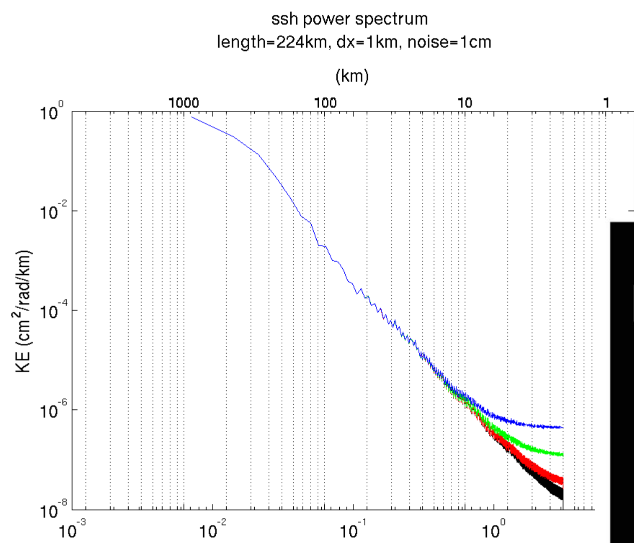
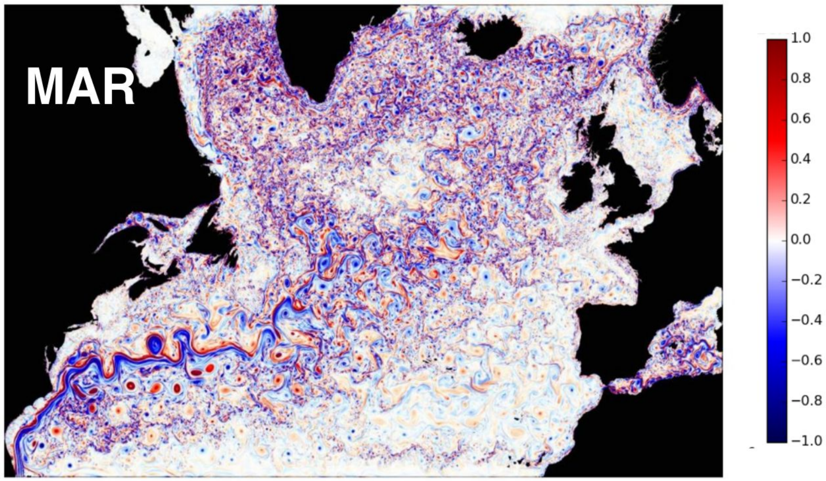
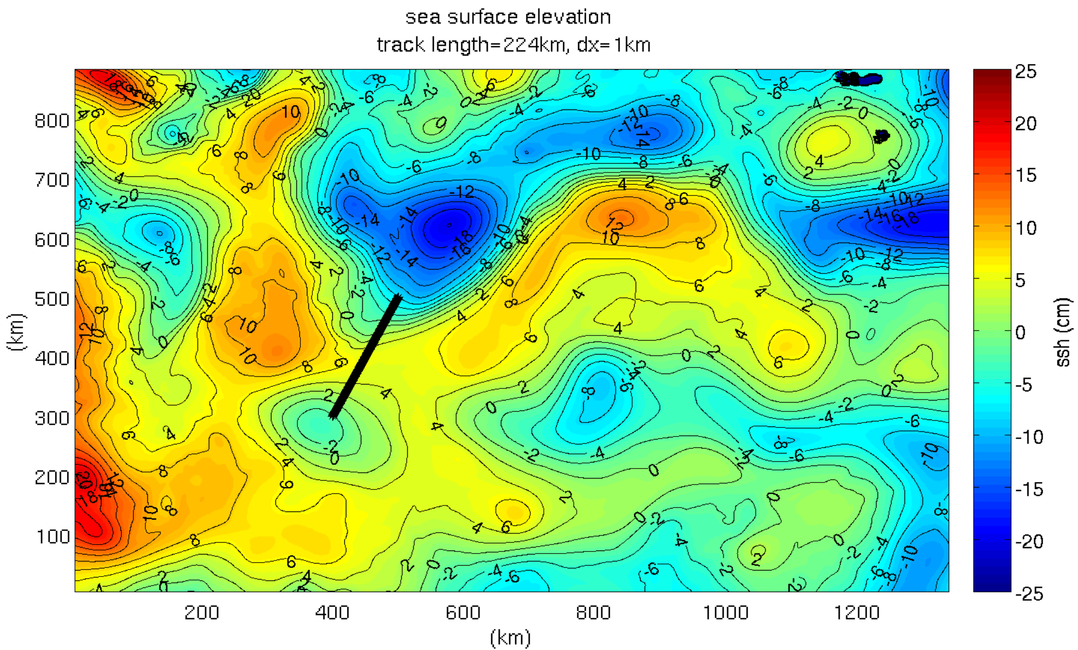
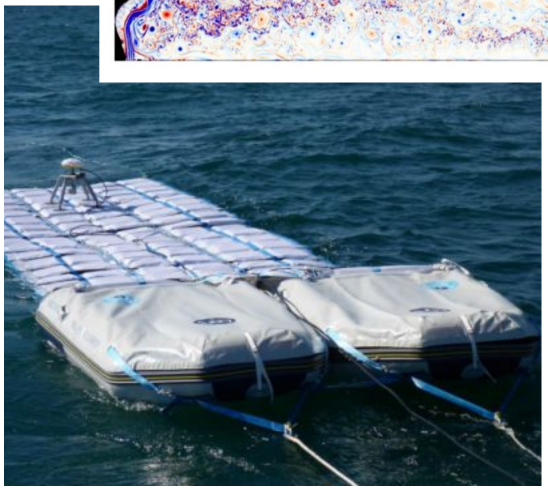
French modelling CalVal activity

BIOSWOT team

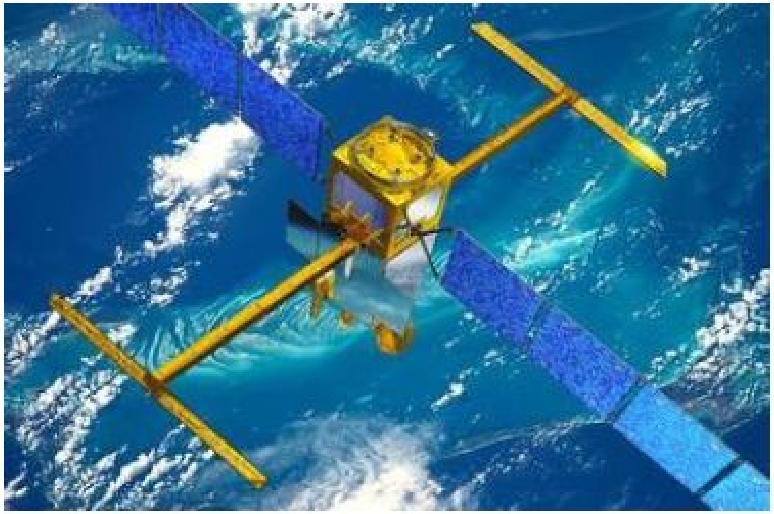




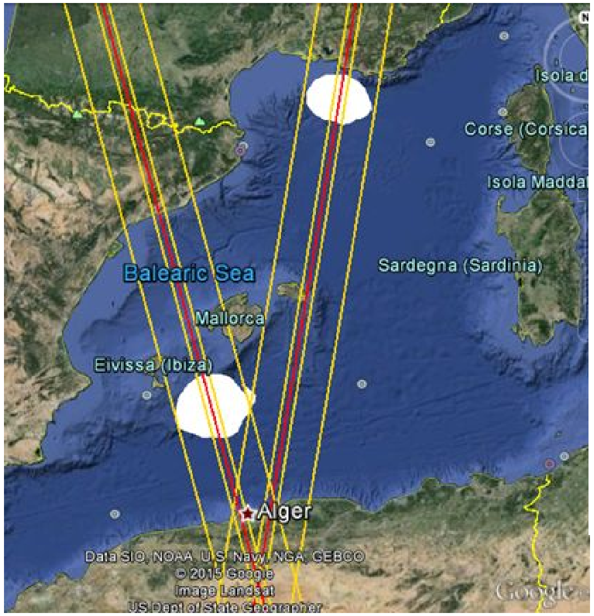




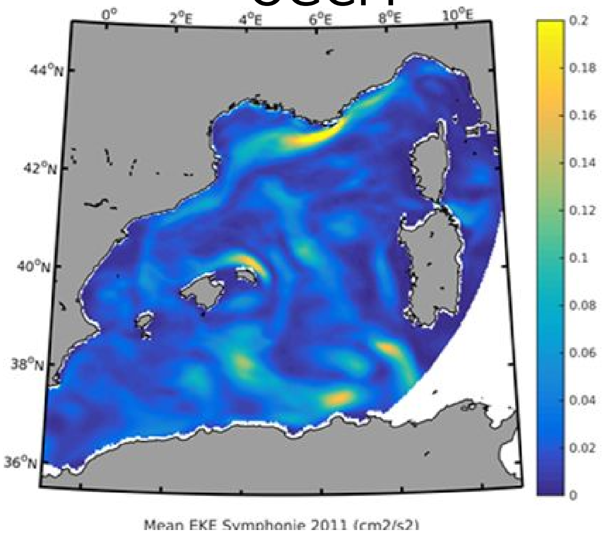
Reconstructing 2D sea surface height from future SWOT data : application in the Western Mediterranean Sea



Fast sampling tracks & potential CalVal sites



Symphonie 1 km OGCM



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ollecte Localisation Satellites, Toulouse

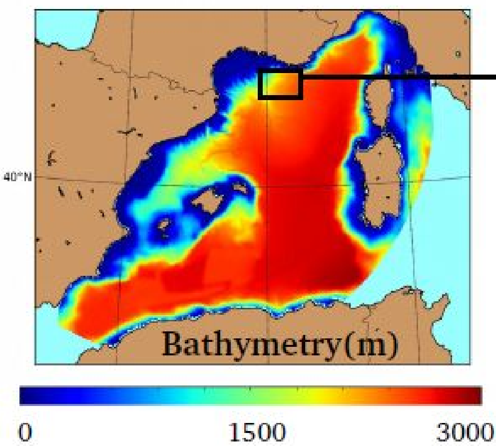
cnes CNRS LEGOS CLS Université de Toulouse Université Paul Sabatier TOULOUSE III

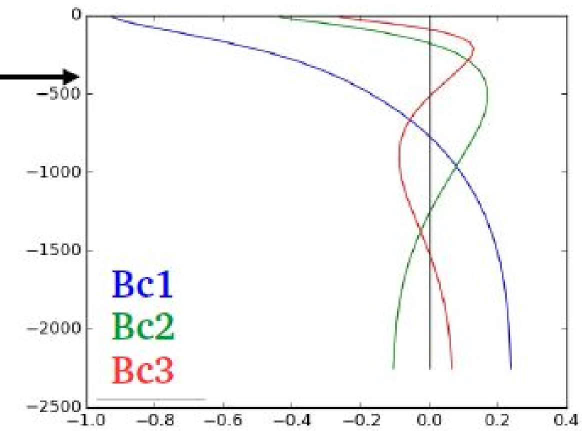
Using model analyses to understand CalVal sampling – to which depths ?

2 dominant modes in the Western Mediterranean Sea

Surface pressure:
a proxy of the SSH

Decomposition on
vertical modes

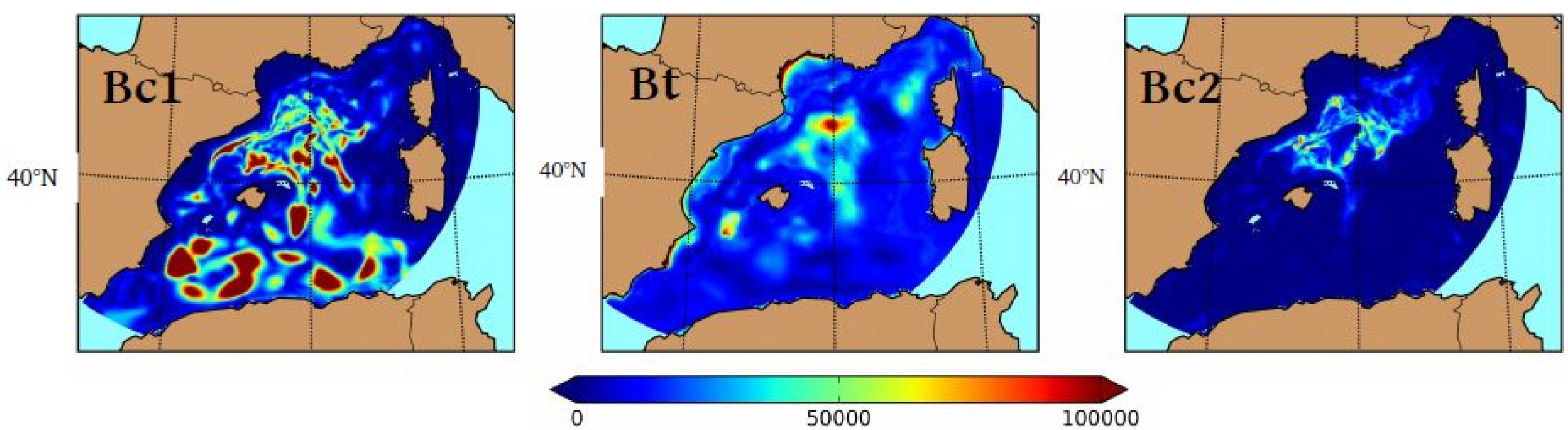




First baroclinic mode dominant

Importance of the barotropic mode near the coast

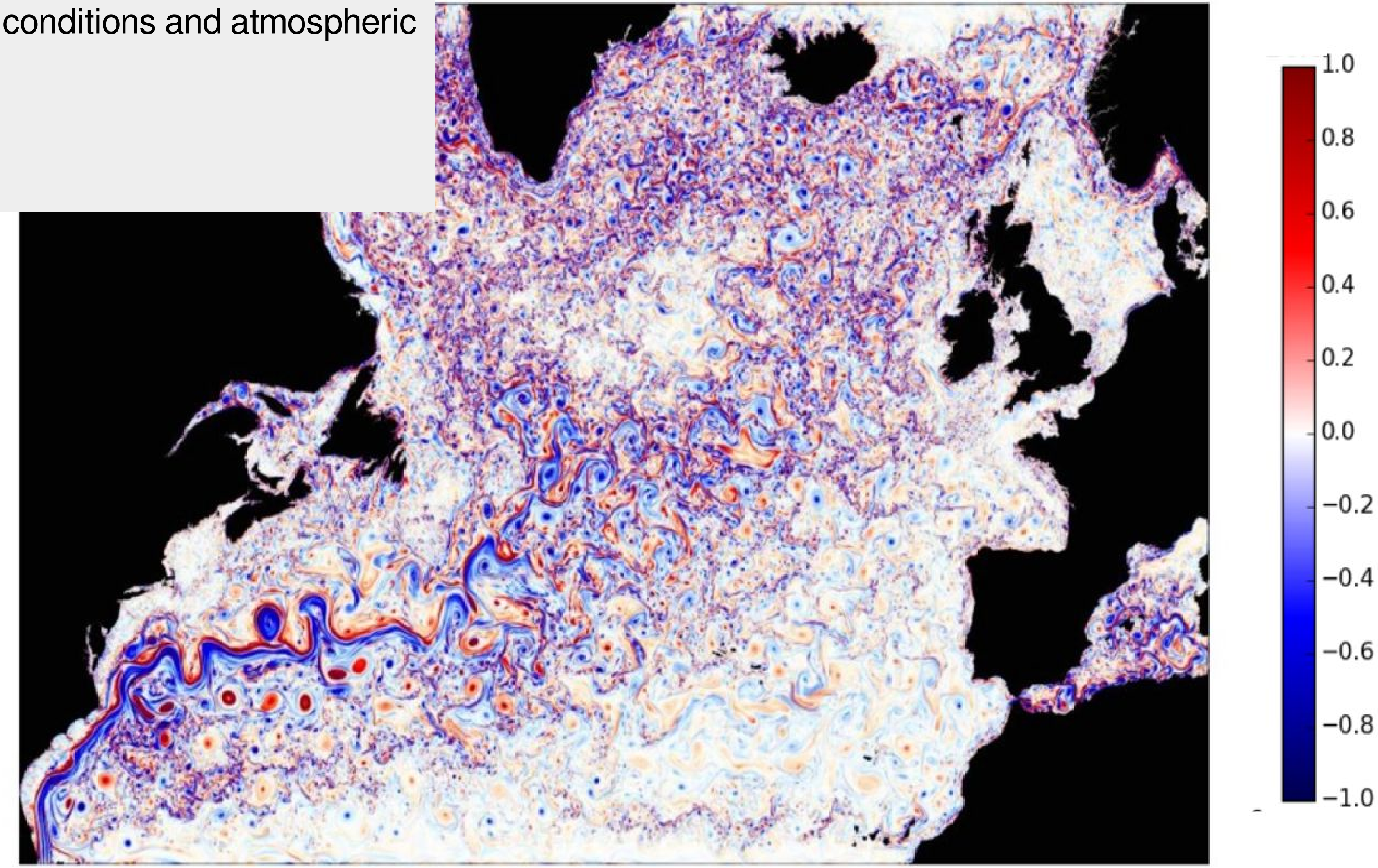
Mean variance of the pressure amplitude for barotropic and the two first baroclinic modes over March



NATL 60 Model configuration and numerical experiment

- numerical code : NEMO v3.6
- horizontal grid : 1/60° (dx = 0.8-1.6 km)
- vertical grid : 300 levels (dz = 1m to 30 m)
- realistic boundary conditions and atmospheric forcing

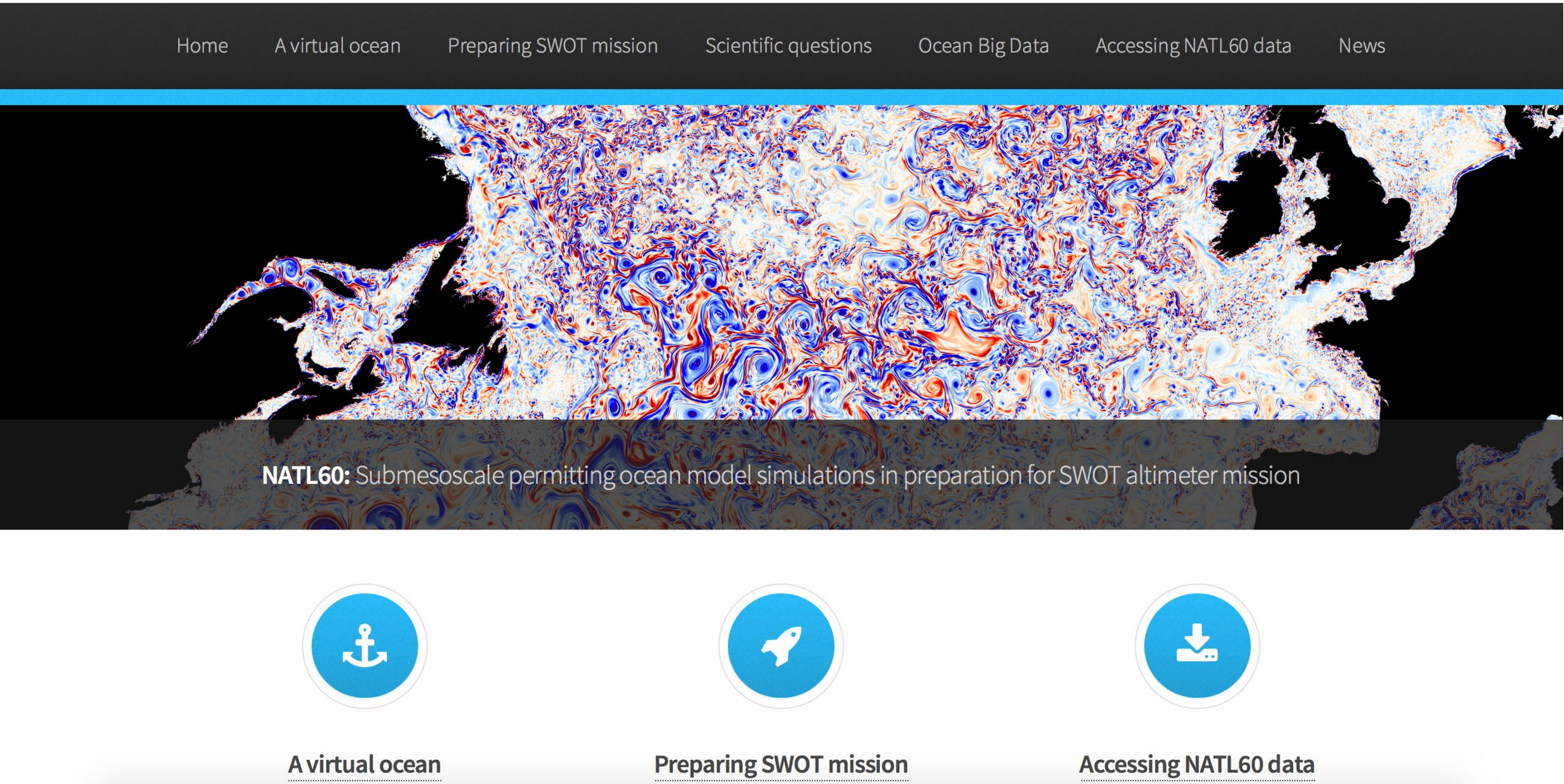
BIOSWOT



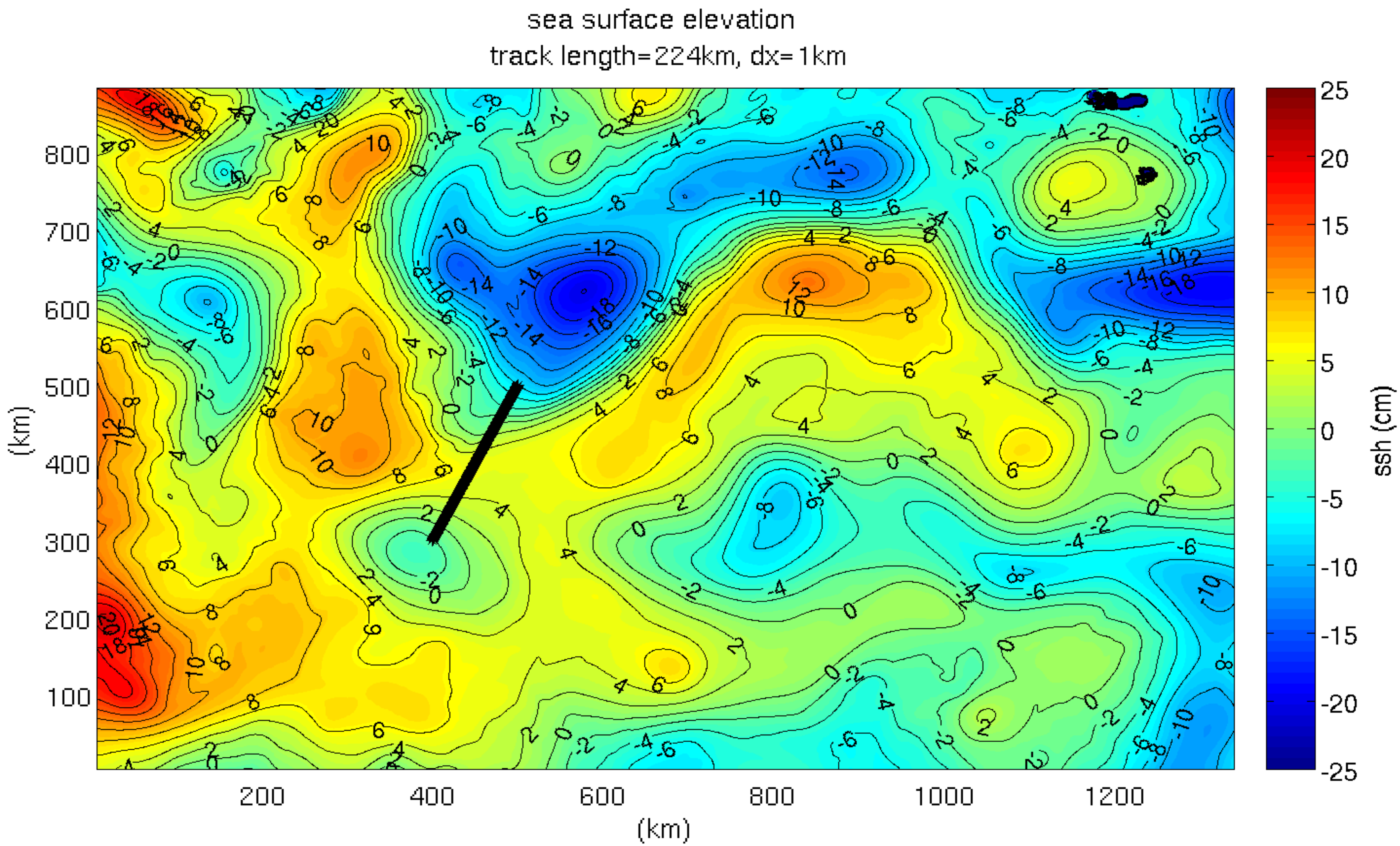
Surface relative vorticity in winter Courtesy of J. LeSommer

NATL60 :
basin scale, submesoscale permitting ocean model simulations in preparation for SWOT altimeter mission

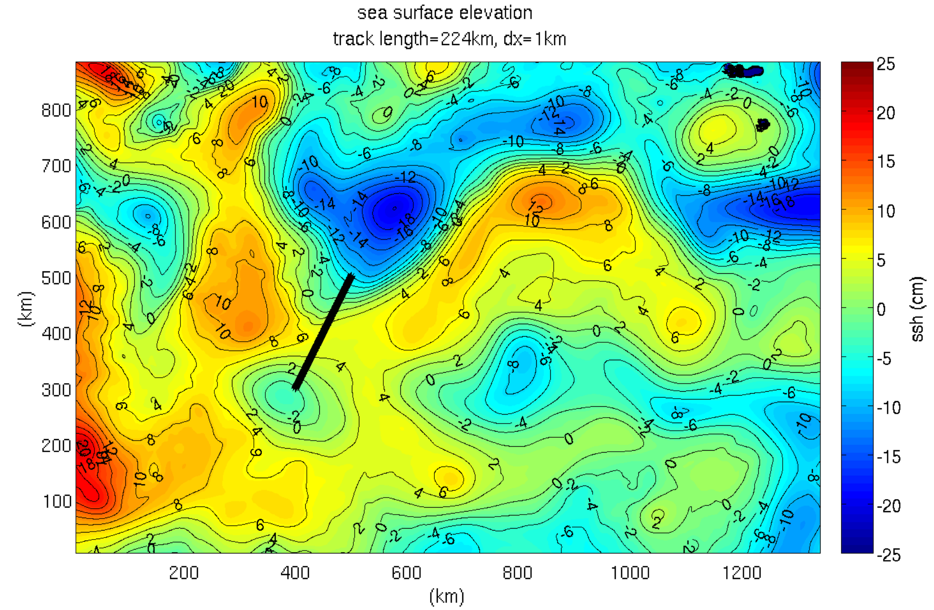
Open data dissemination to SWOT ST



For more information, see http://meom-group.github.io/swot-natl60/



sea surface elevation
track length=224km, dx=1km
(km)
800
700
600
500
400
300
200
100
200
400
600
800
1000
1200
(km)
ssh (cm)
25
20
15
10
5
0
-5
-10
-15
-20
-25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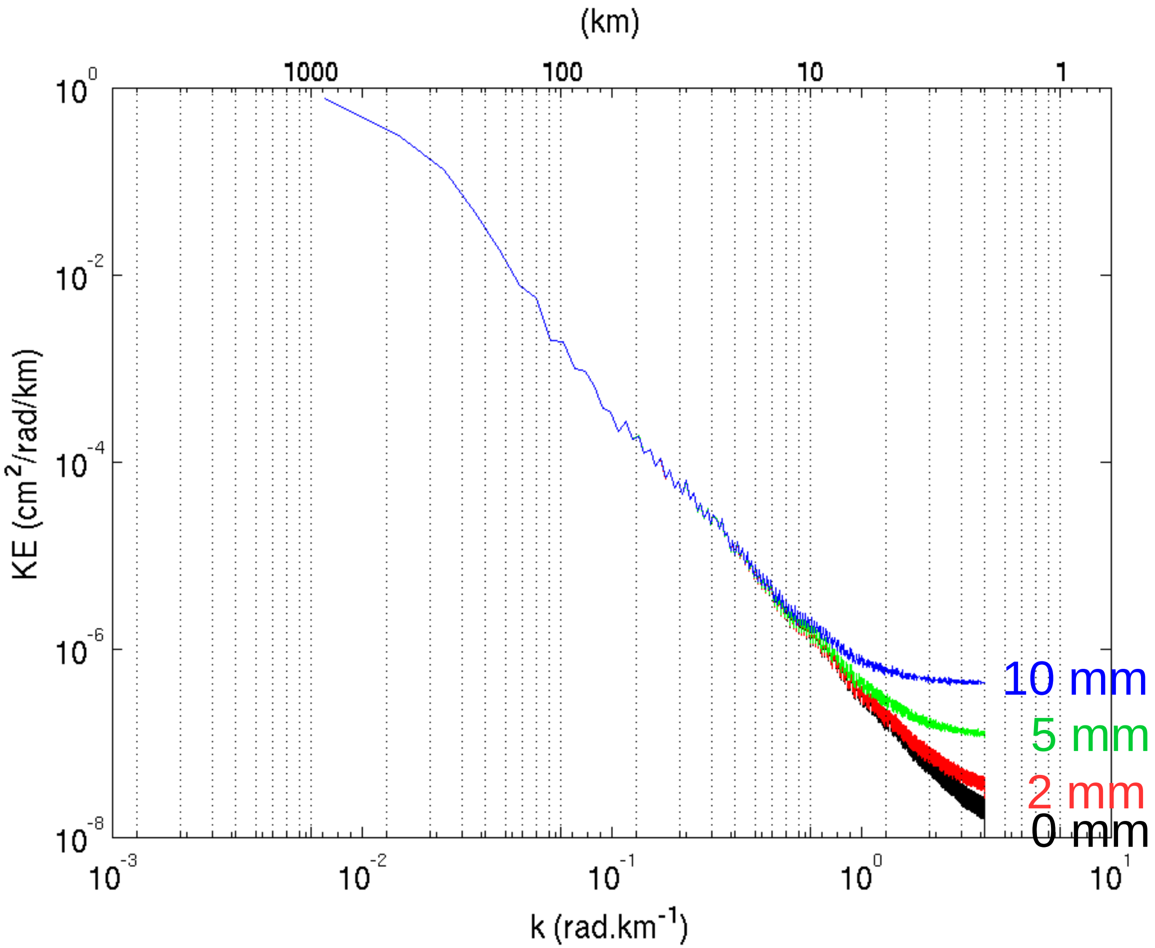
600
800
1000
1200
(km)
25
20
15
10
5
0
-5
-10
-15
-20
-25
ssh (cm)

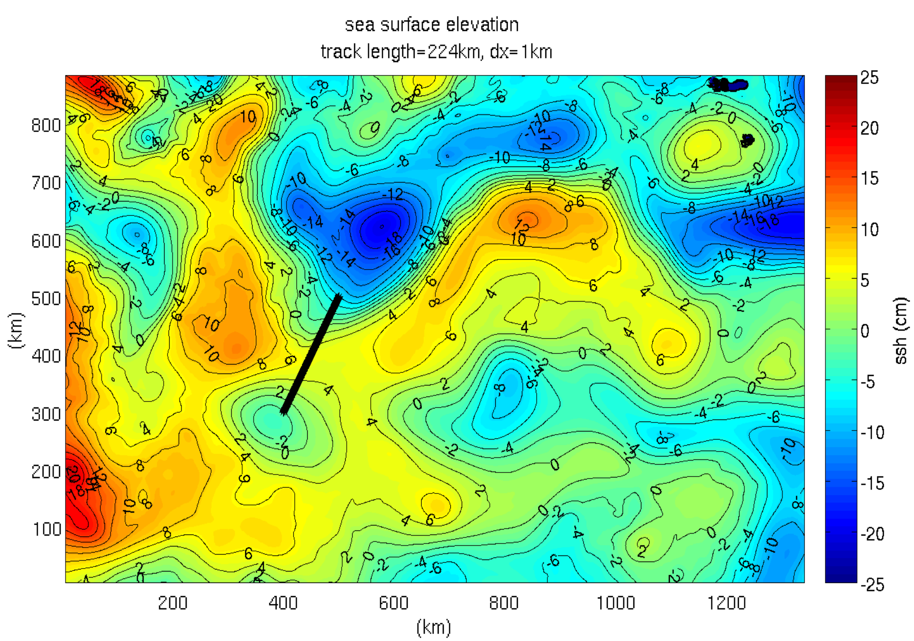
2D spectrum


(km)
1000
100
10
1
10^0
10^{-2}
10^{-4}
10^{-6}
10^{-8}
KE (cm^2/rad/km)
10^{-3}
10^{-2}
10^{-1}
10^0
10^1
k (rad.km^{-1})
10 mm
5 mm
2 mm
0 mm

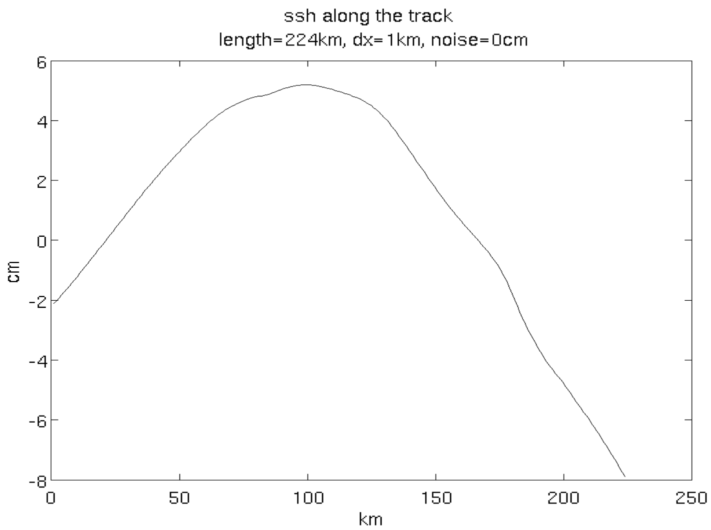
Example 1: “carpet” like

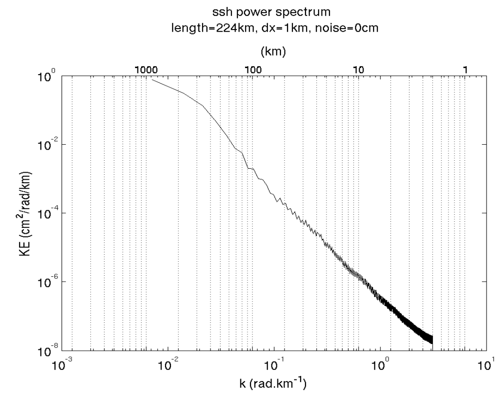
- advantage: high resolution SSH
- caveat: small-scale spatial variability has short life times: O(hour)
- idealized version of any combination of:
    - one ship towing one carpet: asynoptic, hence good for scales O(10-30 km) only
    - multiple ships (ideally, 5-10 carpets): synoptic, good for scales O(10-200 km)
- For scales larger than 20-30 km, requirement of ~10 fixed stations (land, offshore platforms, or sea bottom sensors + CTD)

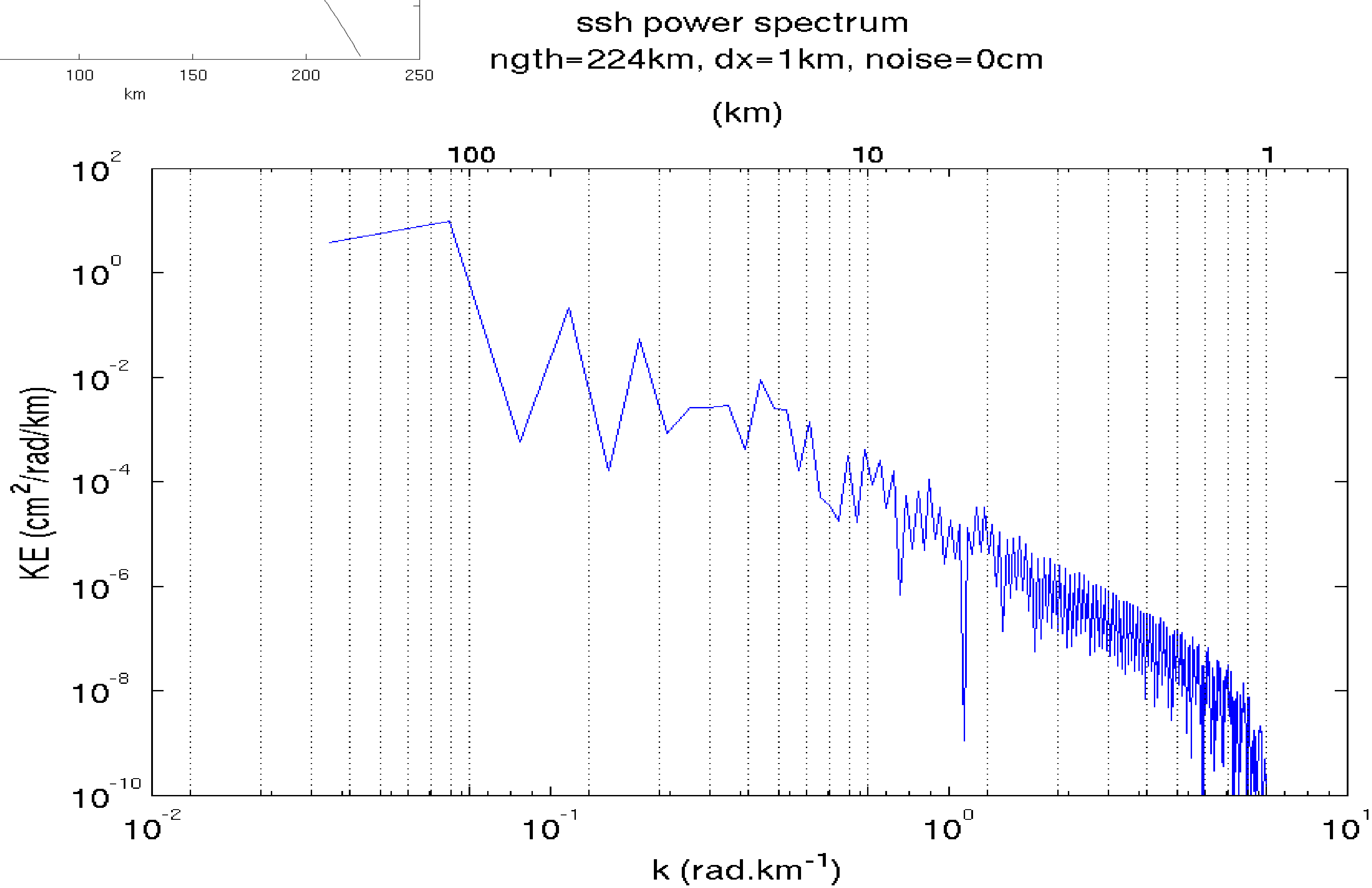
In 1-2 hours, a towing ship can make 15-30 km:
The largest scale resolved is 30*N km, with N number of towing ships (but we may exploit nadir missions)



Track: L~200 km dx=1km







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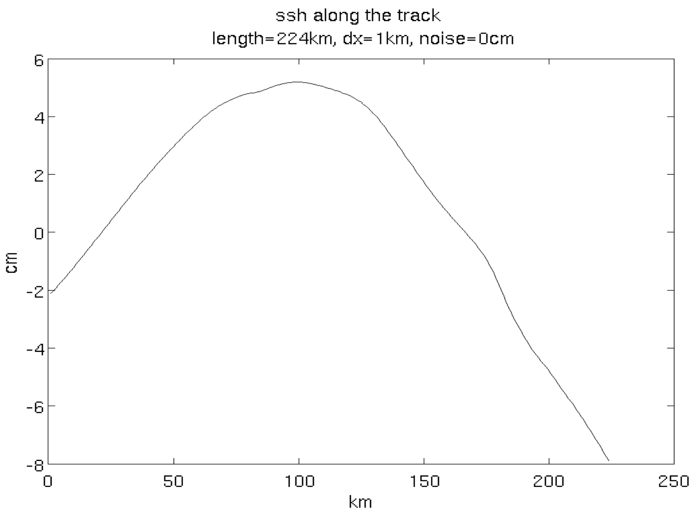
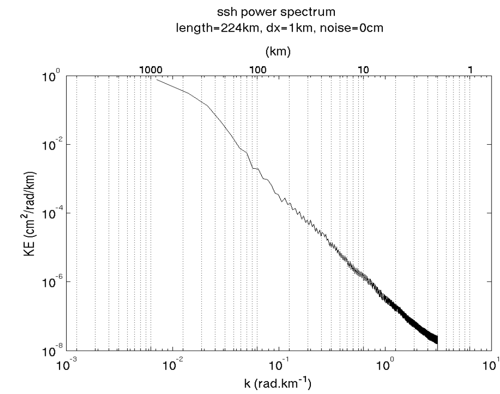
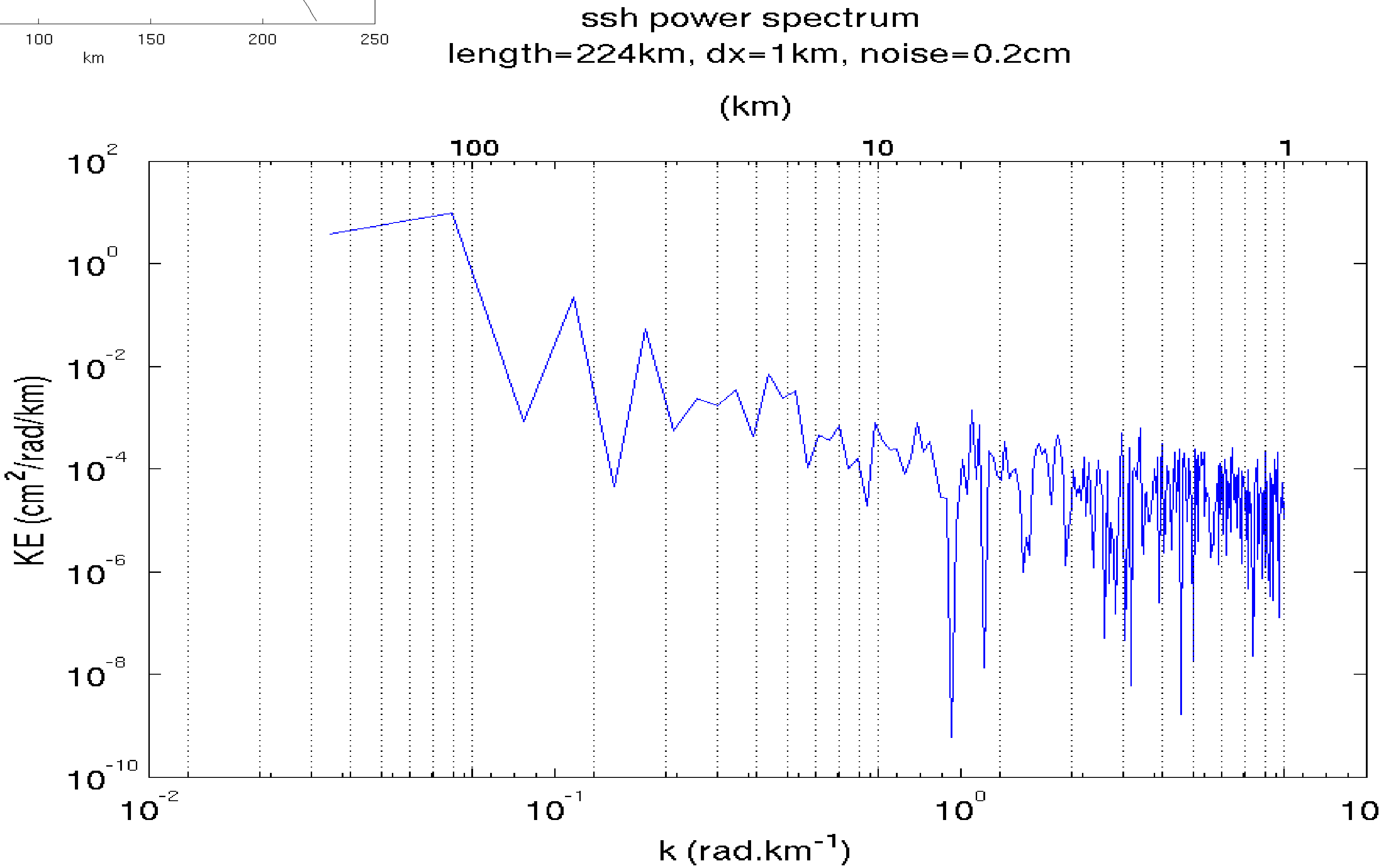
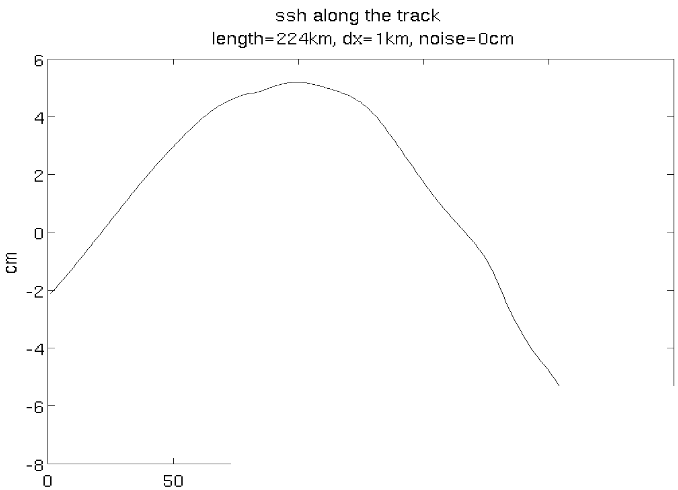
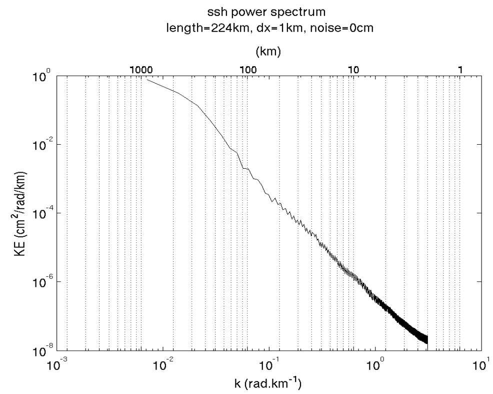


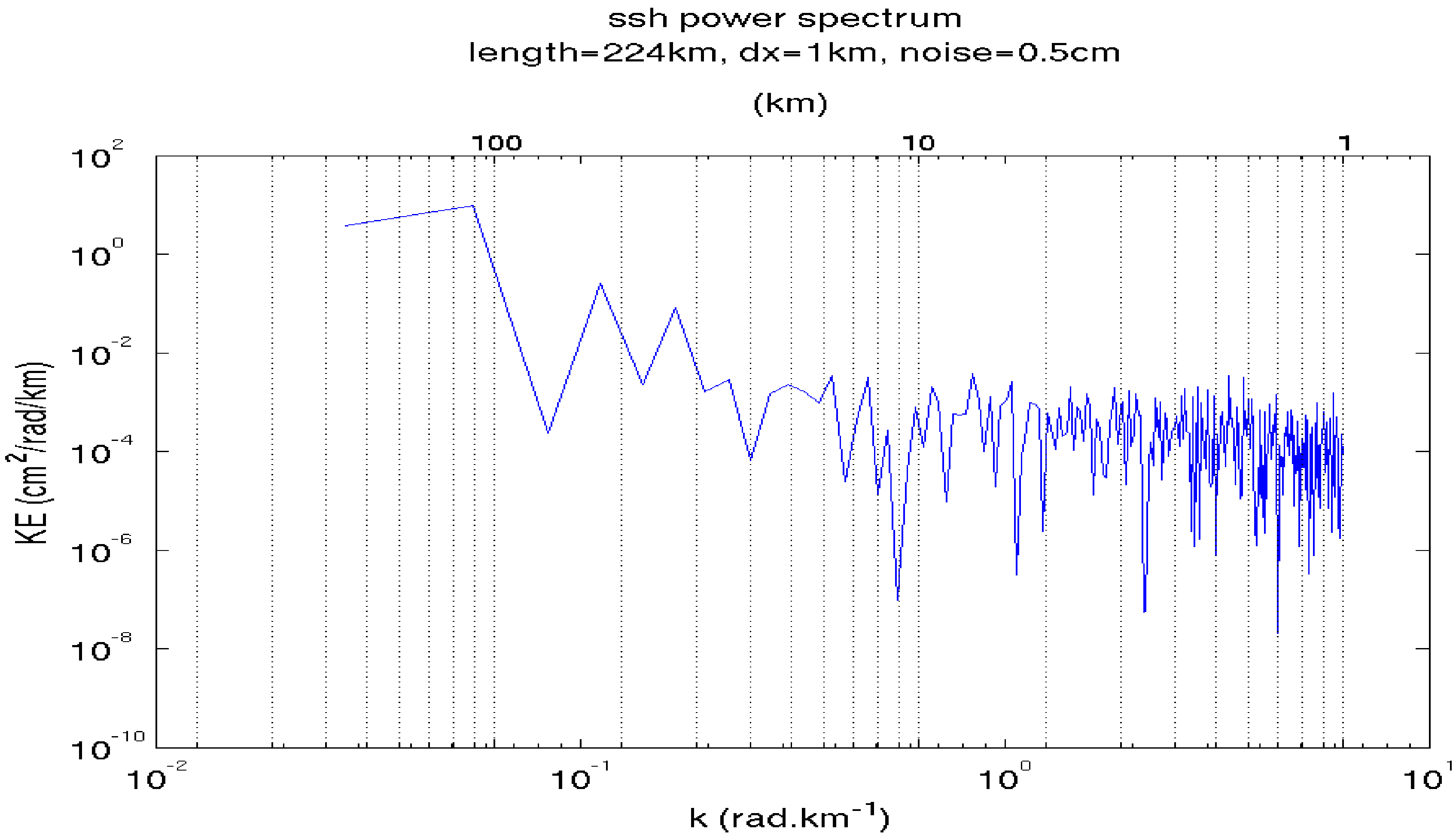




Track: L~200 km dx=1km







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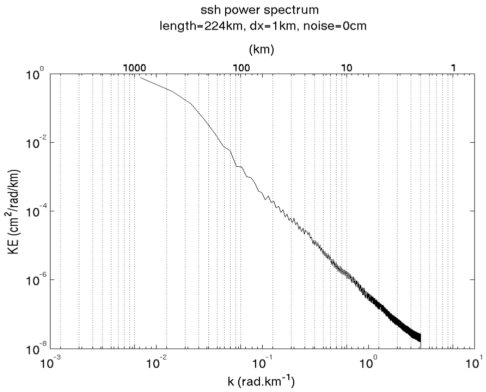
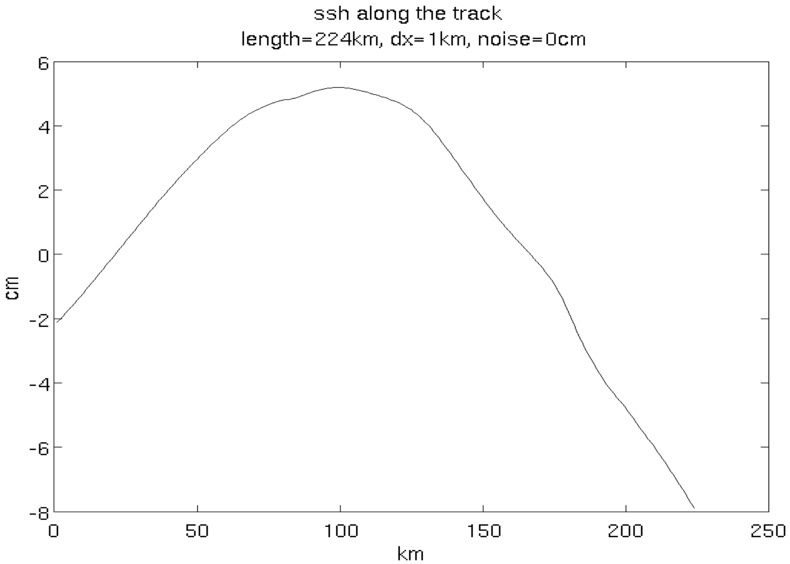
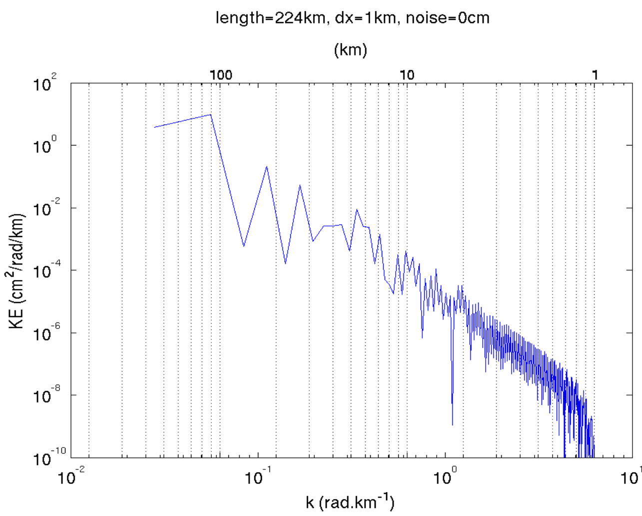
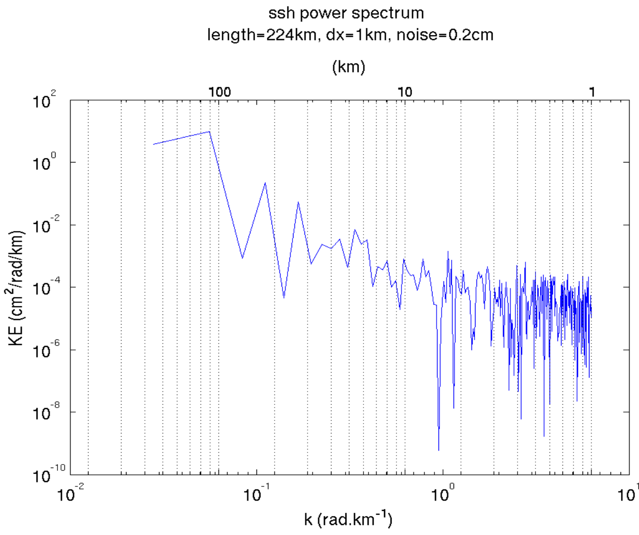
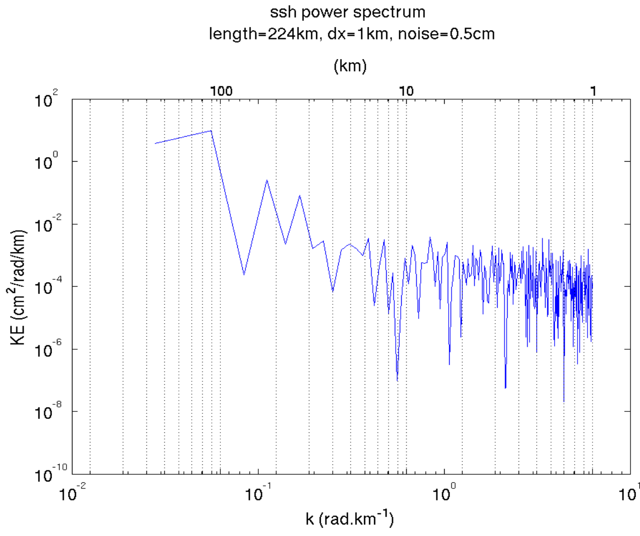


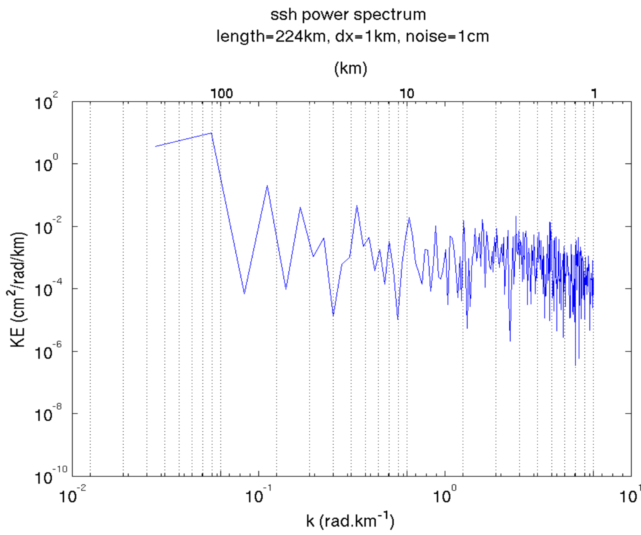




1D spectra with random noise



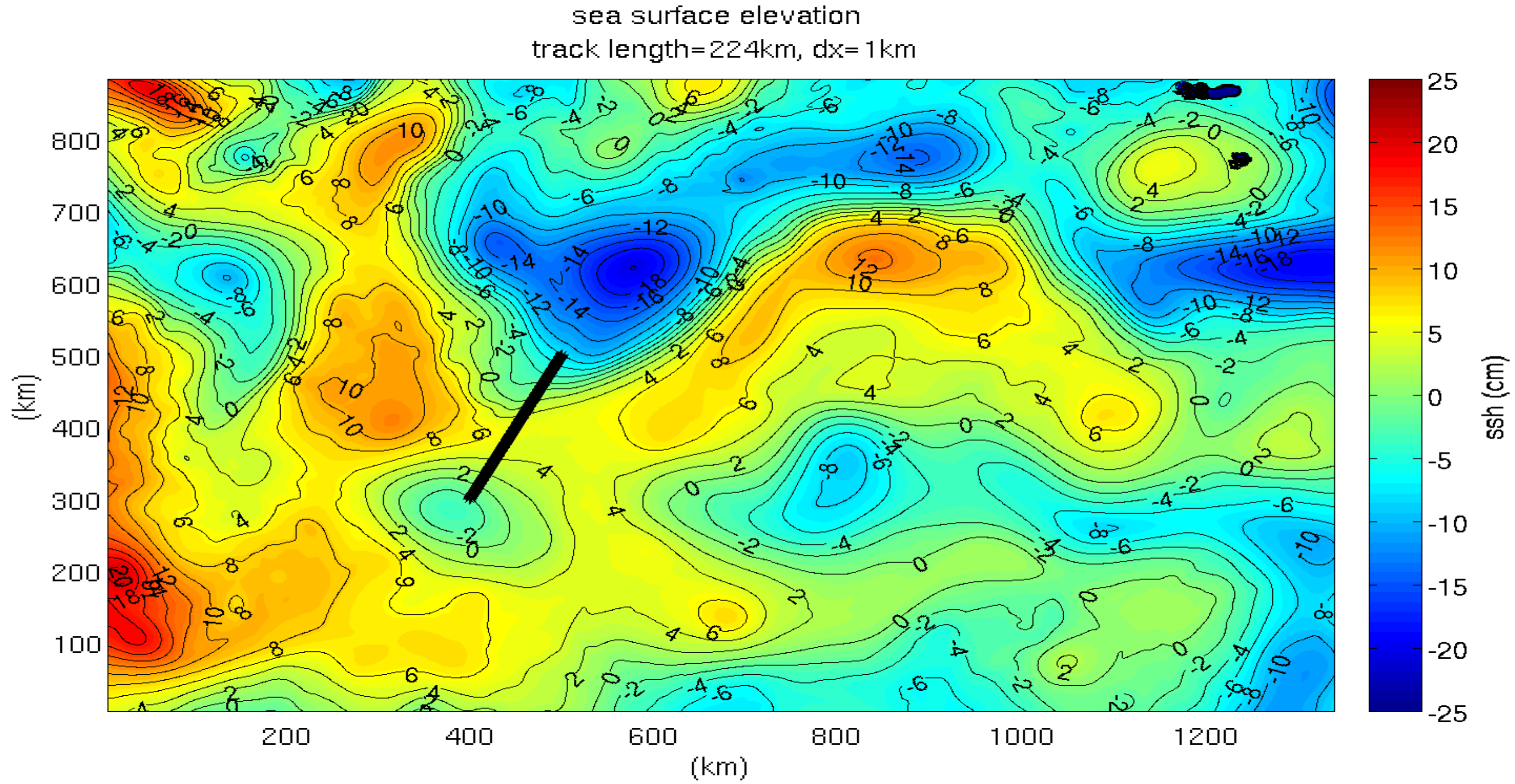




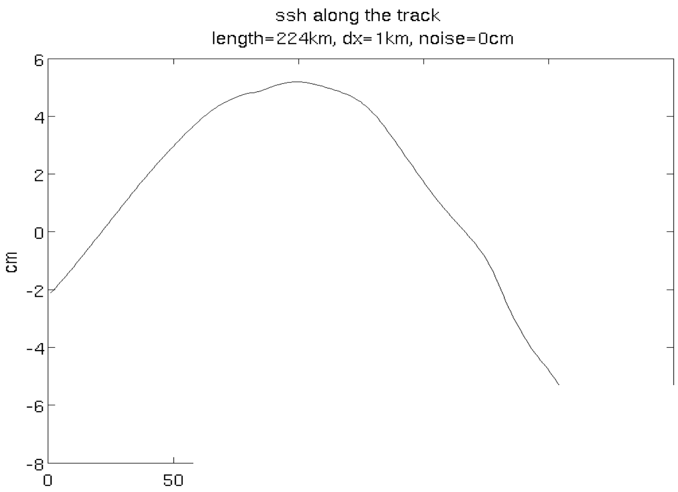
Example 2: 40 GPS buoys

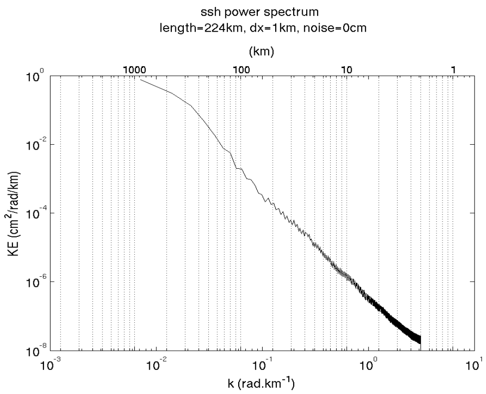
- advantage: synoptic array
- caveat: drifting, not completely recoverable, complex deployment logistic
- For scales larger than 20-30 km, requirement of **~10 fixed stations** (land, offshore platforms, or sea bottom sensors + CTD), **or use along track nadir altimetry**

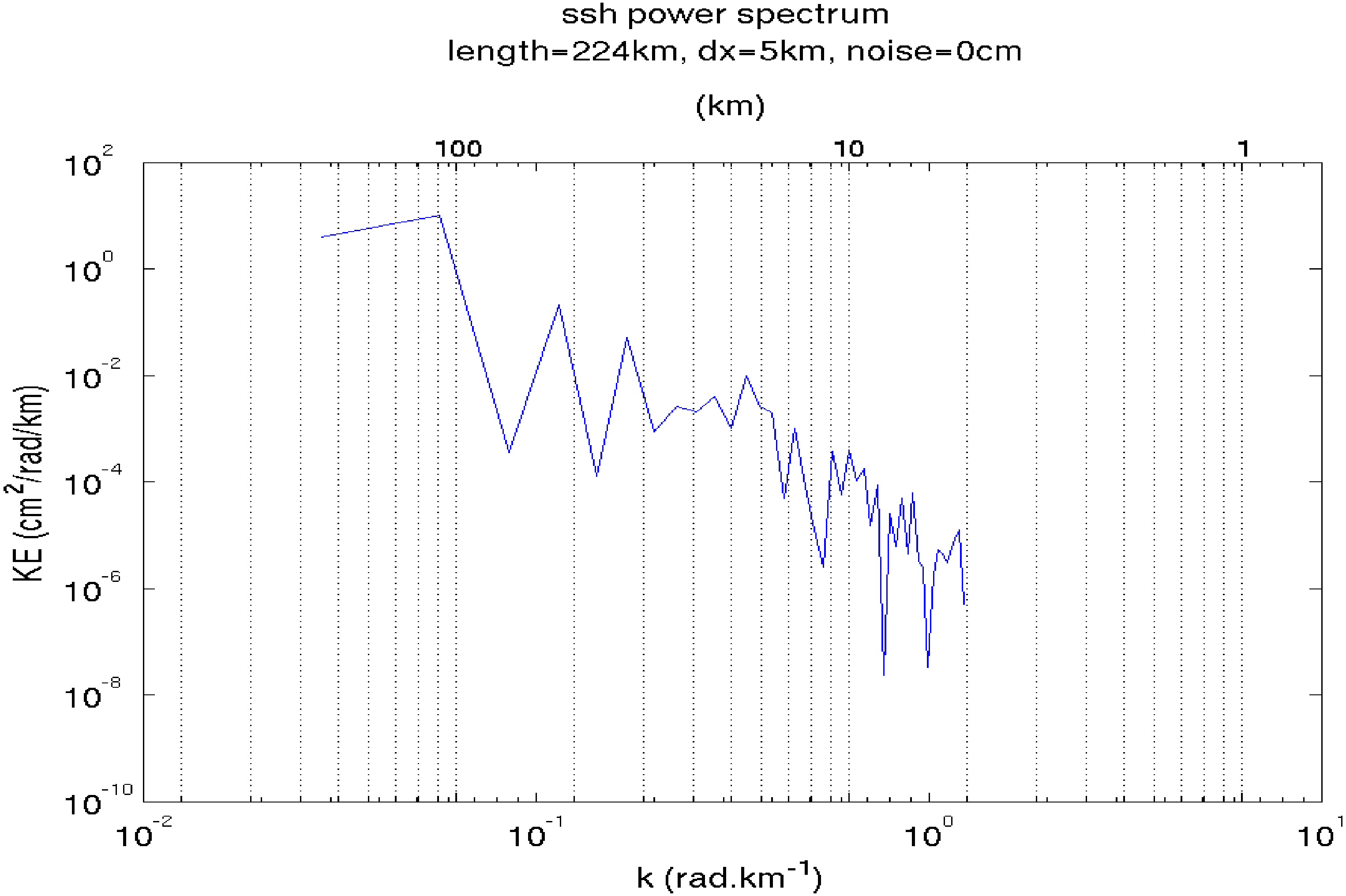
NB: cross-front configurations tend to drift and to align to the front on timescales of ~10 days.



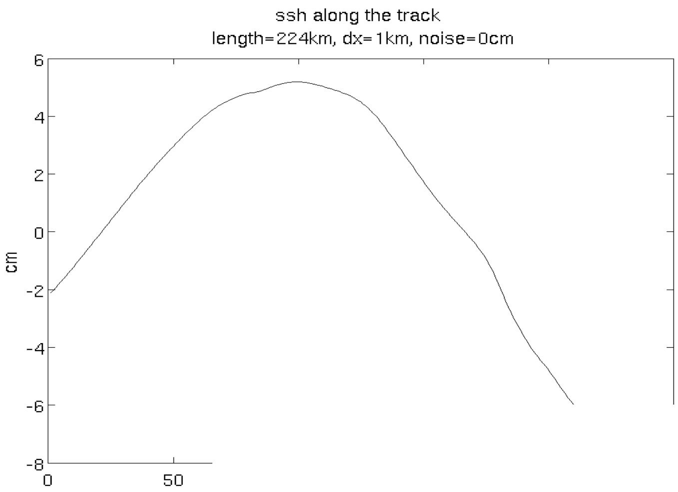
Track: L~200 km dx=5km

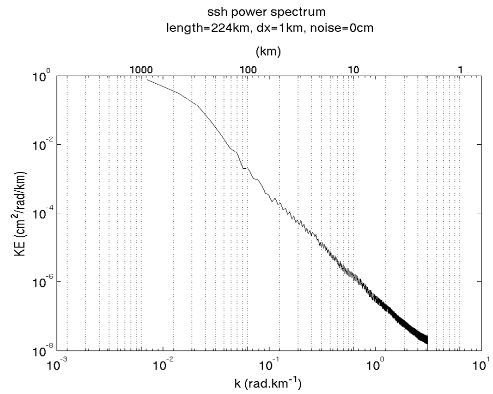


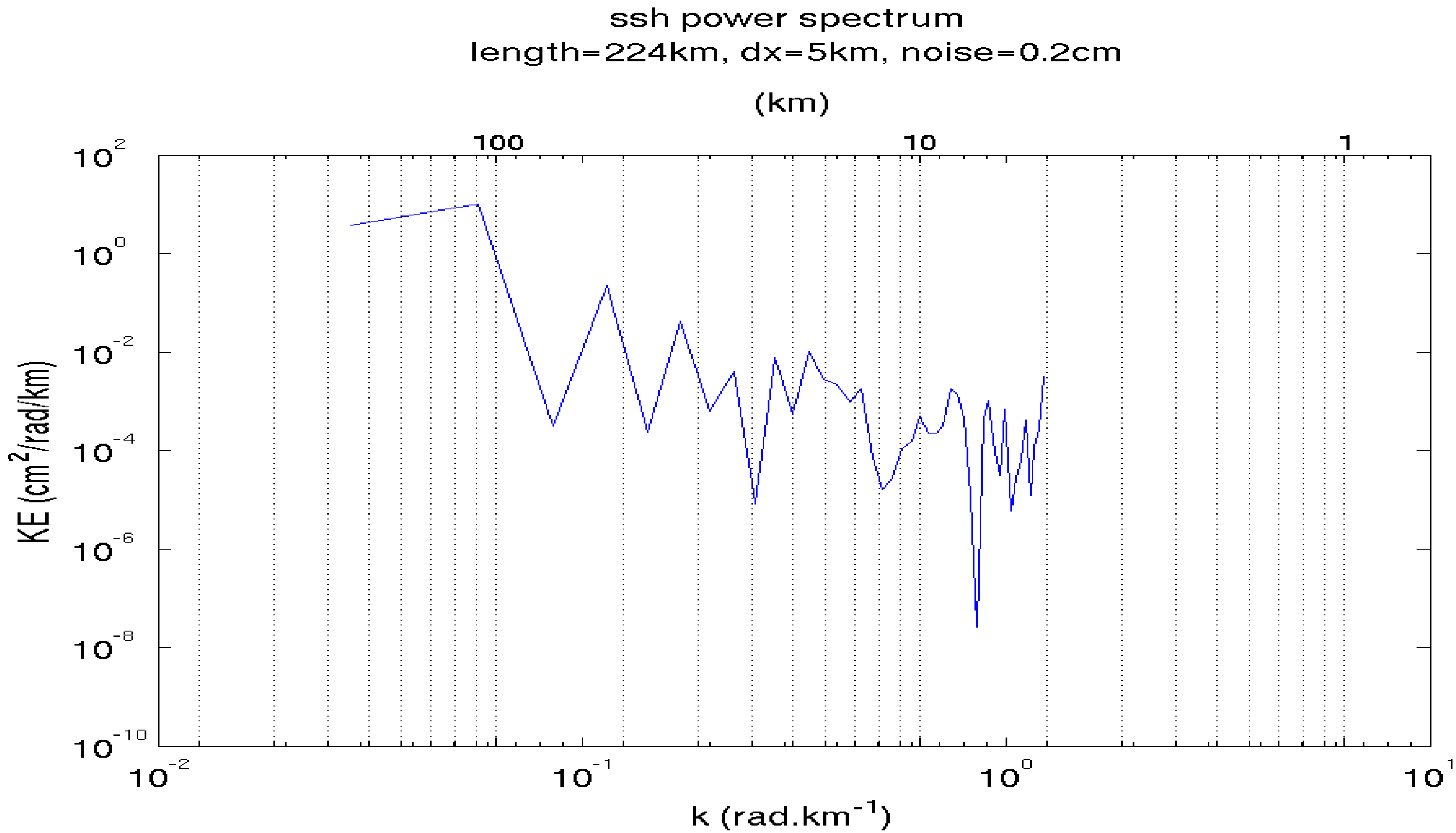




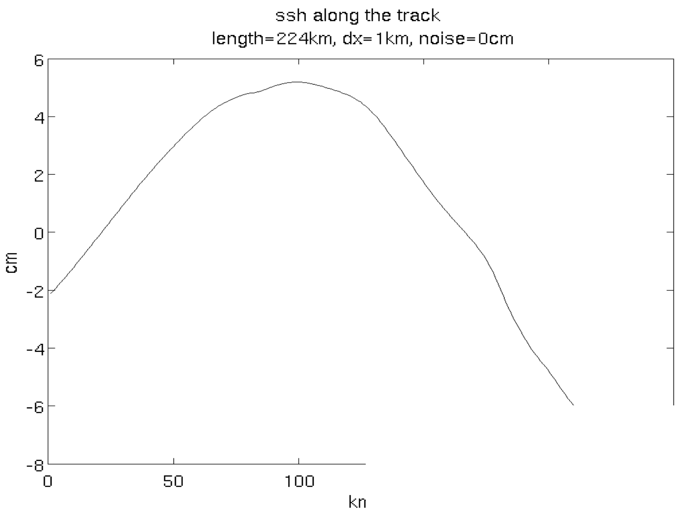
Track: L~200 km dx=5km

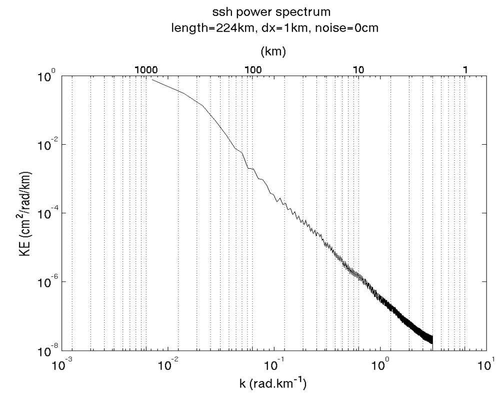


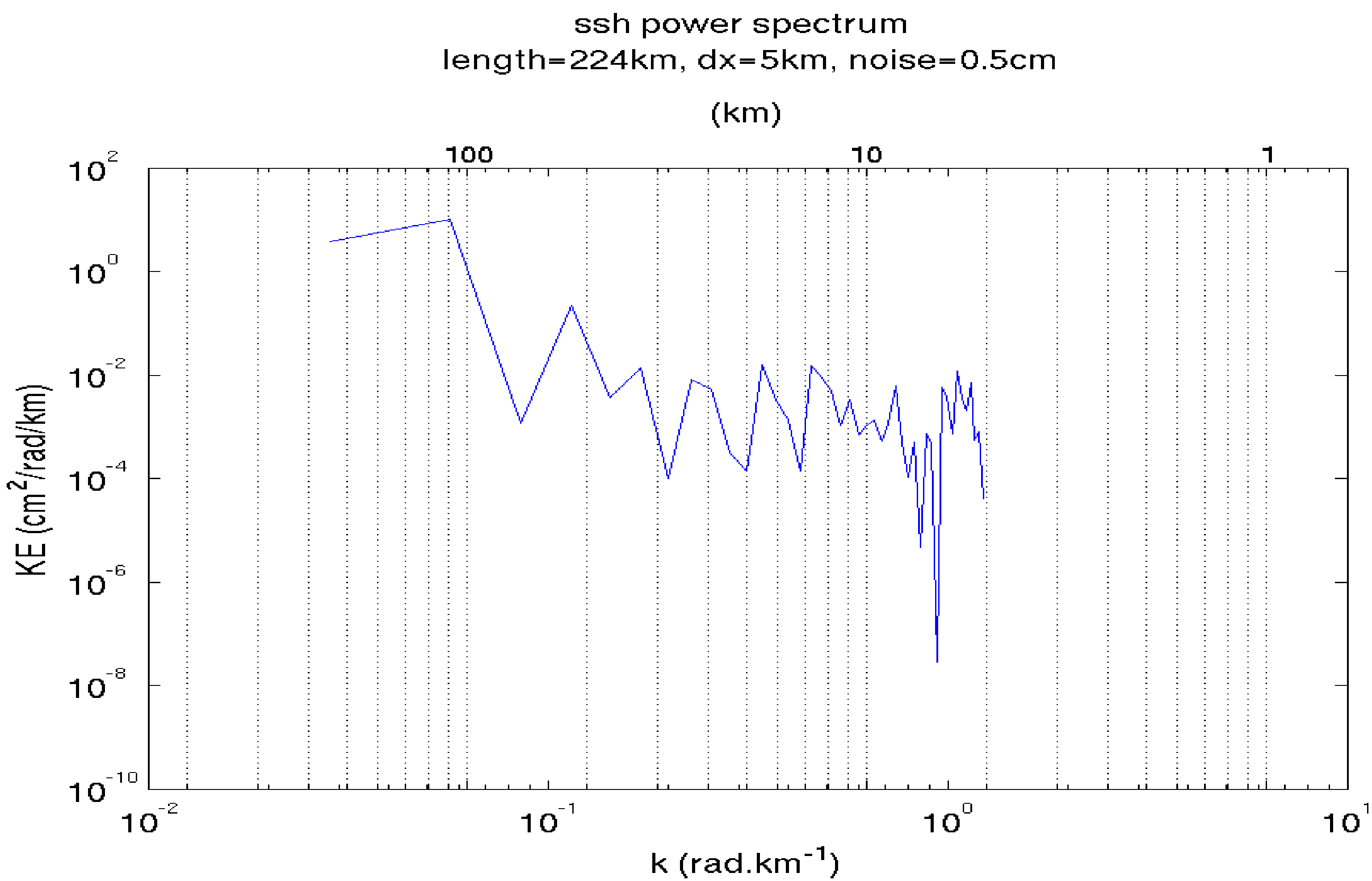




Track: L~200 km dx=5km







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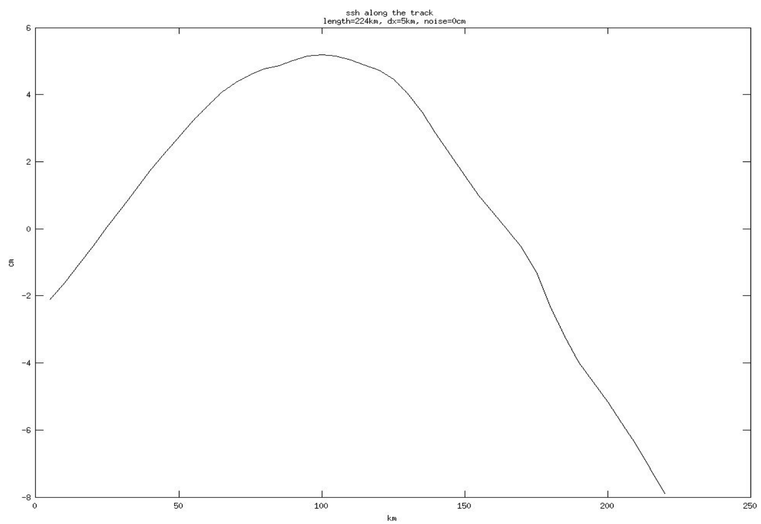

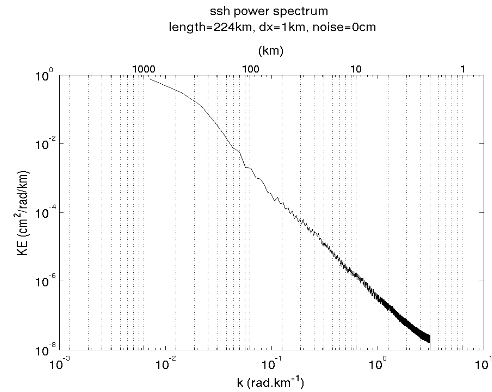

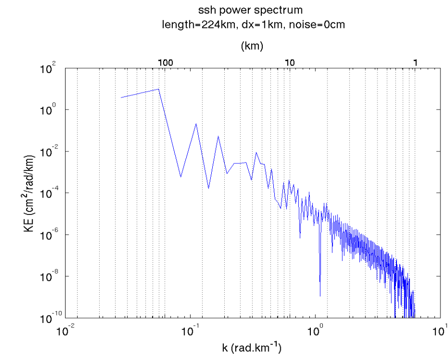

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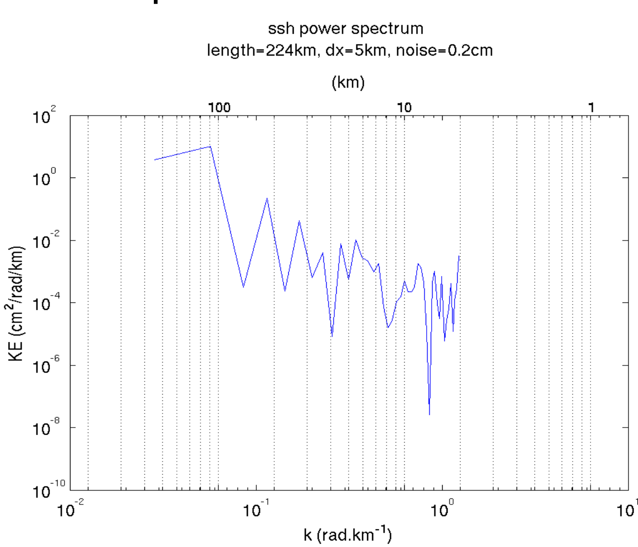
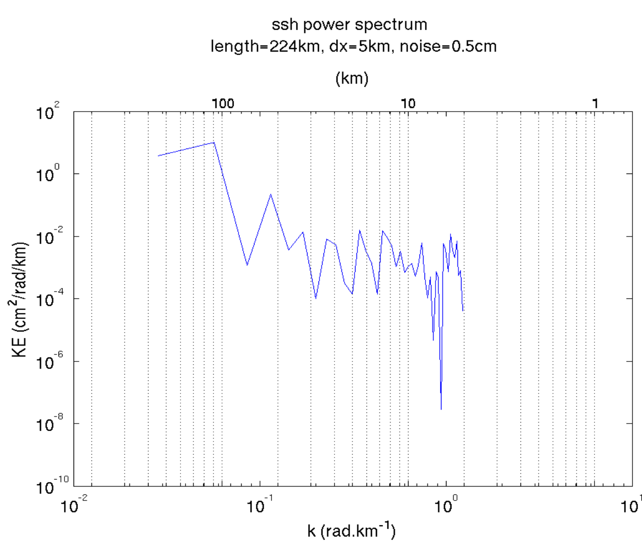
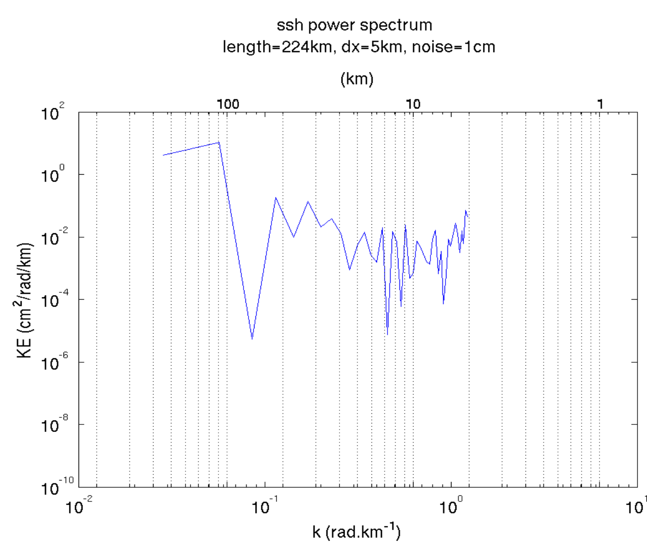






Preliminary conclusion

Network type: ~40 GPS buoys; either nadir or 5-10 “fixed points” (ground stations, offshore platforms, bottom pressure+CTD,..); one or more towed carpets or lidar

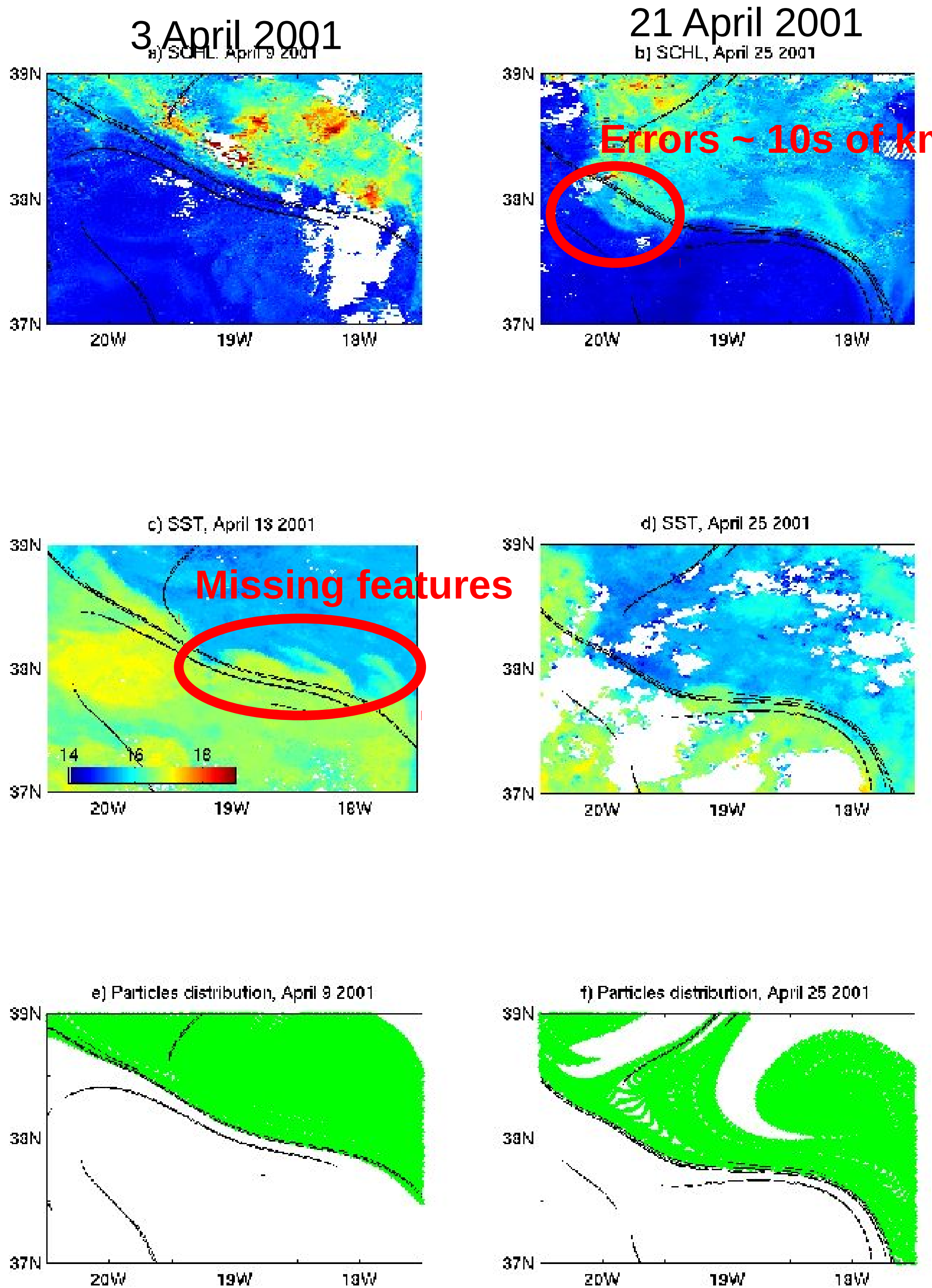
Synergy with other Nadir altimetry missions

- for constraining large-scale SSH of in situ network
- for spectral comparison with SWOT

Spectral requirement: possibly

Robustness: vulnerable to sea state, flexibility may depend on the site (e.g., Gulf of Lyon vs open ocean) and number of ships involved

Synergies with other sensors



Chl

SST

Numerical tracer

Limits and errors observed for nadir altimetry:

Missing “pure” submesoscale features (e.g. mixed layer instabilities)

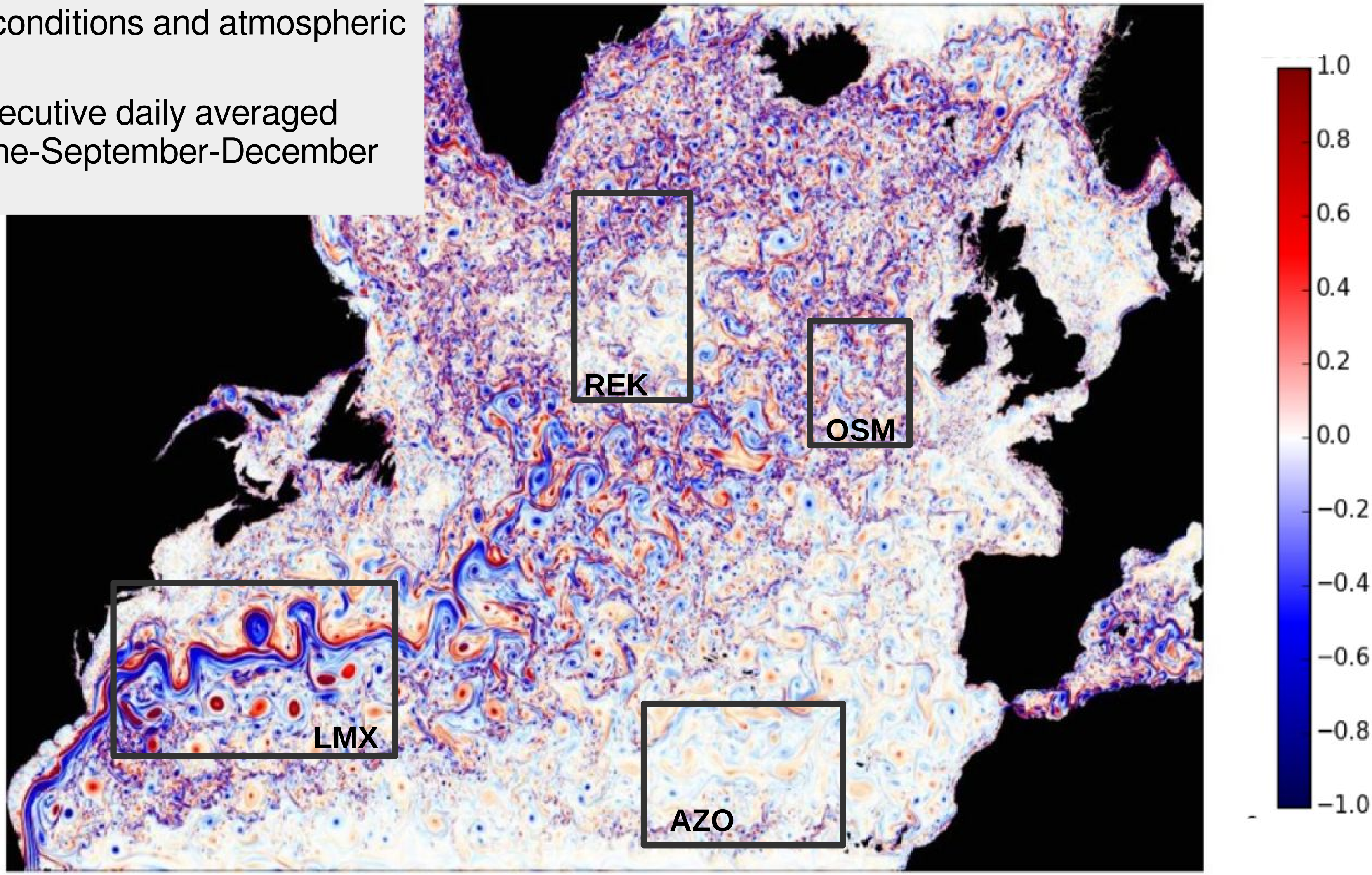
Typical mismatch of ~10s km at SST and Chl fronts

SWOT must perform better

Lehahn et al. 2007

NATL 60 Model configuration and numerical experiment

- numerical code : NEMO v3.5"
- horizontal grid : 1/60° (dx = 0.8-1.6 km)
- vertical grid : 300 levels (dz = 1m to 30 m)
- realistic boundary conditions and atmospheric forcing
- 4 series of 10 consecutive daily averaged outputs in March-June-September-December



Surface relative vorticity in winter Courtesy of J. LeSommer

Vertical velocity in the ocean

Vertical exchanges in the ocean

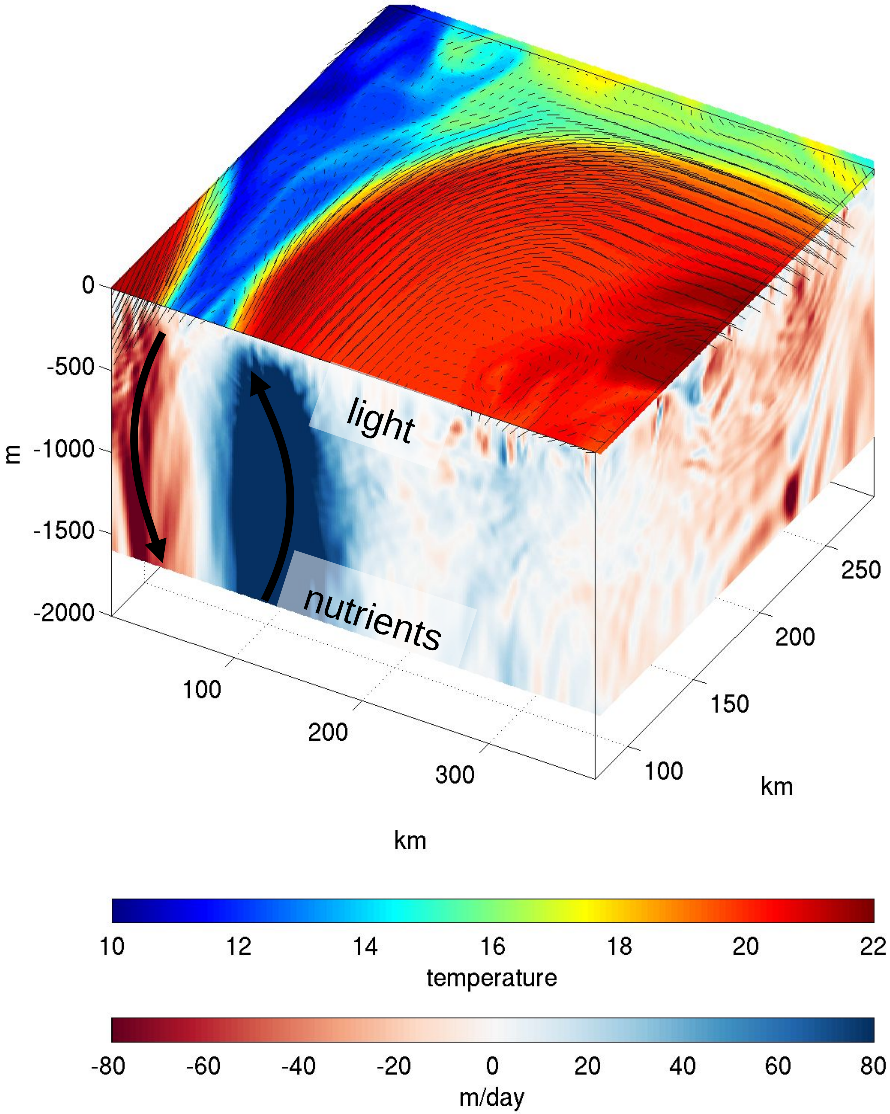
- supply nutrients to the euphotic zone
- subduct matter in the deep ocean
- can be strong when driven by meso and submesoscale dynamics

→ vertical velocity is driven by different sources:

- deformation of the main flow at different vertical and horizontal scales
- surface forcing
- Inertia-gravity waves
- …

→ it is difficult to observe

- localized, small spatial scale
- low intensity
- rapid variability



Vertical velocity in the ocean

w is usually inferred through calculation

- Surface Quasigeostrophy (Lapeyre and Klein 2006; Klein et al. 2009)
- Inverse method (Thomas et al. 2010)
- **the Omega equation** (the more widely used)

How well does the Omega equation represent the vertical circulation in terms of scale, intensity and pattern?

- how much depends on the dynamic of the flow ?
- how much depends on the method and the available data?

The omega Equation

$$f^2 \frac{\partial^2 w}{\partial z^2} + \nabla_h (N^2 . \nabla_h w) = \nabla . \boldsymbol{Q}$$

Different forcing can drive vertical velocity: $\boldsymbol{Q} = \boldsymbol{Q}_{TW} + \boldsymbol{Q}_{AG} + \boldsymbol{Q}_{FL} + \boldsymbol{Q}_{TD}$

TW : « frontogenesis»

Deformation of the flow

- geostrophic velocity : $\boldsymbol{Q}_{TWg}(\rho, \frac{\partial \rho}{\partial (x,y)})$
- total velocity : $\boldsymbol{Q}_{TW}(\rho, \vec{v}_h, \frac{\partial \rho}{\partial (x,y)}, \frac{\partial \vec{v}_h}{\partial (x,y)})$

AG : Deformation of the thermal wind imbalance

$\boldsymbol{Q}_{AG}(\frac{\partial \vec{v}_h}{\partial (x,y)}, \frac{\partial \vec{v}_{ag}}{\partial z})$

FL : Turbulent fluxes of momentum and buoyancy

Can be prescribed from atmospheric fluxes (wind, heat fluxes)

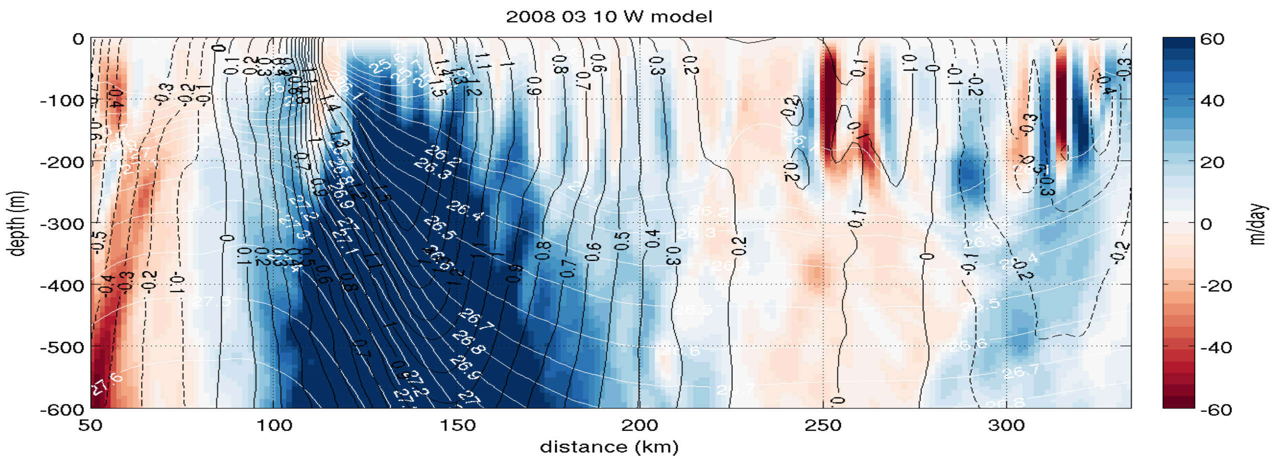
$\boldsymbol{Q}_{FL}(\frac{\partial \boldsymbol{F}}{\partial (x,y)}, \frac{\partial \boldsymbol{X}}{\partial z})$

TD : Trend of the thermal wind imbalance

- Symmetric instability, inertial and sub inertial dynamics, …
- Can't be inferred from observations

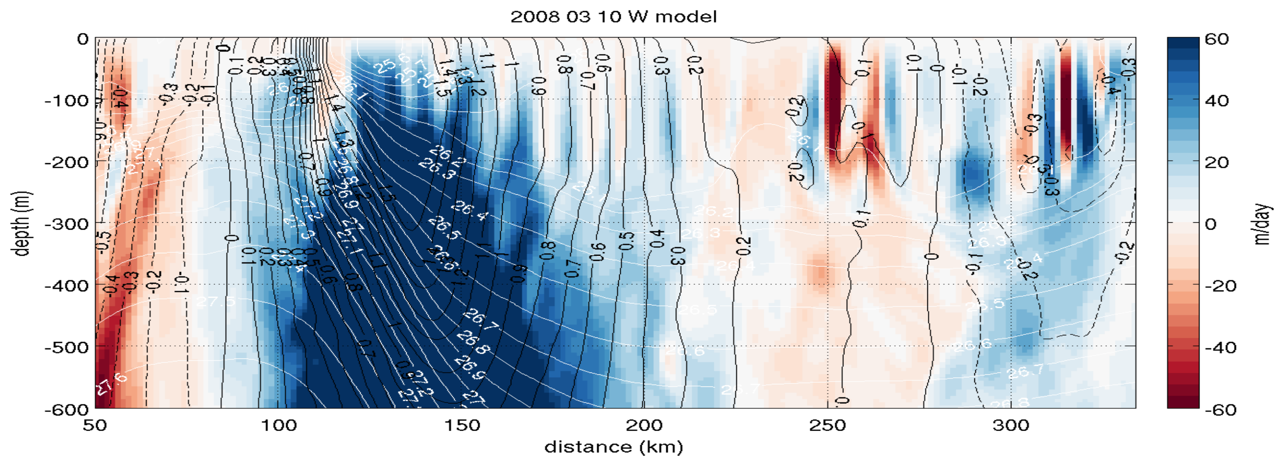
$\boldsymbol{Q}_{TD}(\frac{d}{dt}(\frac{\partial \vec{v}_{ag}}{\partial z}))$

Gulf Stream : 10 March 2008

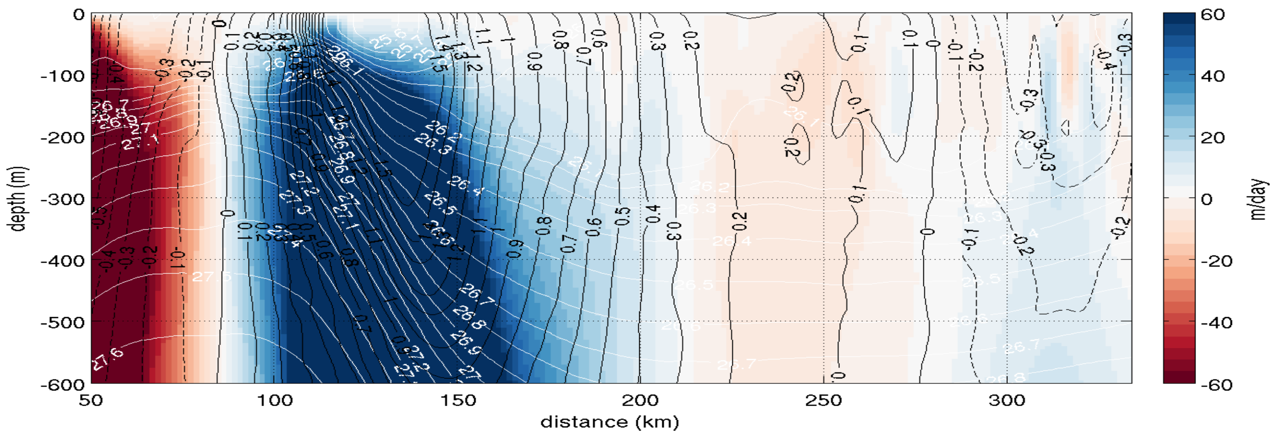


Vertical velocity in the model
Gulf stream region
10 March 2008

Gulf Stream : 10 March 2008



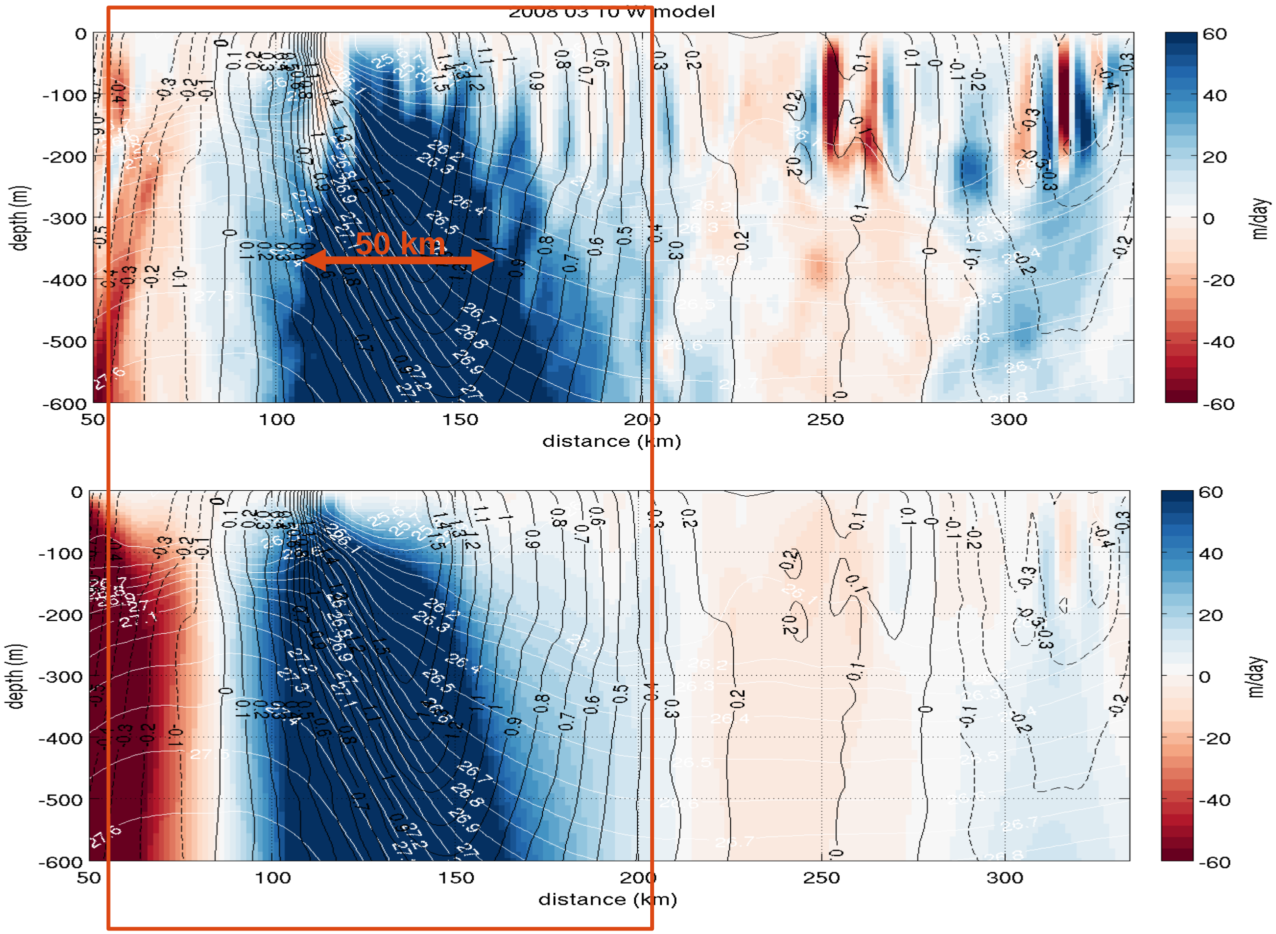
Vertical velocity in the model
Gulf stream region
10 March 2008



Twg

Vertical velocity from the quasi geostrophic omega equation

Gulf Stream : 10 March 2008



Vertical velocity in the model
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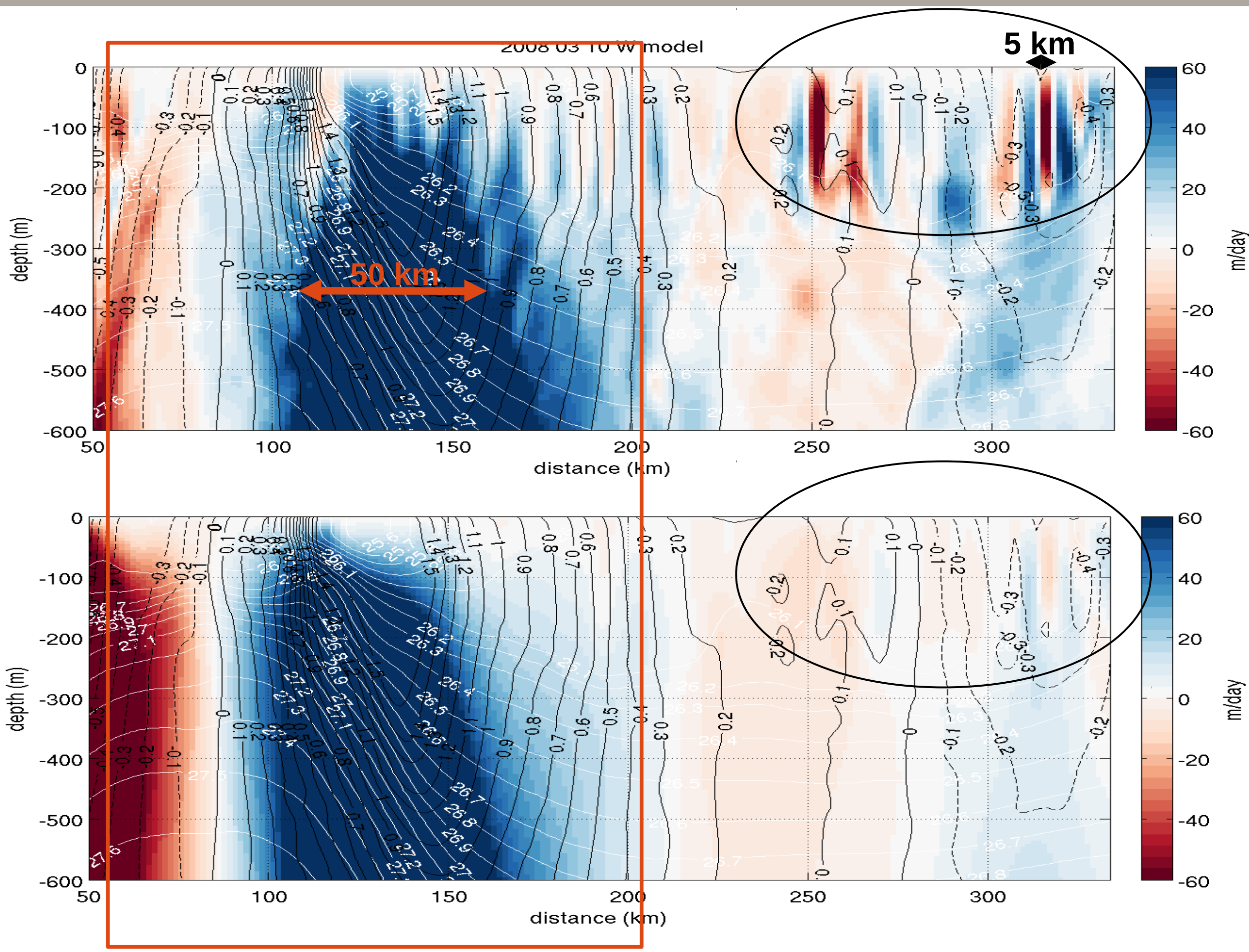
Vertical velocity from the quasi geostrophic omega equation

Gulf Stream : 10 March 2008



Vertical velocity in the model
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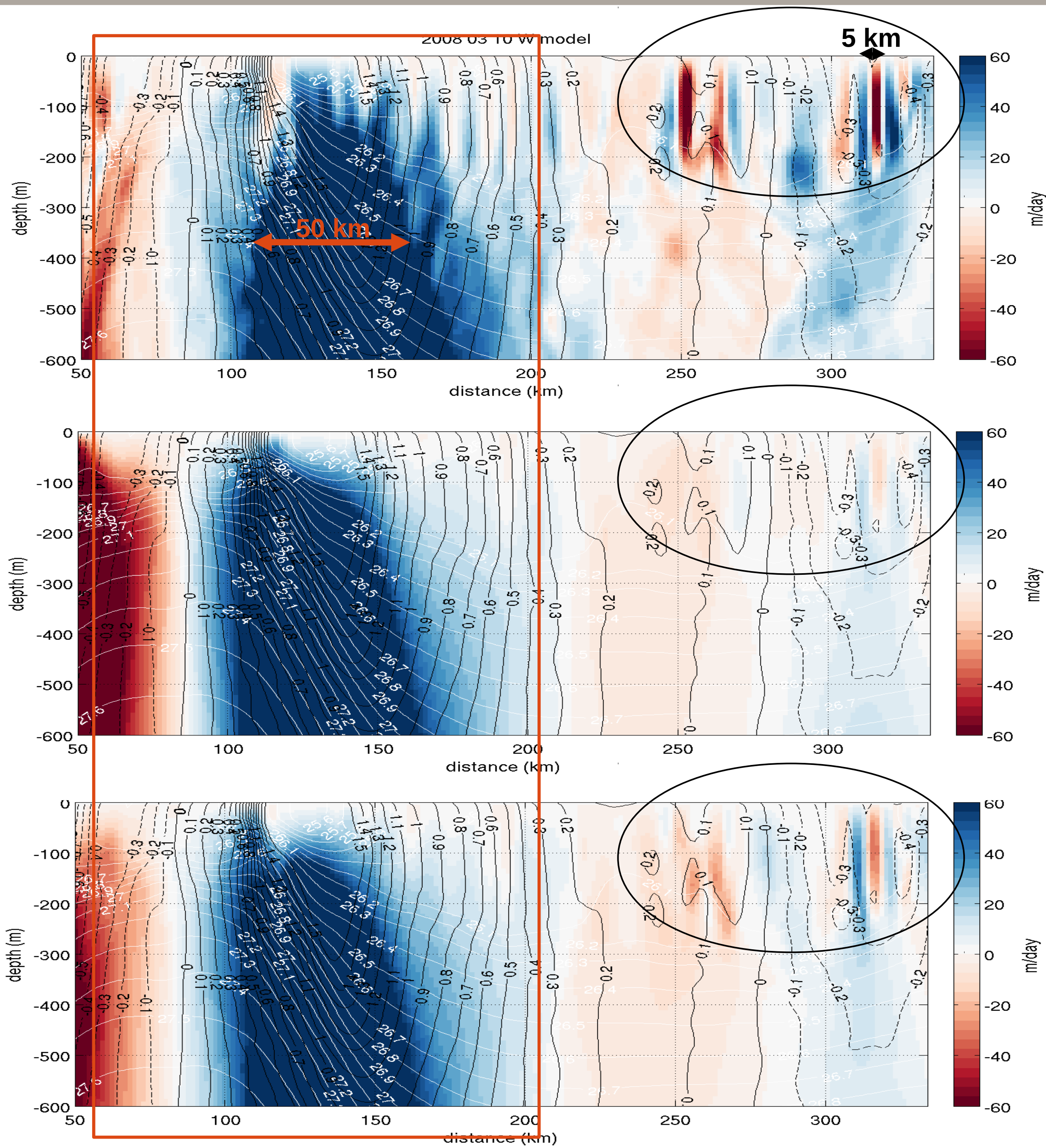


Vertical velocity in the model
Gulf stream region
10 March 2008

Twg

Vertical velocity from the quasi geostrophic omega equation

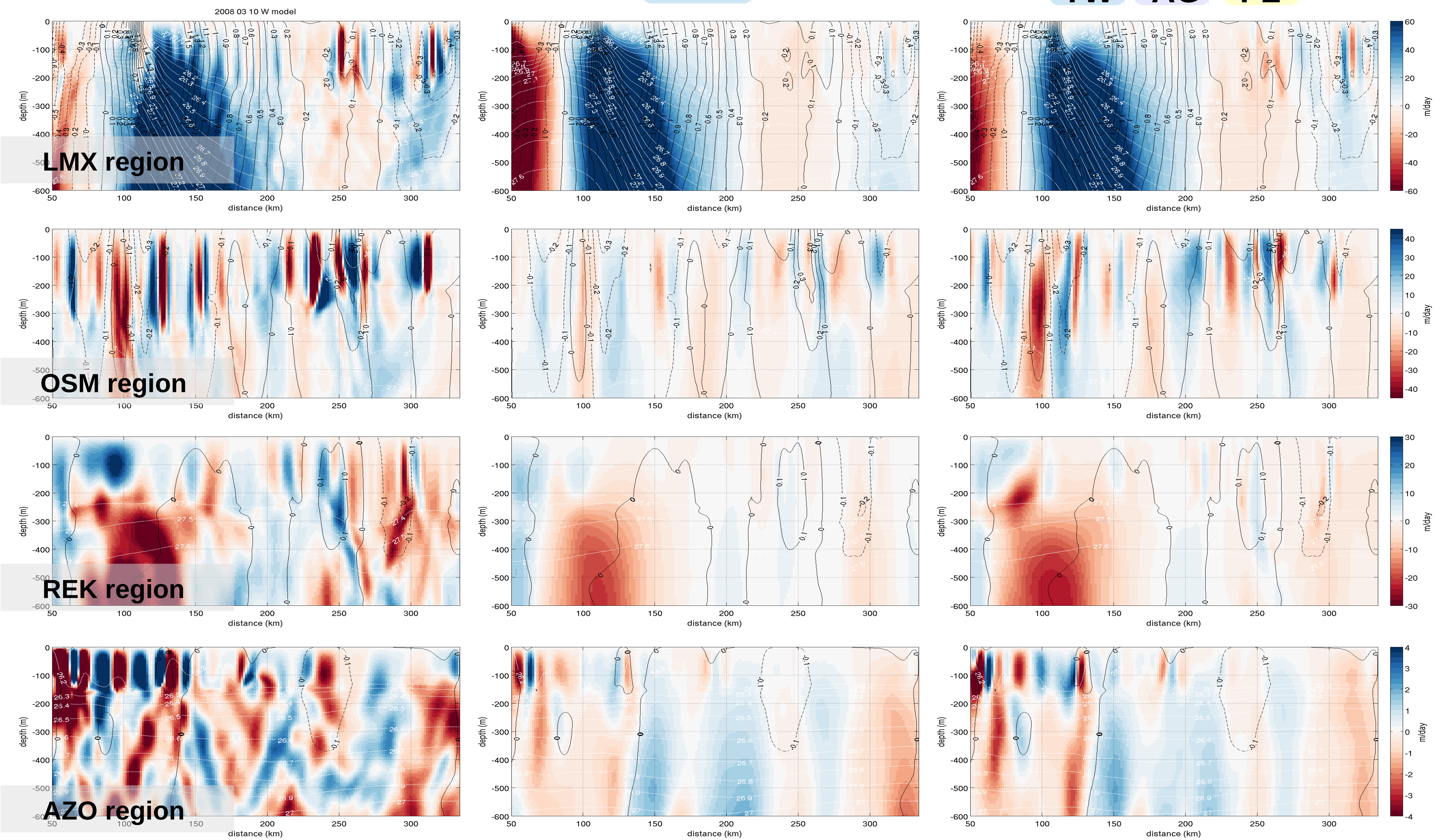
TW + AG + FL

Vertial velocity from the omega equation including the ageostrophic field and the windstress

Four regions: 10 March 2008

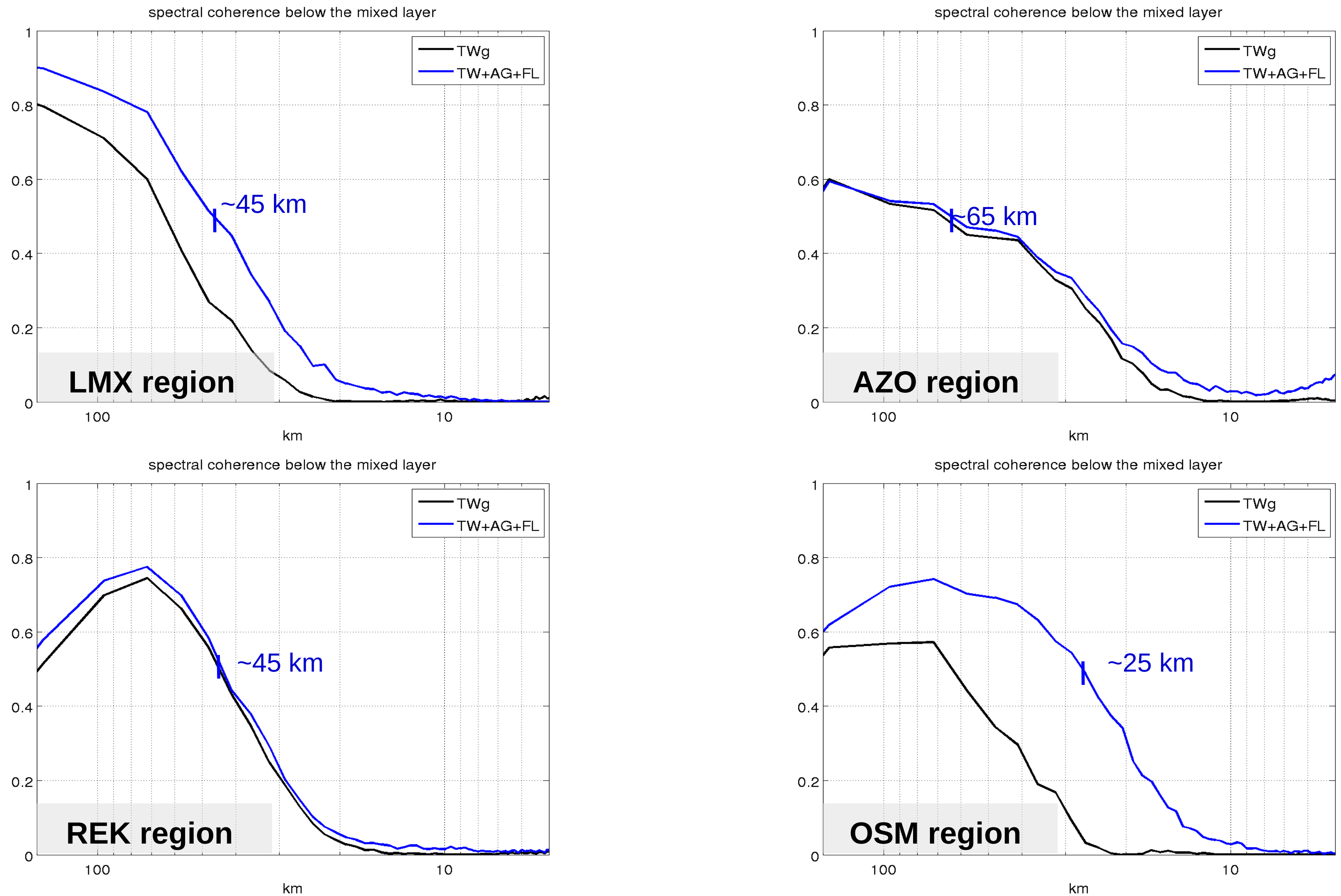
w model | **w omega equation**

TWg | TW + AG + FL



Four regions

Spectral coherence between w model and w from the omega equation below the mixed layer in the four regions :

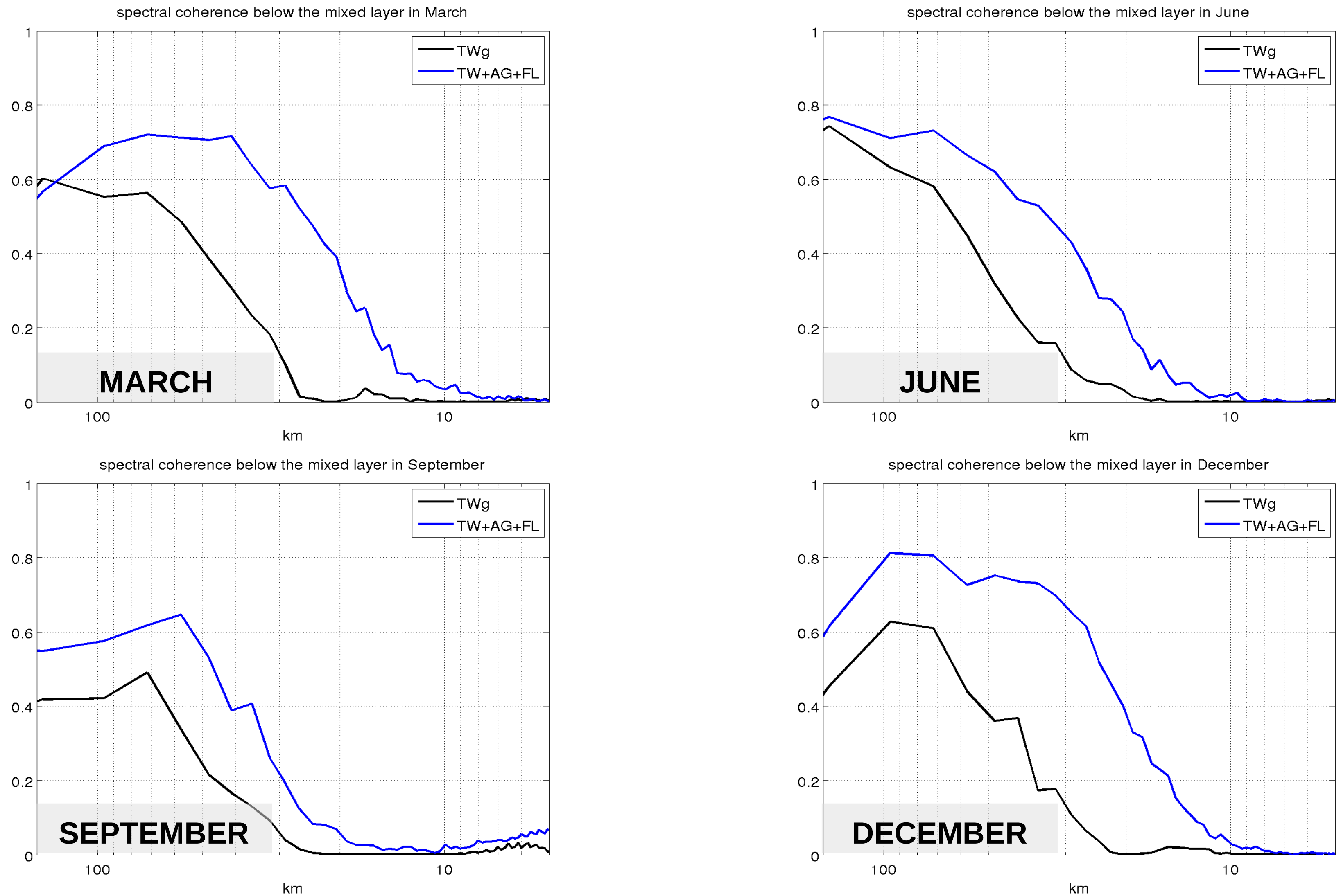


→ the reconstruction from deformation has different skills depending on the region

→ improvement due to the inclusion of the others terms is also region dependant

OSM – 4 seasons

Spectral coherence between w model and w from the omega equation below the mixed layer :



→ the reconstruction from deformation has different skills depending on the season

→ improvement due to the inclusion of the others terms is also season dependant

Conclusions

- ***How well does the Omega equation represent the vertical circulation ?***

→ The vertical velocity inferred from the omega equation represent well the mesoscale energetic patterns.

→ It doesn't give good results at submesoscale (below few tens of kilometers) in any dynamical regime.

- ***How much depends on the dynamic of the flow, how much is inherent to the method ?***

→ The regime of the flow is crucial to assess the scale of the circulation that can be retrieved and whether or not the higher order dynamics is important to reconstruct the *w* signal.

How useful will SWOT information be to reconstruct w ? What additional subsurface information will be needed to complement the SSH data ?

Ongoing work

- *Investigate the **trend term** of the generalized omega equation*

$$Q_{TD}\left(\frac{d}{dt}\left(\frac{\partial \vec{v}_{ag}}{\partial z}\right)\right)$$

SWOT

- ***Lower the resolution of the subsurface data***

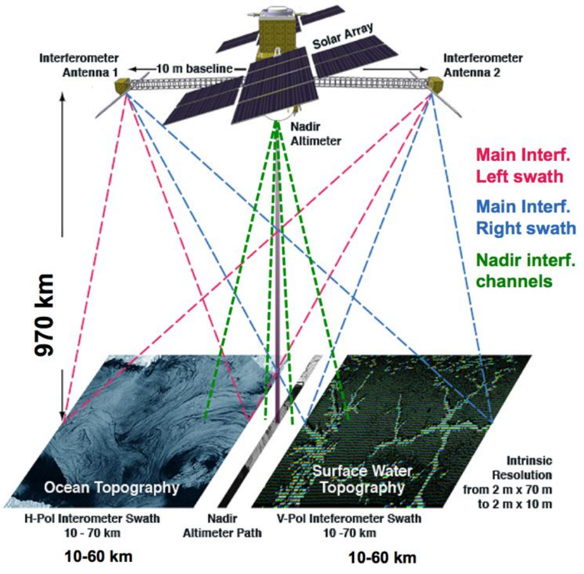
→ how is the solution impacted by a reduced resolution in subsurface while the surface information stays high resolution.

→ what kind of *in situ* information would be needed to resolve *w* depending on the regime.

- ***Q vertical variability***

→ how to propagate the inforation on the subsurface ?

→ can vertical modes of variability be identified ?

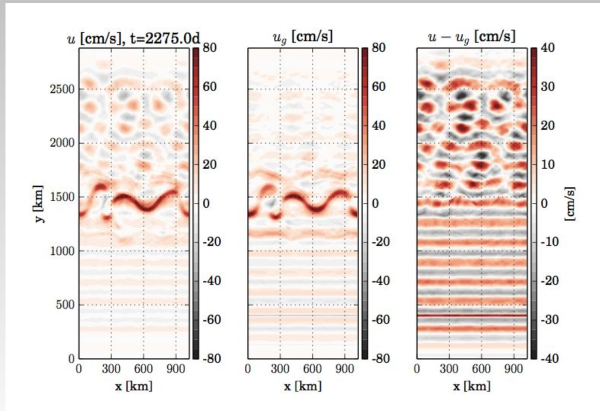


Accounting for internal waves and tides in SWOT data

Aurélien PONTE, Michael Dunphy, Patrice Klein (LPO, Ifremer)

MOTIVATION

- Internal waves and tides appear to have significant signatures on sea level at the length scales newly resolved by SWOT (15-100 km) (see white papers)
- These contributions will affect estimates of the ocean circulation from the data
- We need to develop methods to mitigate these issues



Scientific objectives

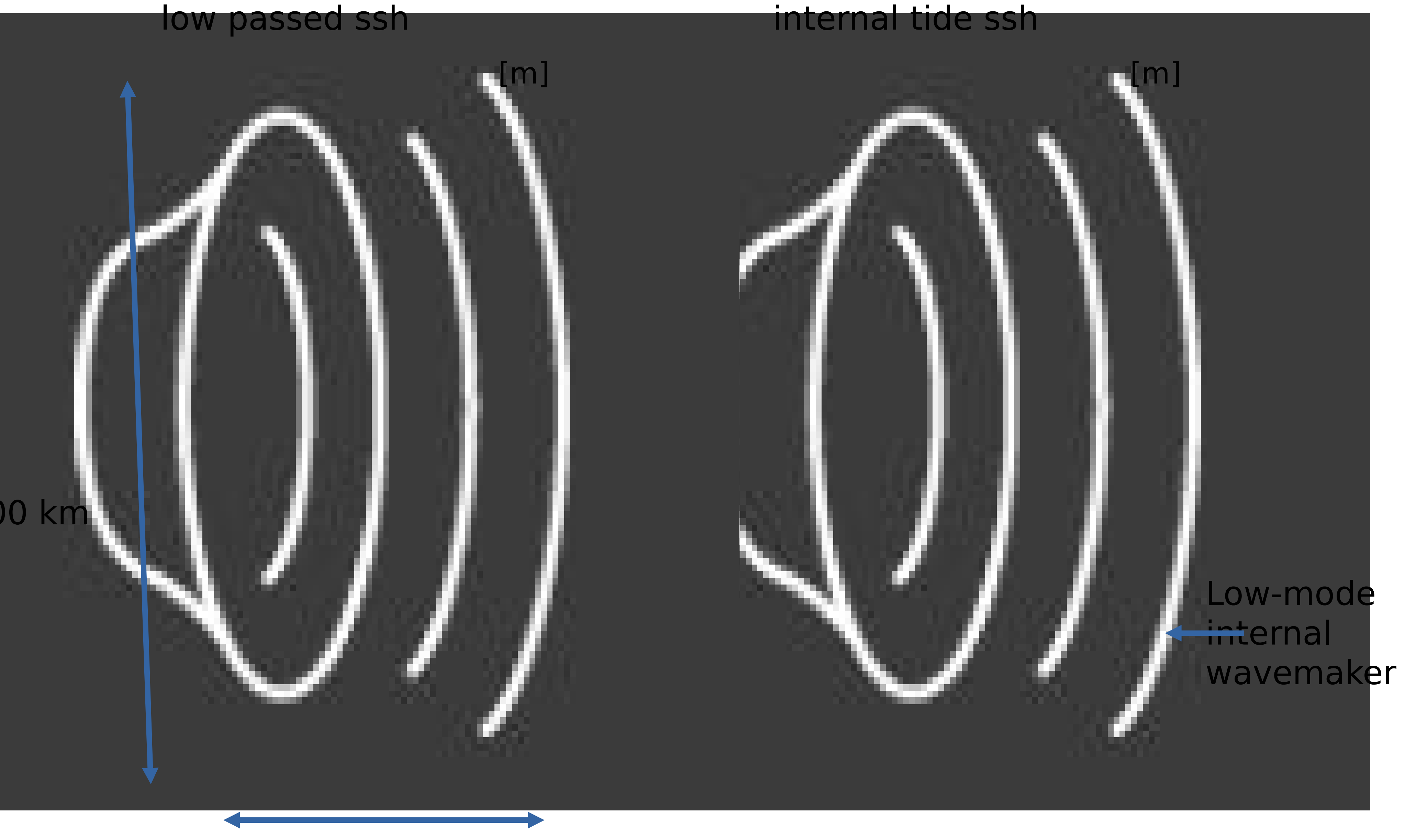
About the signature of internal tides:

- What dynamics controls the propagation of internal tides in a eddy field?
- Can we design a simplified model of internal tide propagation in such situation?
- How do eddies affect internal tide predictability (or coherence)?

About internal waves in general:

- Can we design methods that filter out internal waves sea level fluctuations from that associated with mesoscale/submesoscale?

Tool: an idealized numerical ocean



dx=2km, 100 vertical levels

Results: dynamics of internal wave - eddy interactions (on going)

Scientific objectives

- What dynamics controls the propagation of internal tides in a eddy field?
- Can we design a simplified model of internal tide propagation in such situation?
- How do eddies affect internal tide predictability (or coherence)?

$$\partial_t \hat{u}_n - f\hat{v}_n + \partial_x \hat{p}_n = I_n^u(\hat{\mathbf{u}}, \bar{\mathbf{u}}),$$

$$\partial_t \hat{v}_n + f\hat{u}_n + \partial_y \hat{p}_n = I_n^v(\hat{\mathbf{u}}, \bar{\mathbf{u}}),$$

$$\partial_t \hat{p}_n + c_n^2 \nabla_h \cdot \hat{\mathbf{u}}_{h,n} = I_n^p(\hat{\mathbf{u}}, \bar{\mathbf{u}}, \hat{p}, \bar{p}),$$

$$\hat{w}_n = c_n^2 \nabla_h \cdot \hat{\mathbf{u}}_{h,n},$$

Projections onto vertical modes

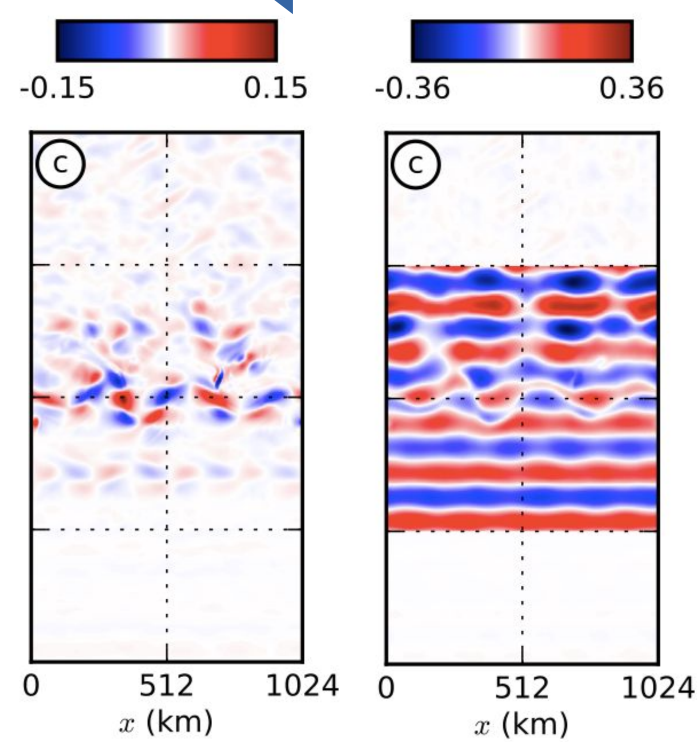
$$(u_n, v_n, p_n) = \langle (u,v,p)\phi_n \rangle,$$

$$w_n = c_n^2 \nabla_h \cdot \mathbf{u}_{h,n}.$$

Coupling terms evolution eq. quantify interactions between the internal wave and the eddy field.

We studied:

- sensitivity to knowledge of the slow flow (temporal/spatial (hor., vert.) resolutions)
- scalings with strength of the flow, internal wave mode number



Dunphy et al. submitted to JPO

Future work

- Compare the skill of simplified models of wave propagation
- Assessment in a more realistic setting