Joint estimation of Balanced Motions and Internal Tides from future wide-swath altimetry

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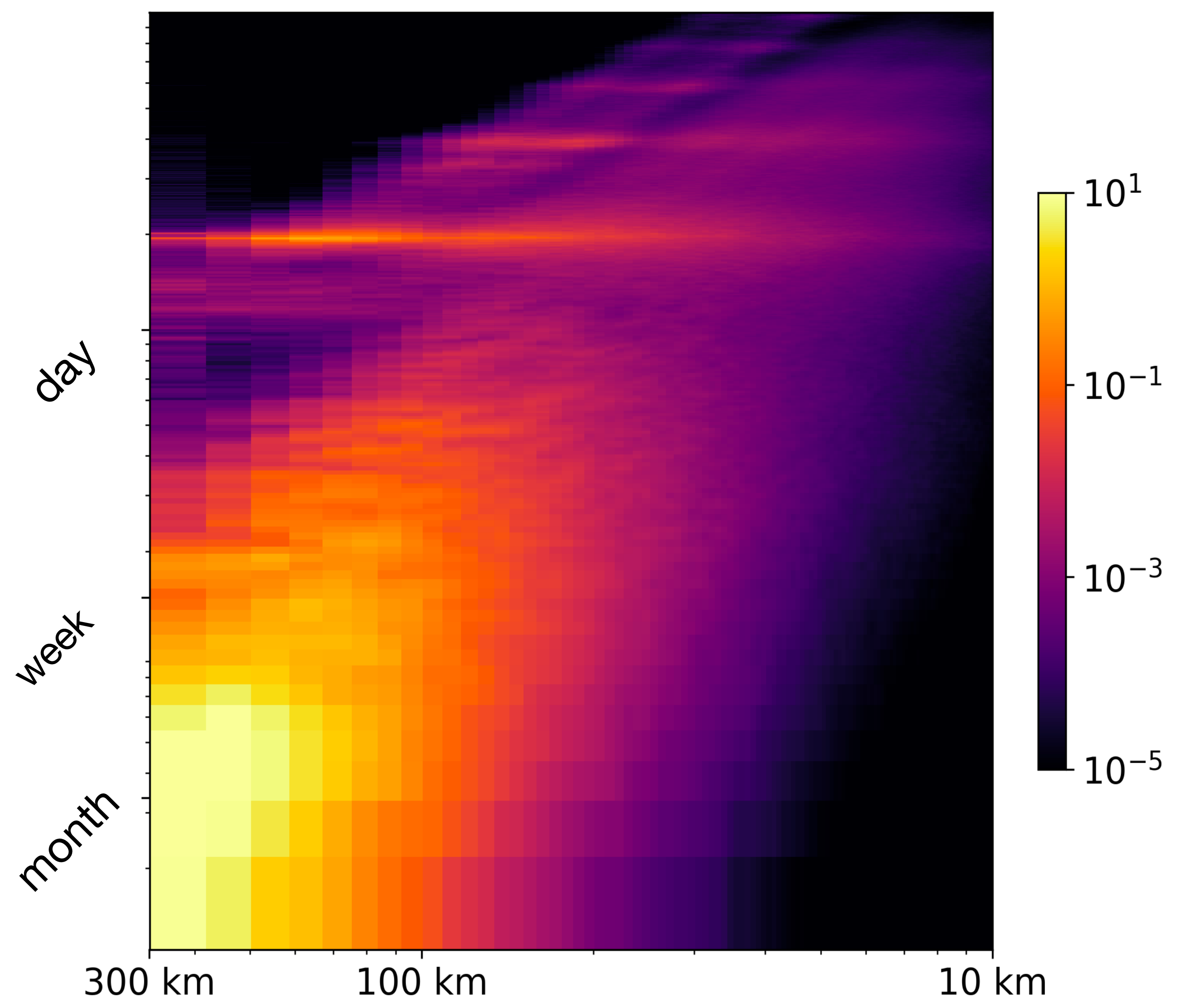
OSTST - 2022

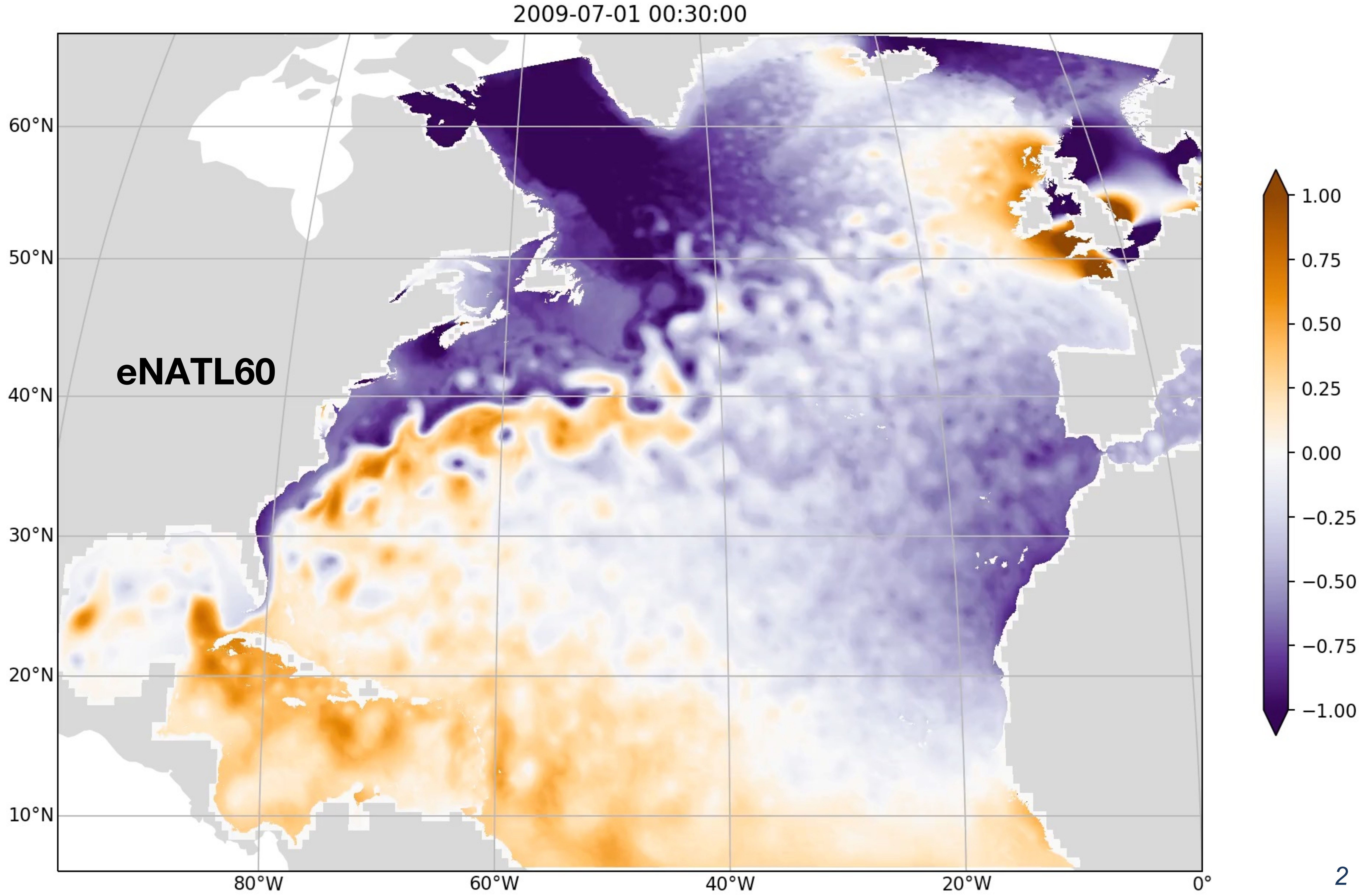
Introduction

Ocean surface dynamics from models

SSH reflects the signature of various dynamical regimes with distinct space-time scales:

SSH Wavenumber-Frequency spectra





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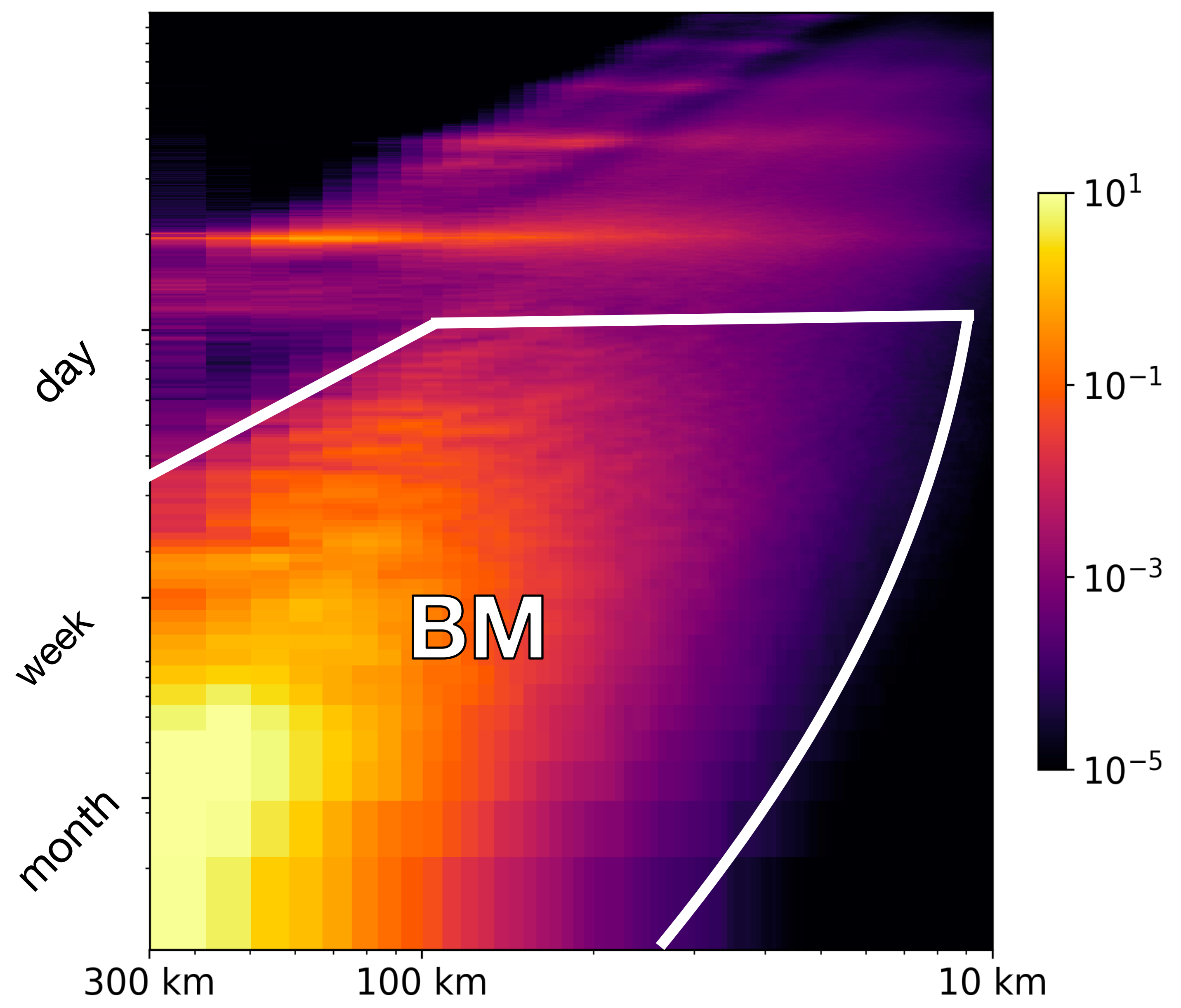
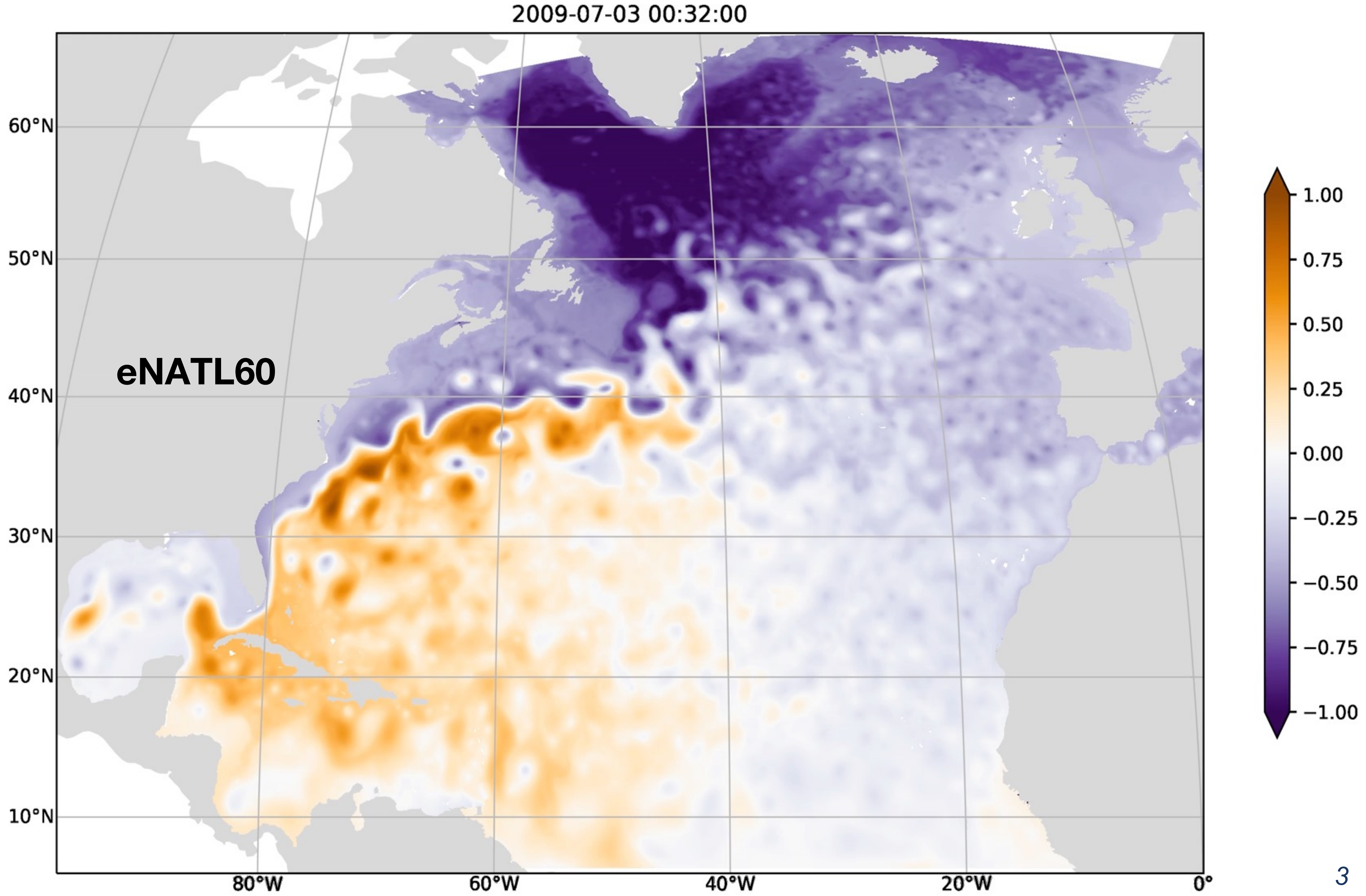
- Balanced Motions (BM)

SSH Wavenumber-Frequency spectra





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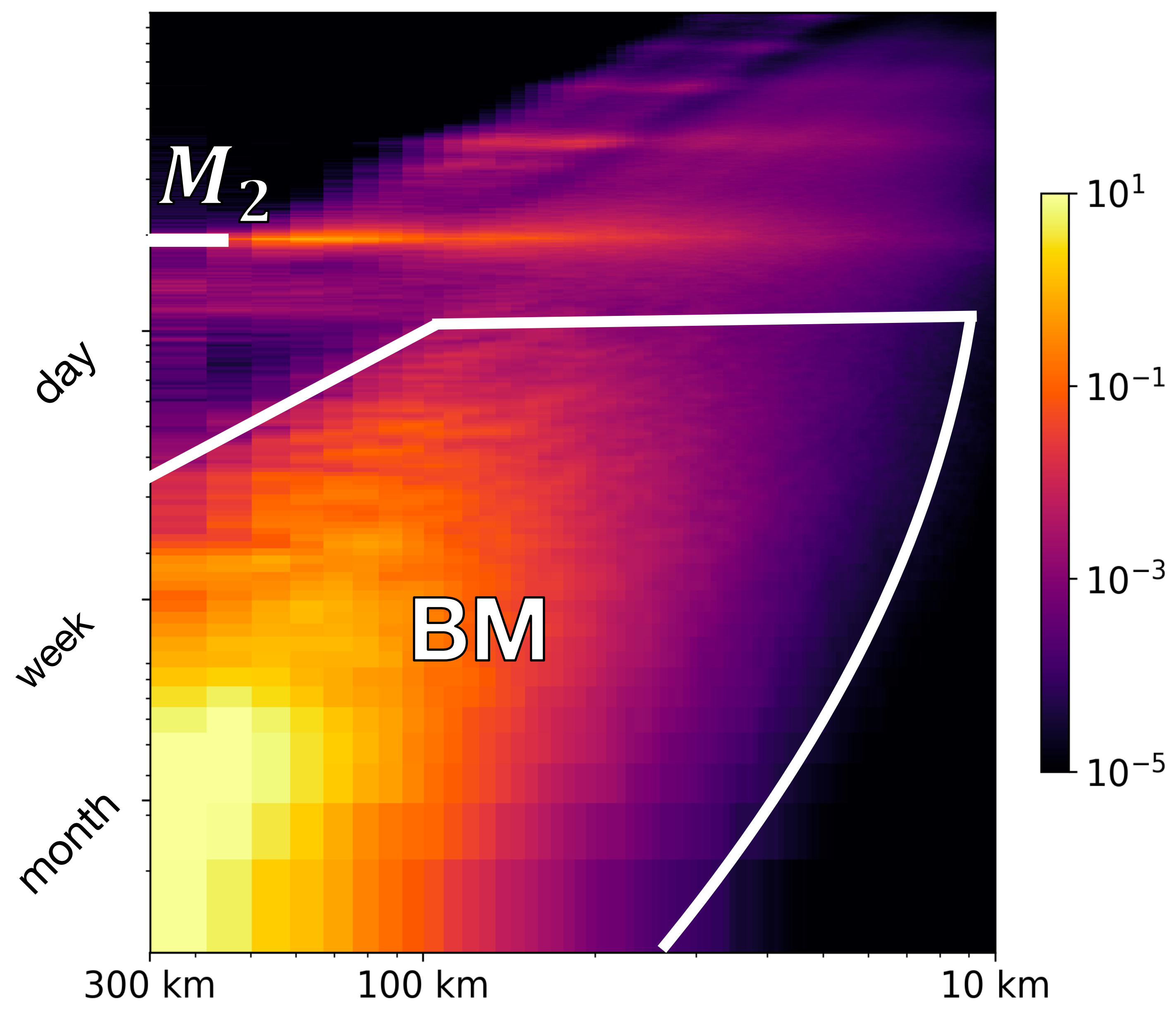
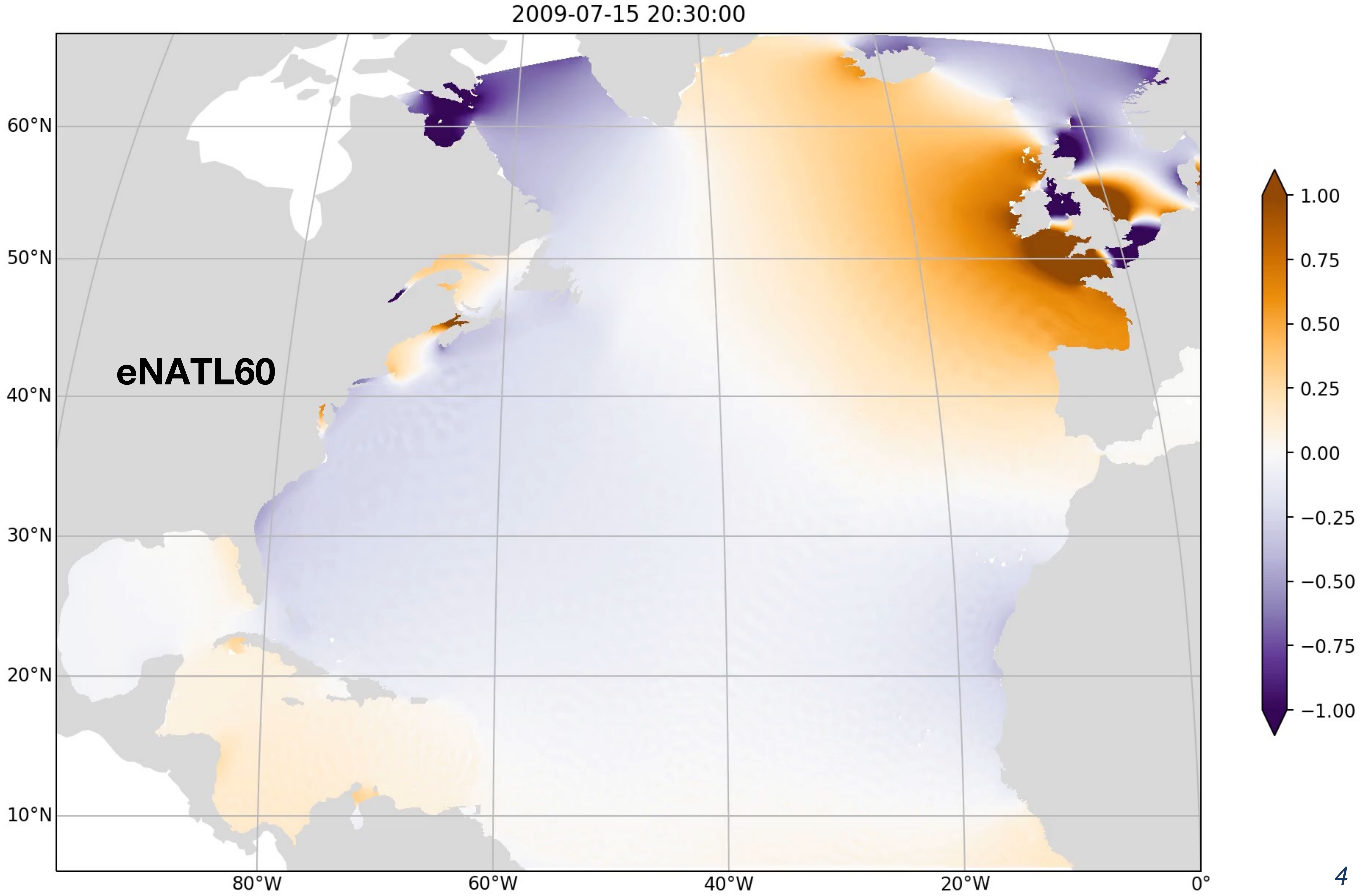
Ocean surface dynamics from models

SSH reflects the signature of various dynamical regimes with distinct space-time scales:

- Balanced Motions (BM)
- Barotropic Tides (e.g. M2)

SSH Wavenumber-Frequency spectra





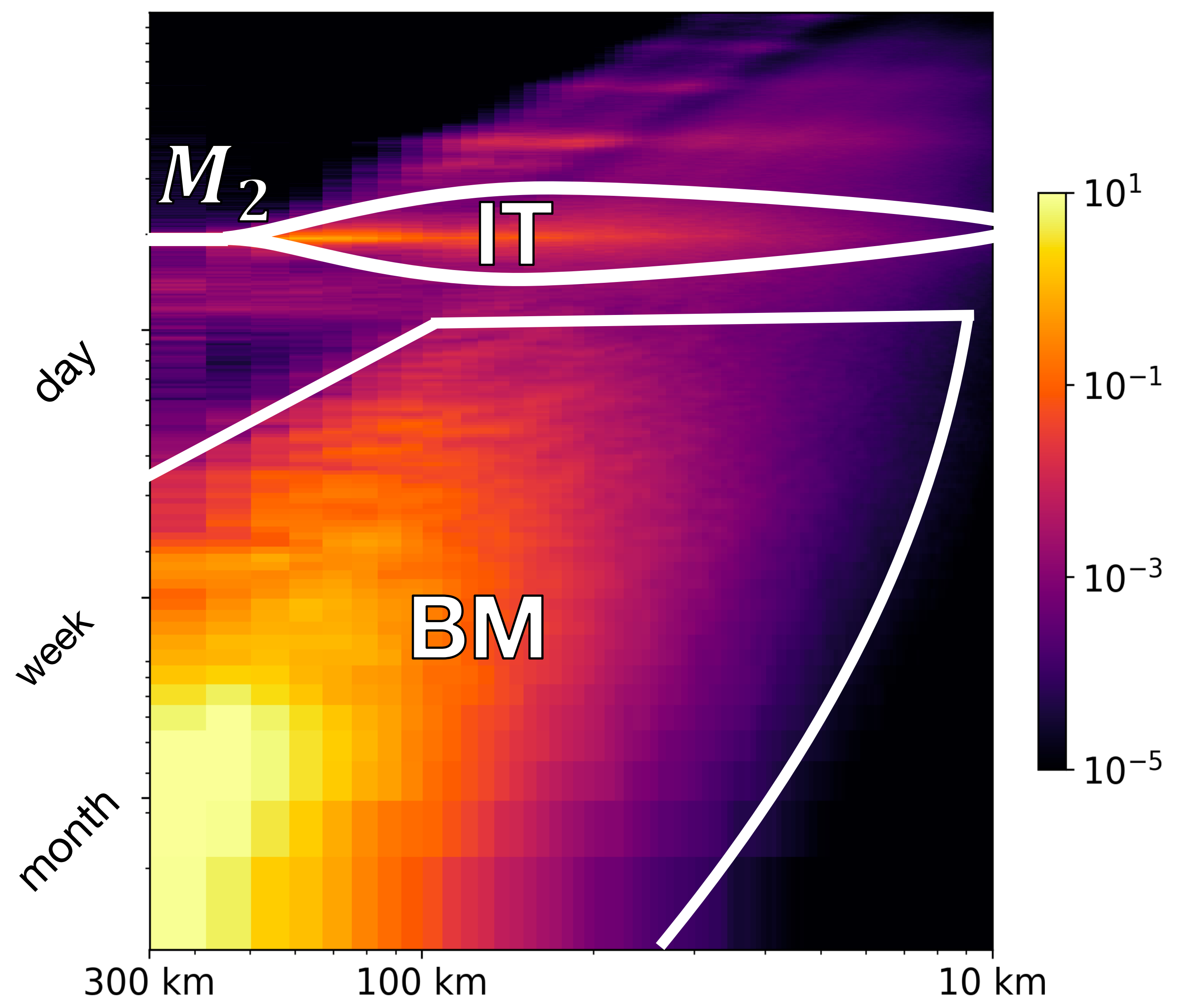
Introduction

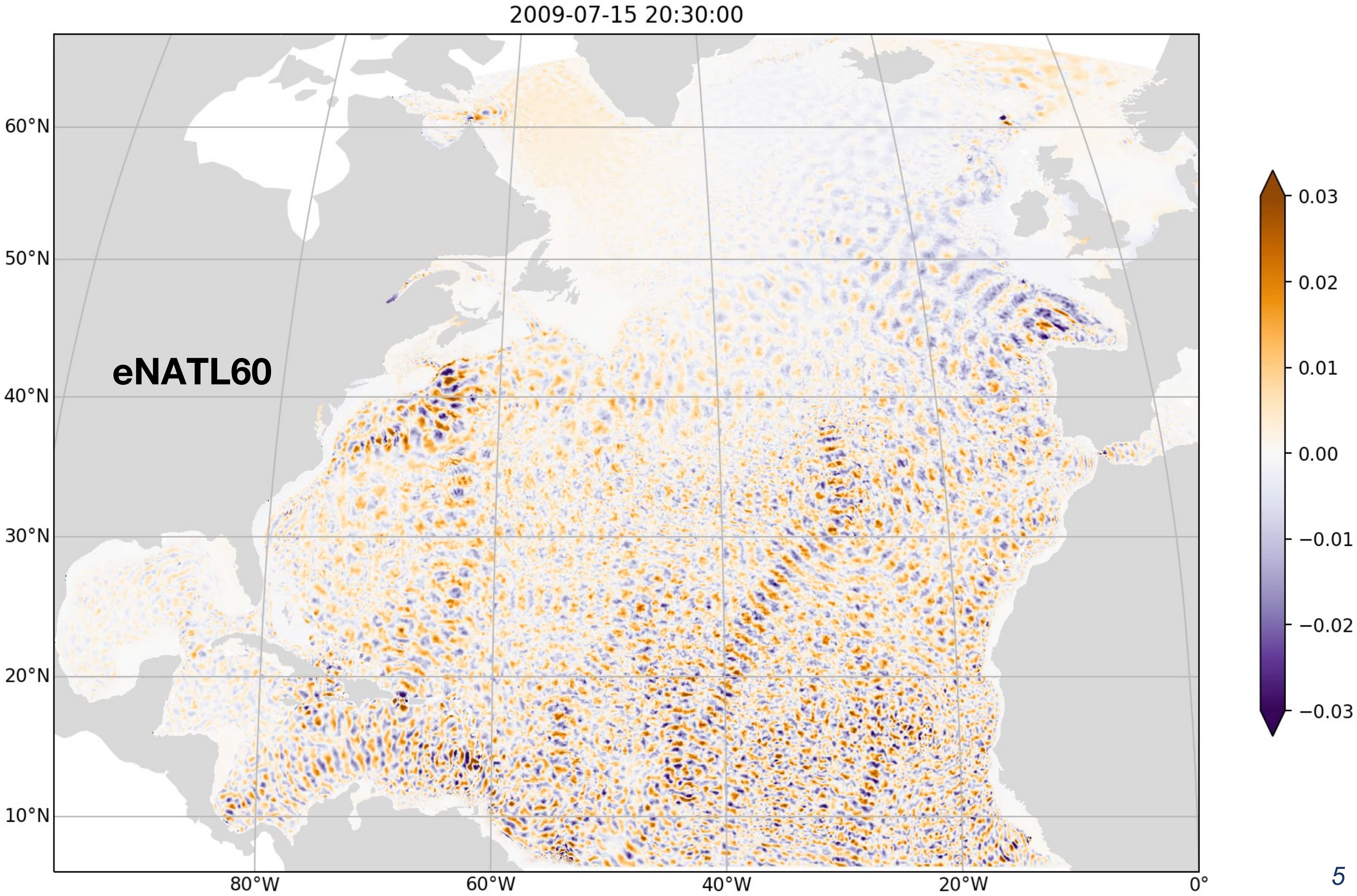
Ocean surface dynamics from models

SSH reflects the signature of various dynamical regimes with distinct space-time scales:

- Balanced Motions (BM)
- Barotropic Tides (e.g. M2)
- Internal Tides (IT)

SSH Wavenumber-Frequency spectra



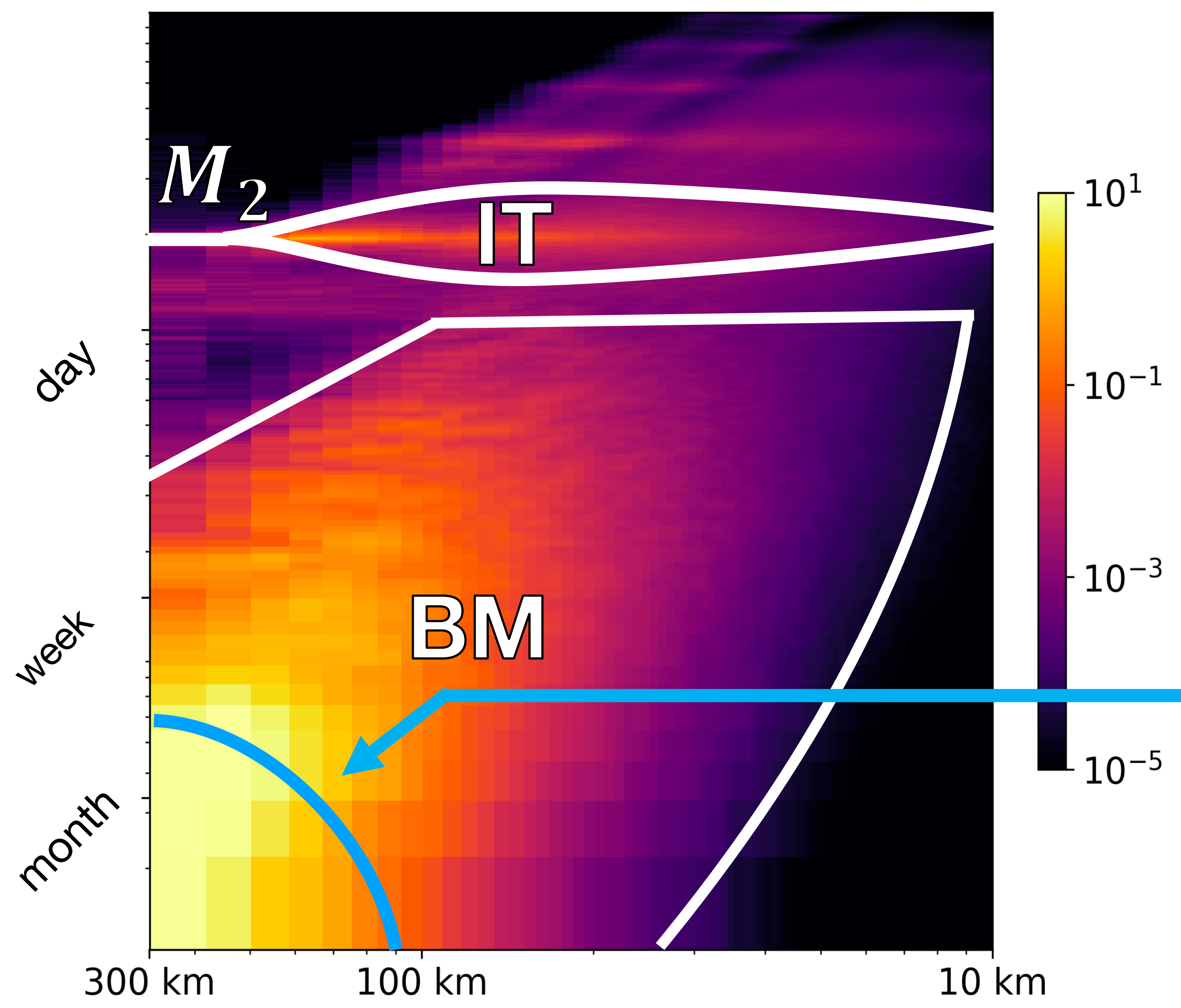


Introduction

Conventional altimetry reflects large mesoscale dynamics

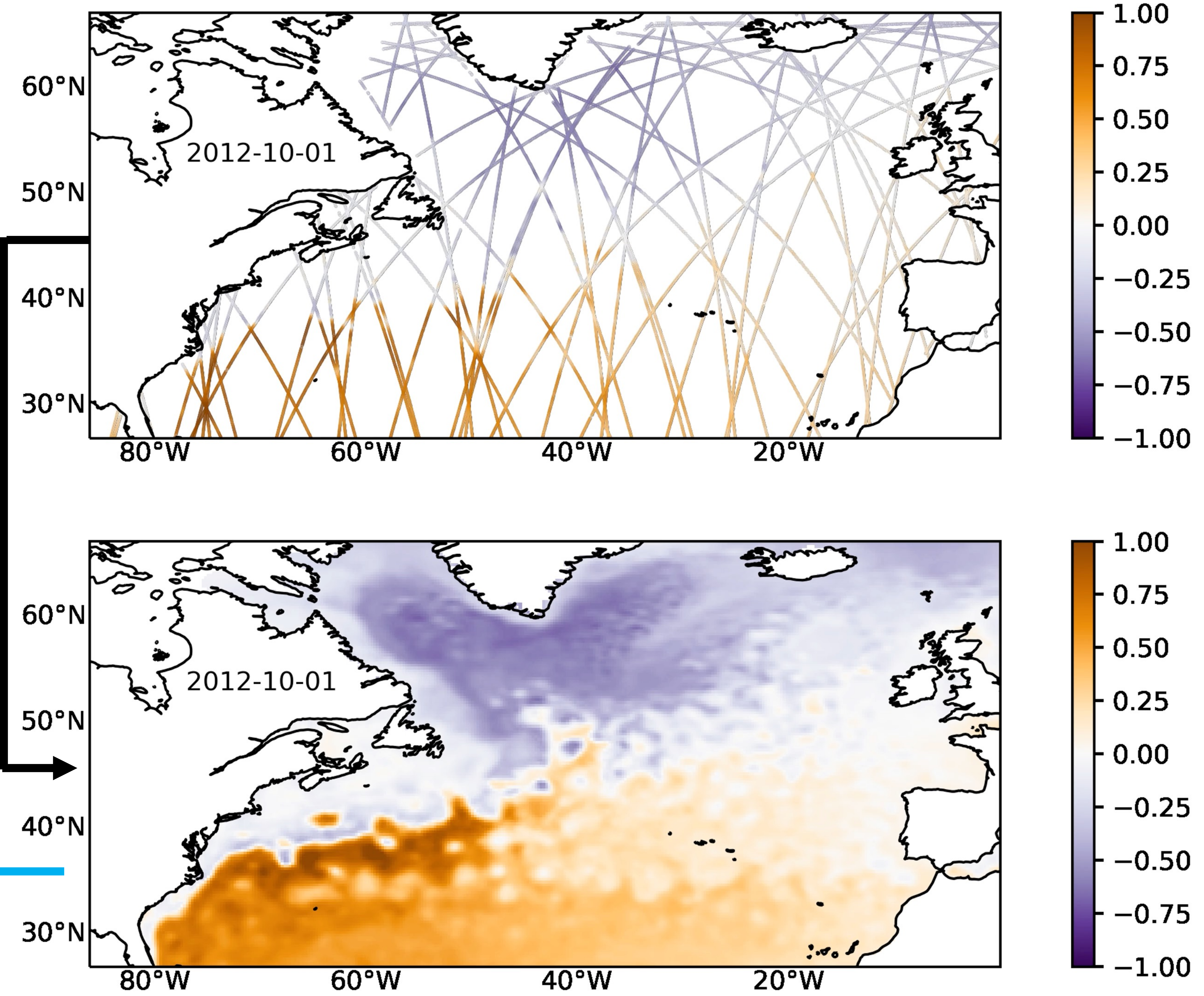
What about observations?

SSH Wavenumber-Frequency spectra



Mapping
L3 —> L4

e.g. DUACS



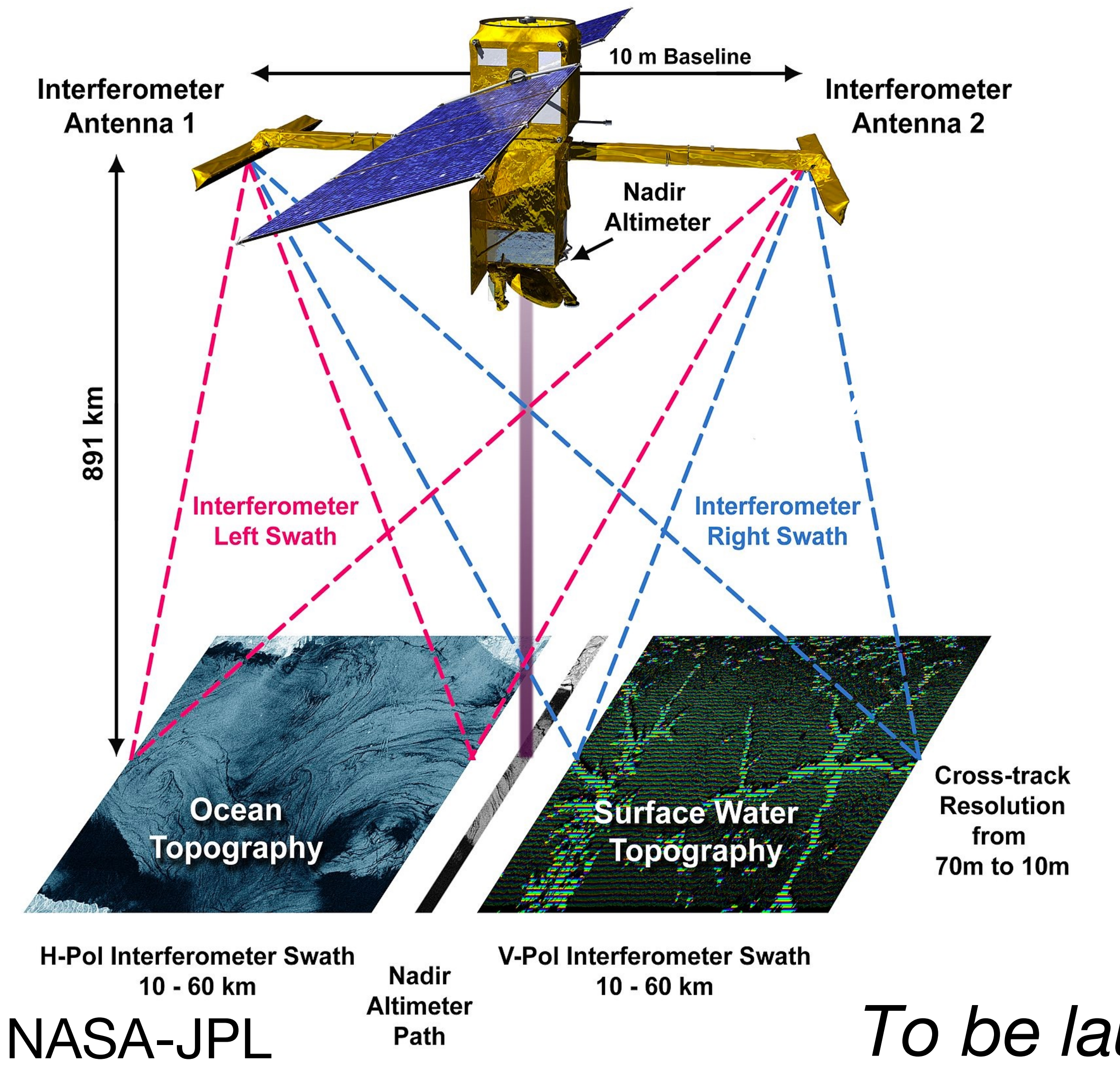
Resolved scales by conventional altimetry
(Ballarotta et al. 2019)

Introduction

The SWOT mission

SWOT — Surface Water Ocean Topography

Morrow et al. (2019)

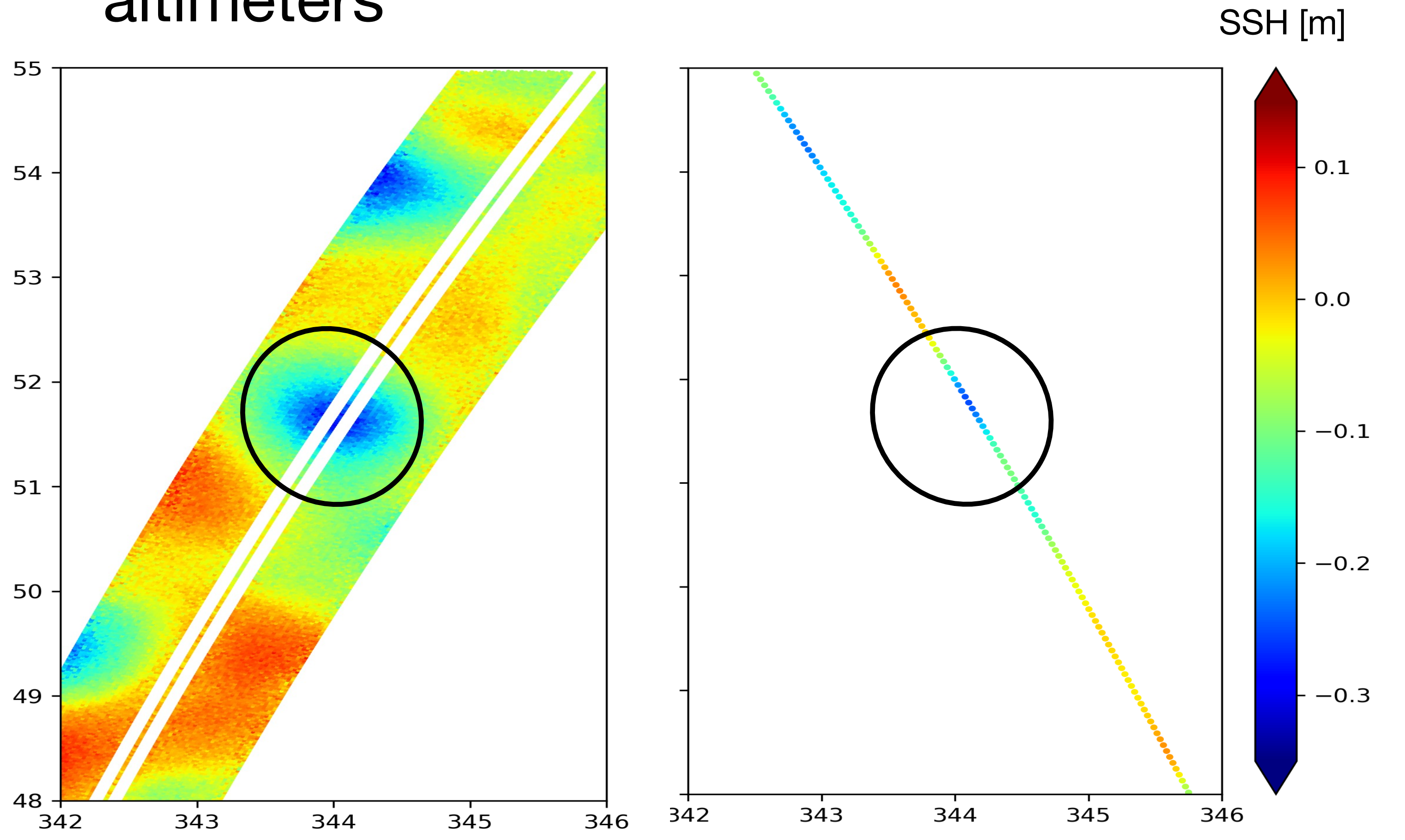


@ NASA-JPL

To be launch in one month !!

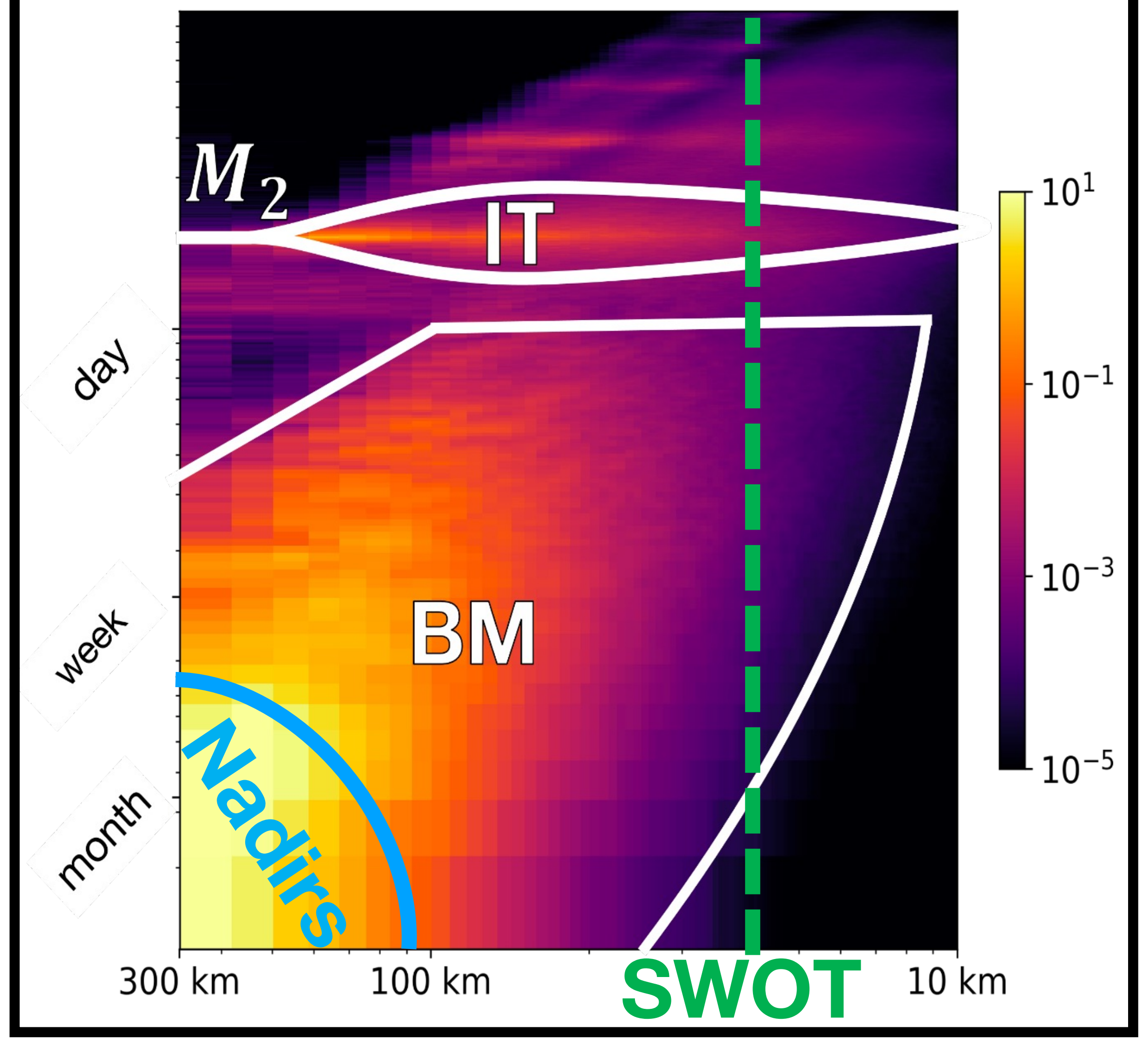
2D kilometric observations

- 120km-wide swath
- Accuracy 10x higher than conventional altimeters



Resolved scales

down to 15km



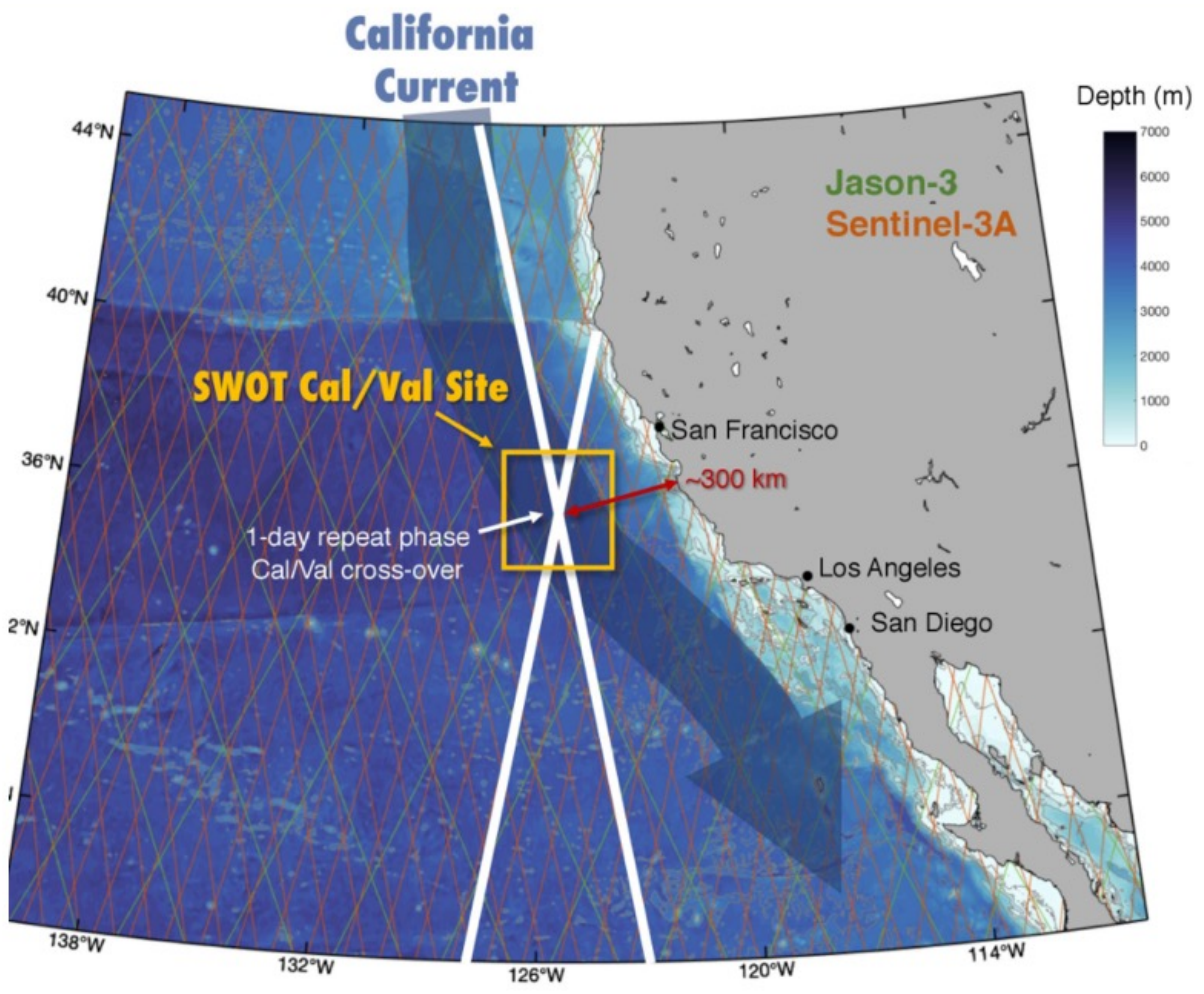
Opportunity: SWOT open the way to the systematic quantification of submesoscale ocean surface dynamics, including BM and IT.

Main challenge: quantify BM & IT separately (e.g. to estimate associated currents).

Our strategy: Data Assimilation using simple dynamical models and well-chosen control parameters.

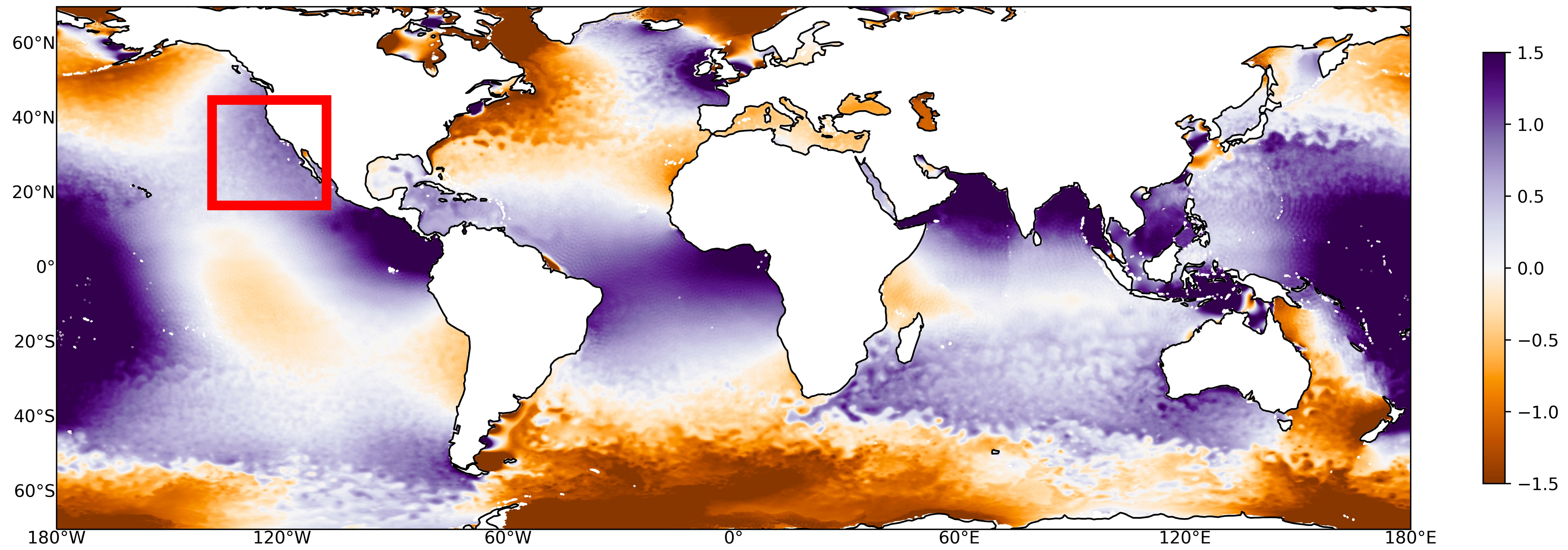
Experimental setup

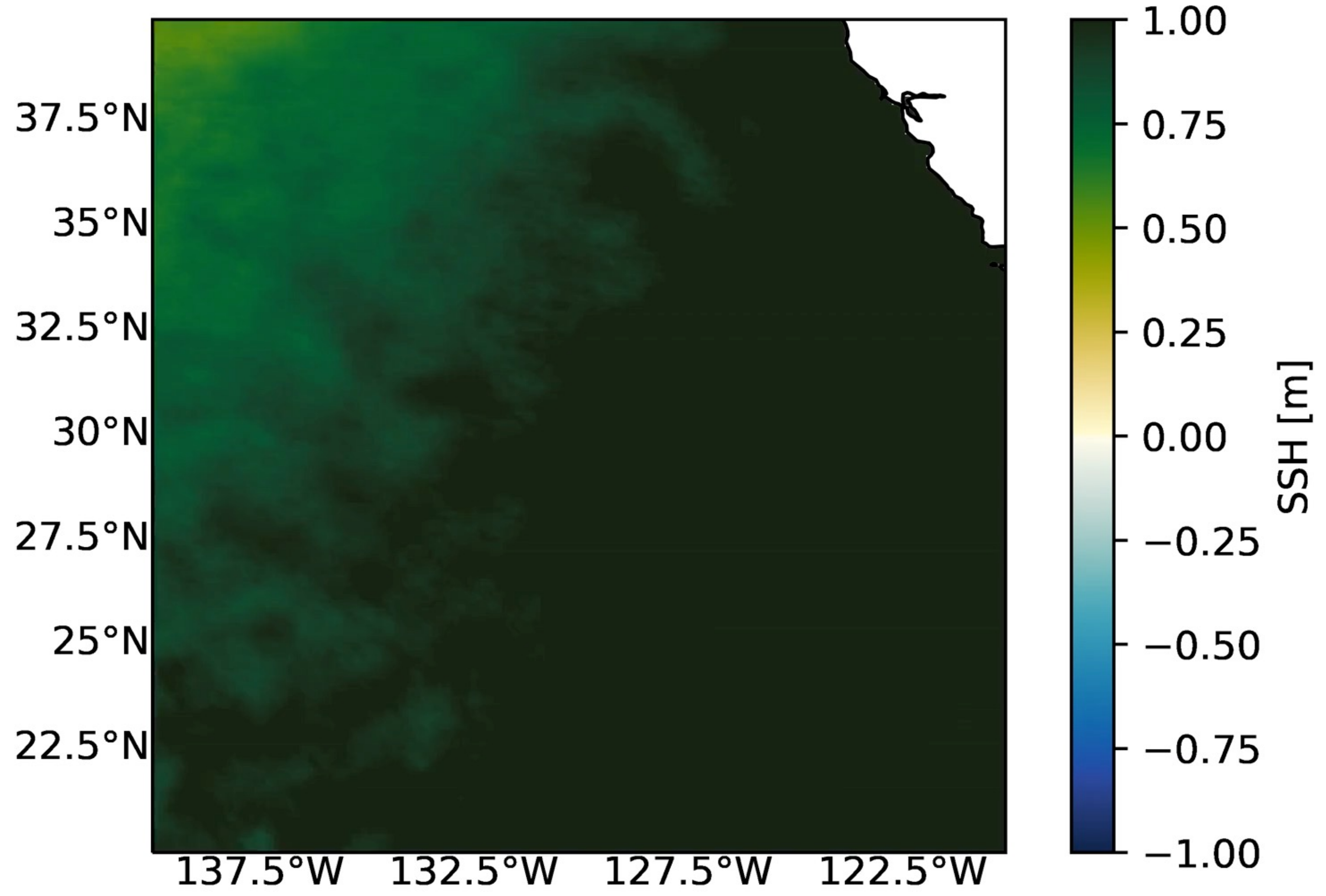
Focus on the SWOT's Californian Xover



- Californian Cross-Over
- 1-day Cal/Val orbit
- International collaboration

- OSSE using MITgcm llc4320 1/48° simulation with tidal forcing



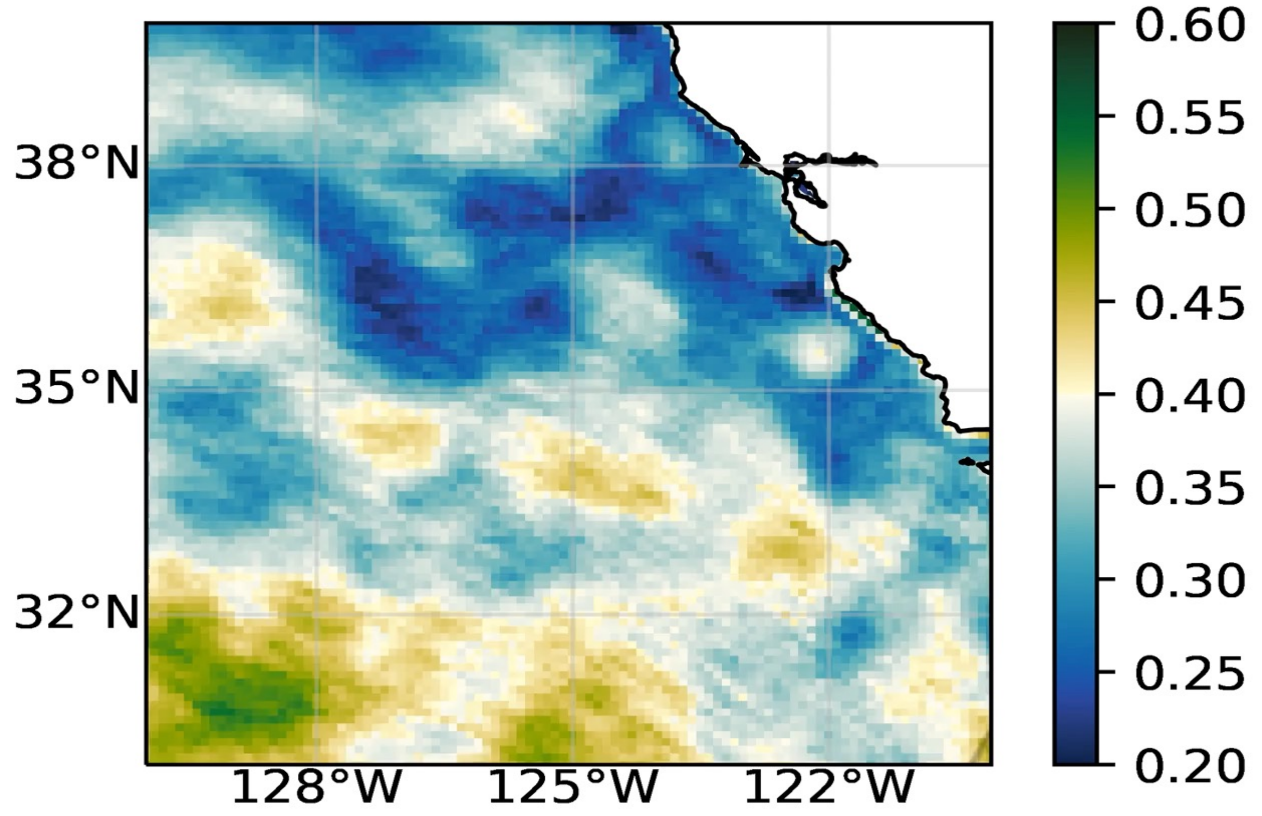


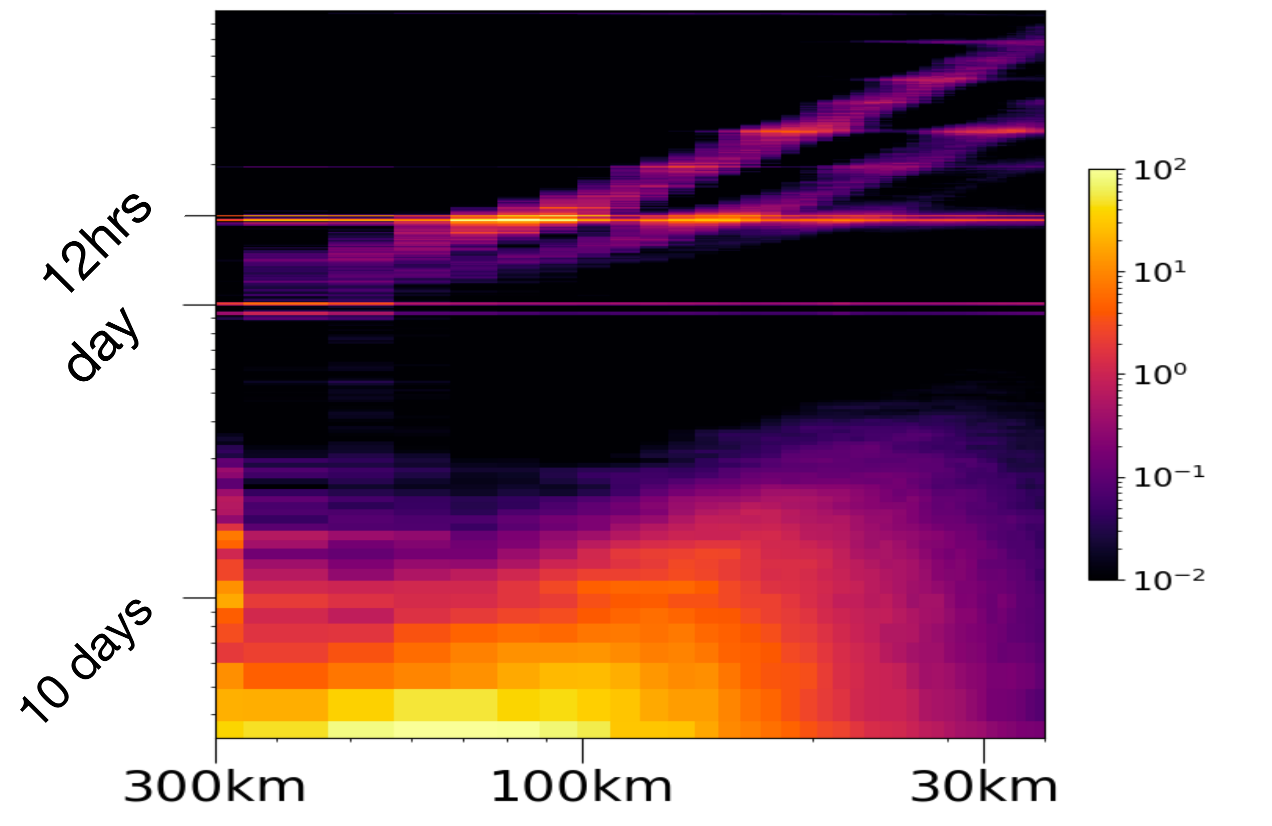
Experimental setup

OSSE - Simulated observations

What we observe

SWOT + 4 nadirs,
corrected of barotropic tide
without measurement noise





Method

Problem statement

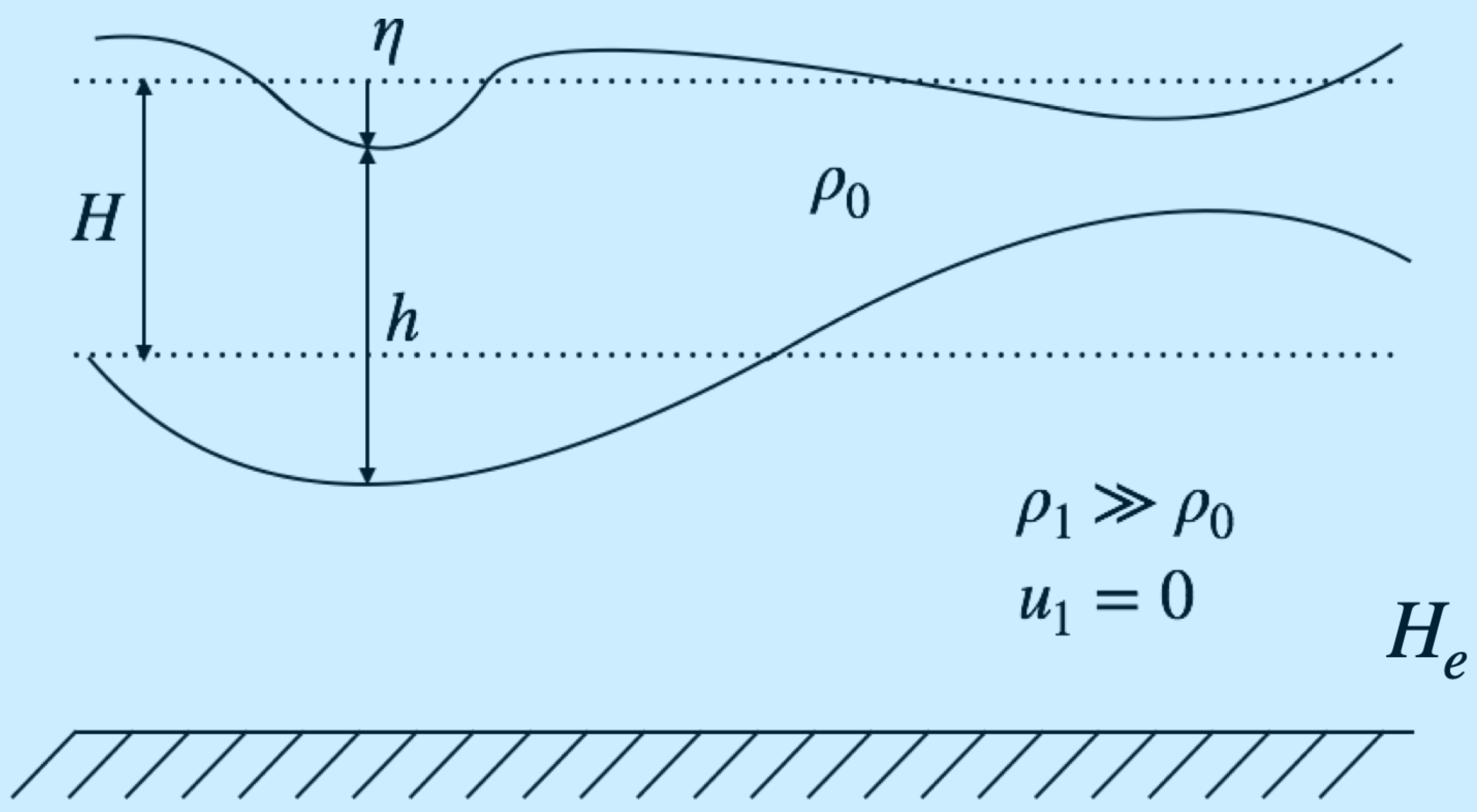
Dynamical models

Assumption: $\boldsymbol{\eta} = \boldsymbol{\eta}^{BM} + \boldsymbol{\eta}^{IT}$

$$\boldsymbol{\eta} = \mathcal{M}^{BM}(\boldsymbol{\phi}^{BM}) + \mathcal{M}^{IT}(\boldsymbol{\phi}^{IT})$$

$\mathcal{M}^{BM}$: Quasi-Geostrophic model, controlled by a forcing term $\boldsymbol{\phi}^{BM}$

$\mathcal{M}^{IT}$: Shallow-Water model, controlled by $\boldsymbol{\phi}^{IT}$, representing open boundary conditions and equivalent depth.



$$H_e = \frac{\rho_1 - \rho_0}{\rho_0} H$$

Data assimilation

4Dvar cost function: $J(\boldsymbol{\phi}^{BM}, \boldsymbol{\phi}^{IT}) =$

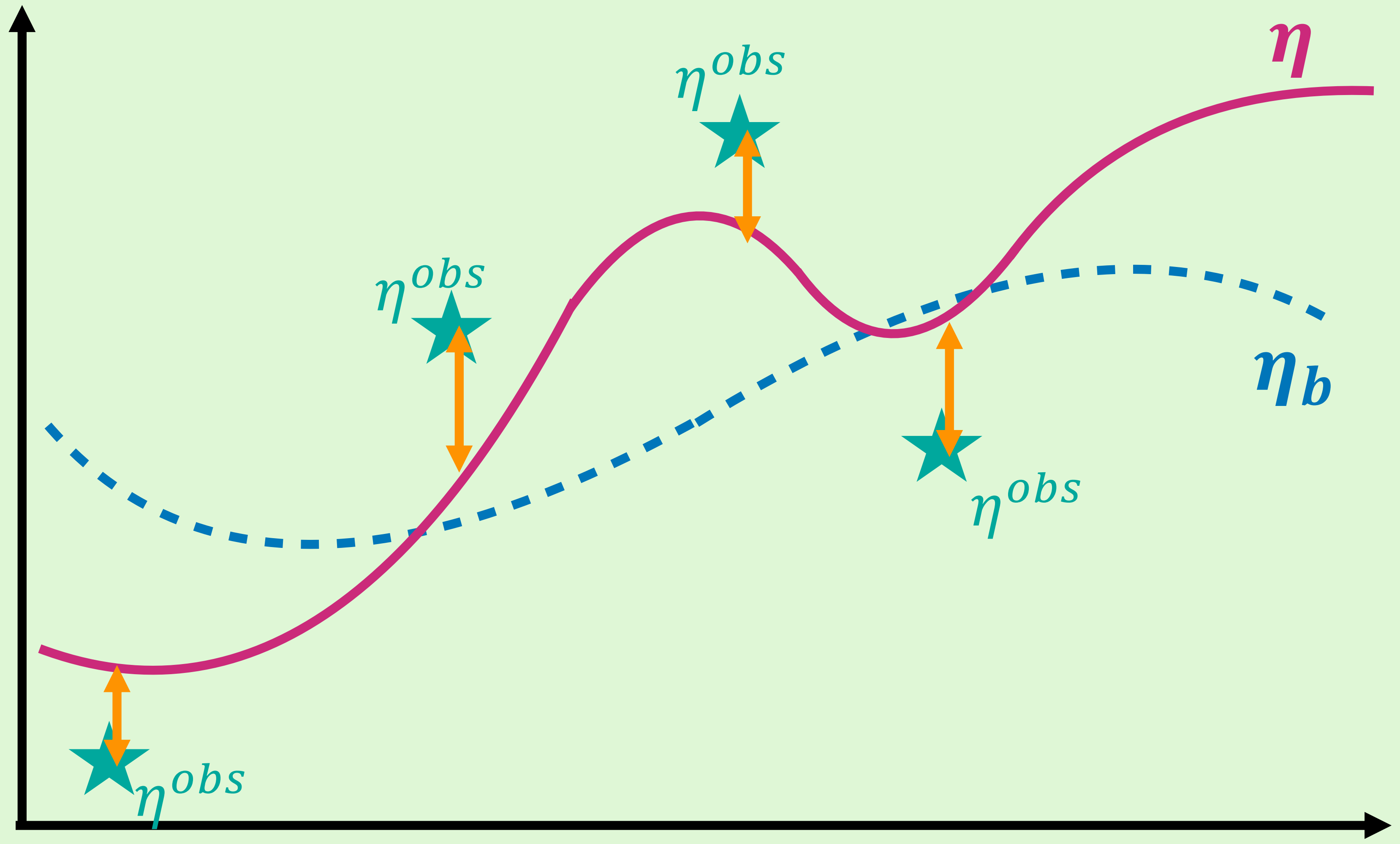
$$\left\|\boldsymbol{\phi}^{BM} - \boldsymbol{\phi}_b^{BM}\right\|^2 + \left\|\boldsymbol{\phi}^{IT} - \boldsymbol{\phi}_b^{IT}\right\|^2 + \left\|\boldsymbol{\eta}^{obs} - \boldsymbol{\eta}\right\|^2$$

Order reduction using reduced basis:

$$\boldsymbol{\phi} = \begin{pmatrix} \phi_1 \\ . \\ . \\ \phi_m \end{pmatrix} = \sum_{i=1}^{r} \psi_i \boldsymbol{\Gamma}_i = \boldsymbol{\Gamma} * \begin{pmatrix} \psi_1 \\ . \\ \psi_r \end{pmatrix} = \boldsymbol{\Gamma}\boldsymbol{\psi}$$

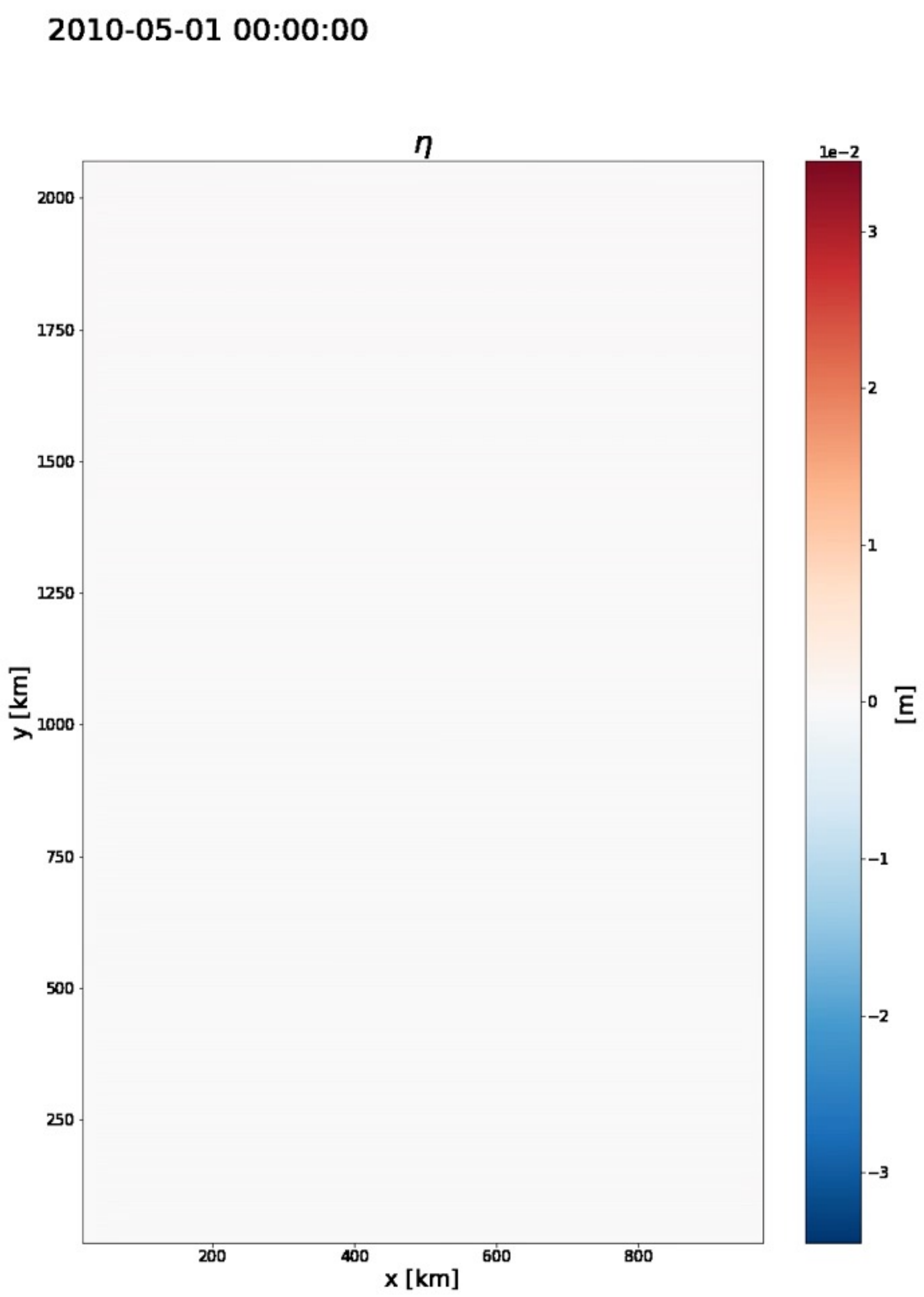
$\boldsymbol{\Gamma}^{\mathbf{BM}}$: wavelet functions

$\boldsymbol{\Gamma}^{IT}$: gaussian functions



Method

A close-up on the IT part



Shallow-water equations

$$\begin{cases} \dfrac{\partial u}{\partial t} + fv = -g\partial_x \eta \\ \dfrac{\partial v}{\partial t} - fu = -g\partial_y \eta \\ \dfrac{\partial \eta}{\partial t} = -H_e(\dfrac{\partial u}{\partial x} + \dfrac{\partial v}{\partial y}) \end{cases}$$

What controle the dynamics?

- Incoming waves η^{ext} through open boundary
- Equivalent depth field H_e

$$\boldsymbol{\phi^{IT} = (\eta^{ext}, H_e)}$$

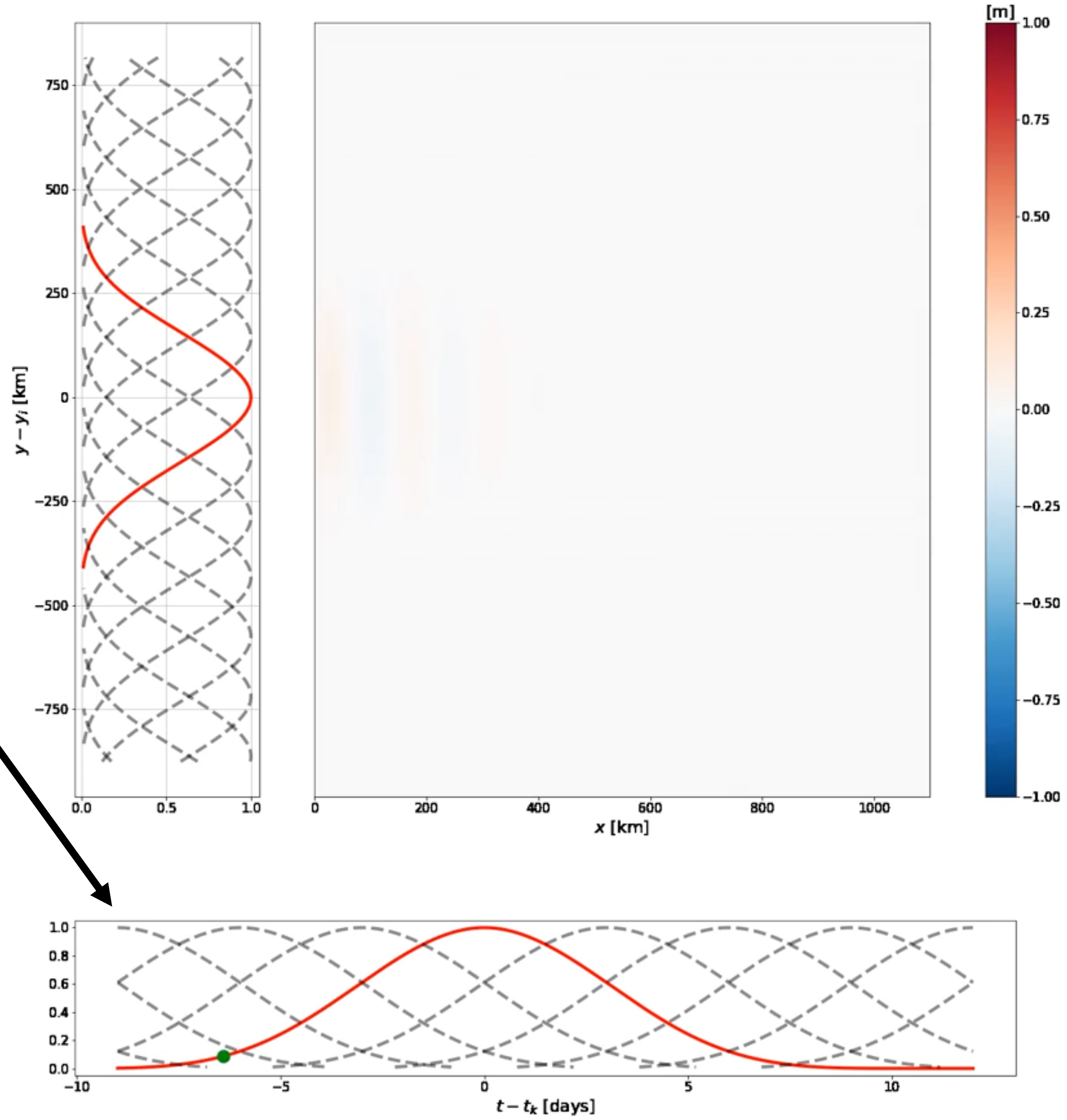
Method

A close-up on the IT part

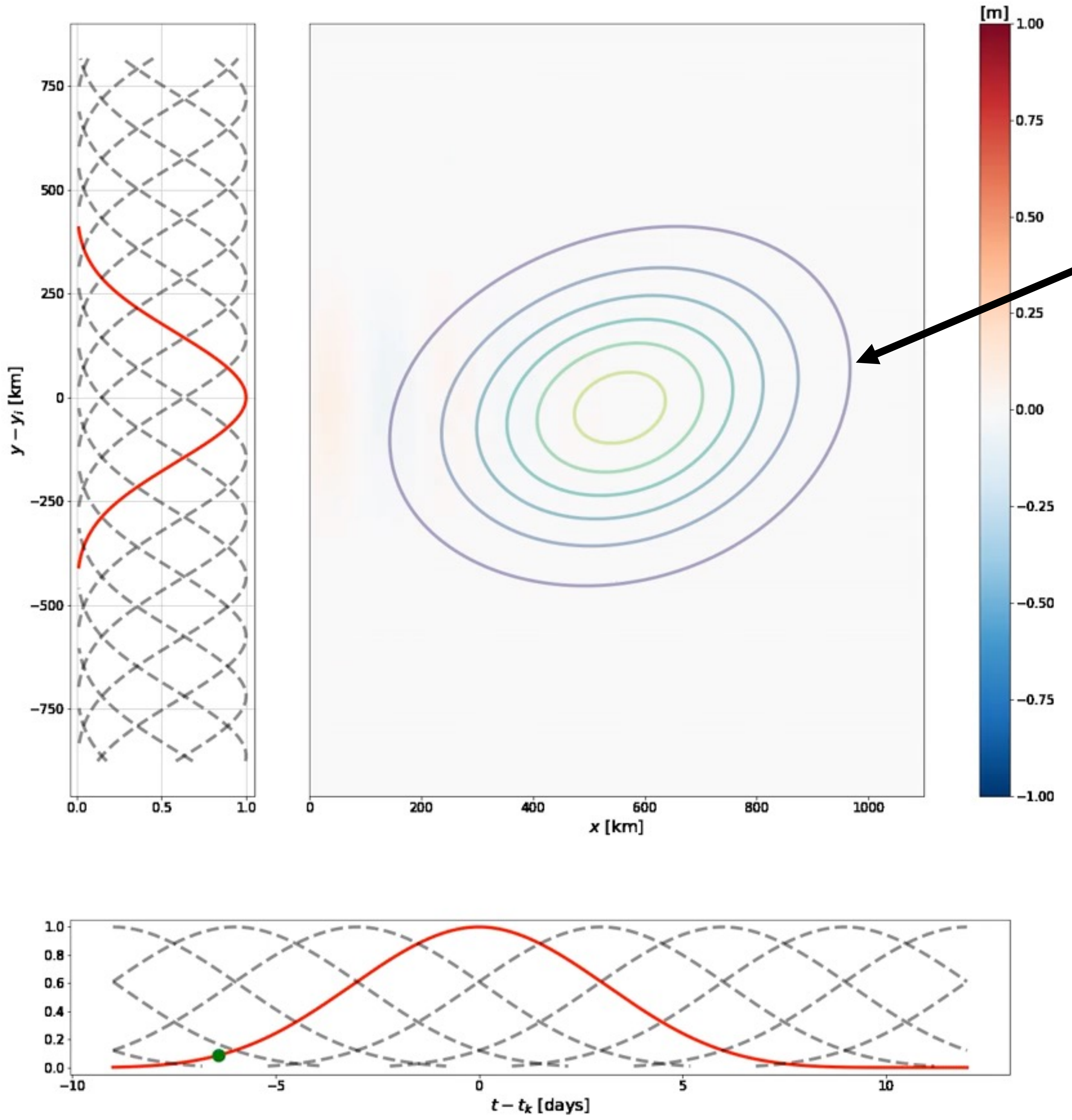
$\boldsymbol{\phi}^{IT} = (\boldsymbol{\eta}^{ext}, \boldsymbol{H_e})$

$$\boldsymbol{\phi} = \begin{pmatrix} \phi_1 \\ \cdot \\ \cdot \\ \phi_m \end{pmatrix} = \sum_{i=1}^{r} \psi_i \boldsymbol{\Gamma_i} = \boldsymbol{\Gamma} * \begin{pmatrix} \psi_1 \\ \cdot \\ \psi_r \end{pmatrix} = \boldsymbol{\Gamma}\boldsymbol{\psi}$$

One $\boldsymbol{\Gamma_i}$ for $\boldsymbol{\eta}^{ext}$

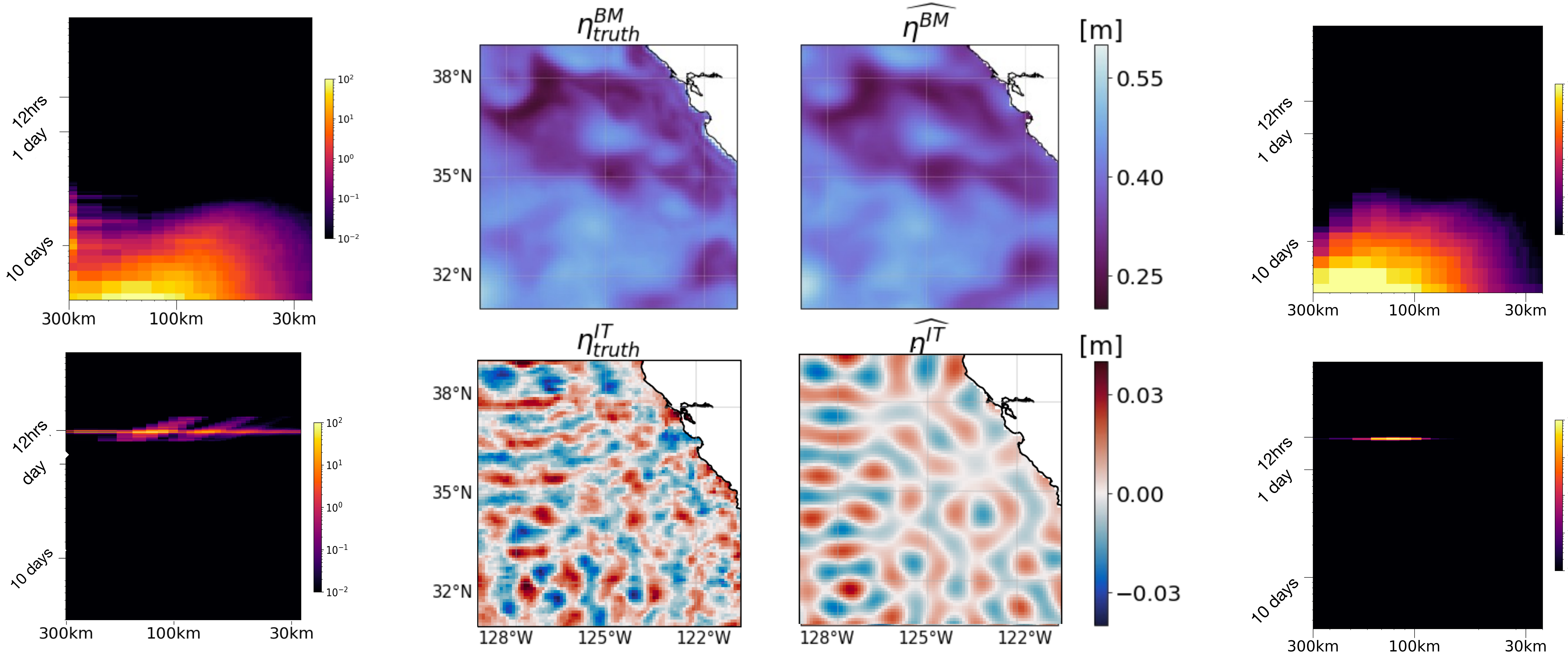


One $\boldsymbol{\Gamma_i}$ for $\boldsymbol{H_e}$



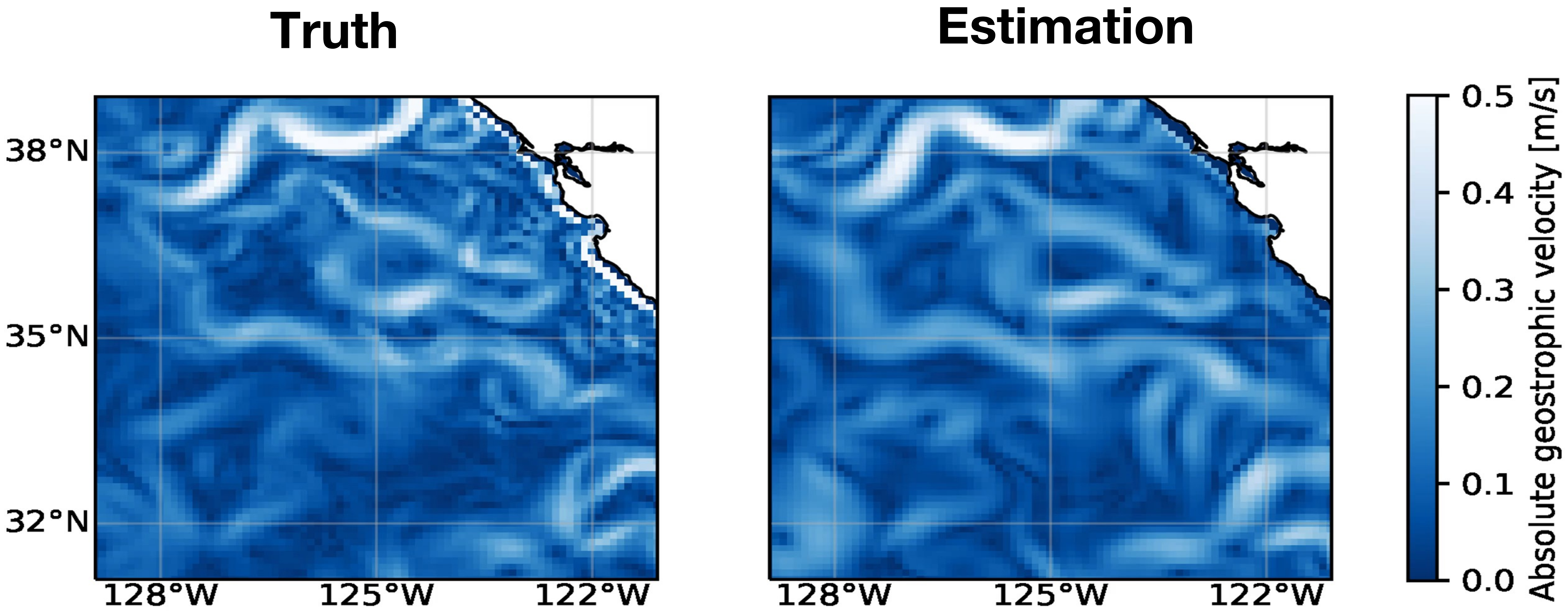
Results

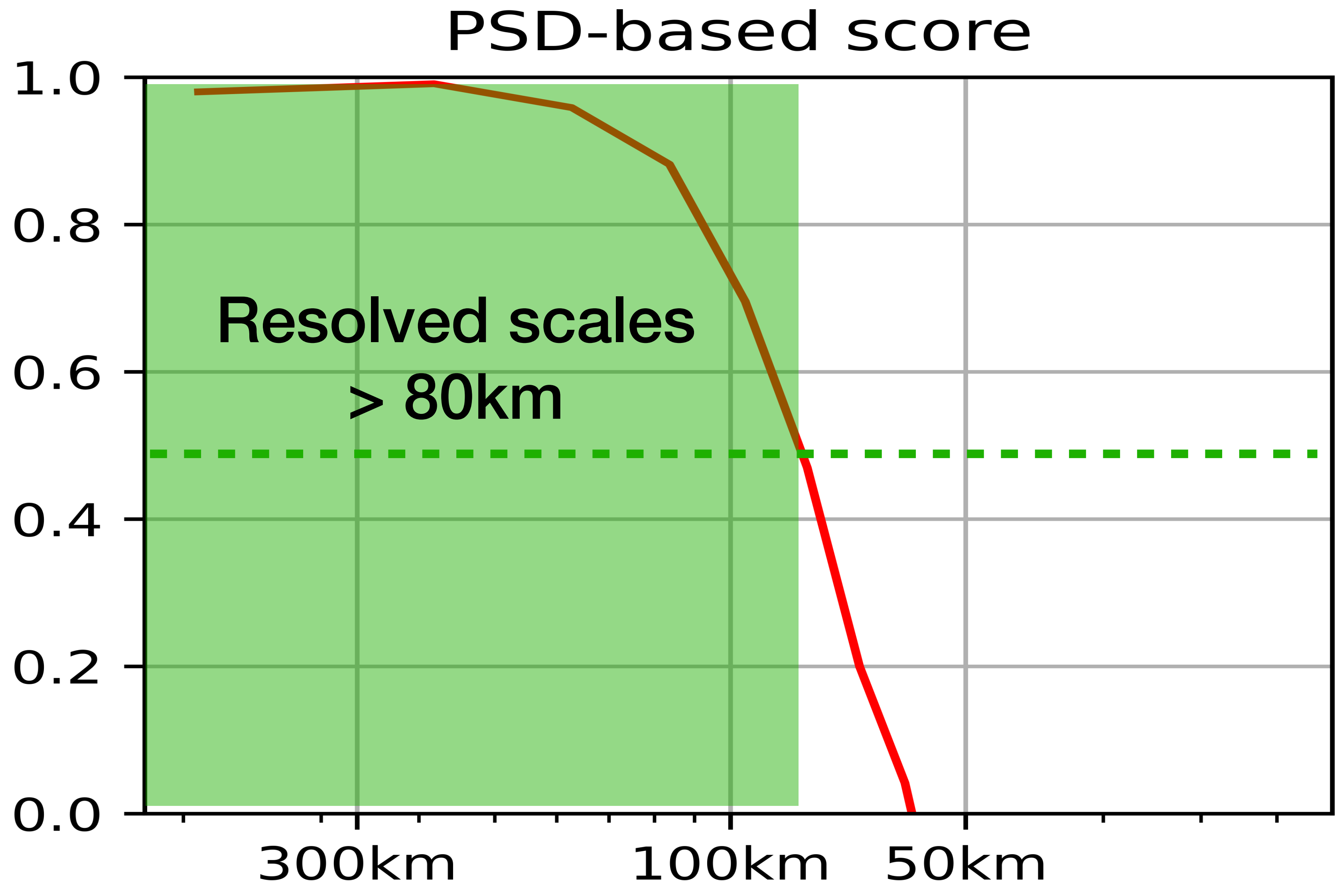
Separation

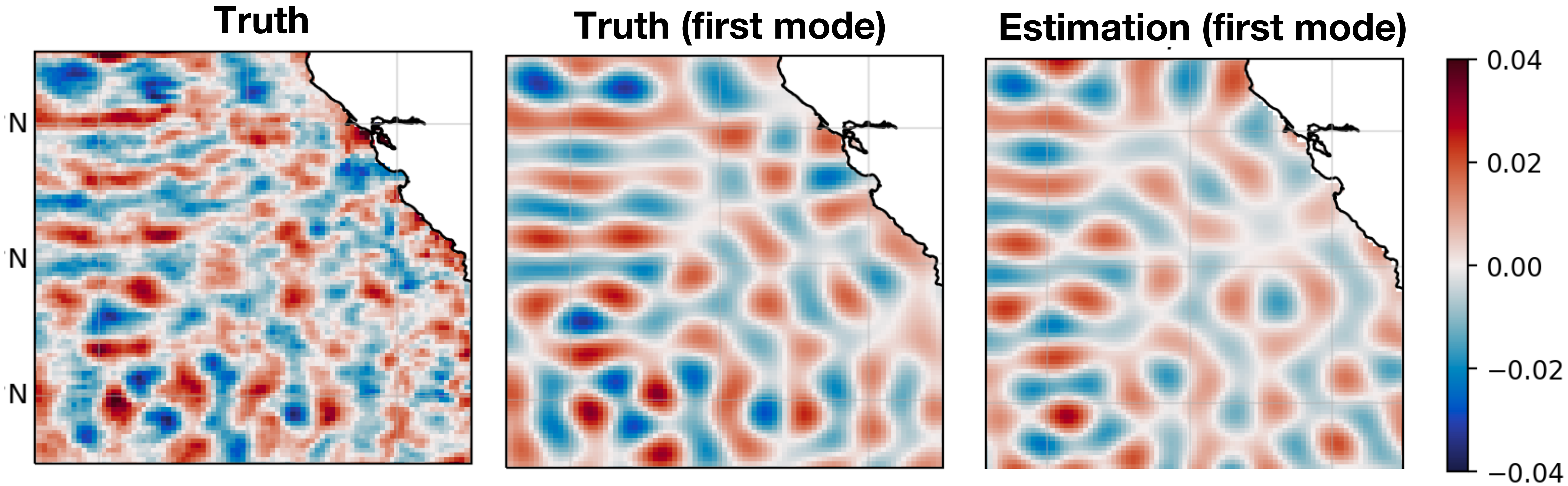


Results

Diagnostics







RMSE Score:

40% w.r.t mode 1
30% w.r.t all modes

Conclusions

Summary / Perspectives

- We developed an original data assimilation method based on **simple physical models** and **reduced basis** to separate Balanced Motions and Internal tides in SSH maps derived from altimetry.
  → To be improved to handle wave generation in the study domain

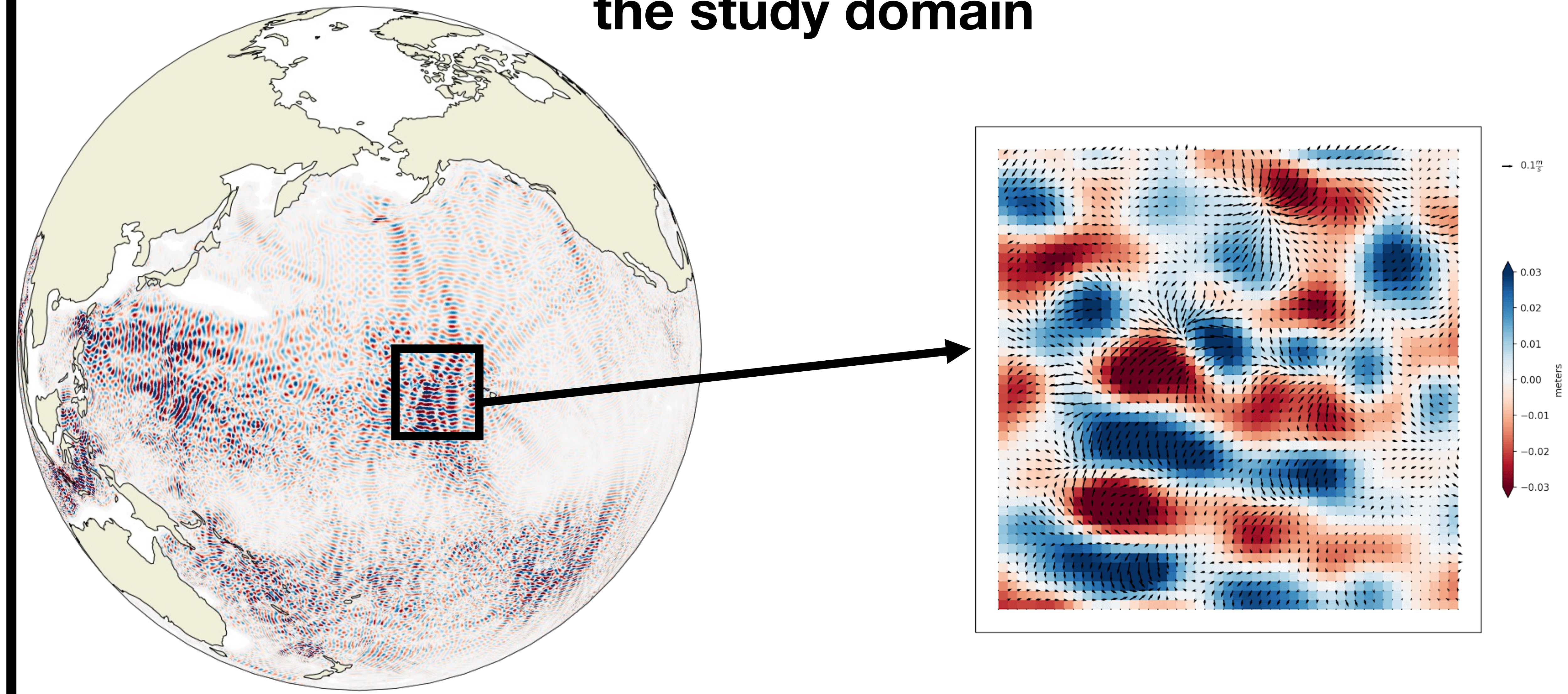
- The method has been tested with a realistic OSSE focussing on the **SWOT Californian Xover**.
  → To be improved to handle SWOT random/correlated errors

- First results suggest **successfull seperation** of Balanced Motions (scales >80km) and Internal Tides (30% of the total signal).
  → To be tested with upcoming real data (Cal/Val & Science phases)

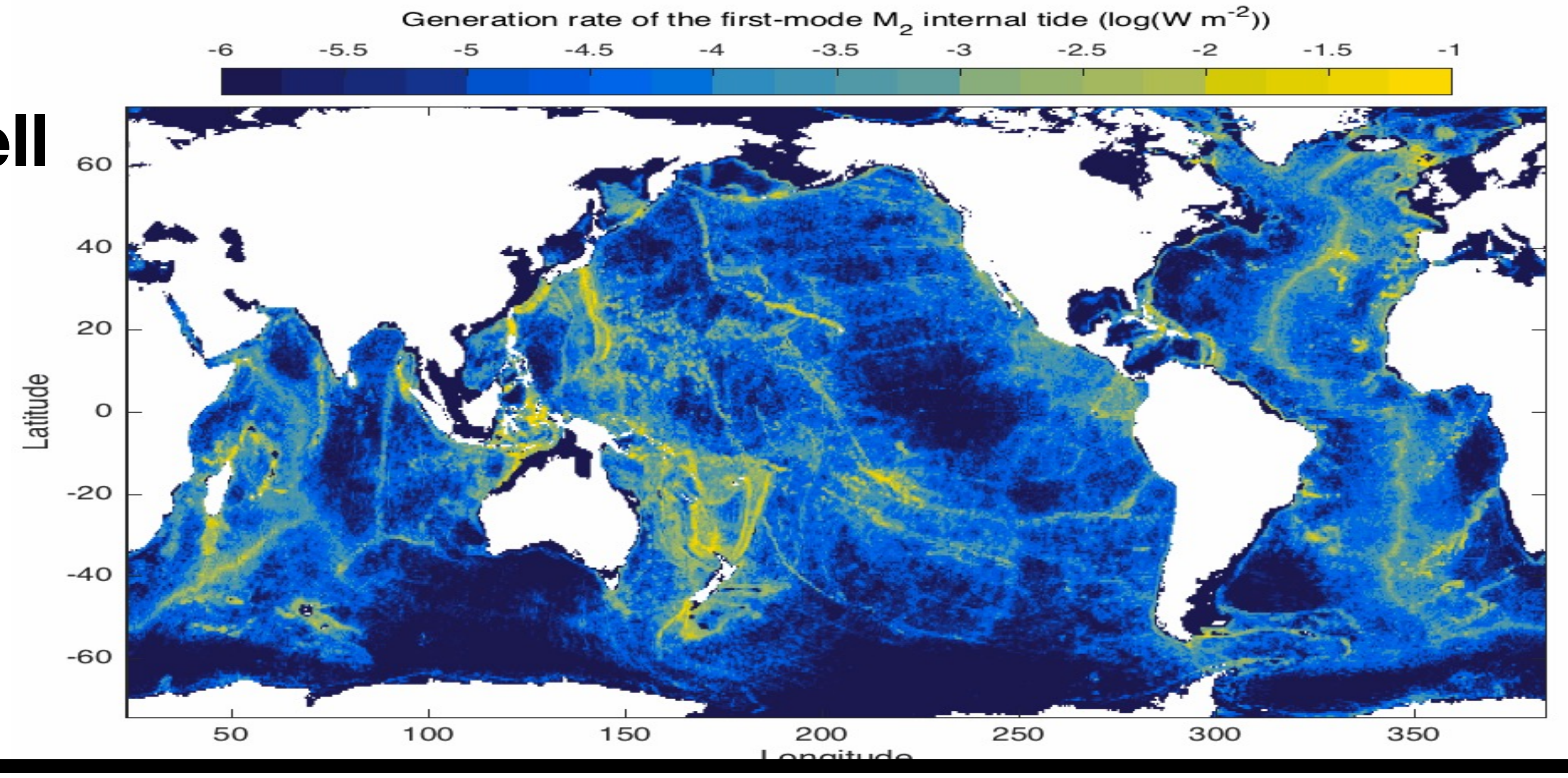
Conclusions

Next steps

Handle situations where internal tides are generated inside the study domain



The source locations are well known



Falahat et al 2014

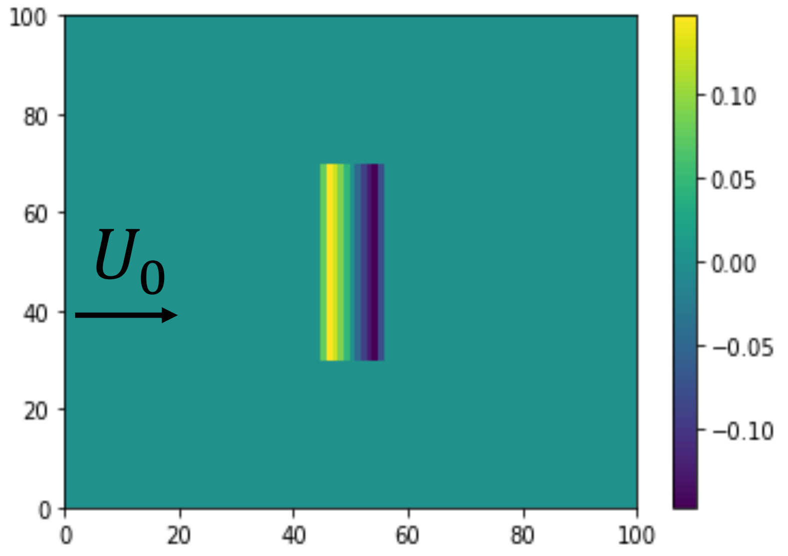
Future work will adress the following:

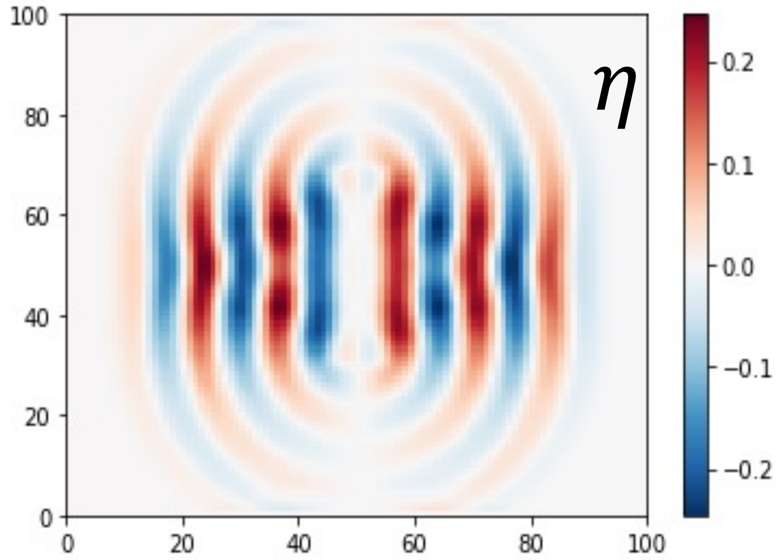
How to model internal tide generation inside the domain?
How to define (and estimate) the controlling parameters?

Exemple: $$\partial_t \eta = -H_e(\partial_x u + \partial_y v) + F_b$$

$$F_b \propto U_0 \cdot \nabla H$$

Bathimetry gradient ∇H





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Method

A close-up on the IT part

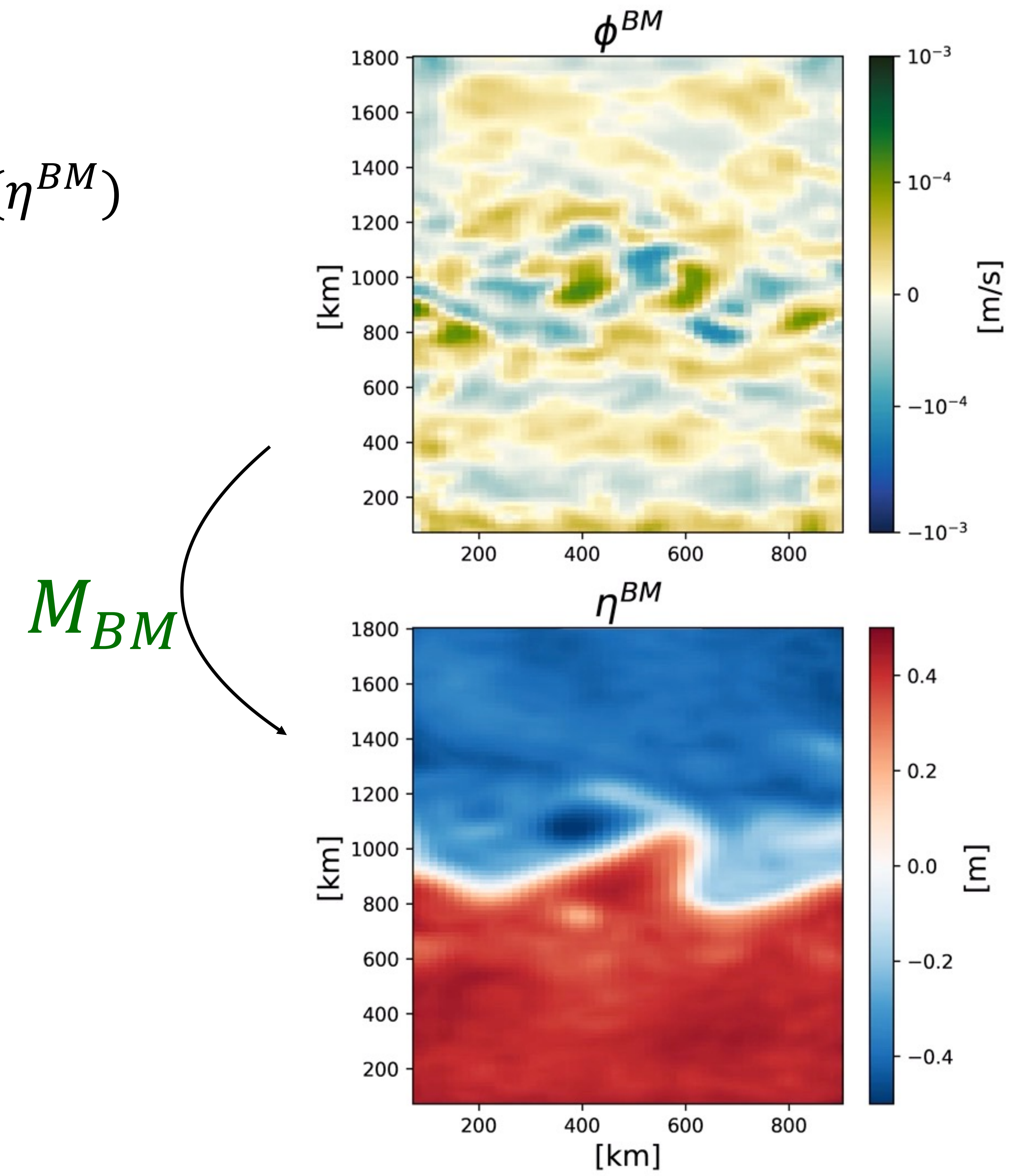
1.5-layer quasi-geostrophic model

$$\left.\begin{aligned} \psi &= \frac{g}{f}\eta \\ q &= \nabla^2\psi - \frac{1}{{L_R}^2}\psi \\ \partial_t q &+ J(\psi, q) = 0 \end{aligned}\right\} \quad \frac{\partial \eta^{BM}}{\partial t} = M_{QG}(\eta^{BM})$$

… forced by an additional term, representing the model error ϕ^{BM}:

$$\frac{\partial \eta^{BM}}{\partial t} = M_{QG}(\eta^{BM}) + \phi^{BM}$$

$$\eta^{BM}_{(t,x,y)} = M_{BM}(\phi^{BM})$$



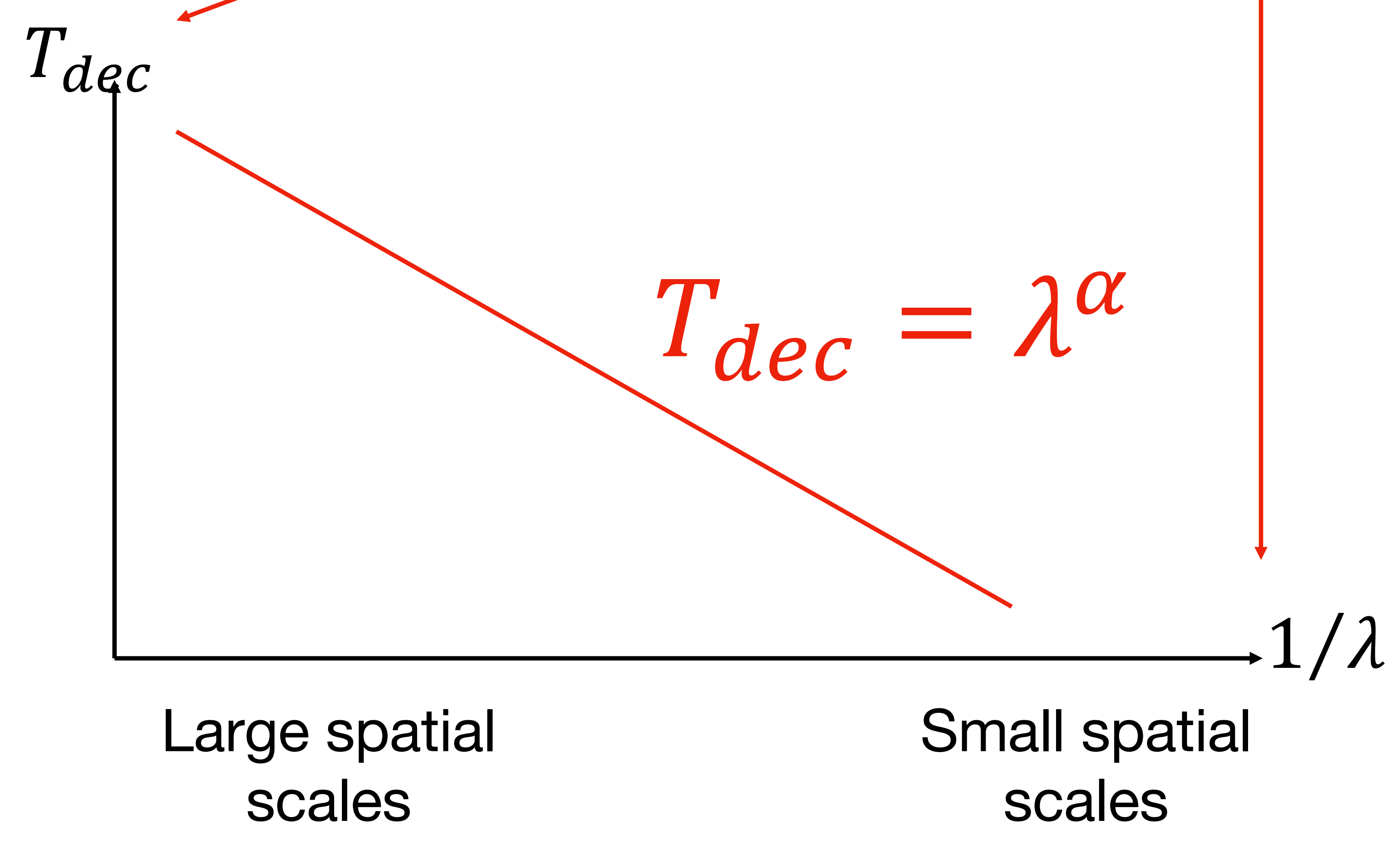
Data assimilation

Reduced basis: for BM

$$\phi^{BM} = \sum_{i}^{N} G_i^{BM} \times \psi_i^{BM} = G^{BM} \cdot \psi^{BM}$$

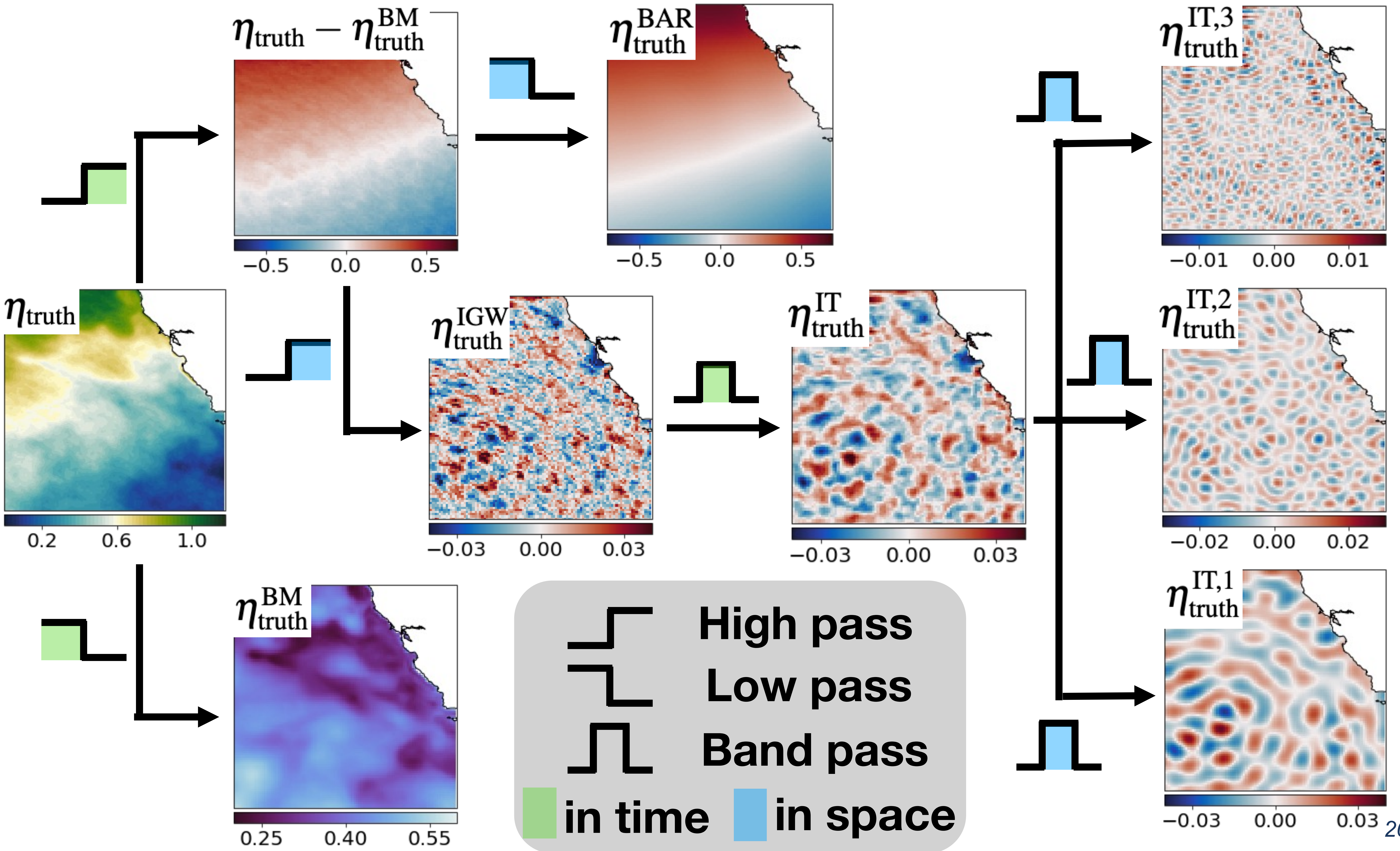
with space wavelet functions local in time and space :

$$G_i^{BM}(t,\mathbf{r}) = e^{-\left(\frac{||\mathbf{r}-\mathbf{r_i}||}{D}\right)^2} \cdot e^{-\left(\frac{t-t_i}{T_{dec}}\right)^2} \cdot e^{i\left(\frac{2\pi}{\lambda}\boldsymbol{\kappa}_\theta \cdot \mathbf{r} \pm \frac{\pi}{2}\right)}$$



Experimental setup

OSSE - Reference simulation



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de l'environnement

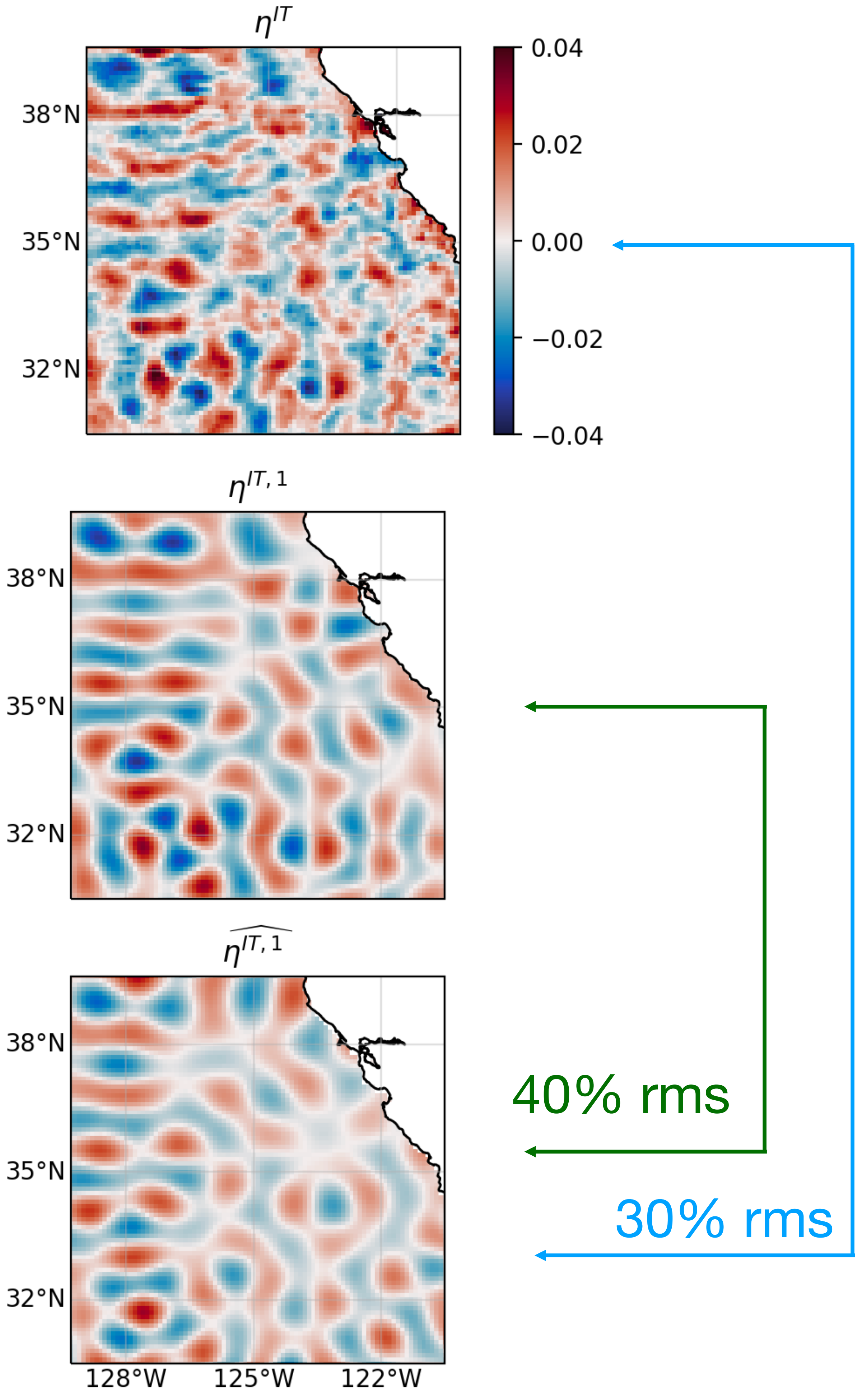
Experimental setup

OSSE - Reference simulation

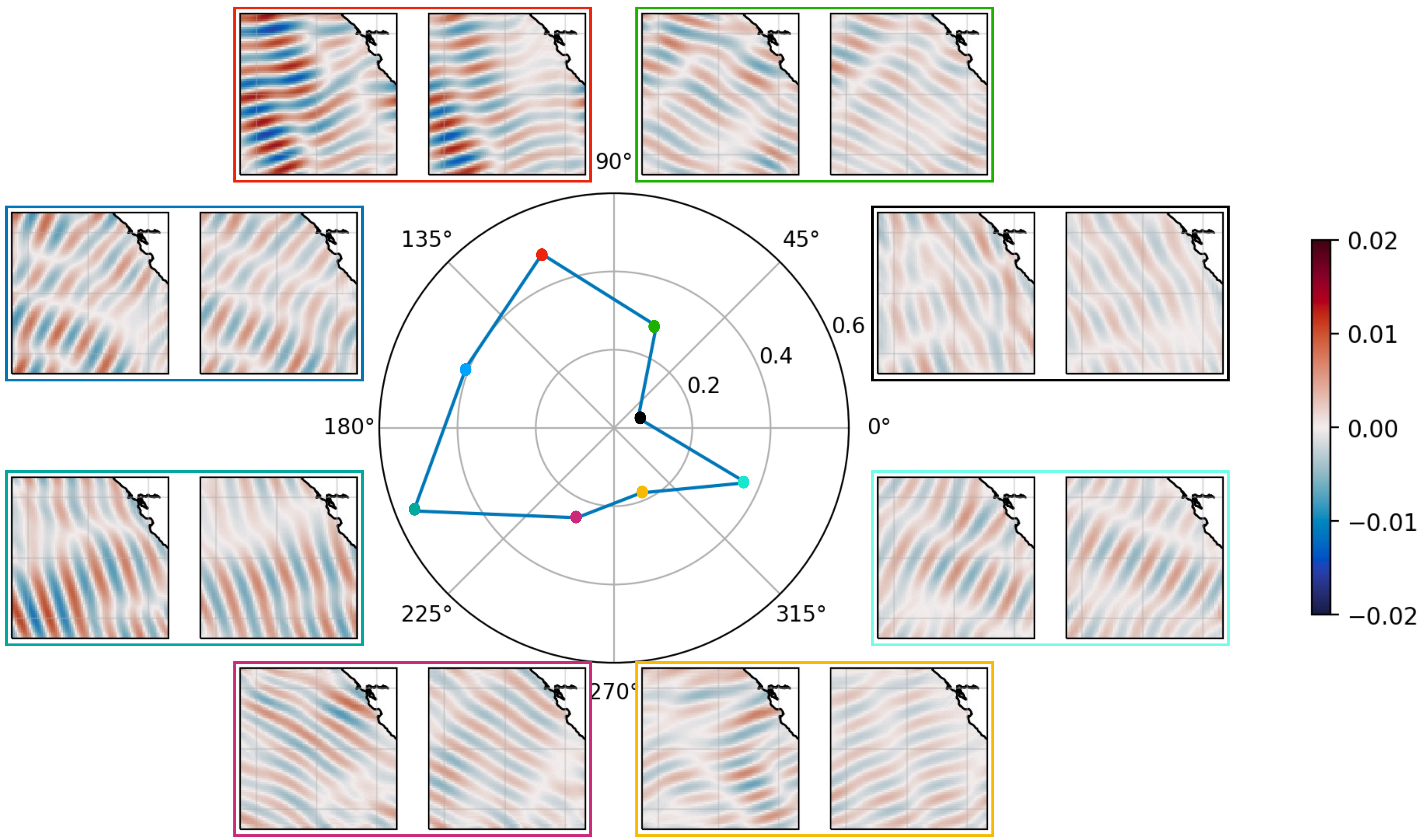
esa

Results

Internal tides



Plane wave decomposition



Results

Internal tides