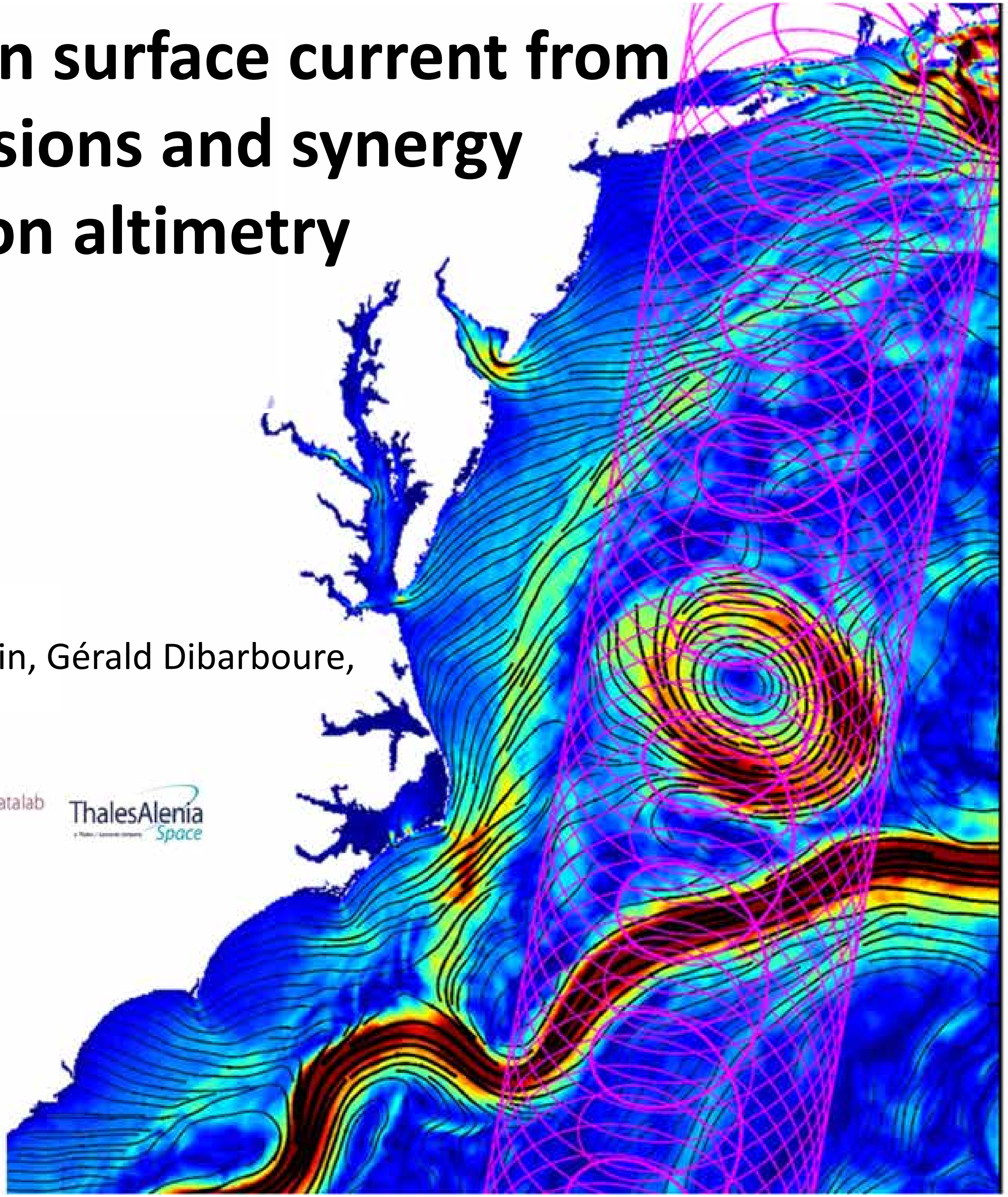
Mapping the Ocean surface current from future current missions and synergy with high-resolution altimetry



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Introduction

- SKIM concept proposed for ESA EE9 (PI: F. Ardhuin): rotating beams with Doppler processing: **See poster next room!**

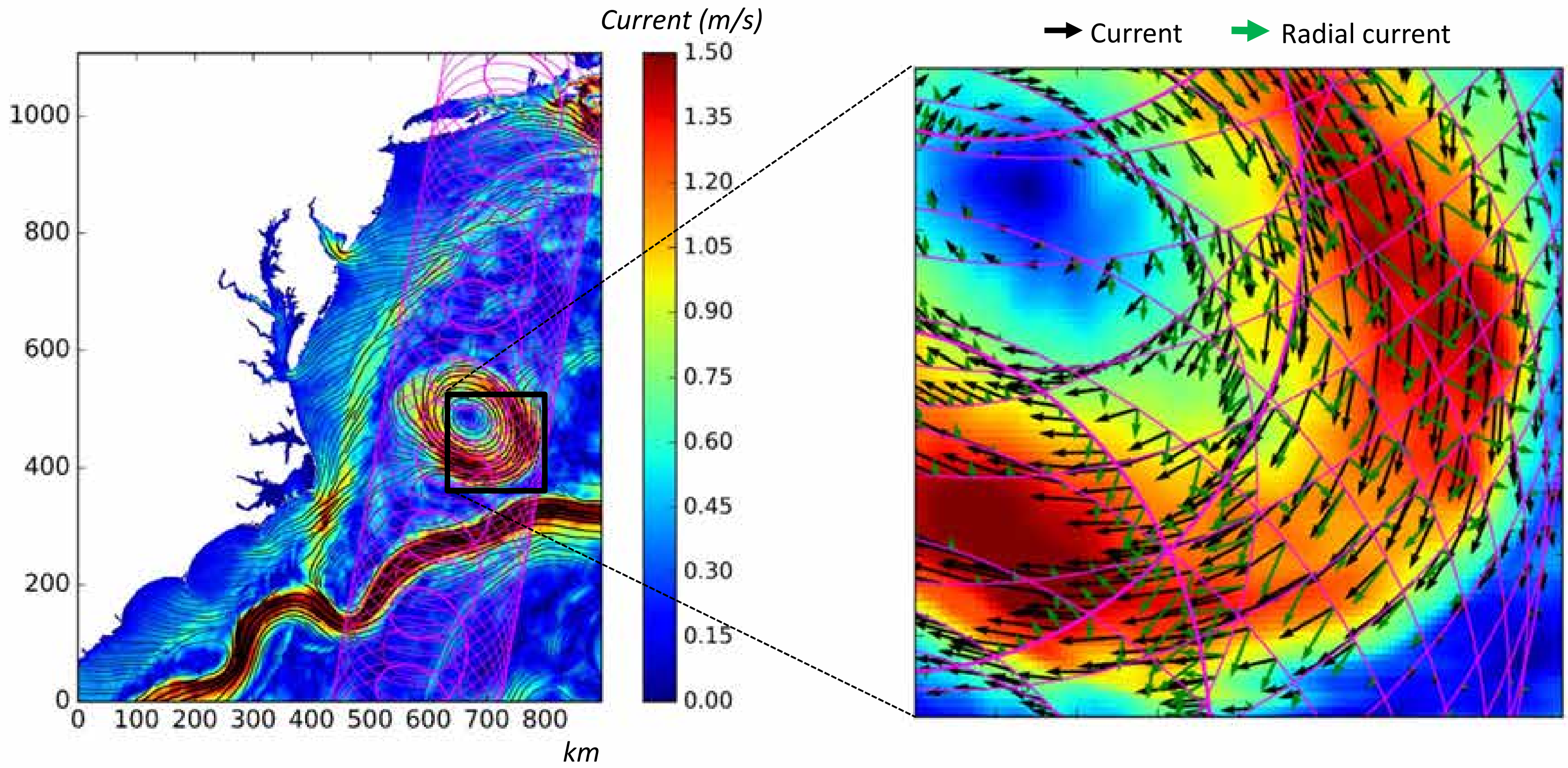
- This is an opportunity to explore full surface current mapping methods from a distribution of doppler (radial) measurements

- And to characterize the resolving capabilities and the added value to other sensors

Outline

- Realistic OSSEs of SKIM concept with a multi-variate mapping of synthetic SKIM radial velocities from MITgcm-llc4320 current scene
- Two levels of products for SKIM: swath and gridded (time/space)
- Effective resolution expected at both levels, in different regions
- Synergy with wide-swath altimetry

OSSEs with the SKIM concept



- SKIM mission concept: rotating beams with Doppler processing
- A SKIM simulator was built to do OSSE studies:

→ Realistic surface **current scenes from MITgcm-LLC4320**

→ Realistic **sampling of multi-angle radial velocities** (8 beams) with account for expected **instrument noise**. Sentinel-1 Orbit (12-day repeat)

→ **How well can we reconstruct the 'true' current scene?**

From sparse radial velocities to current maps

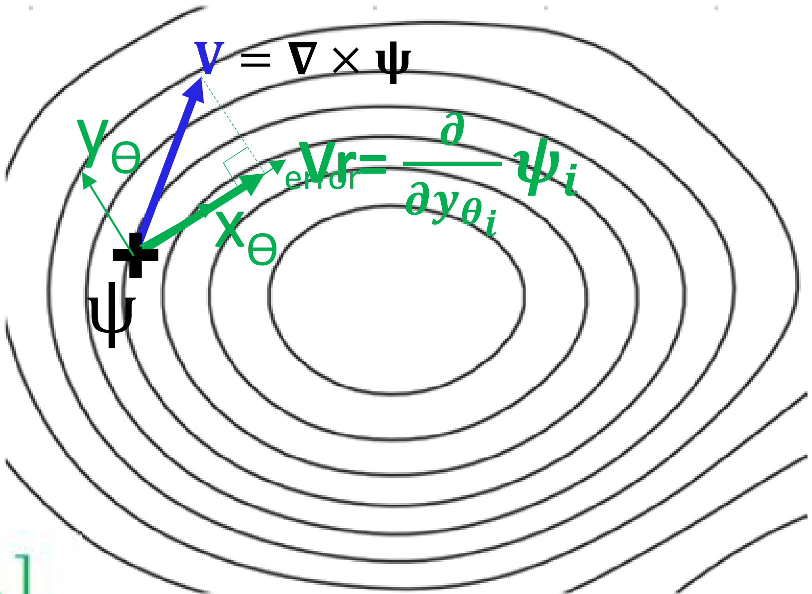
Multi-variate OI formula standardly used for HF radar (e.g. Kim et al., 2010) :

$$[Vx \ldots Vy \ \ldots] = BH^{T}(HBH^{T}+R)^{-1}[Vr \ldots]$$

State vector) ; (Ux,Vx) covariances ; COV(err,err) ; data (Vr)

- Covariance models proposed in the HF radar literature were not optimal for open Ocean mesoscales

- We propose to apply OI in the rotational and divergent current function space:

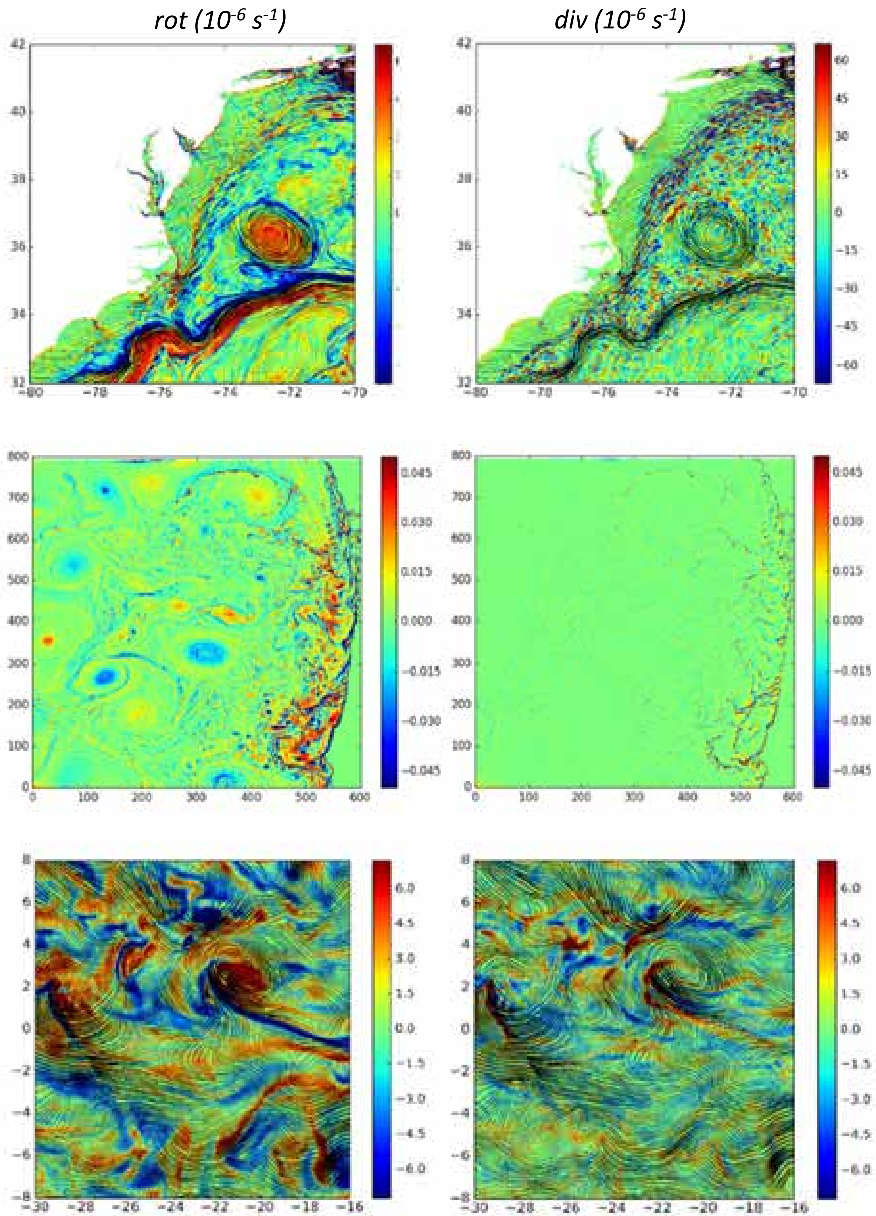


$$[\psi \ldots \xi \ldots] = BH^{T}(HBH^{T}+R)^{-1}[Vr \ldots]$$

(ψ,ζ) covariances

- Specify covariance model for **ψ** and **ζ : quite isotropic and independant (see next slide)**
- Reconstruction of **(Vx,Vy)** directionnal components

Rationale for $[\psi, \xi]$ decomposition



- At mesoscale (target for SKIM), off the Equator, rotational field is strongly dominent
→We can focus on the covariances of this single scalar field in many regions

- Near the Equator, divergence has ~20% of the variance at target scales for SKIM

- Rotationnal is quite isotropic and the assumption of uncorrelation with divergence was found reasonnable

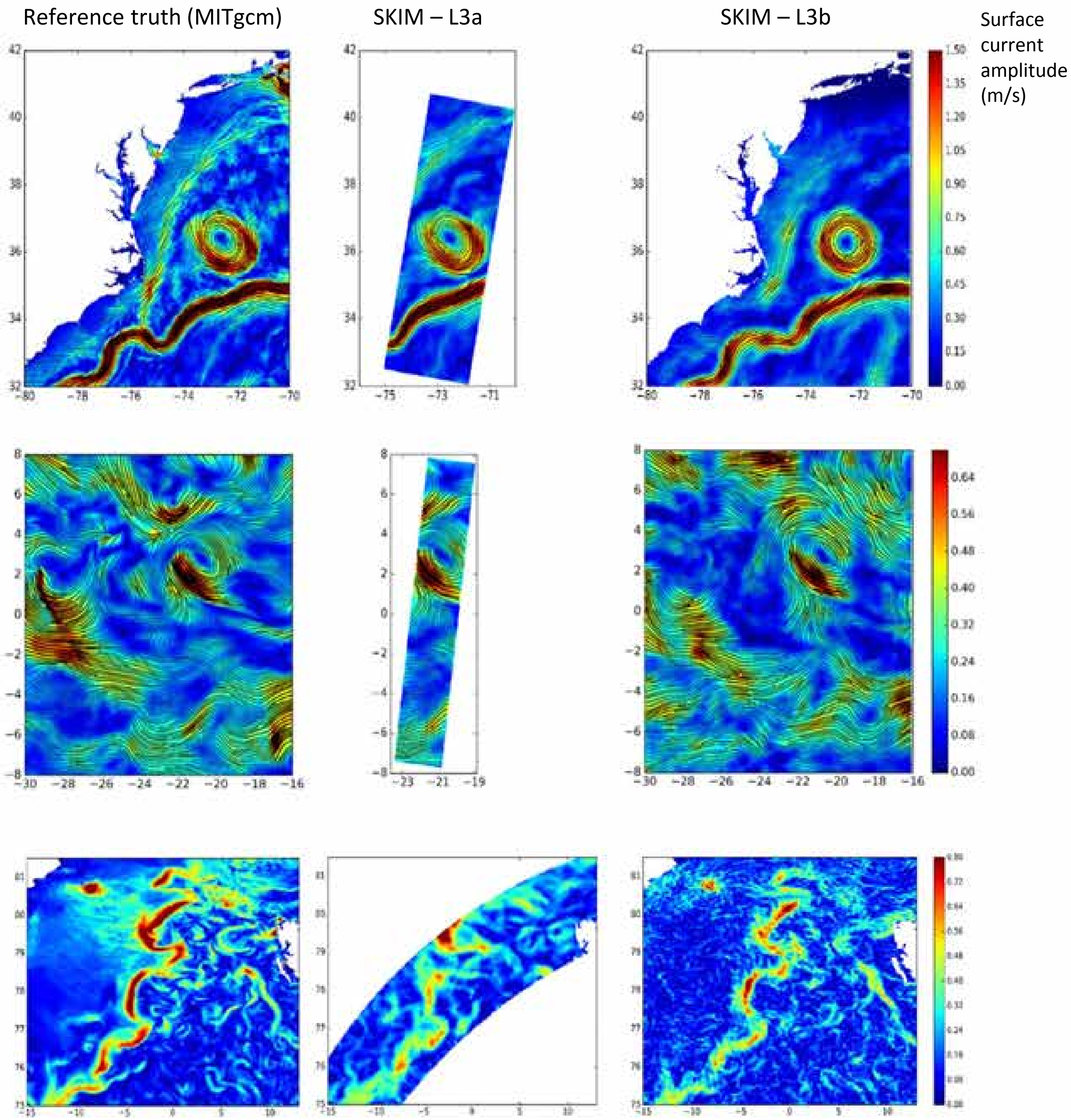
→ A 1D isotr. spectrum is specified for $\boldsymbol{\psi}$ and $\boldsymbol{\zeta}$ independantly, then inverted in covariance functions to fill **B** matrix

Results: swath and gridded reconstructions

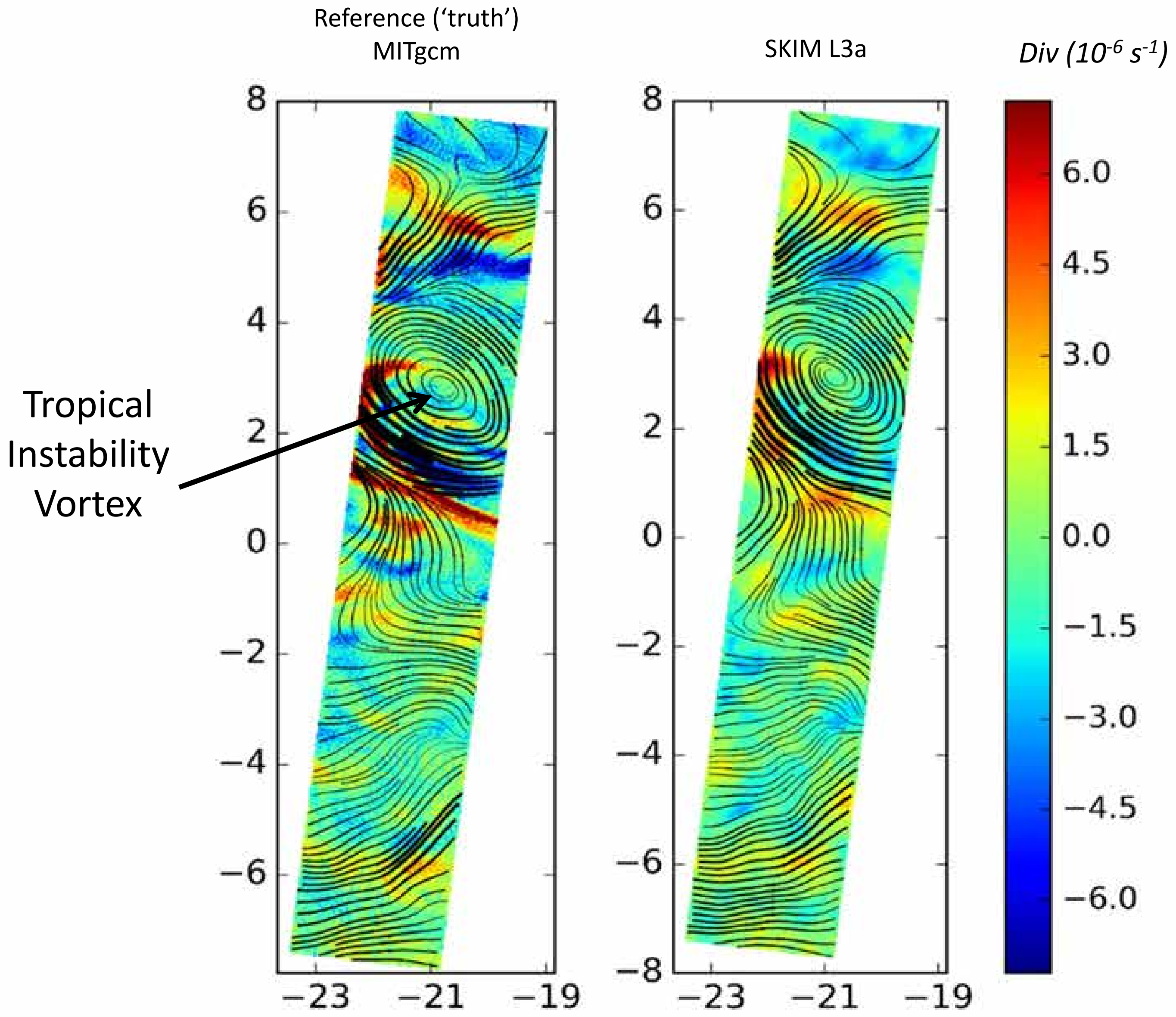
• We define two levels of products: swath and gridded

• Qualitatively: good reconstruction of mesoscale eddies wrt reference scene

• A resolution limit to be quantified



Recovering a snapshot of divergence in the Equatorial Upwelling

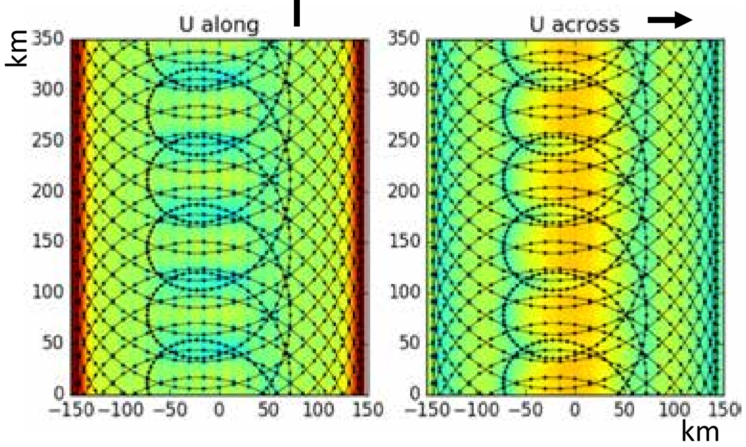


Quantification of effective resolution

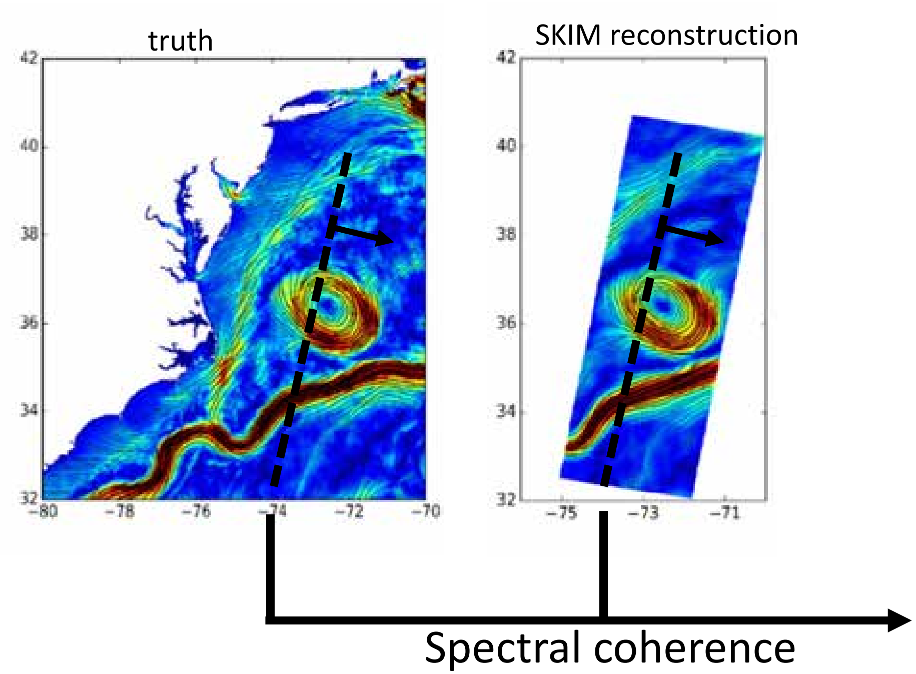
Across-swath velocity is the less accurate component, especially at near nadir

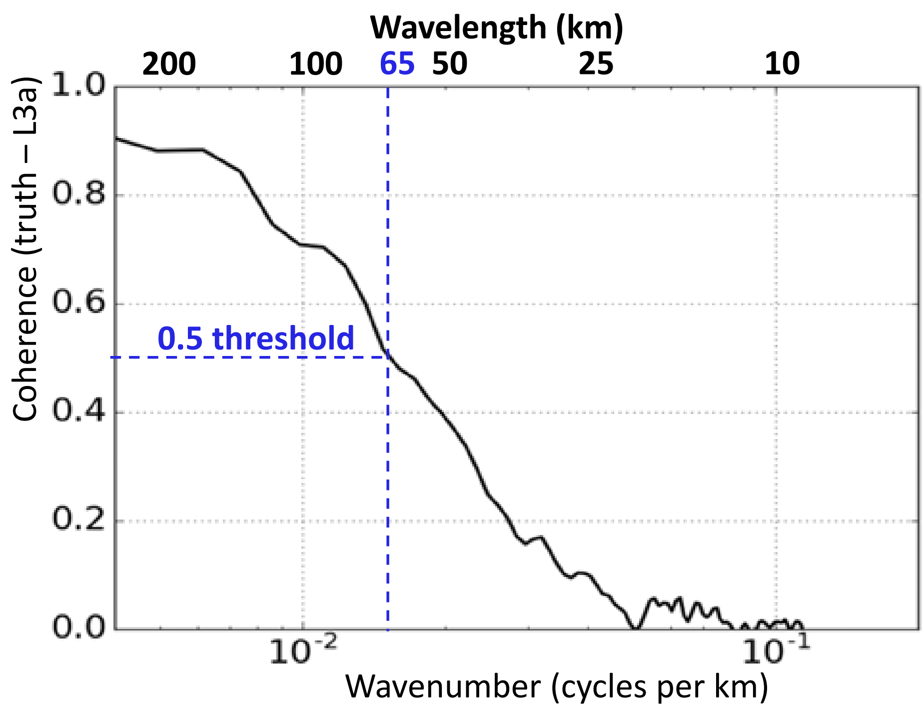
→ We propose to study the resolving capability with respect to Uac

Formal error derived from OI



Definition of effective resolution:



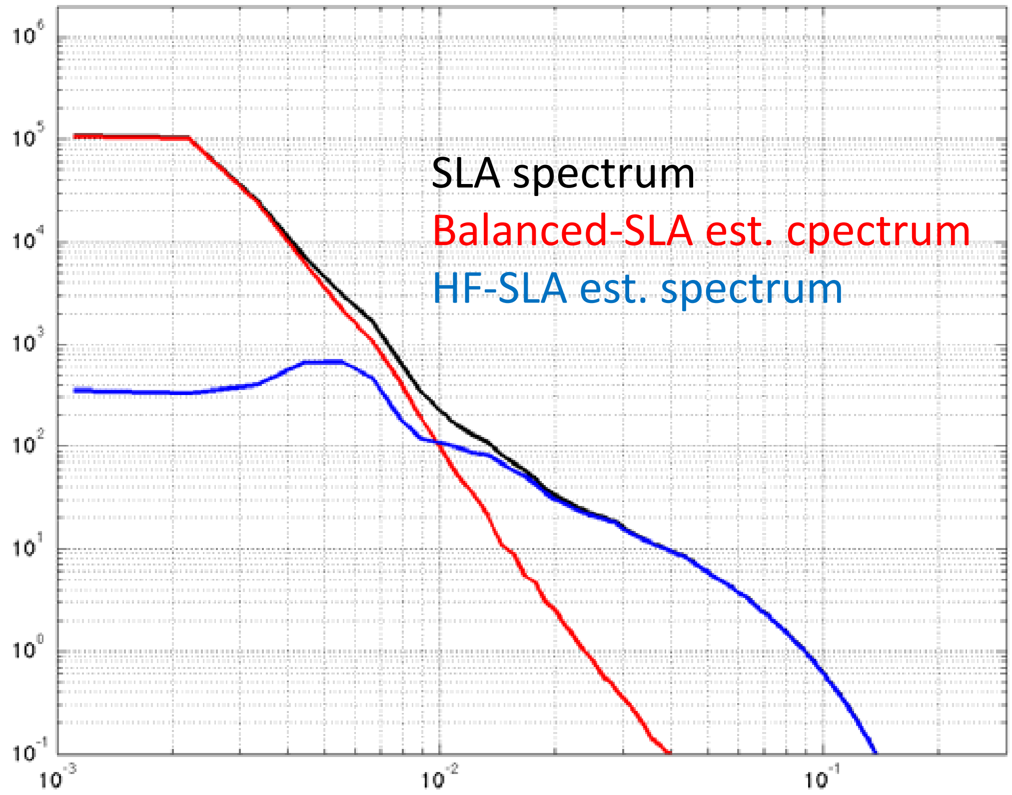


Resolving capabilities for different regions

Regions	Equator	Gulf-Stream	Oregon coast	Fram
Input Level-2 error (12 & 6° beams)	0.08 & 0.15 m/s	0.16 & 0.20 m/s	0.16 & 0.20m/s	0.10 & 0.16 m/s
Level-2B error (along&across track) and effective resol.	0.03 & 0.05 m/s 89km	0.09 & 0.14 m/s 65km	0.04 & 0.05 m/s 90km	0.11 & 0.14 m/s 59km
Level-3A error (zonal&meridional) and effective resol.	0.14 & 0.18 m/s 290km	0.23 & 0.24 m/s 71km		0.12 & 0.13 m/s 62km

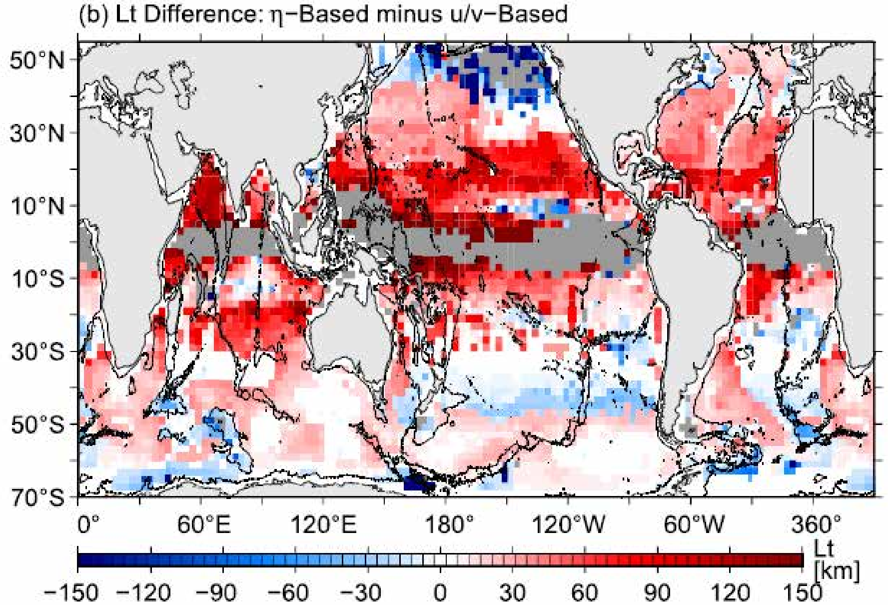
- Lower resolution than SWOT on the swath (15-20km)
- But interesting synergies to consider

Internal waves in LLC-4320



- transition wavelength Lt (defined in Qiu et al., 2017)

Internal waves in LLC-4320



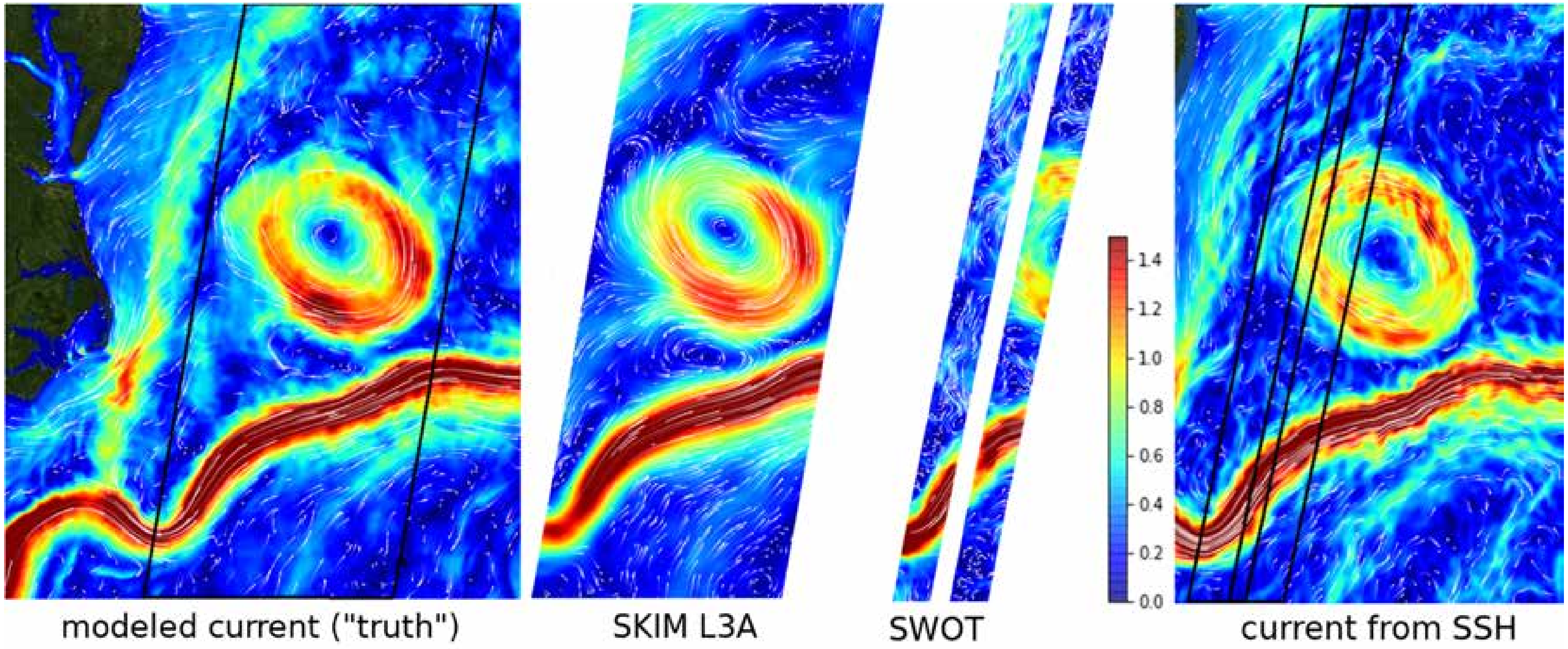
difference

From Qiu et al., 2017, submitted to JPO

- Transition wavelength would occur at shorter scale for velocity than SSH

- **The velocity, even if observed at lower resolution than SSH on the swath, could bring additional information on balanced motions**
- **And therefore, might be used for cleaning internal wave in SWOT**

Synergy: Current & SSH



- Indeed, internal tides blur the velocity estimation from SSH under 80km in the Gulf Stream
- Substraction of the SKIM field to the SWOT-derived

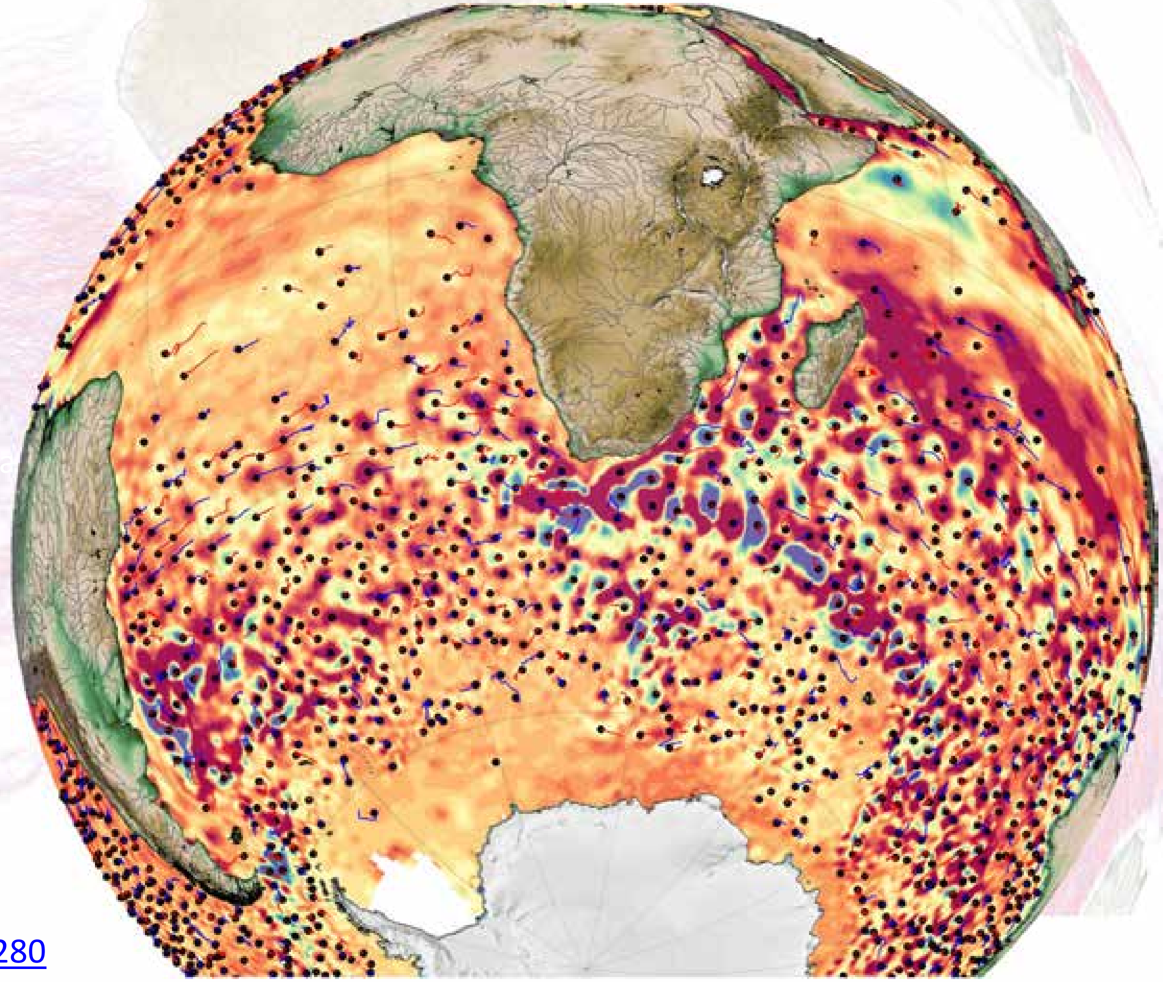
Conclusions

- We proposed a multi-variate OI method to map doppler current: specific implementation (rotational & divergence functions) efficient for mesoscales. Could be applied to other studies (WaCM concept, DopplerSCAT, …)

- The OSSEs with SKIM concept demonstrated interesting capabilities and possible synergies with high-resolution altimetry :
  → Effective resolution under 100km on a wide (290km large) swath allowing short revisit with global coverage
  → The total surface current contains much more than the geostrophic part

Global Mesoscale Eddy Trajectory Atlas now on Aviso+

A new "Mesoscale Eddy Trajectory Atlas" was released in october 2017 on the Aviso altimetry portal. This atlas follow 272,000 tracks over the last 24 years. This dataset was produced and validated by CLS in collaboration with D. Chelton and M. Schlax from Oregon State University. It takes over the dataset formerly produced and distributed at OSU, and is regularly updated by the SSALTO/DUACS team and distributed by AVISO+.

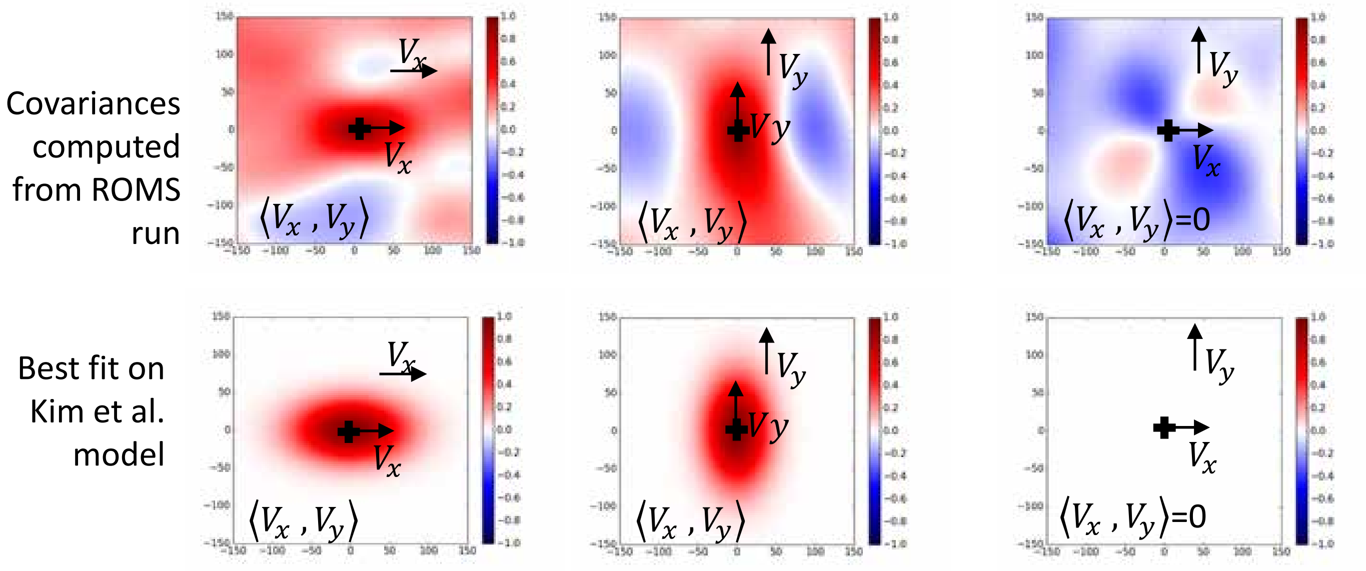


https://www.aviso.altimetry.fr/index.php?id=3280

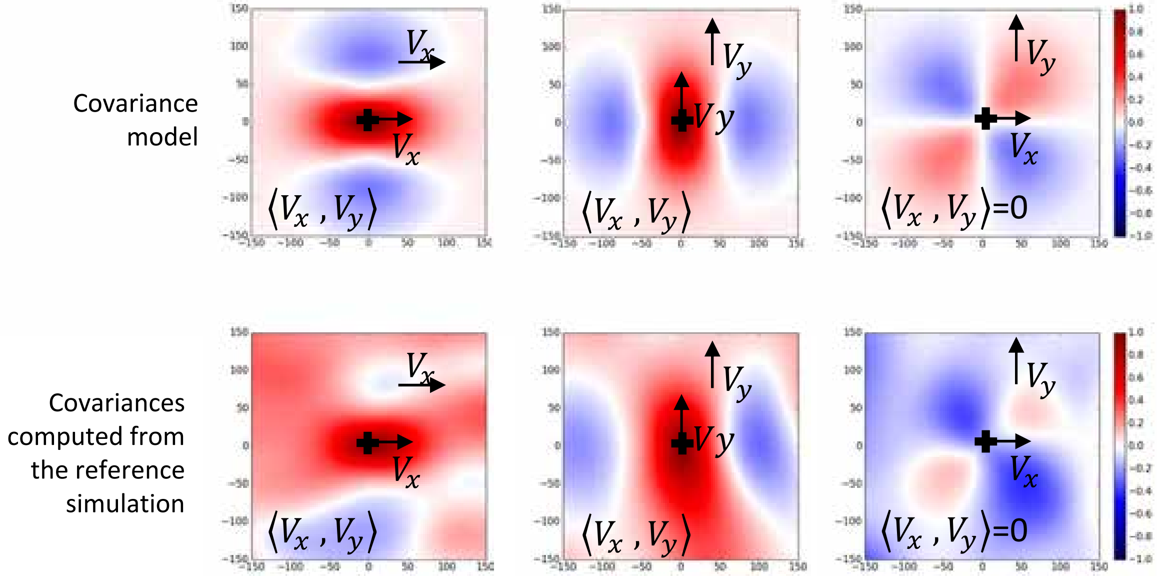
Backup

First option: a Gaussian shape model, e.g. Kim et al., to fill covariance matrices

We consider the full velocity vector [Vx … Vy …] as the state vector of dimension 2*g if g is the number of grid points.
The observation error covariance matrix $\mathbf{R}$ is filled according to the best knowledge of error statistics
The error-free (grid,data) and (data,data) covariance matrices, $\mathbf{BH^T}$ and $\mathbf{HBH^T}$, are explicitely written using a Gaussian correlation model assuming no-correlations between Vx and Vy :

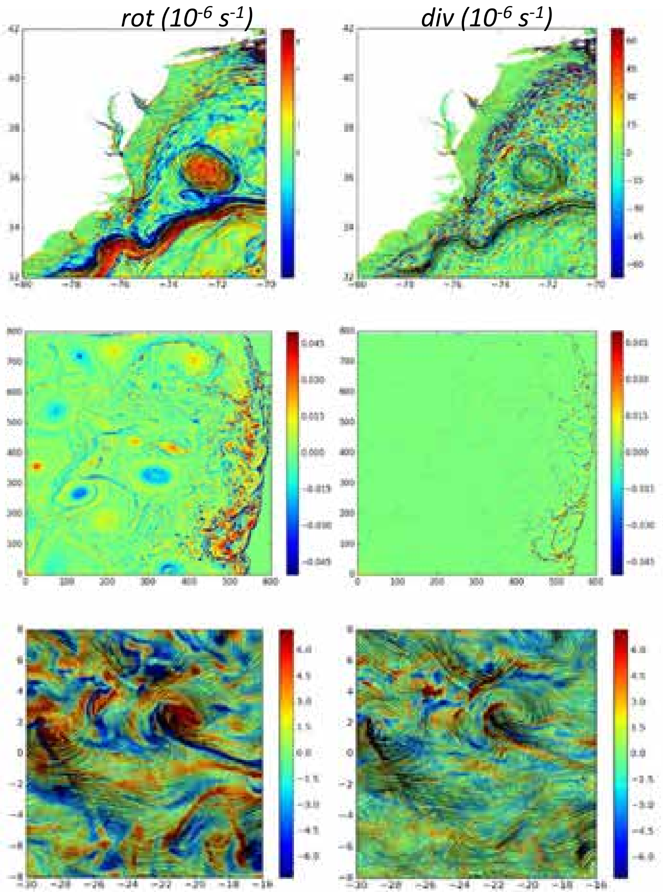


→ The covariance model hardly fits simulated data …



Covariance model
Covariances computed from the reference simulation
V_x
V_y
$\langle V_x , V_y \rangle$
$\langle V_x , V_y \rangle$=0

Considering rotationnal / divergence properties of the flow



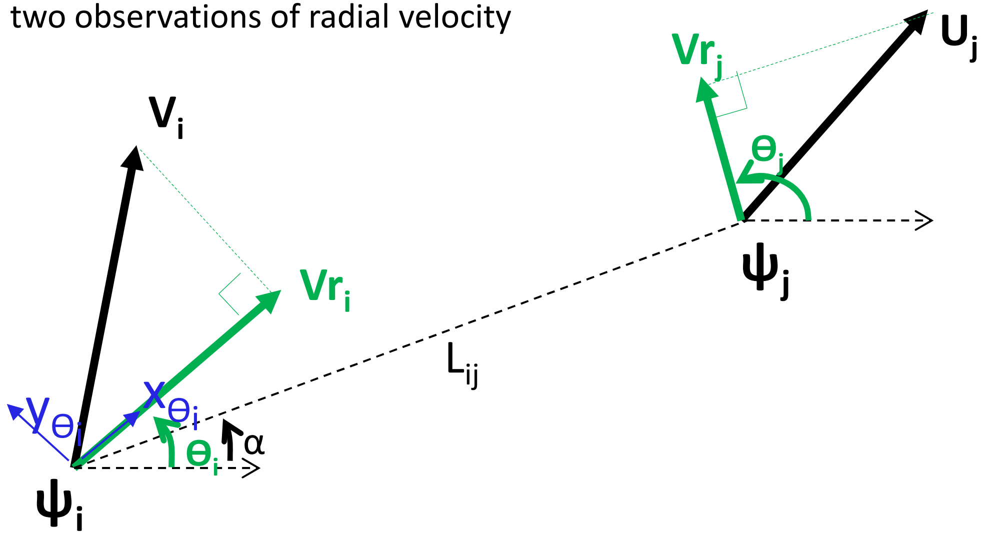
→Off the Equator, the divergent part of the flow is likely not resolvable by SKIM

→ Near the Equator, at scales potentially resolvable by SKIM, divergence has ~20% of the variance

→ It make sense to consider a (Ψ,ζ) decomposition of the flow to perform mapping

Second option: Derivation of a covariance model from the current functions

We assume the isotropic covariance model for the current function, $\langle \boldsymbol{\psi_i}, \boldsymbol{\psi_j} \rangle$=**f**($\boldsymbol{L_{ij}}$). Then, we can derive the model to get the covariance between two observations of radial velocity needed to solve (1):



$$\langle Vr_i, Vr_j \rangle = \left\langle \frac{\partial}{\partial y_{\theta_i}} \psi_i , \frac{\partial}{\partial y_{\theta_j}} \psi_j \right\rangle$$

$$= \frac{\partial}{\partial y_{\theta_i}} \frac{\partial}{\partial y_{\theta_j}} \langle \psi_i , \psi_j \rangle$$

$$= \frac{\partial}{\partial y_{\theta_i}} \frac{\partial}{\partial y_{\theta_j}} f(L_{ij})$$

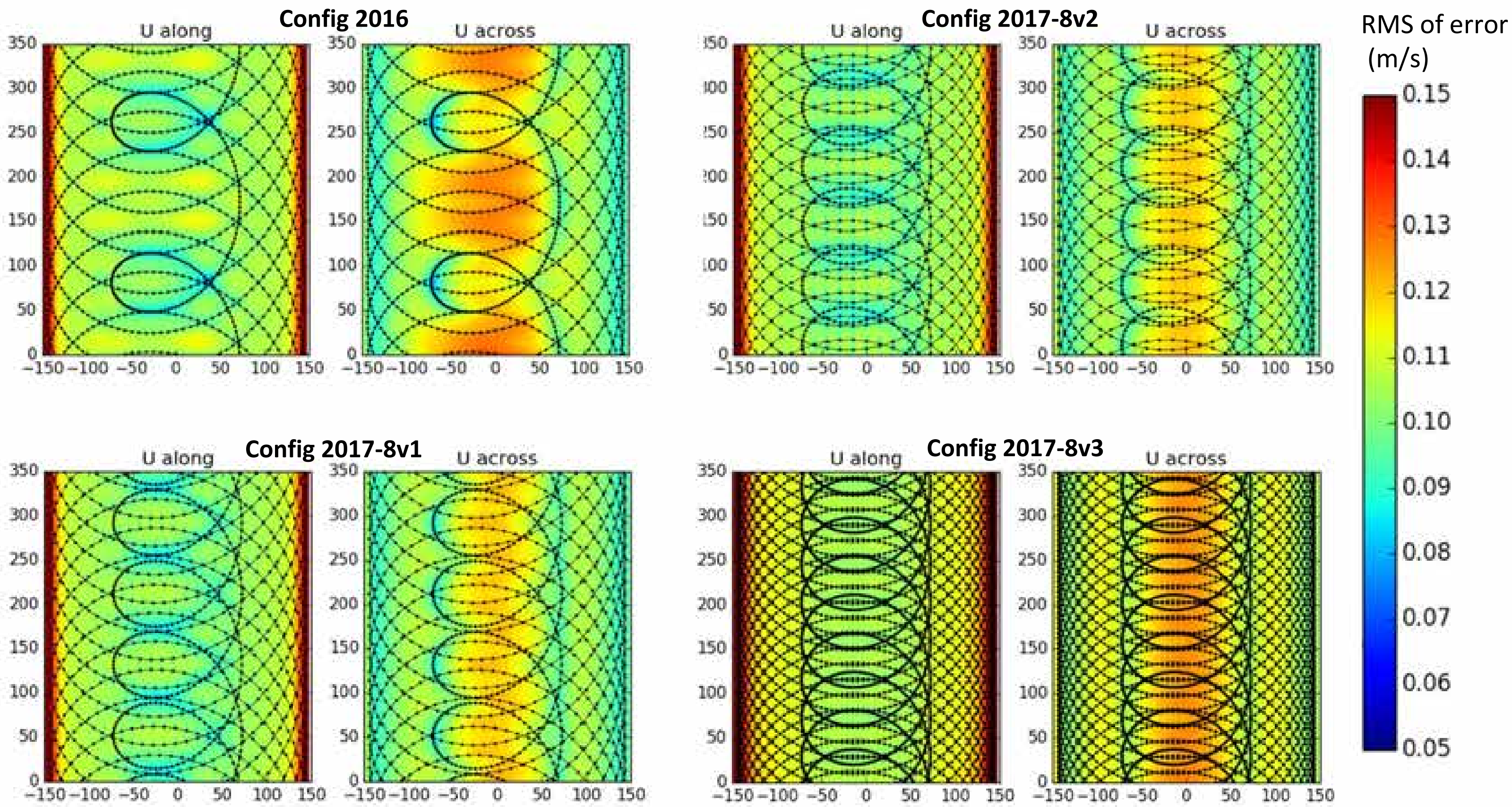
$$= \frac{\partial}{\partial y_{\theta_i}} \left(\sin(\theta_j - \alpha) f'(L_{ij}) \right)$$

$$= f'(L_{ij}) \frac{\partial}{\partial y_{\theta_i}} \left(sin(\theta_j - \alpha) \right) + \sin(\theta_j - \alpha) \frac{\partial}{\partial y_{\theta_i}} f'(L_{ij})$$

$$= f'(L_{ij}) \, cos(\theta_j - \alpha) \frac{\partial}{\partial y_{\theta_i}} \left(\theta_j - \alpha \right) + \sin(\theta_j - \alpha) \sin(\theta_i - \alpha) f''(L_{ij})$$

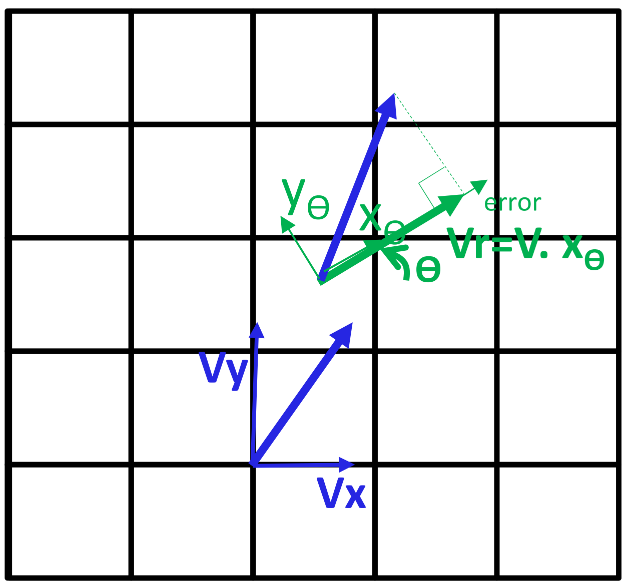
$$\langle Vr_i, Vr_j \rangle = -cos(\theta_i - \alpha) \, cos\left(\theta_j - \alpha\right) \frac{f'(L_{ij})}{L_{ij}} - \sin(\theta_i - \alpha) \sin(\theta_j - \alpha) f''(L_{ij}) \qquad (2)$$

Testing different antenna configurations



From sparse radial velocities to current maps

The observed data (**radial velocity**) is not directly the field to be represented on the grid (**full velocity**).
However, they are linked by a **linear operator** H→ OI is possible:



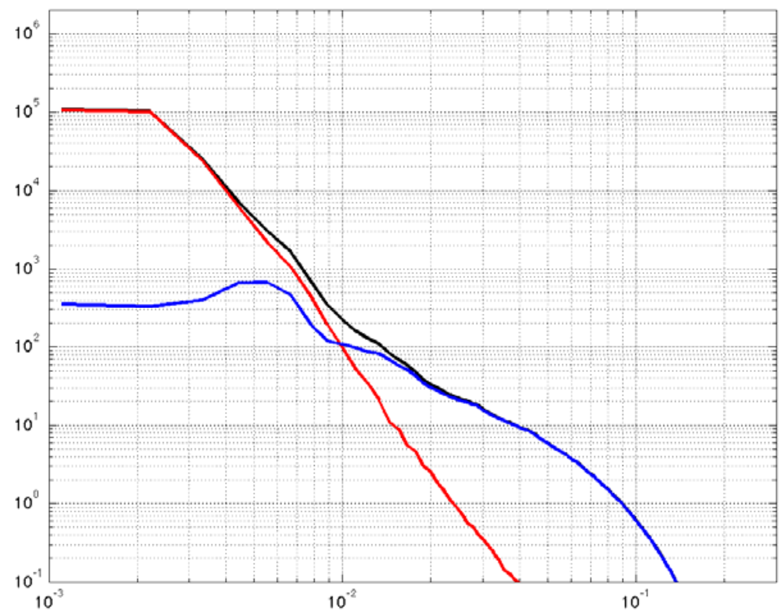
Multi-variate OI formula :

$$[\mathbf{Vx} \ldots \mathbf{Vy} \ \ldots] = \mathbf{BH^T}\left(\mathbf{HBH^T} + \mathbf{R}\right)^{-1}[\mathbf{Vr} \ldots]$$

State vector)
COV(grid,data_noerr)
COV(data_noerr,data_noerr)
COV(err,err)
data (Vr)

This problem has been treated for mapping HF radar data (Kim et al., 2010)

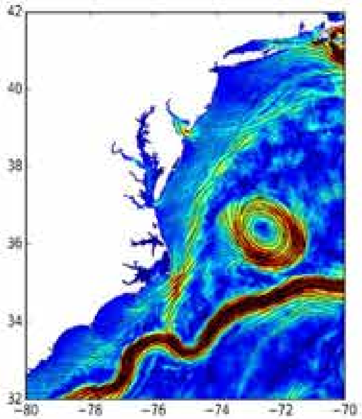
The Kim et al. approach the full gridded velocity vector as the state vector to estimate:



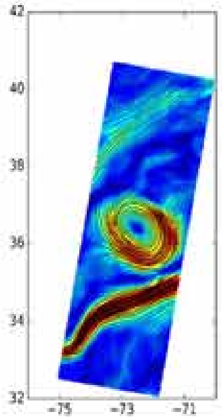
10^{6}
10^{5}
10^{4}
10^{3}
10^{2}
10^{1}
10^{0}
10^{-1}
10^{-3}
10^{-2}
10^{-1}

Beyond geostrophic current: a synergy to be exploited

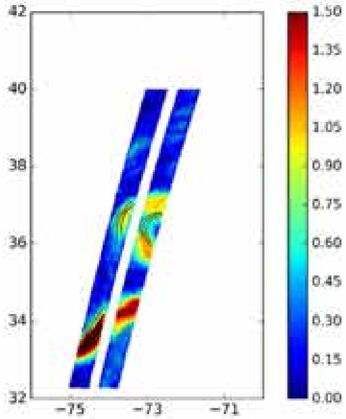
Truth of MITgcm



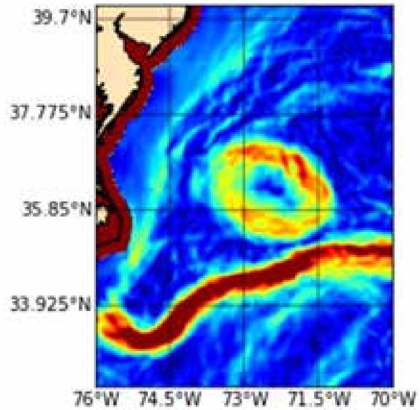
SKIM-L3a



Geostrophic current from SWOT-L3a

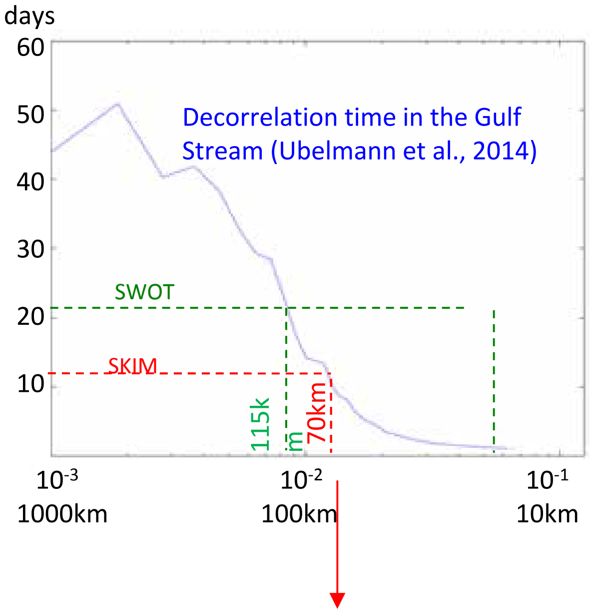


Geostrophic current estimated from SSH containing internal waces …



- Wider swath for SKIM
- Better resolution expected for SWOT in L3a. But ageostrophy and <u>internal waves</u> ….

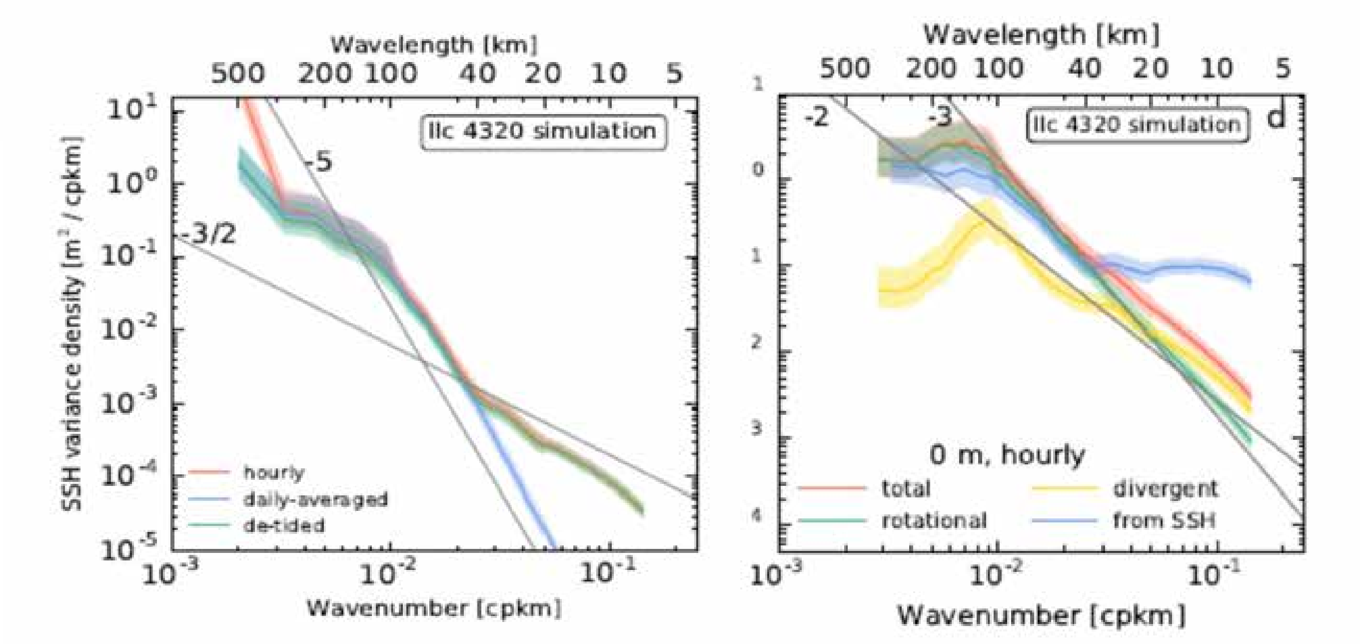
SKIM vs SWOT comparisons under geostrophic assumptions: resolution complementarity



- SKIM would offer a significantly better resolution in L3b thanks to the full coverage at shorter revisits (12 days) → 70km instead of 115km

consistent with the effective resolution found in our L3b SKIM simulations (71km)

Internal waves in LLC-4320



- transition wavelength Lt (defined in Qiu et al., 2017) occurs at shorter scale for velocity than SSH

→ **The velocity field, even if reconstructed at lower resolution than SSH on the swath, would bring more information on balanced motion than SSH**

Introduction

The SKIM concept (ESA EE9) is an opportunity to explore the benefits of a current mission

We propose here:

→ A multi-variate mapping method for doppler measurement
→ Realistic OSSE to assess resolving capabilities
→ Address synergy with altimetry

Introduction

- Last year presentation (D. Chelton) on WaCM concept:

  → Comparison with expected SWOT derived current (under geostrophy assumption)

  → If SWOT has higher resolution on the swath, the wide swath of WaCM allows better repetitivity and therefore higher resolving capabilities for currents

- The SKIM concept (ESA EE9) was an other opportunity to explore the benefits of a current mission and to complement WaCM analysis. We propose here:

  → A multi-variate mapping method for doppler measurement
  → Realistic OSSE to further assess resolving capabilities (SKIM case)
  → Address synergy with altimetry, beyond geostrophy