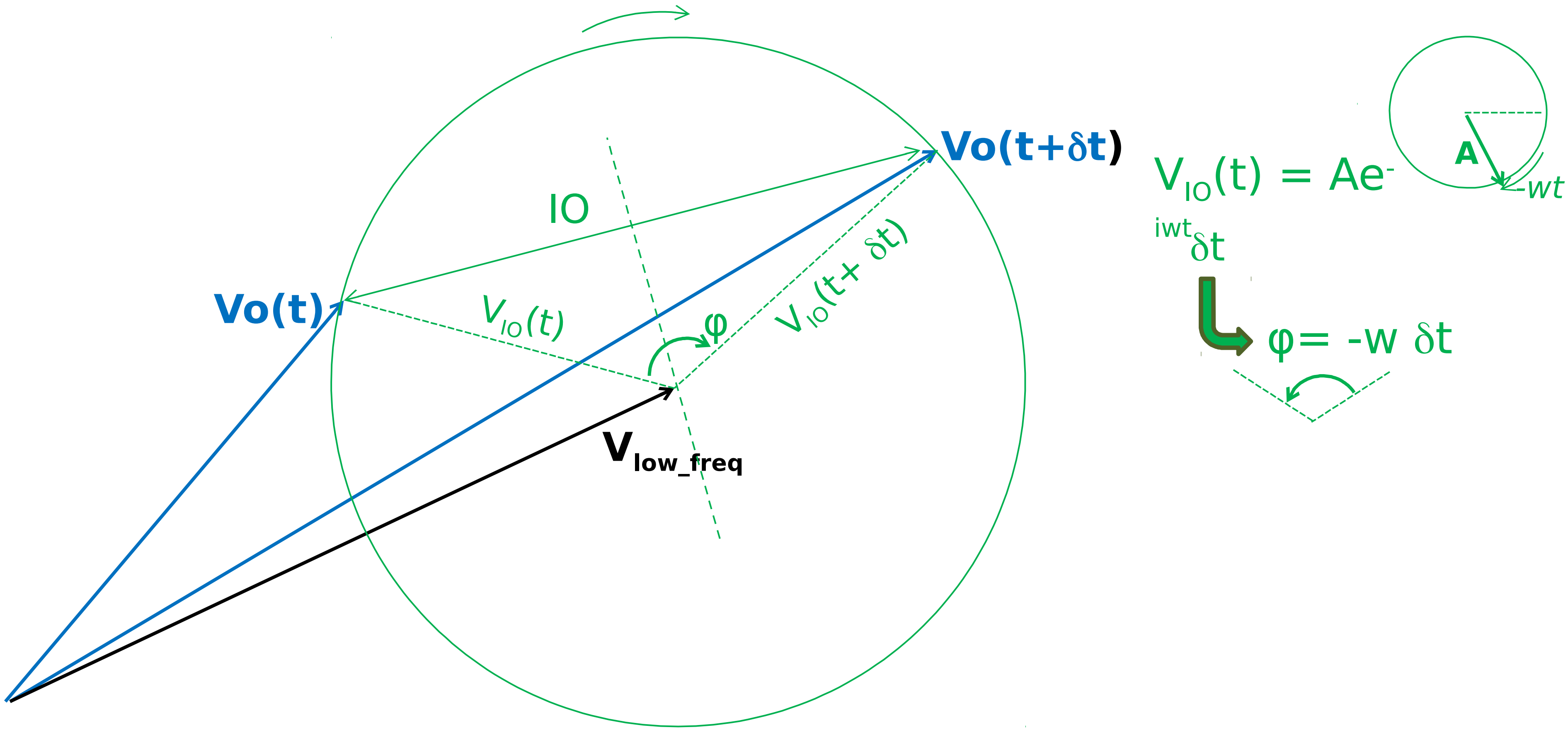
Specific OI scheme for IO : quick idealized experiment



With longer decorrelation and **R** boosted : Less aliasing, but altered signal …

Need to optimally handle low frequencies and near inertial oscillations

Some geometry...

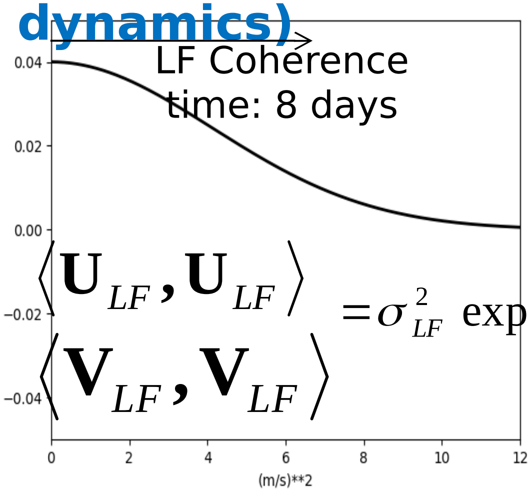


Possible disentenglement

Let’s formulate the inverse problem

Covariances for ‘low-freq’ + IO

Low frequencies (balanced dynamics)

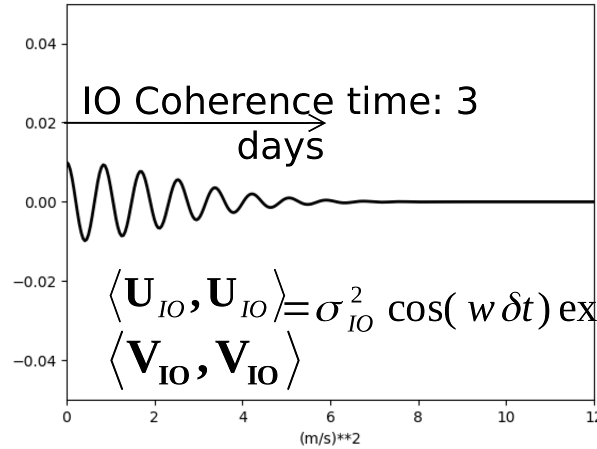


$$\langle \mathbf{U}_{LF}, \mathbf{U}_{LF} \rangle = \sigma_{LF}^2 \exp\left(- \frac{\delta t^2}{\tau_{IO}^2} \right)$$

$$\langle \mathbf{V}_{LF}, \mathbf{V}_{LF} \rangle$$

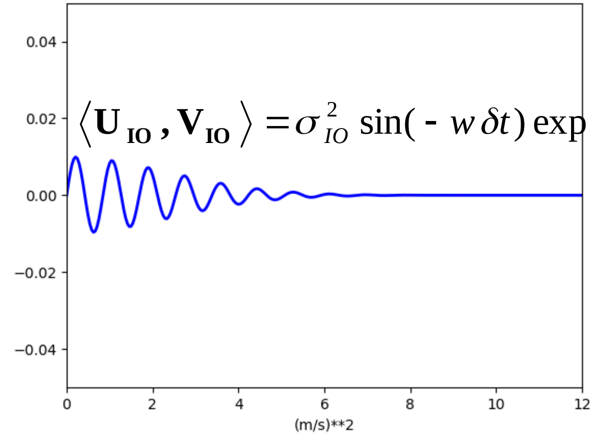
$$\langle \mathbf{U}_{LF}, \mathbf{V}_{LF} \rangle = 0$$

Inertial Oscillations



$$\langle \mathbf{U}_{IO}, \mathbf{U}_{IO} \rangle = \sigma_{IO}^2 \cos(w\,\delta t) \exp\left(- \frac{\delta t^2}{\tau_{IO}^2} \right)$$

$$\langle \mathbf{V}_{\mathbf{IO}}, \mathbf{V}_{\mathbf{IO}} \rangle$$



$$\langle \mathbf{U}_{\mathbf{IO}}, \mathbf{V}_{\mathbf{IO}} \rangle = \sigma_{IO}^2 \sin(-w\,\delta t) \exp\left(- \frac{\delta t^2}{\tau_{IO}^2} \right)$$

We assume no LF / IO correlation:

$$\langle \mathbf{U}_{LF}, \mathbf{U}_{IO} \rangle = 0 \qquad \langle \mathbf{V}_{LF}, \mathbf{V}_{IO} \rangle = 0 \qquad \langle \mathbf{U}_{LF}, \mathbf{V}_{IO} \rangle = 0$$

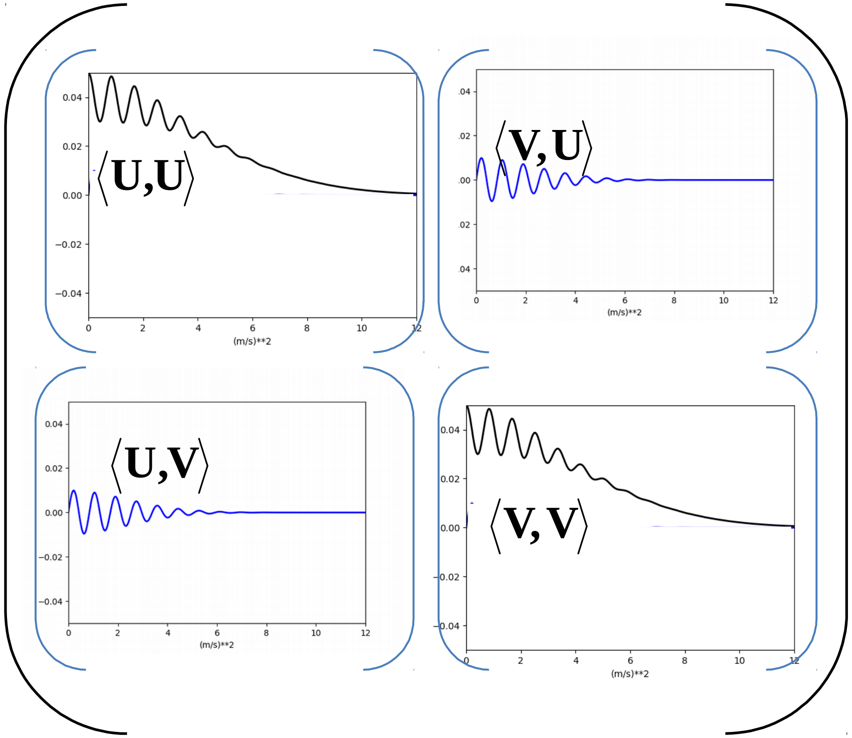
Optimal filtering of IO: the new B matrix

$$\begin{pmatrix} Ua \\ \vdots \\ Va \\ \vdots \end{pmatrix} = \mathbf{B}\mathbf{H}^{T}(\mathbf{H}\mathbf{B}\mathbf{H}^{T} + \mathbf{R})^{-1} \begin{pmatrix} Uobs \\ \vdots \\ Vobs \\ \vdots \end{pmatrix}$$

Obs operato r

Signal cov.

Error cov

$\mathbf{B} =$ 

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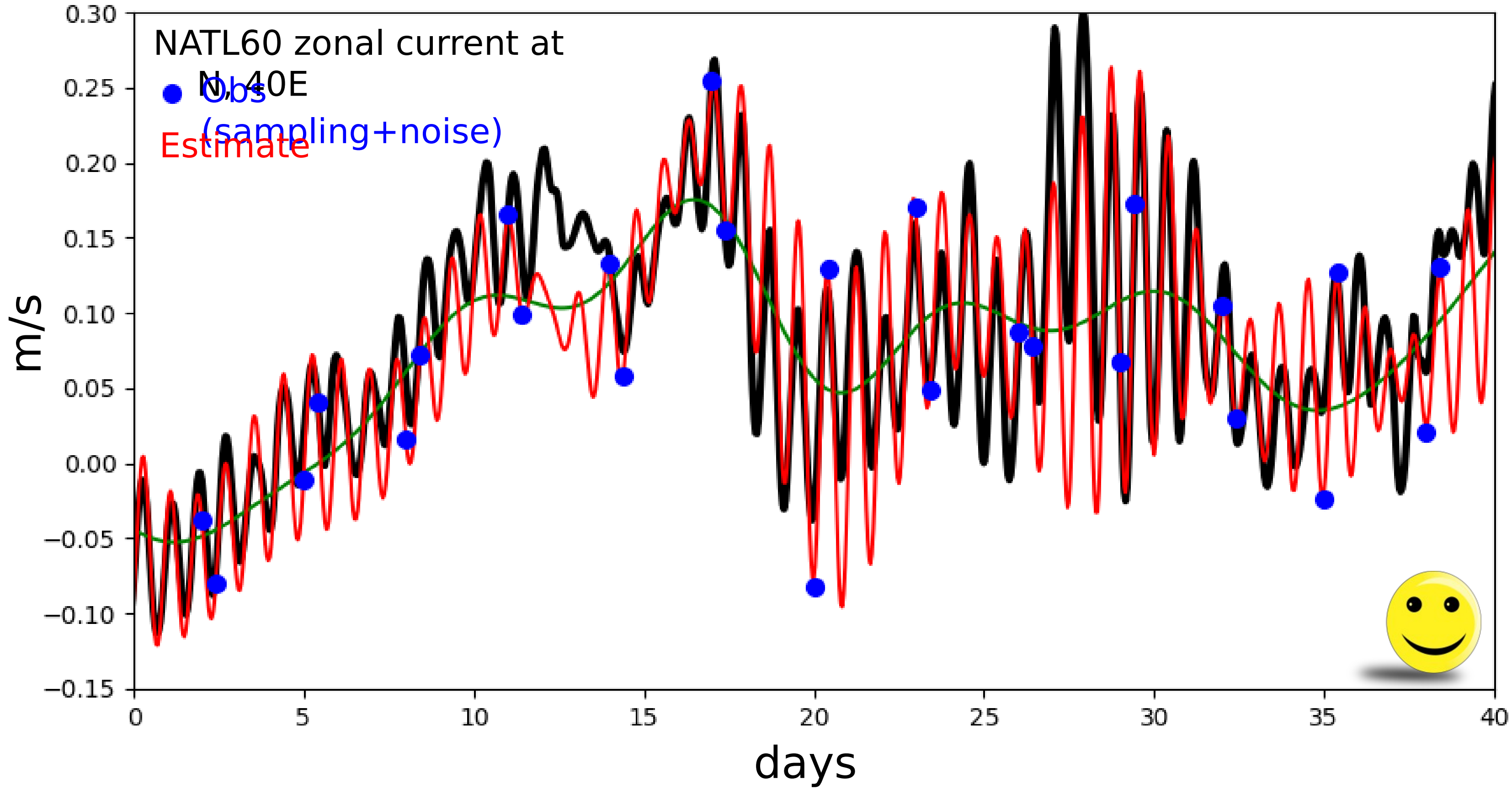

• A hanfull of observations allows good estimation of the signal (thanks to IO coherency): LF, IO (amplitude, phase)

• Perspective to propose <u>two separate Level 4 products:</u> balanced dynamics and_mapped inertial oscillations (no more a noise to get rid of!)

•**The performances will rely on the ratio time revisit / time+space coherency**

•**We propose to make a survey of Inertial Oscillation coherency**

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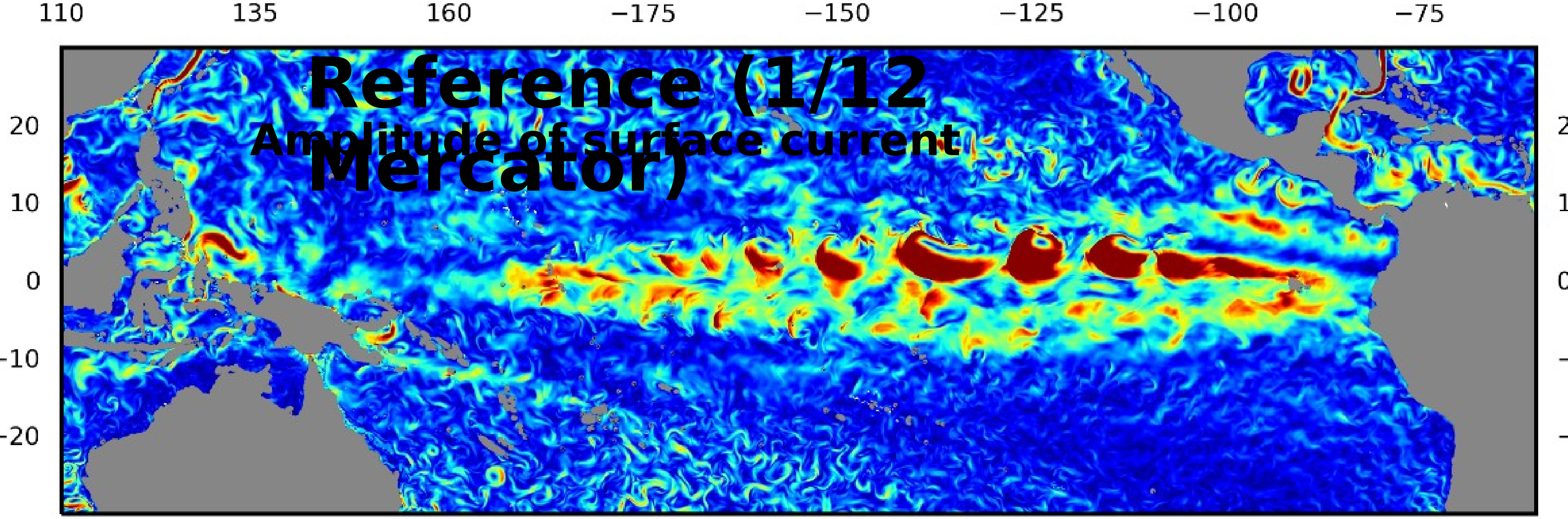
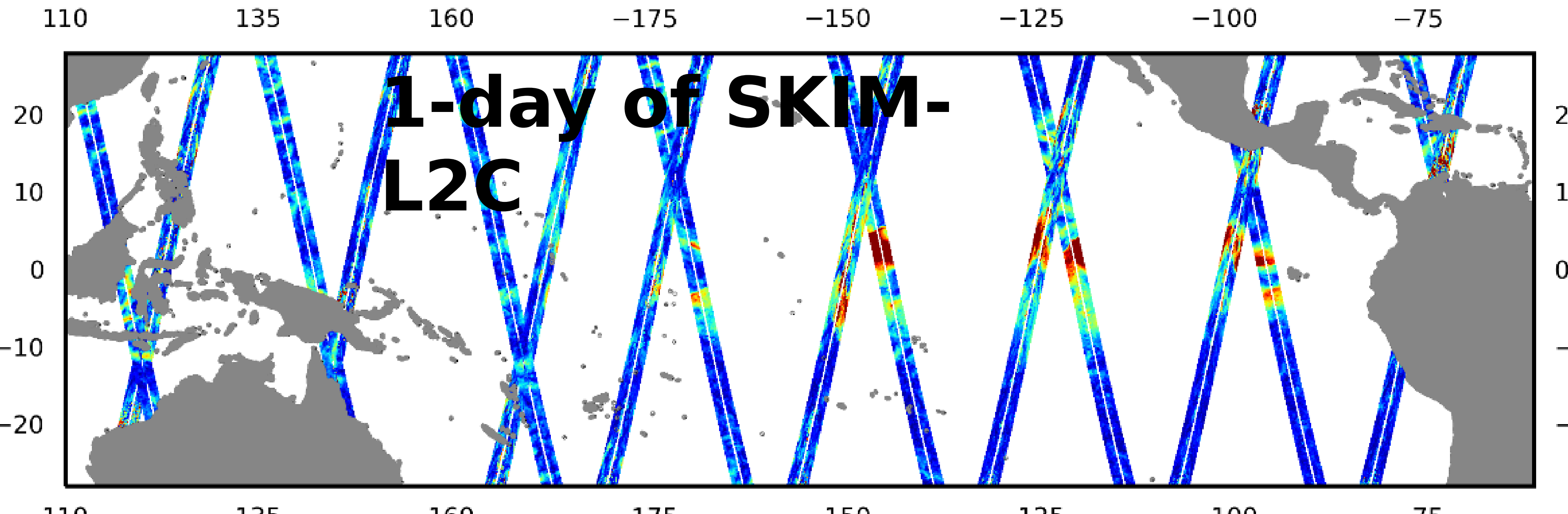
2-year simulation in Tropical Pacific (for SciSoc)





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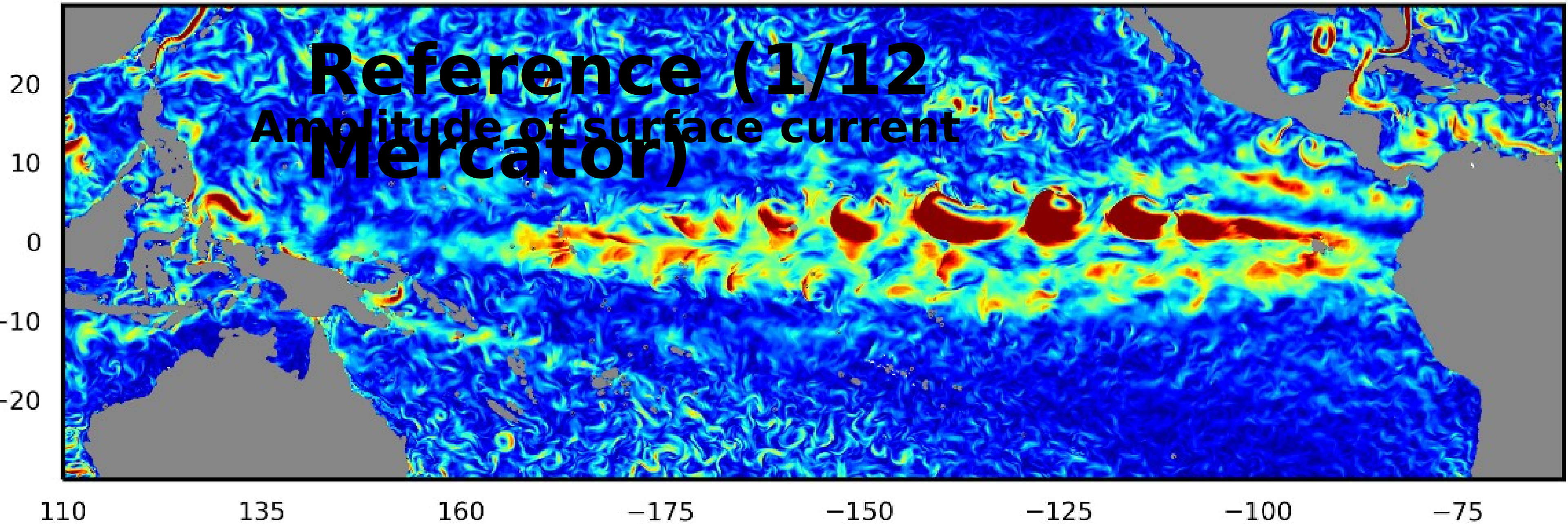

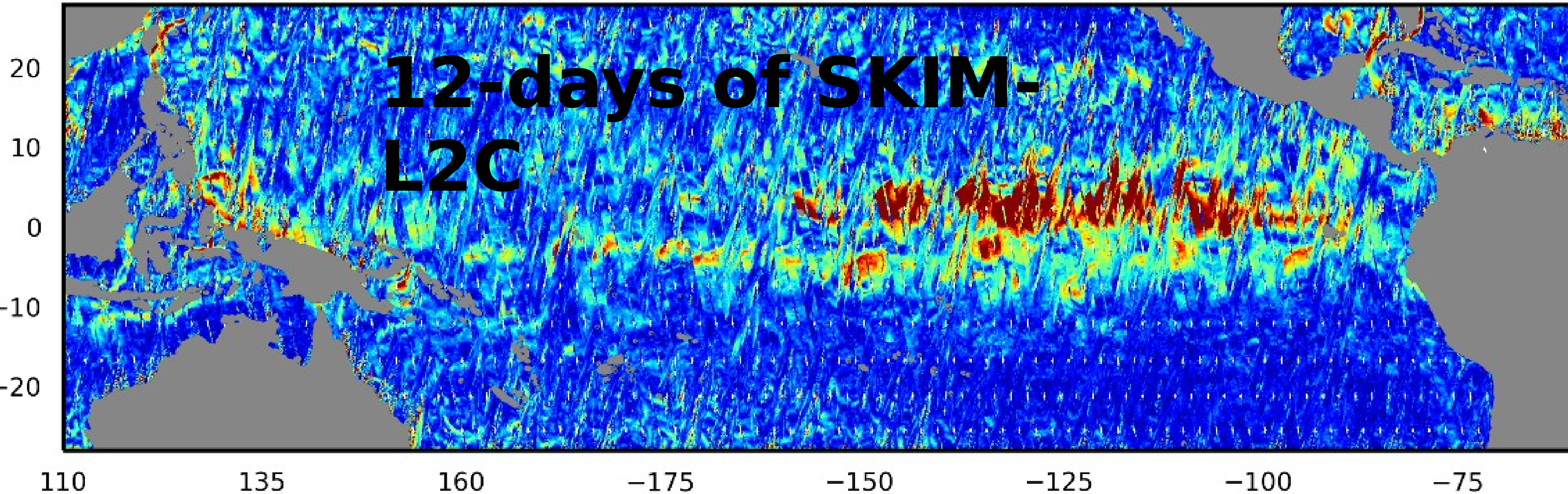

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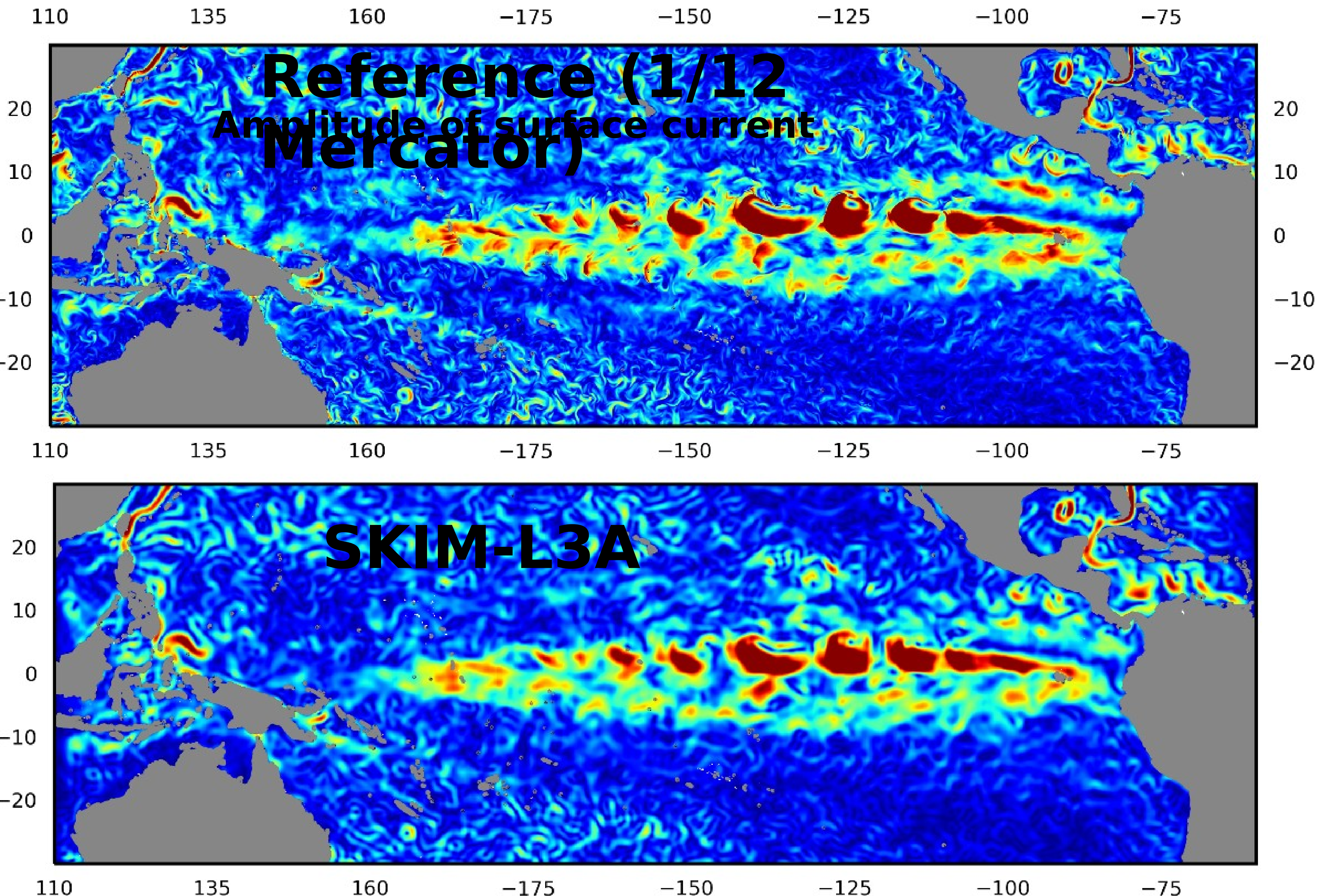

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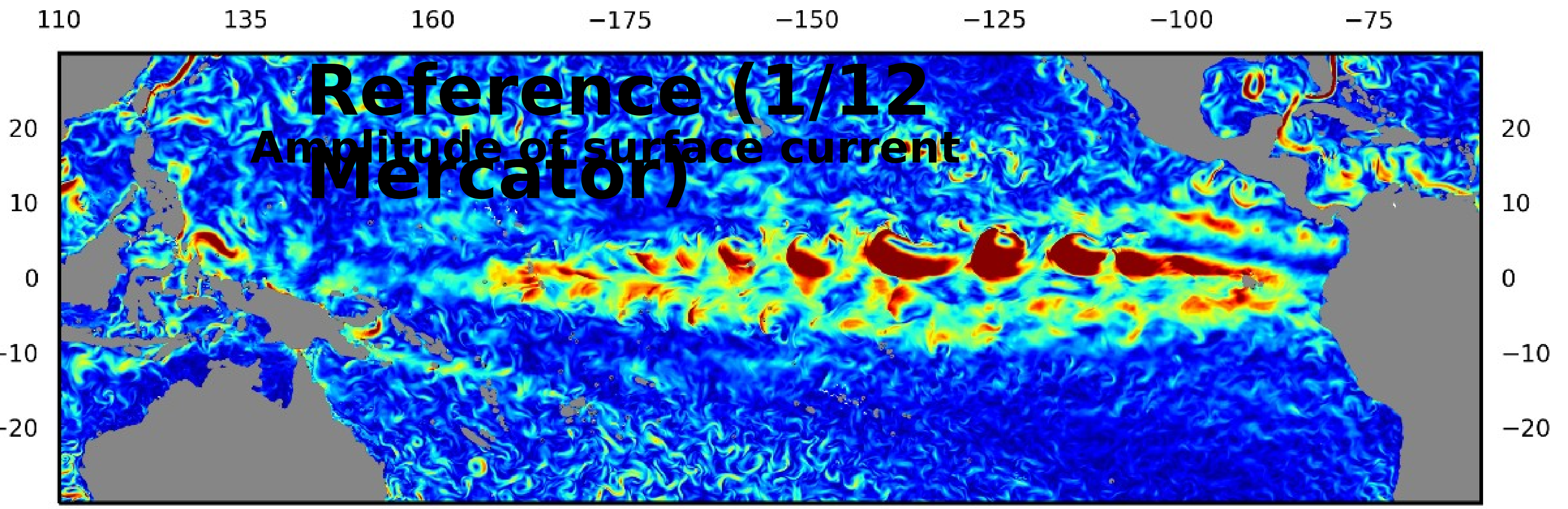
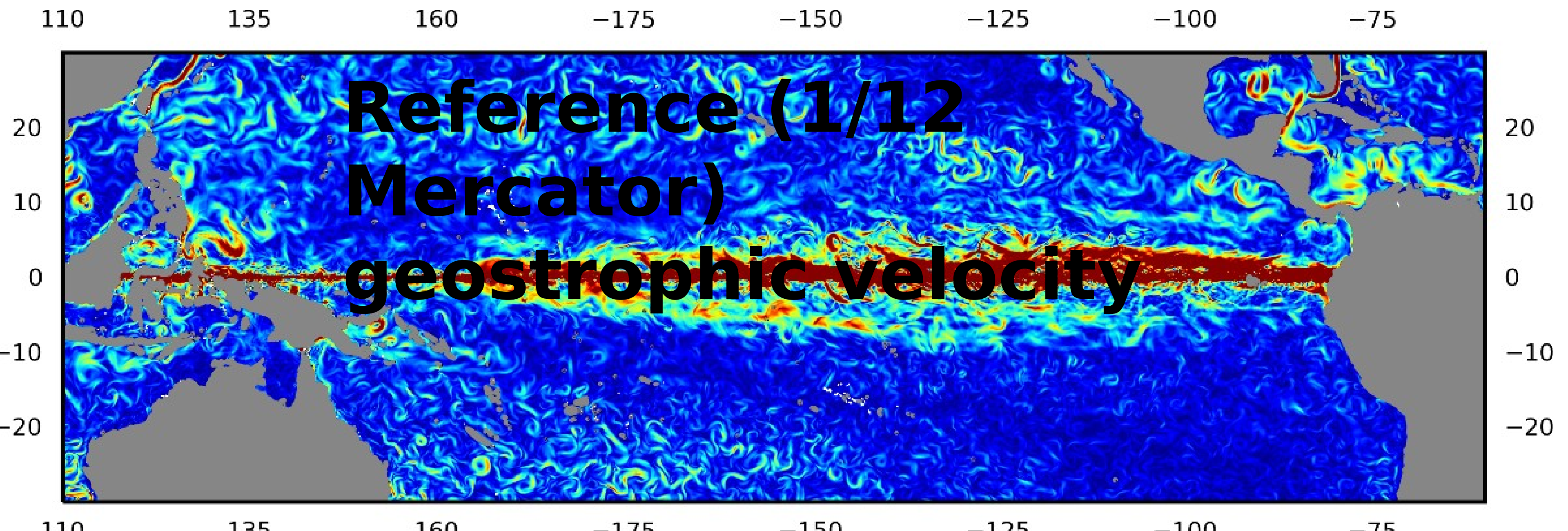




Conclusions

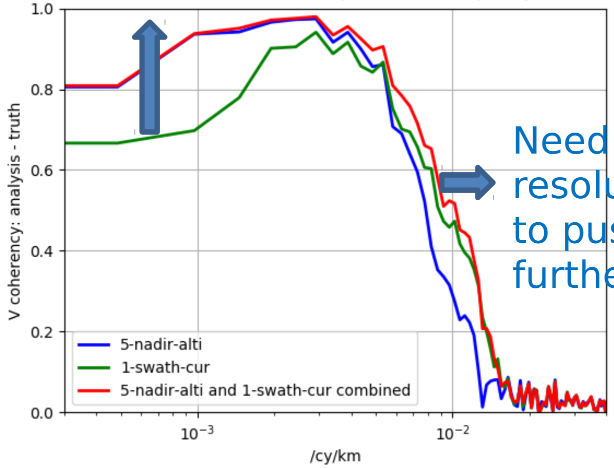
- Spaceborne direct-current observations (not involving a derivative!) would substancially improve the capacity to map currents even in geostrophically-dominent flows (SKIM alone ~ 5altimeters)

- So far, inertial Oscillations are considered as a noise to get rid of. Why not a signal to resolve? Any scientific interest? (e.g. quantities to derive from?)

- In Equatorial regions, the added value is obvious. Plans for in-depth analysis on all types of waves that could be captured (2D spectrum metrics…)

- More revisits would always help: several missions, constellation, …

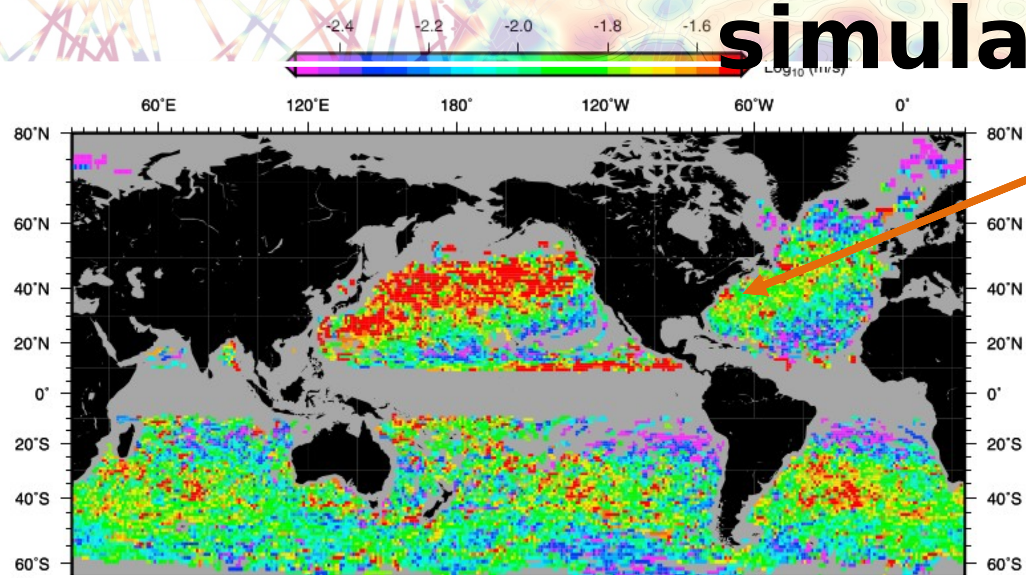
Need more time repeat (or smart ideas) to handle ageostrophy



Need spati resolution to push further.

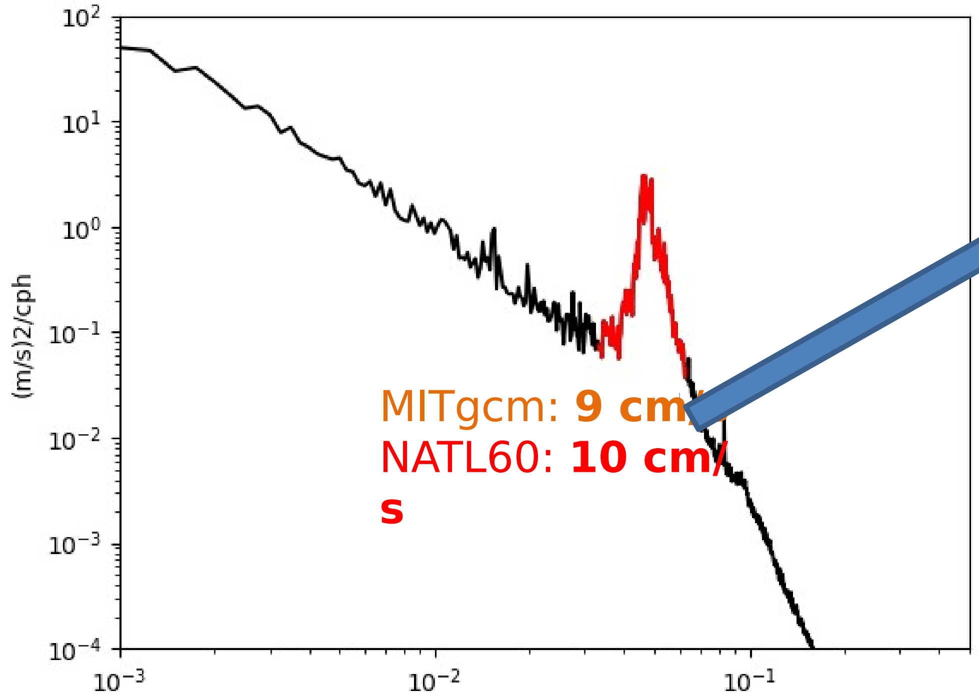
Backup

Are inertial motions realistic in the simulation?



Drifters:
~13 cm/s in
Gulf Stream

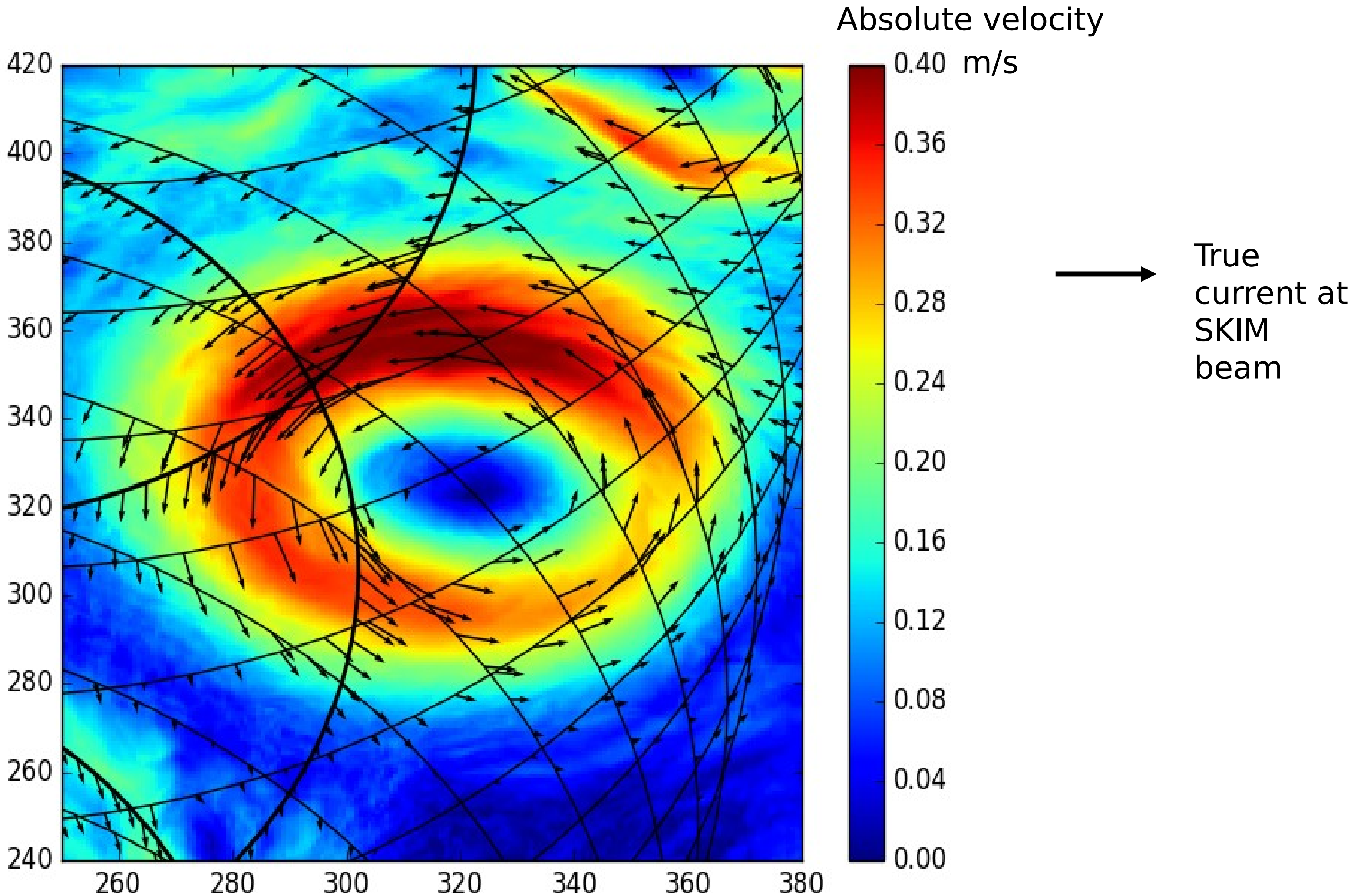
From Elipot et al., 2010: variance of near inertial motions from drifters



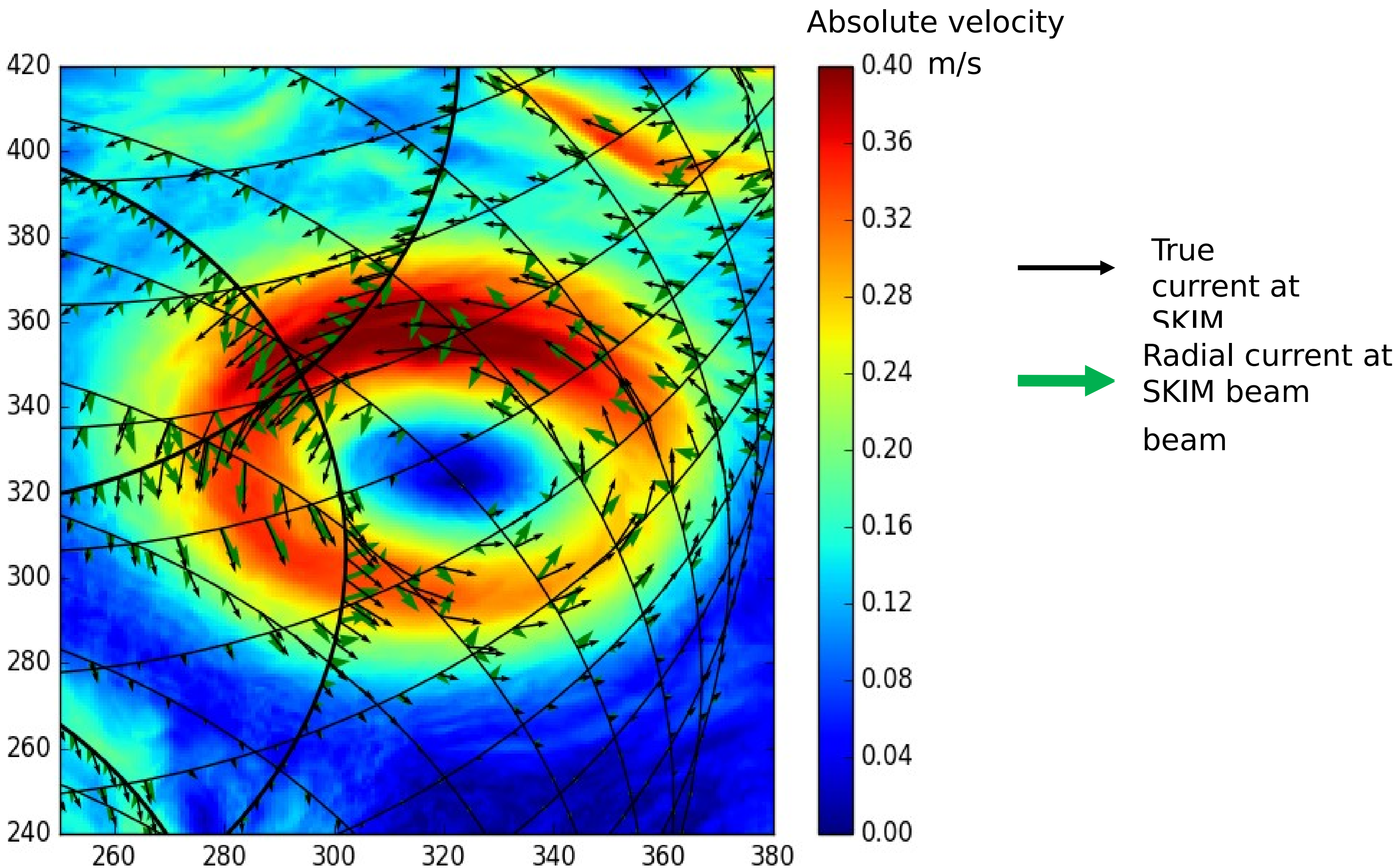
MITgcm: **9 cm/s**
NATL60: **10 cm/s**

Models would underestimate inertial motions, but not dramatically

To be further analysed on longer time series



Absolute velocity
m/s
0.40
0.36
0.32
0.28
0.24
0.20
0.16
0.12
0.08
0.04
0.00
420
400
380
360
340
320
300
280
260
240
260
280
300
320
340
360
380
True current at SKIM beam



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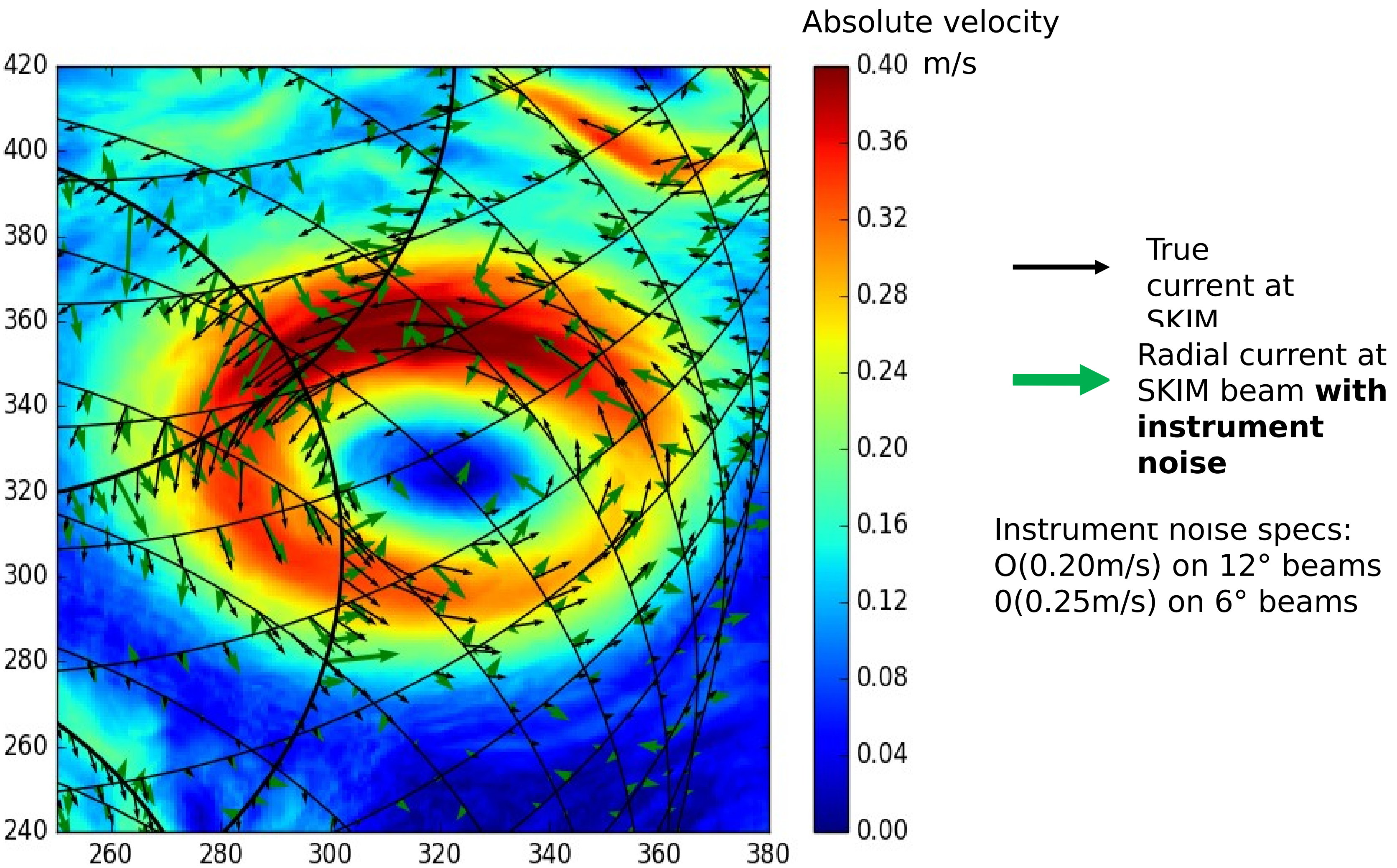
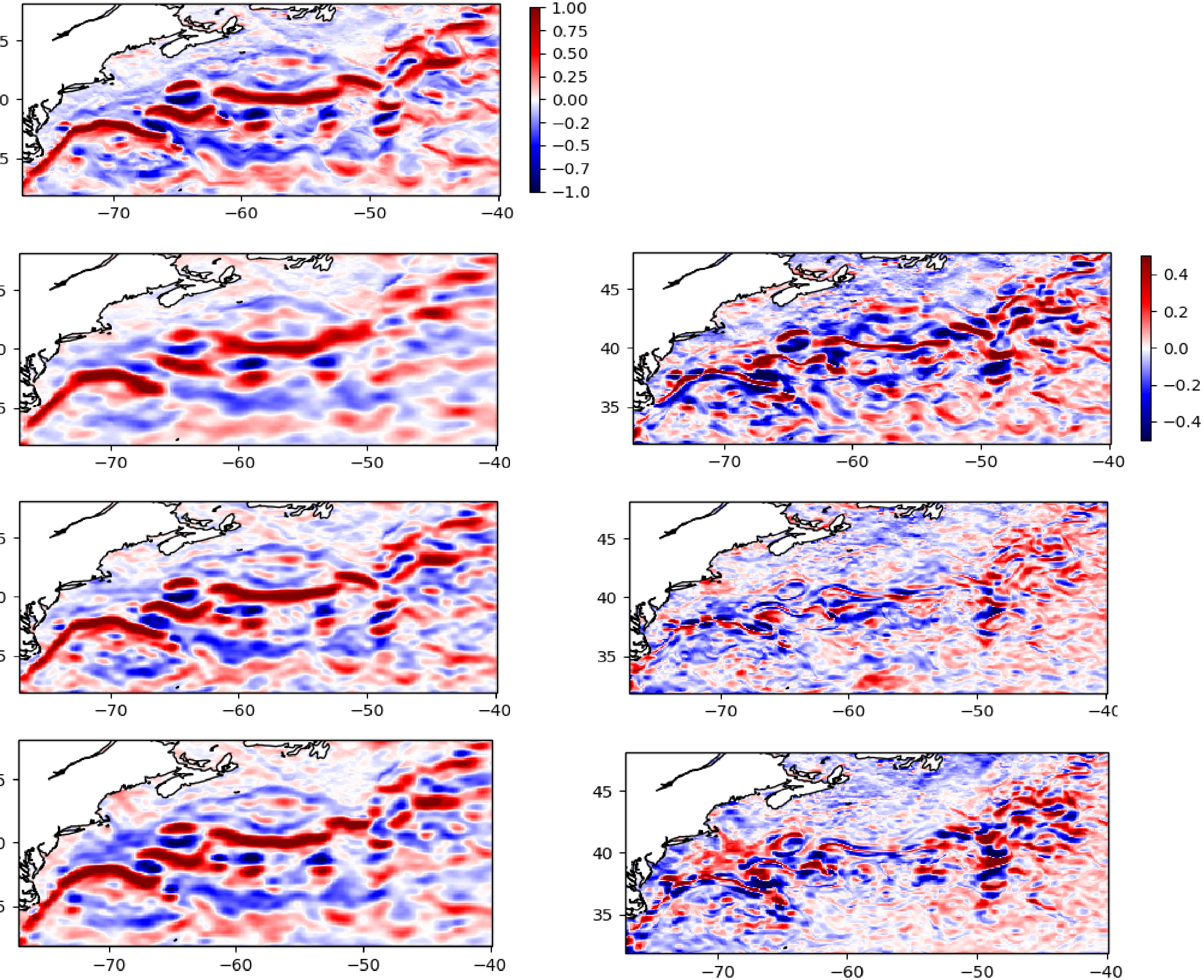
400
380
360
340
320
300
280
260
240
260
280
300
320
340
360
380
True current at SKIM
Radial current at SKIM beam
beam

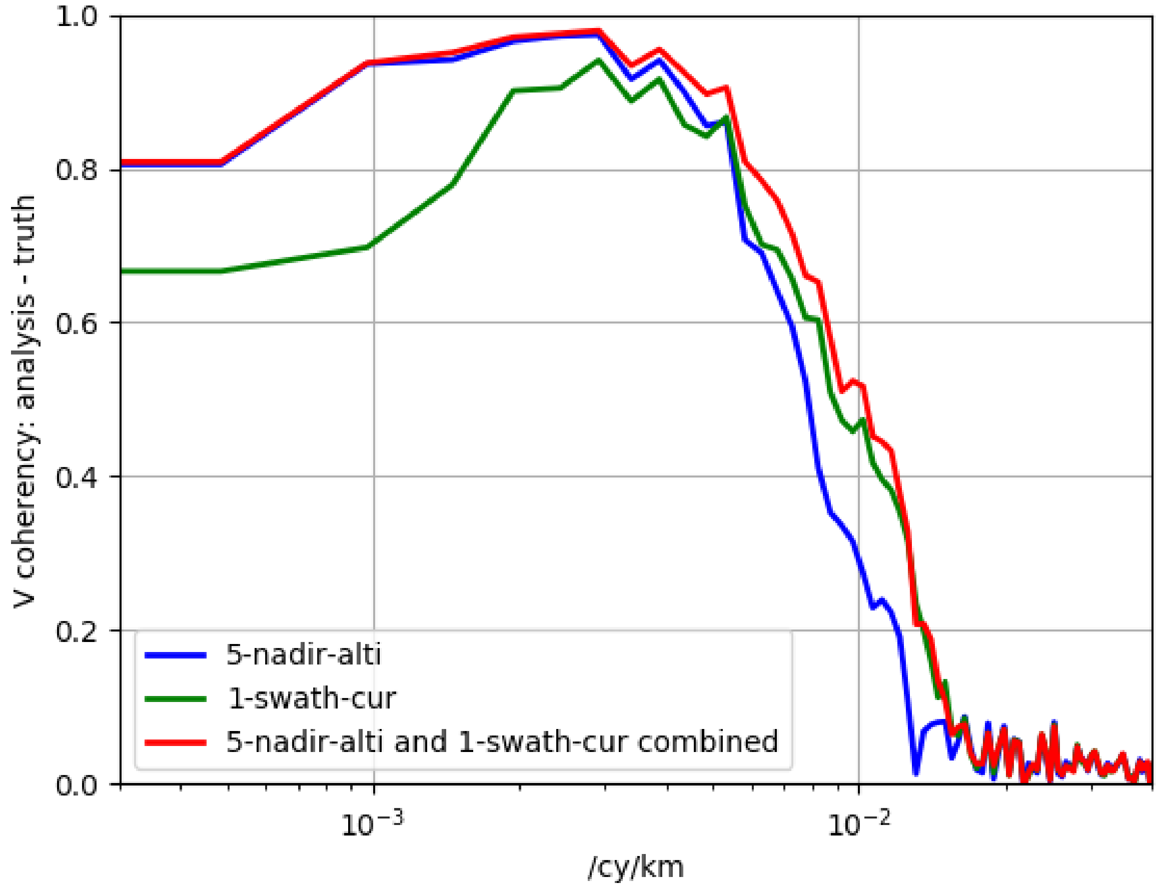


Instrument noise specs:
O(0.20m/s) on 12° beams
0(0.25m/s) on 6° beams

Examples of mapping errors



Performances from cross-spectral analysis



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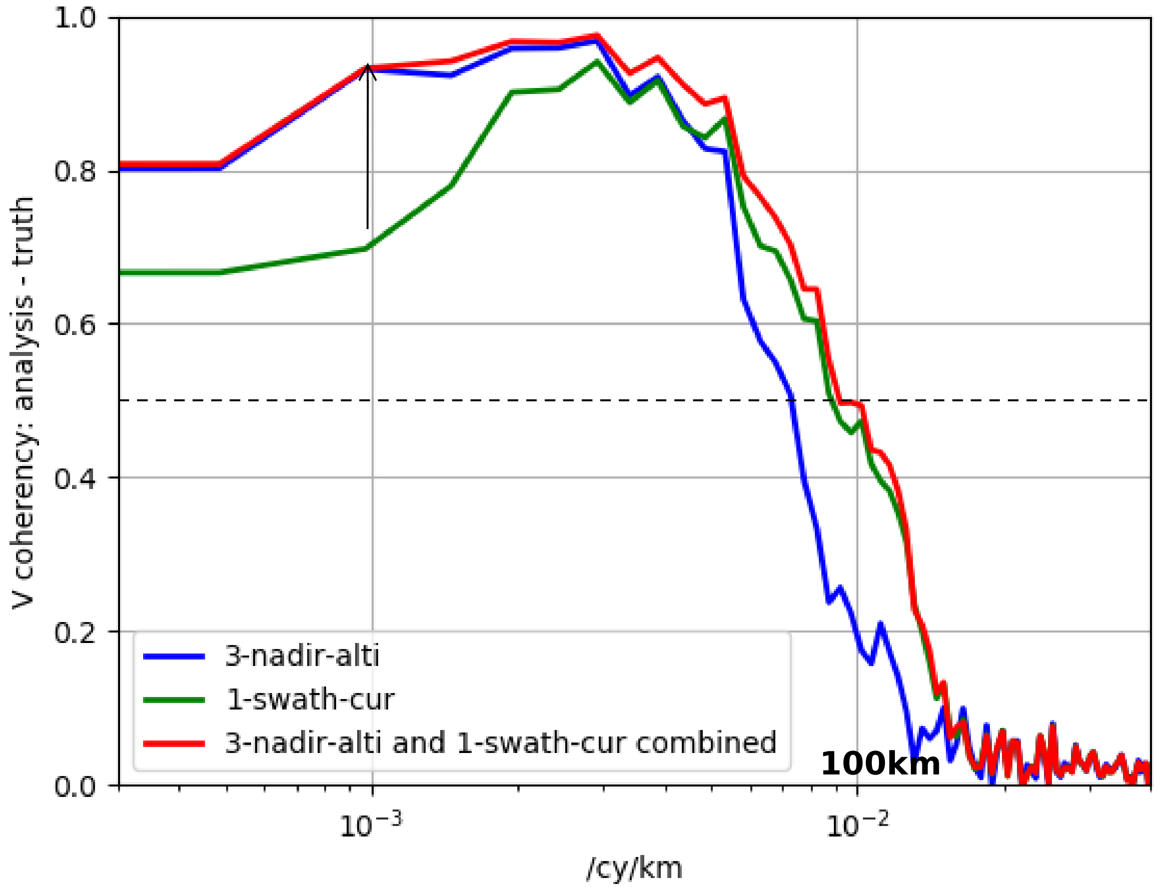
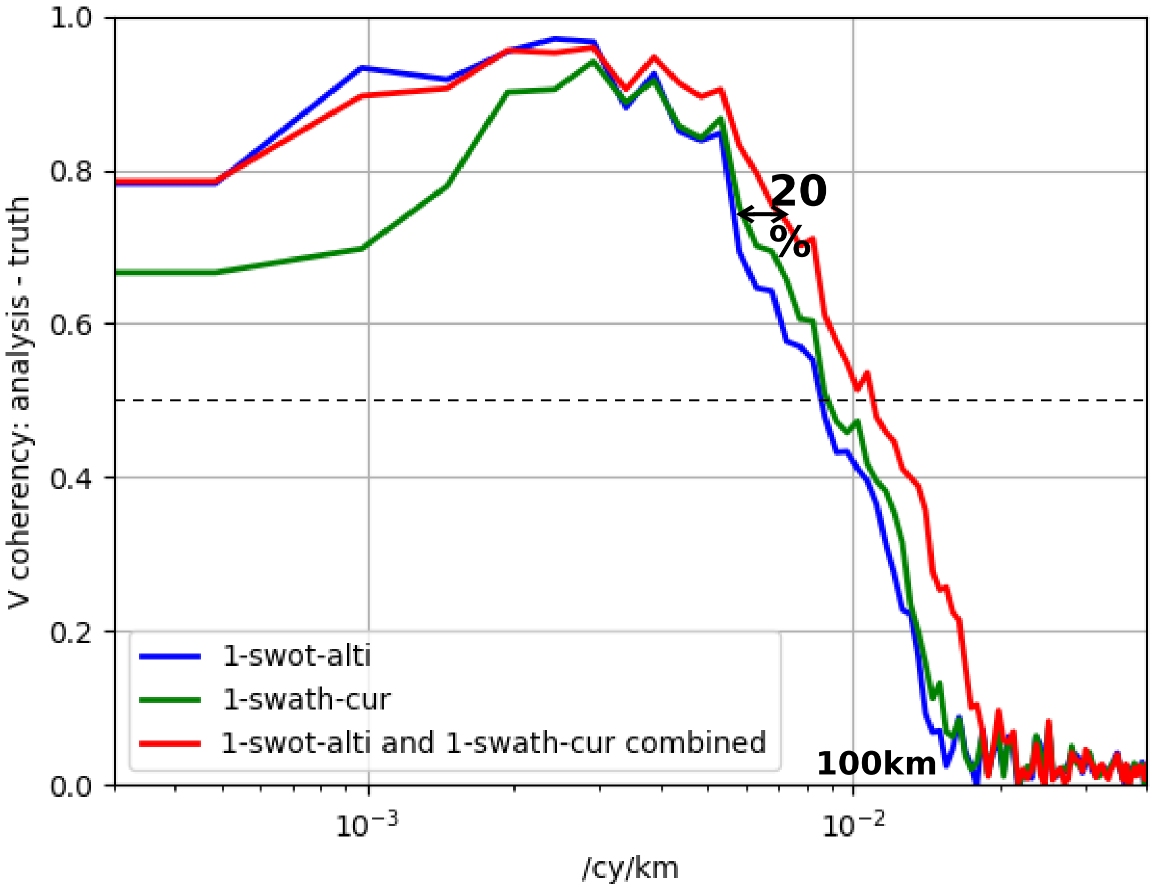


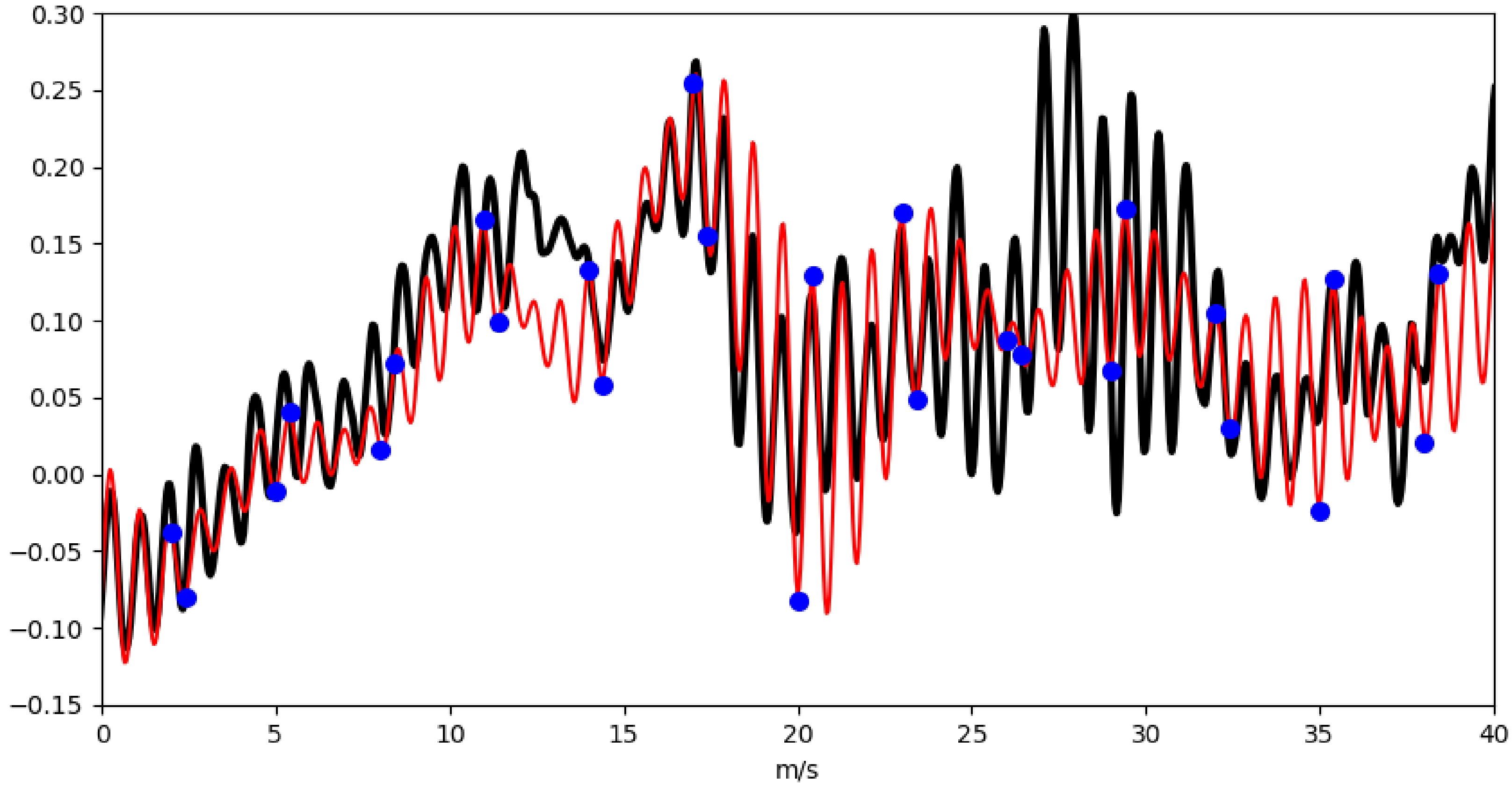
- Large scale current is more accurate from altimetry
- Short scale is more accuracte from doppler current
- The combination allows the best at each scale

Performances from cross-spectral analysis

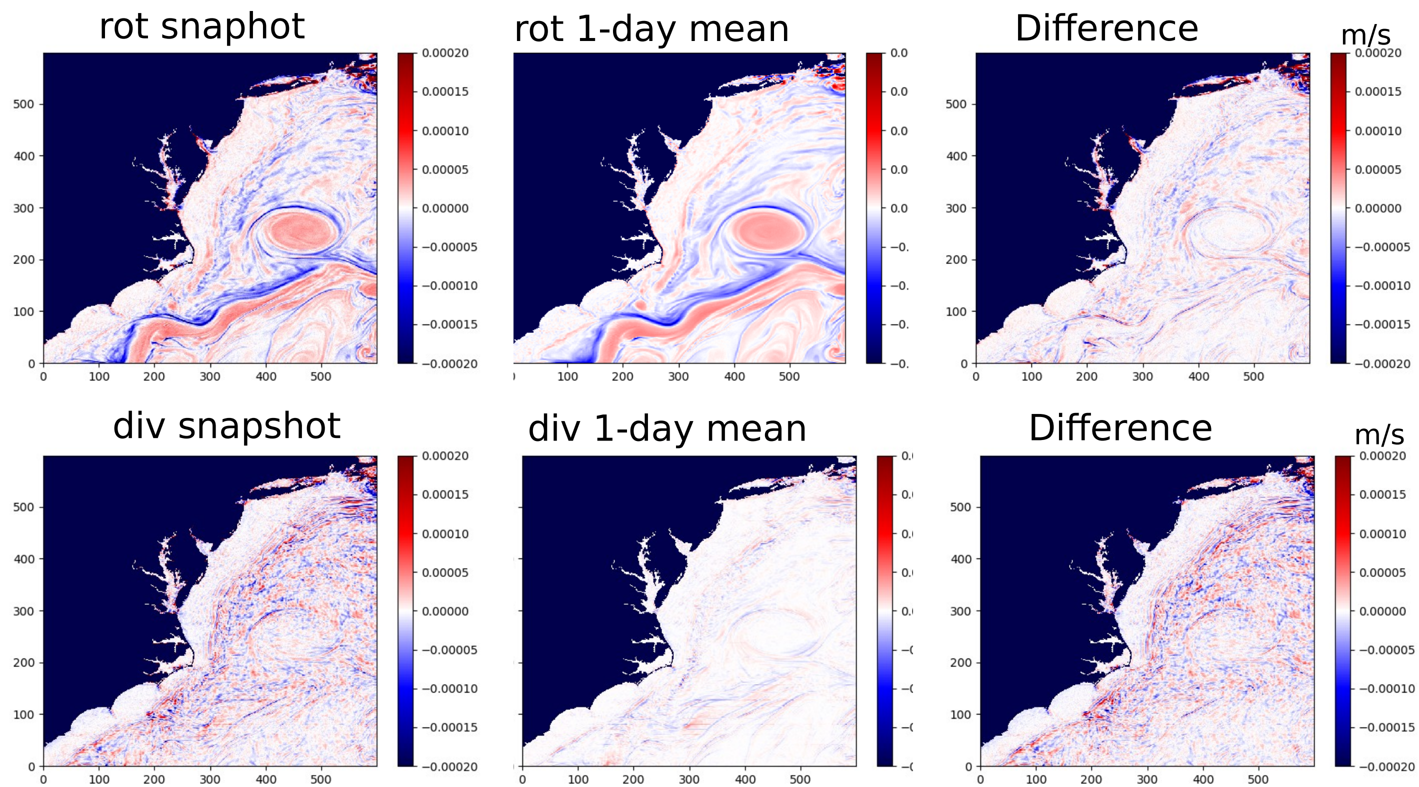


- With SWOT: comparable to the doppler swath at short scales
- **20% extra gain in synergy**

Optimal filtering of IO



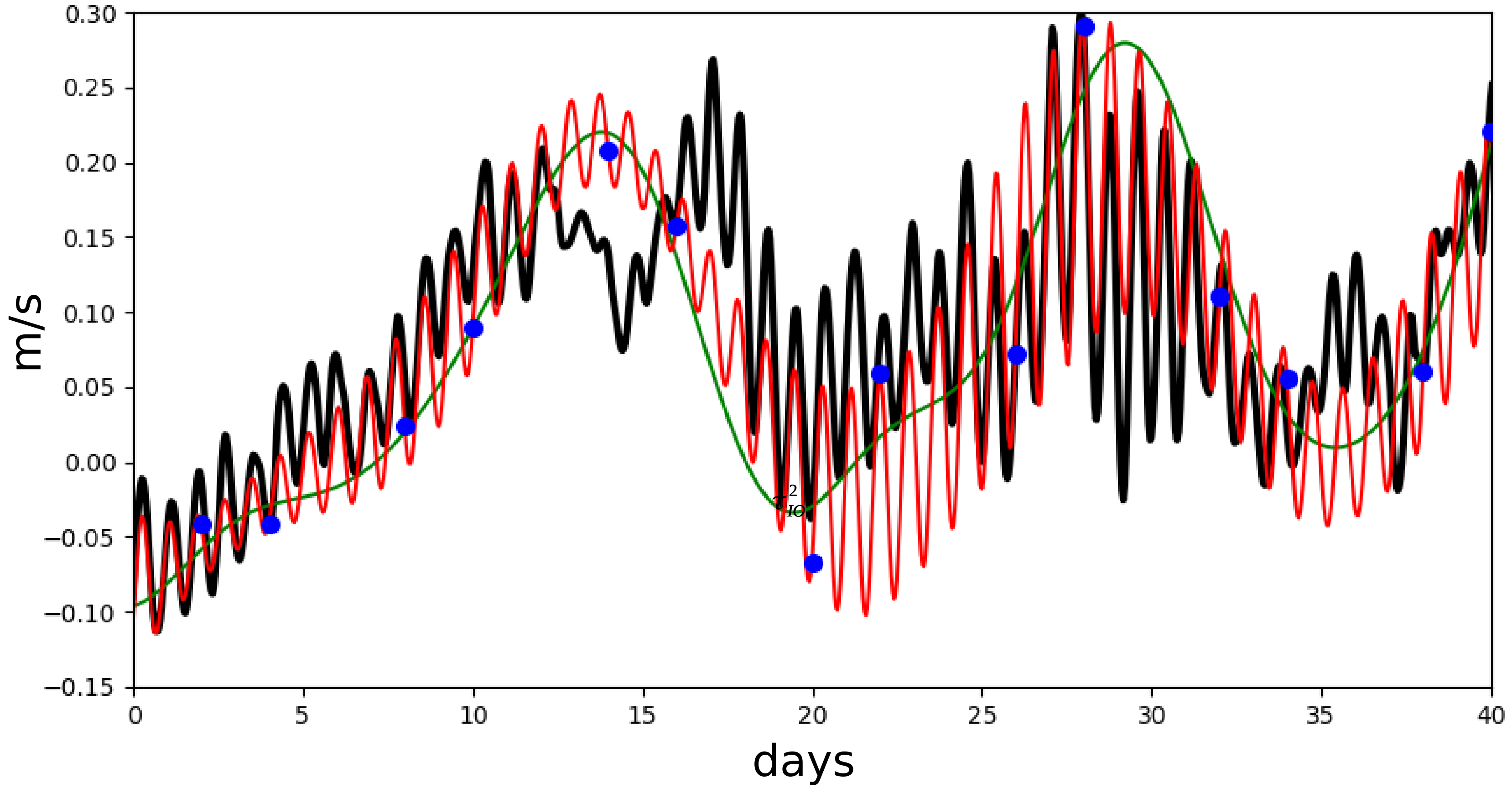
Ongoing track: use rot/div properties to filter HF ageostrophy



- High-frequency current seems mostly divergent
  ✉ **restrict the HF covariance functions to divergent-only fields**

- Since geostrophy is purely rotationnal **we hope to get better performances to separate HF signals**

Optimal filtering of IO



More realistic of SKIM-alone ….

$$\tau_{IO}$$