NEW CHALLENGE FOR SATELLITE ALTIMETERS:

IMPACT OF SUBMESOSCALES ON THE OCEAN DYNAMICS

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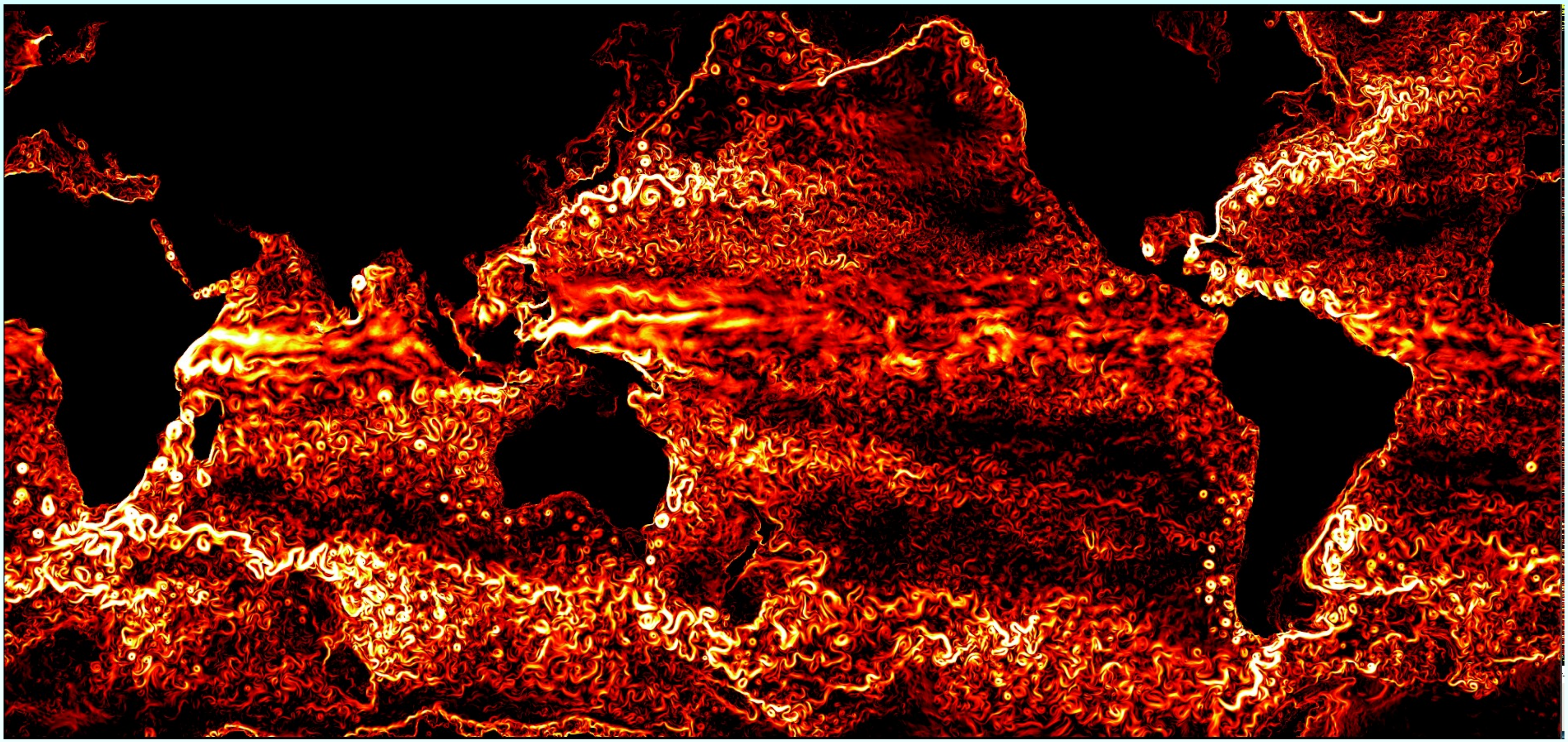
A fully turbulent ocean !

All the oceans are crowded with a large number of mesoscale eddies (>100 km). This vision has been confirmed by modelling studies (OFES, POP - 2003) with a 1/10th degree resolution performed on the ES



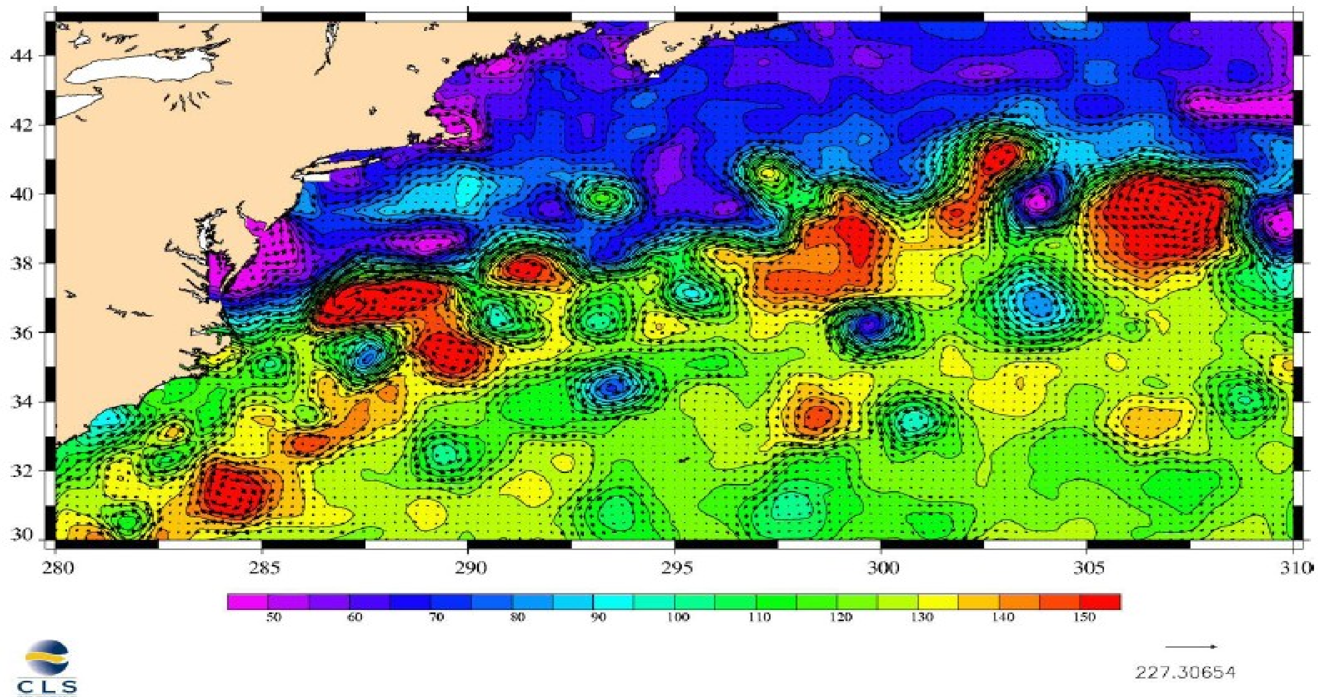
(Courtesy Raf Ferrari)

Ocean surface currents are presently monitored on a global scale from satellite observations (from altimeters, microwave radiometers, ...).

The main assumption is the geostrophic approximation or its more elaborated version : the Surface Quasi Geostrophic (SQG) approximation

=> Using these satellite datasets has shown great success in capturing surface motions but only at mesoscale (> 100 km) because of the altimeter noise level

Estimations of surface currents from altimeters using the geostrophic approximation have revealed that mesoscale eddies represent about 80% of the total kinetic energy of the oceans !



High resolution description from the real time merging of Jason-1, ERS-2 and GFO

The SQG approximation further allows to exploit the synergy between altimeter data and microwave radiometer data (AMSR E)

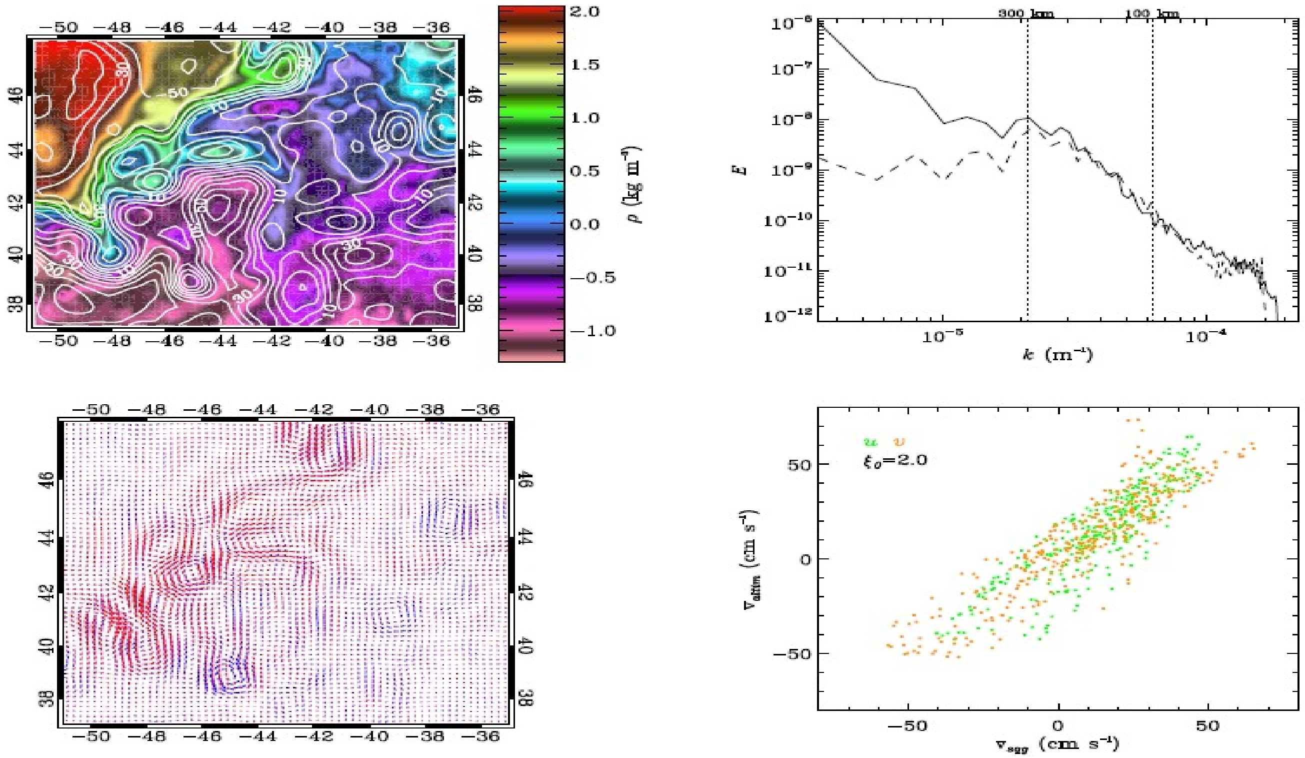
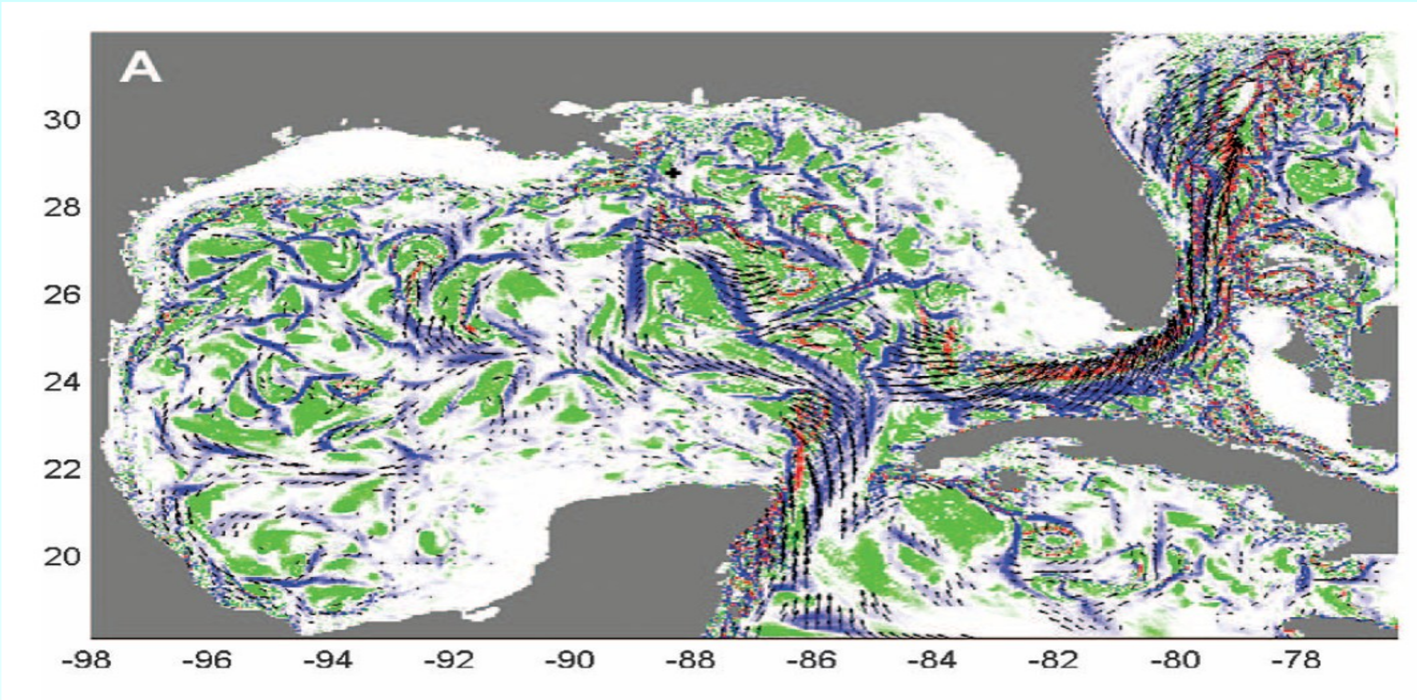


Figure 1. From left to right and from top to bottom: SST image with Absolute Dynamic Height contours overplotted (solid line), energy spectrum derived from SST data (solid line) and SSH (dashed line), comparison of velocities derived from microwave SST (red) and altimetry (blue) for the band between 100 km and 300 km and scatter plot of the velocities located in regions with $\xi > \xi_0$. These plots correspond to the image of January 5, 2005 for the area limited by 37N-48N, 51W-35W.

From Isern et al, GRL, 2006

The blended satellite products allow to estimate the impact of surface currents on the biogeochemical transport, on the dispersion of pollutants and oil spills



Forecast of oil spill dispersion in the Gulf of Mexico on 25 june 2010: red and blue show regions of strong oil dispersion within 3 days. This diagnosis, based on altimetric data, compared well with what was observed (Mezic et al, Science, 2010).

However these satellite datasets (altimetric and microwave data) cannot capture ocean dynamics at scales smaller than 100 km because of the resolution (or/and noise level).

What about smaller scales ?

Scales < 100km well observed on HR Ocean Color and SST images : large number of <u>submesoscales (< 50km)</u> produced by the mesoscale eddy interactions.

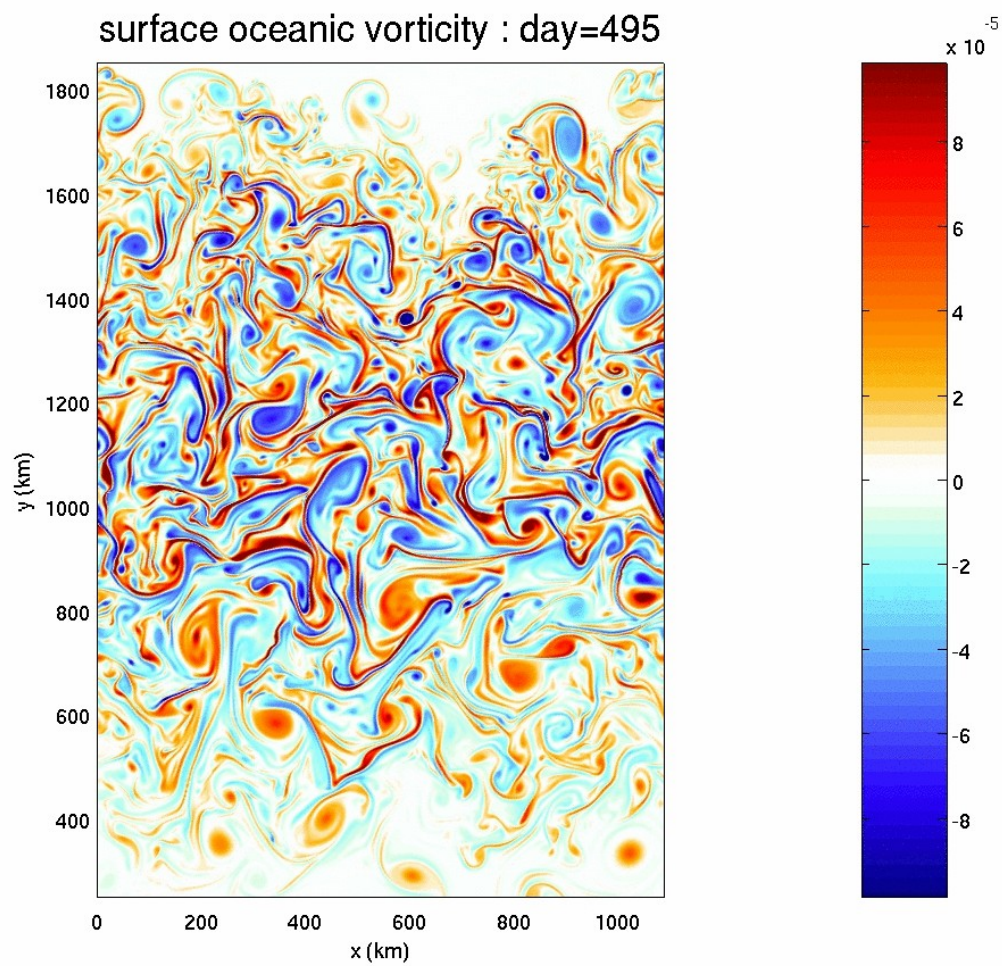
Unfortunately, these satellite images do not provide any dynamical information on these submesoscales

=> these smaller scales were considered until a few years ago to have <u>no impact on the ocean dynamics</u> !

In the last 5 years, several high resolution (1 km) numerical simulations of the ocean have been performed in large domain (3000km*2000km) and have revealed **the strong dynamical impact of submesoscales ...**

Submesoscales (<50km) are more energetic than expected and drive most of the W field in the first 500 m below the surface !

(Klein et al, JPO, 2008, Capet et al.,2008)



Main results from high resolution numerical studies

(Capet et al.'08; Klein et al.'08,10; Levy et al.'10)

*They point out that submesoscales are driven by **frontal dynamics** and therefore associated with a significant W-field.*

*=> **~50% of the W-field** in the first 500m is within submesoscales*

*=> Surface velocity spectrum slope can be **shallower than** k^{-3}*

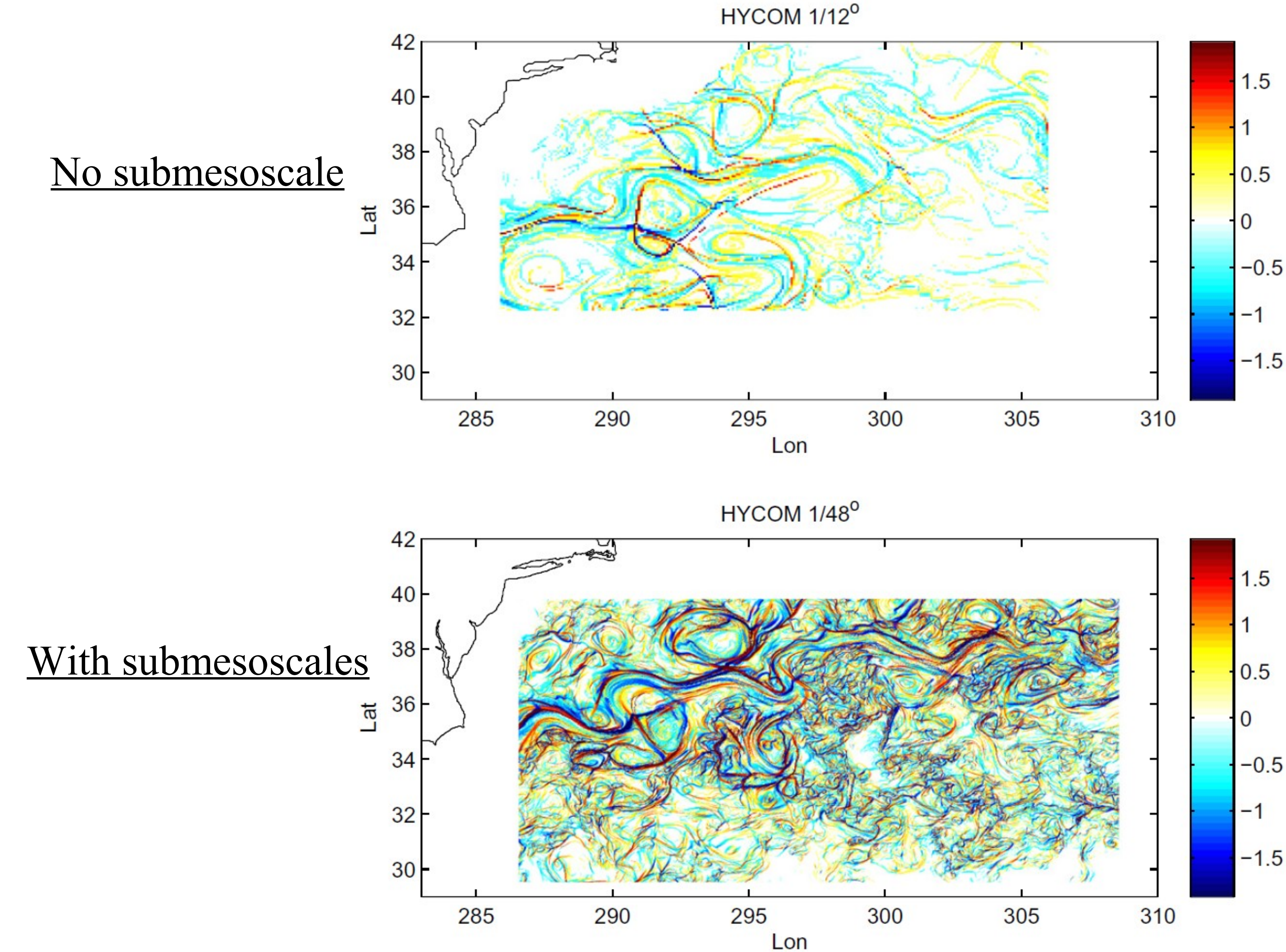
*=> Surface dynamics is **SQG-like** (instead of QG), i.e. **≠ properties***

As a consequence they have a <u>strong impact on the larger oceanic scales.</u>

*=> **Total EKE is larger** (~X2) when submesoscales are taken into account*
*=> **Contribution of submesoscales** to the total meridional heat transport is **equivalent to that of mesoscales***

Some of these results have been confirmed by observations...

Finite size Lyapounov Exponents

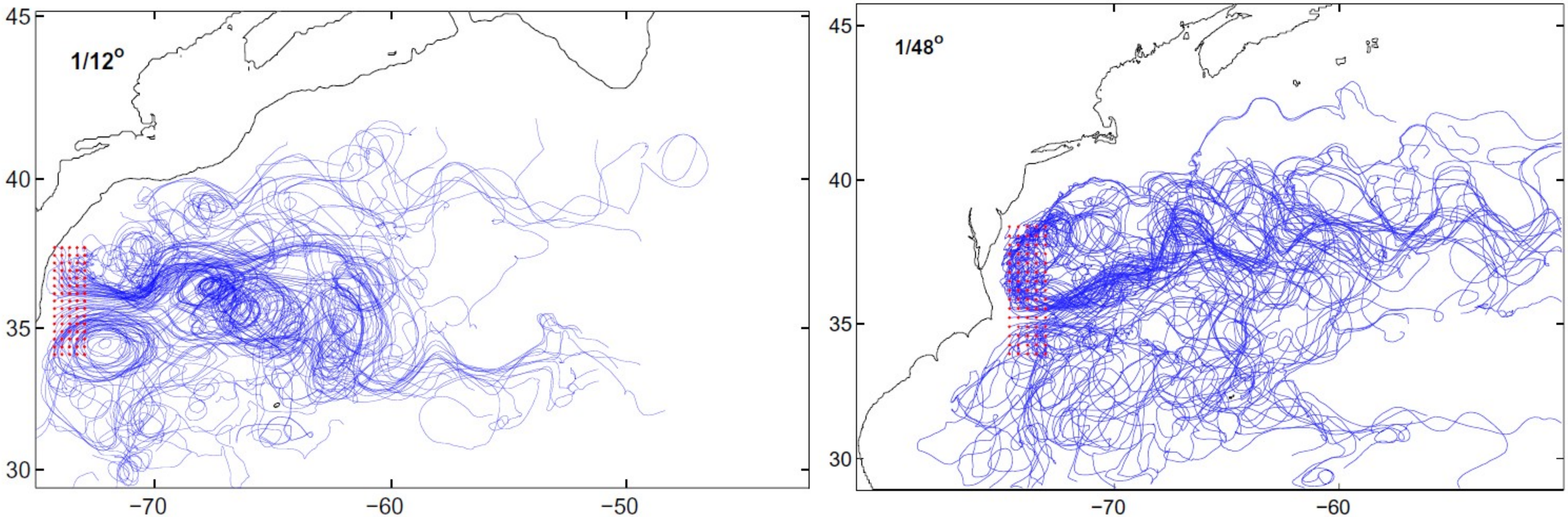


[From Haza et al., OM 2012]

Fig. 1. FSLE branches from 1/12° (upper panel) and 1/48° (lower panel) HYCOM simulations in the Gulf Stream region. Note the rich submesoscale field in the higher resolution case. The color panels indicate FSLE in 1/days. Blue colors show inflowing/stable LCS from forward in time, and red colors out-flowing/unstable LCS from backward in time particle advection. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this paper.)

A.C. Haza et al./Ocean Modelling 42 (2012) 31–49

No submesoscale | With submesoscales



Three-month long trajectories of a synthetic cluster launched near Cape Hatteras (red circles) from HYCOM 1/12° (top left panel), HYCOM 1/48° (top right panel),

[From Haza et al., OM 2012]

SQG-like behavior
(with submesoscales)
(grey dashed line)

QG-like behavior
(with NO submesoscale)
(grey solid line)

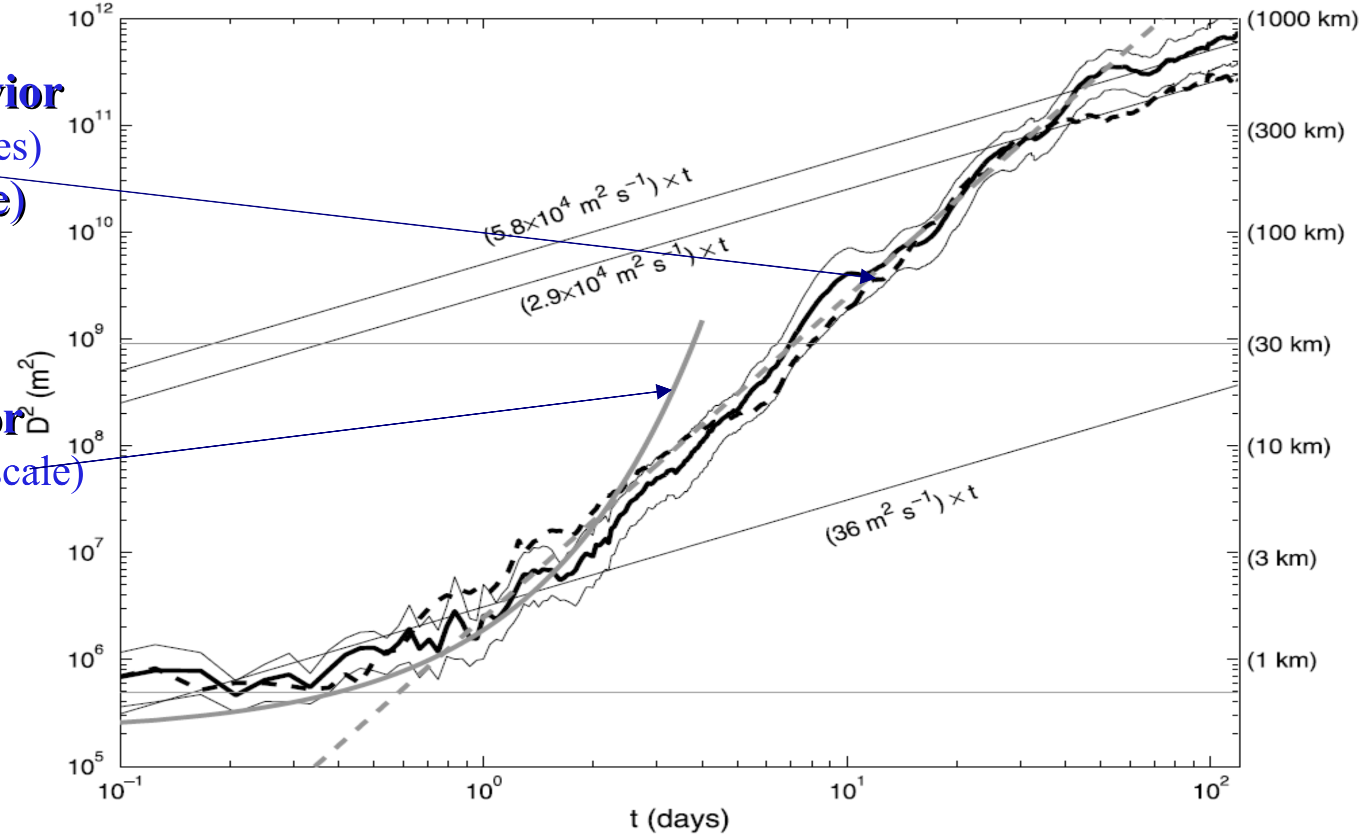


Figure 8. Zonal (heavy black solid curve) and meridional (heavy black solid dashed) dispersion of 55 CLIMODE drifter pairs. Axis on right indicates root-mean-square separation distance. Time *t* is days after release. The 95% confidence intervals from bootstrap resampling are shown for zonal dispersion (thin black curves); errors in meridional dispersion are similar. Thin horizontal gray lines indicate the estimated noise level for separation, (700 m)^2, and the squared deformation radius (30 km)^2. Slanted black lines indicate random walk behavior with constant relative diffusivity (in m^2 s^{-1}) indicated by the labels. Best fits obeying Richardson's law in the range 1–40 days (gray dashed line) and exponential growth in the range 7 h to 1 day (heavy gray curve) are superimposed (see text).

« Dispersion is local (driven by eddies of the same scale) instead of nonlocal (driven by larger eddies) » (Lumpkin and Elipot, JGR, 2010)

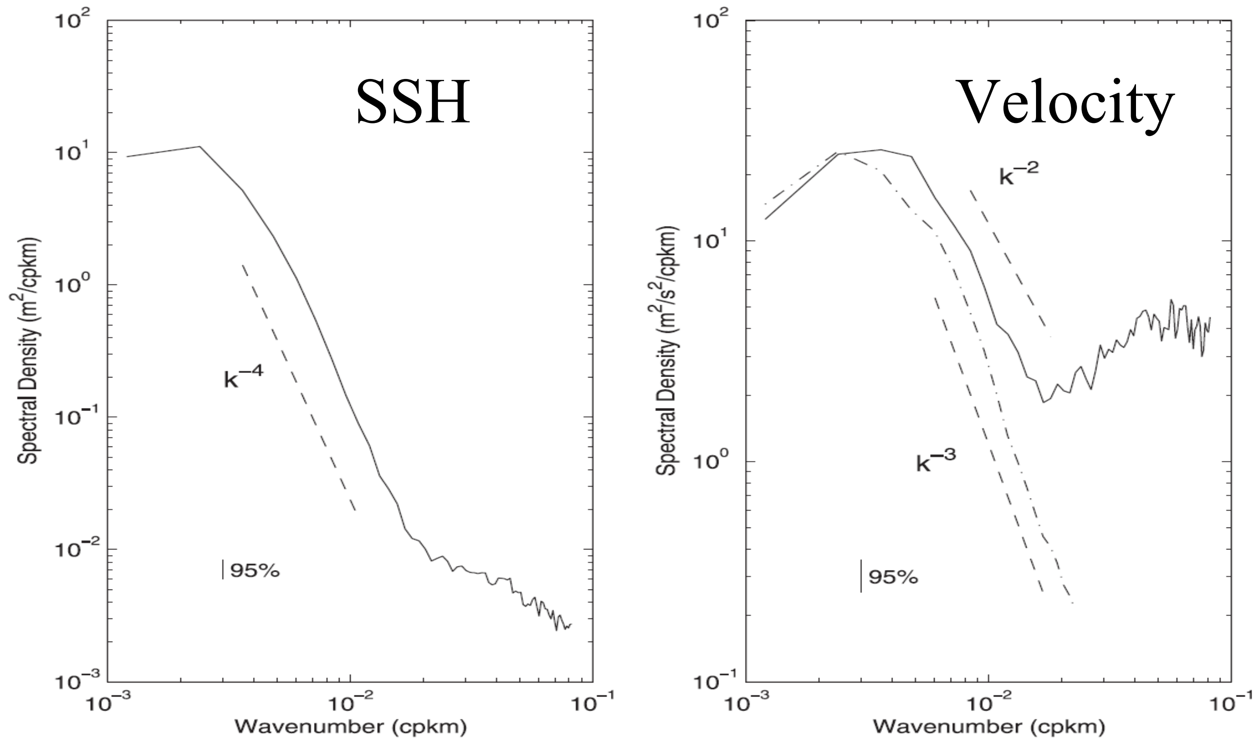


FIG. 3. (left) SSH and (right) geostrophic velocity spectra from altimetry measurements, superimposed with kinetic energy spectrum (dashed–dotted) from *Oleander* observations. Dashed lines indicate slopes of −4, −3, and −2, respectively. The 95% confidence interval is marked.

Wang et al., JPO 2010

Velocity spectrum: $\mathbf{k^{-3}}$ from **ADCP data** (*Oleander* dataset) **steeper than** $\mathbf{k^{-2}}$ from **SSH**

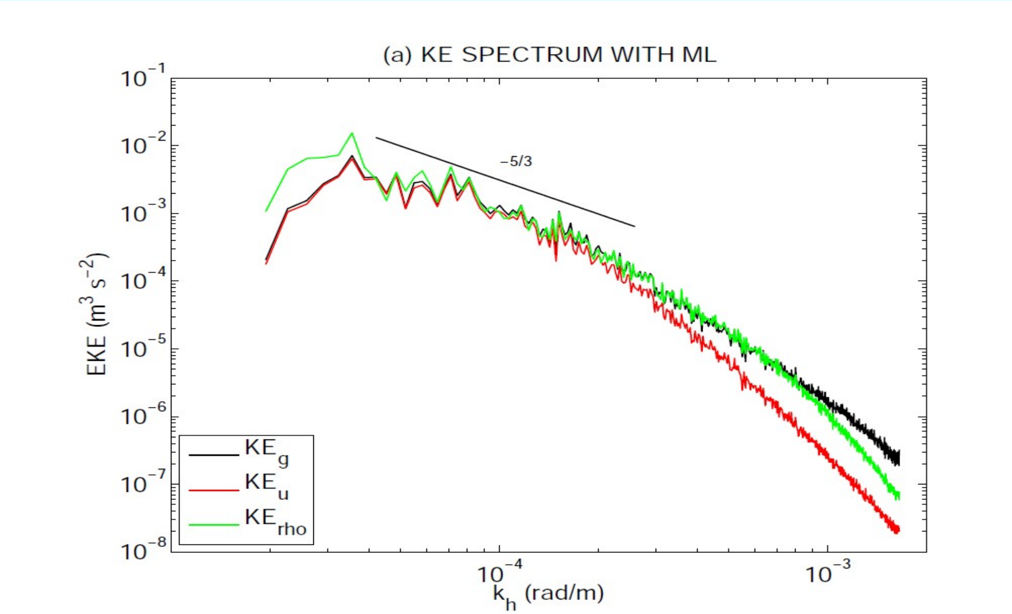
Kinetic energy: **smaller energy** level with ADCP data than altimetric data

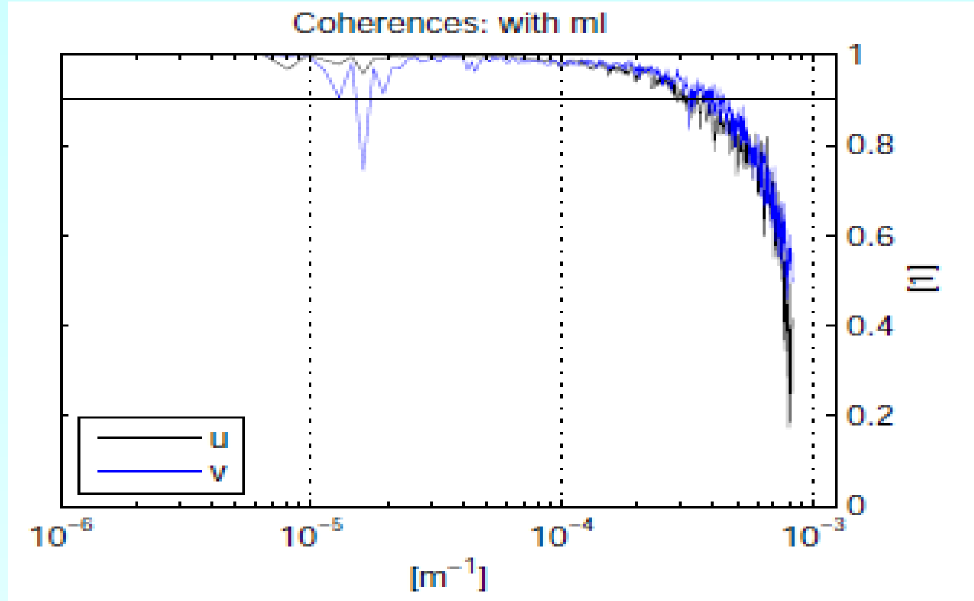
Temperature spectrum: $k^{-2.3}$ (closer to velocity spectrum from SSH)

Wang et al. suggest that these differences are related to the accuracy of altimetric data: these data may be contaminated by noise even for scales larger than 70km !

Other reasons can explain these discrepancies ...

(Klein et al., GRL, 2012)



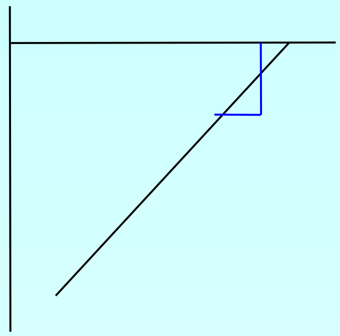


With ML: * velocity spectrum from surface U,V (red) steeper that from SSH (black)

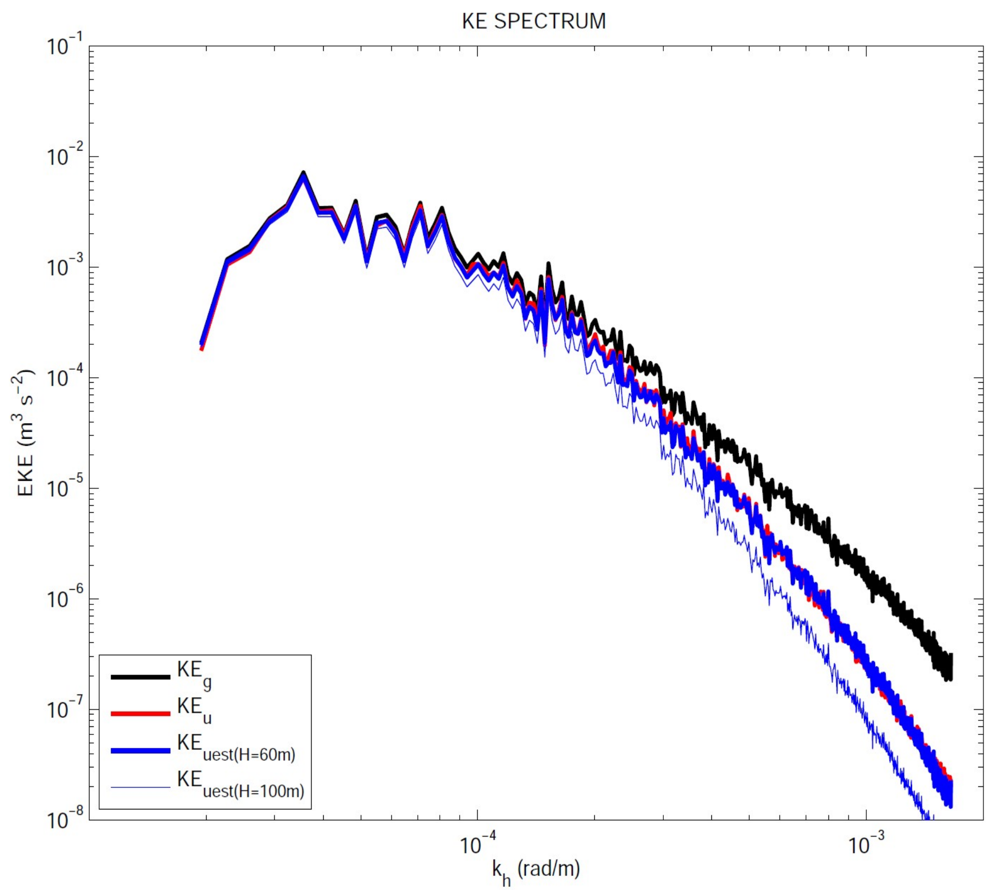
* surface density spectrum still close to velocity spectrum from SSH (green)

Results from high resolution simulations with ML: qualitatively similar to those from Wang et al., JPO 2010

Mixing argument : **vertical mixing within the ML explains the departure from geostrophy**



$$\widehat{\boldsymbol{u_e}}(k_x, k_y) = \widehat{\boldsymbol{u_g}}(k_x, k_y, 0)\frac{f}{kNH}[1 - exp(\frac{-kNH}{f})]$$



Black curve: spectrum from SSH(Ug,Vg)

Red curve: spectrum from observed surface currents

Thick blue curve: spectrum from estimated surface currents assuming that Ug and Vg are well mixed over a ML of depth H **(60m)**

Submesoscales can be affected by the vertical mixing but their dynamics is still consistent with SQG turbulence theory. Future HR **SSH data should be relevant to capture these scales.**

New Challenges:

Operational oceanography and applications **require satellite observations with higher space/time resolution** !
(instead of 100km and 10 days respectively as allowed by conventional Altimeters) !!!

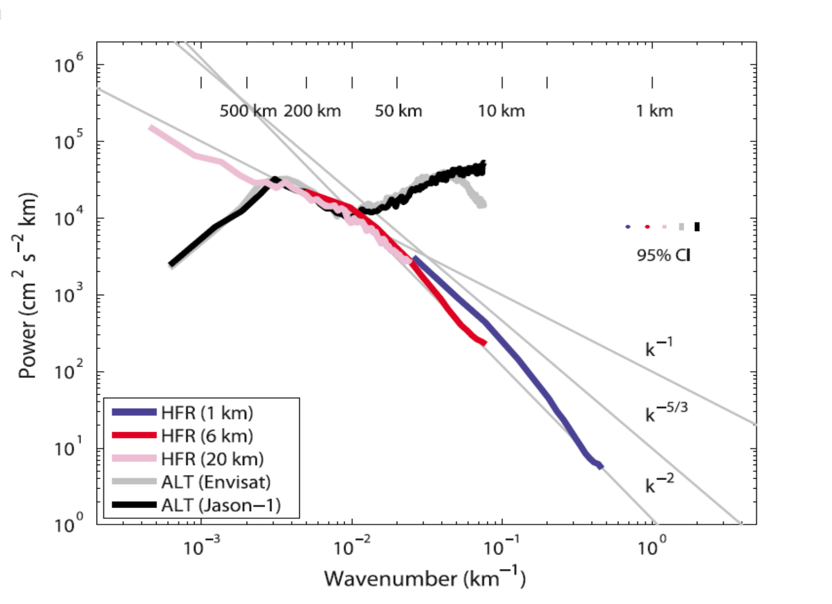
Surface currents at submesoscales can be retrieved from HR SSH and SST data. Parameterization of vertical mixing induced by the air-sea fluxes should improve their estimation.

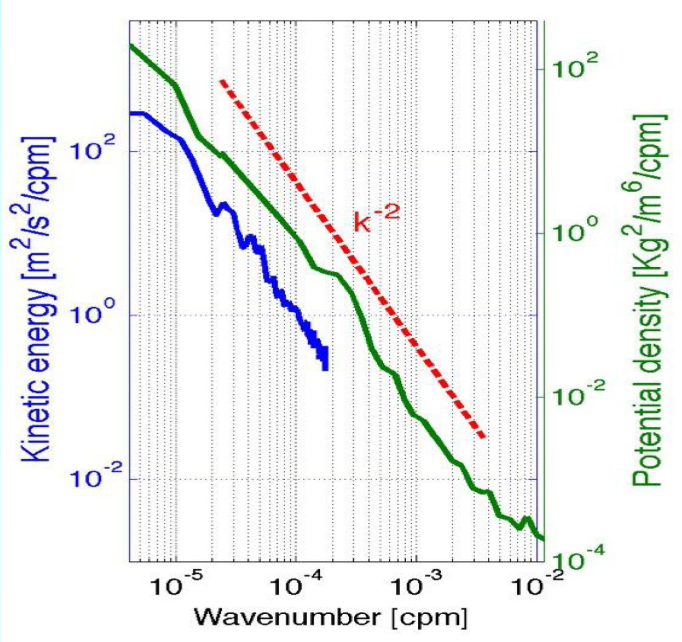
Knowledge of these submesoscales is important not only because of their strong impact on the surface relative dispersion but also because of their strong relationship with the vertical velocity field

=> Strong impact on the 3-D dispersion !

Observations: Le Traon et al. JPO 2008; Xu and Fu JPO 2011; Kim et al. JGR 2011

Observations: from Ferrari & Rudnick, 2000: both velocity and density spectra in **k** $^{-2}$





Recent observations reveal that submesoscales are more energetic: velocity and density spectra have a shallower slope

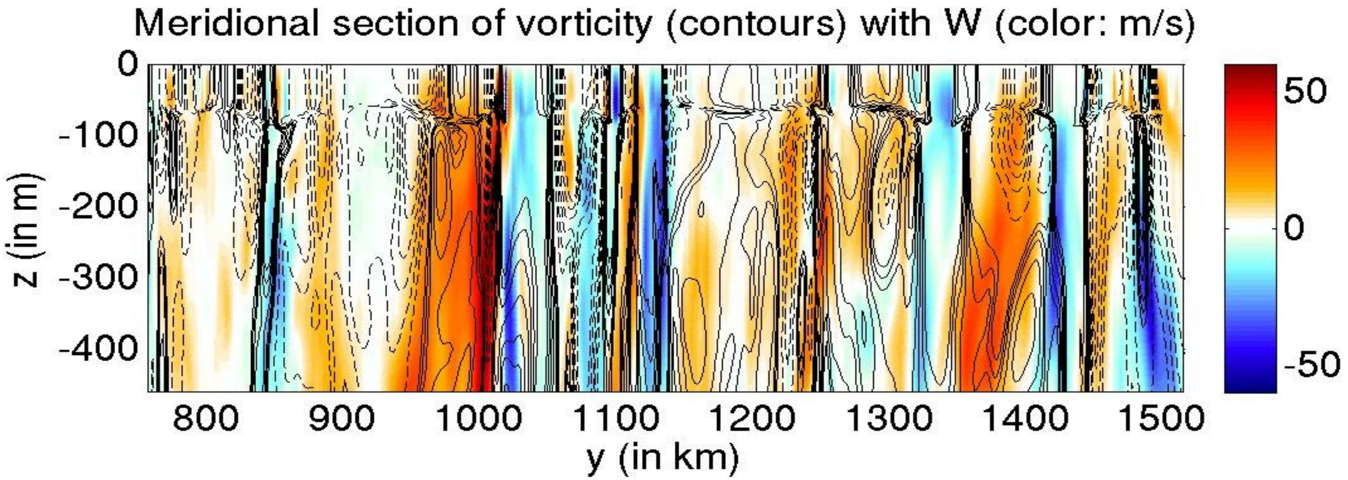
(**k^{-2} instead of k^{-3}** near the surface)

These **ageostrophic motions** induced by mixing are just **confined within the ML**.

They are in part generated by the geostrophic currents since they act to reduce the vertical shear of these currents.

This is what is observed (see also Nagai et al., JGR, 2006).

SSH is still **a good proxy to get the 3D circulation below the ML.**



We hypothesize that vertical mixing within the ML explains the departure of surface currents from geostrophy

$$-f\boldsymbol{k} \times \boldsymbol{u_{ml}} - \frac{\partial}{\partial z} A_v \frac{\partial \boldsymbol{u_{ml}}}{\partial z} = -\frac{1}{\rho_o} \boldsymbol{\nabla} p$$

Coriolis term

Wind-forced mixing

Pressure (ssh) gradients forced by eddy turbulence

After integration over the mixed-layer depth (using the SQG approximation for p), we get :

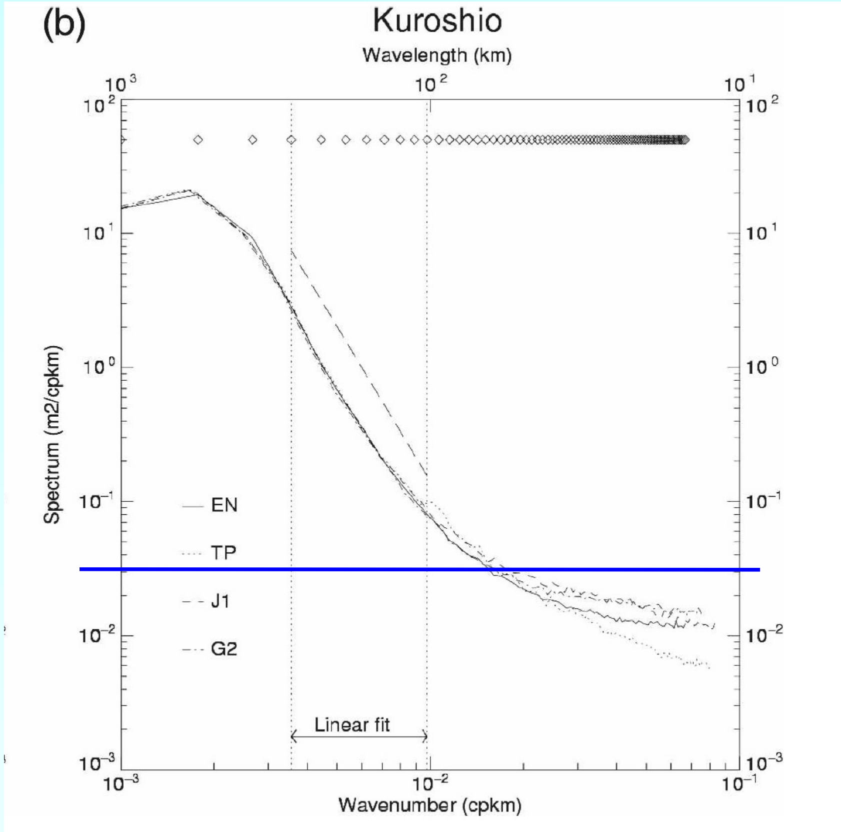
$$\widehat{\boldsymbol{u_e}}(k_x, k_y) = \widehat{\boldsymbol{u_g}}(k_x, k_y, 0) \frac{f}{kNH} [1 - exp(\frac{-kNH}{f})]$$

Surface currents

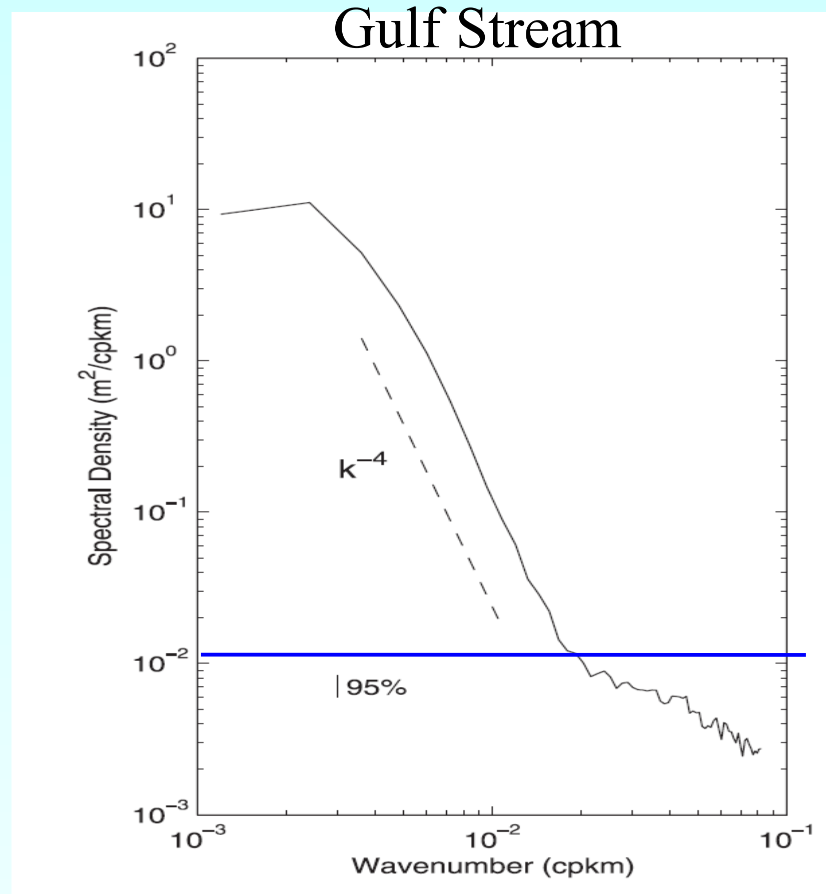
Geostrophic currents (from SSH)

Wind-forced ML depth

A constellation of conventional altimeters only captures eddies with spatial scales > 100 km and time scales > 10 days



Le Traon et al., JPO 2008



Wang et al., JPO 2010

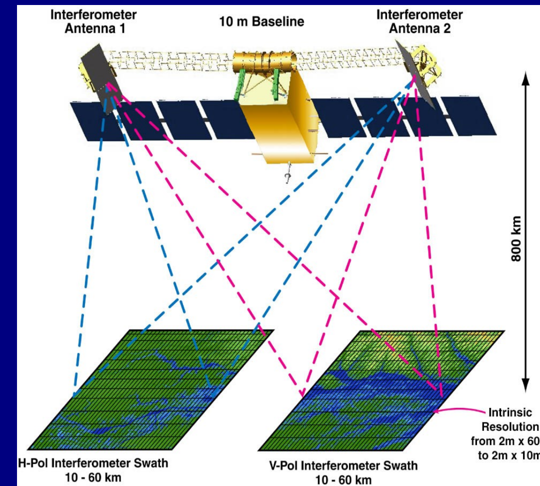
It cannot capture space scales < 100 km and time scales < 10 days
<u>because of the noise level</u> !

A new vision has emerged in the last 5 years:

New supercomputers such as the Earth Simulator have led to a major evolution of numerical models => allowing to use a very high space/time resolution. Related results have pointed out **the strong importance of submesoscales (scales smaller than 50km)!**

Evolution of numerical models is so important that, presently, **observations capabilities lag well behind !**

SWOT



These challenges should be met in the future since

new altimeters such as the wide swath synthetic aperture radar Interferometer altimeter of the SWOT mission (NASA-CNES cooperation) should allow to capture oceanic scales as small as 10-20 km!

Because of the properties of the submesoscales and their relationship with mesoscales, <u>new altimeters will have a stronger potential</u> than conventional altimeters:

<u>High resolution altimetry data</u> should allow to <u>diagnose</u>

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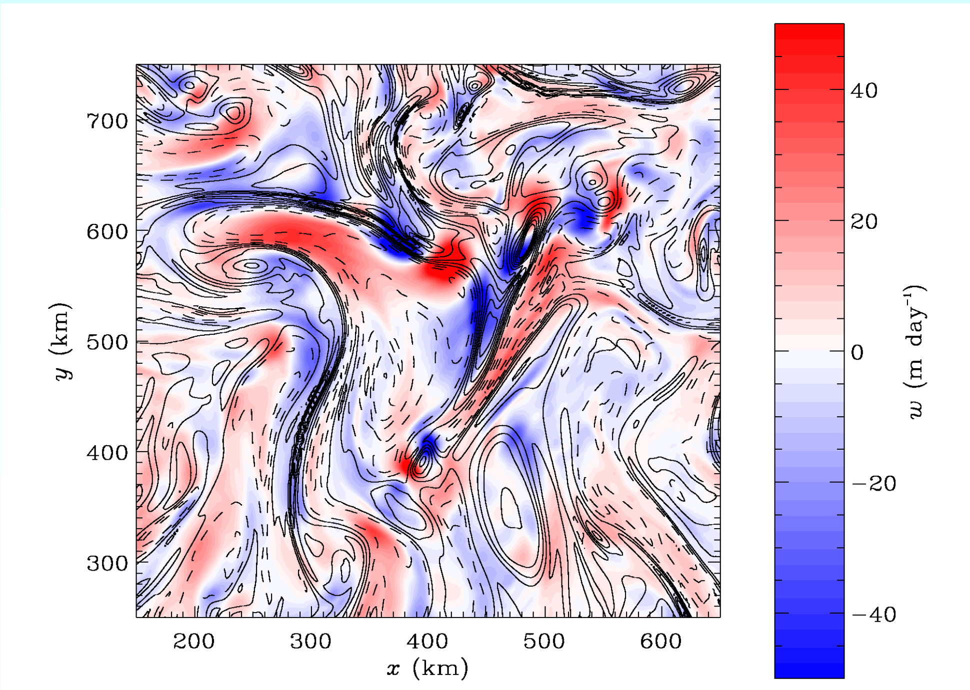
not only the surface currents but also <u>the 3D motions</u>

<u>(including the W velocity)</u> in the first 500m below the surface.

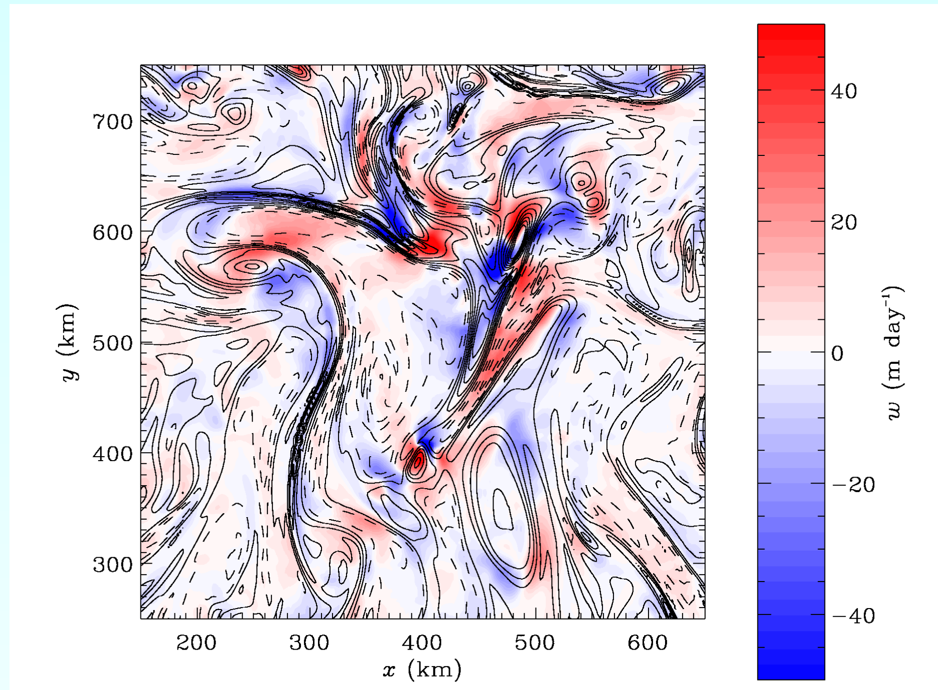
This new potential has been successfully tested:

Reconstruction of 3D currents (u,v,w) 0-500m from high resolution satellitale SSH

Simulated W at 200m by an OGCM



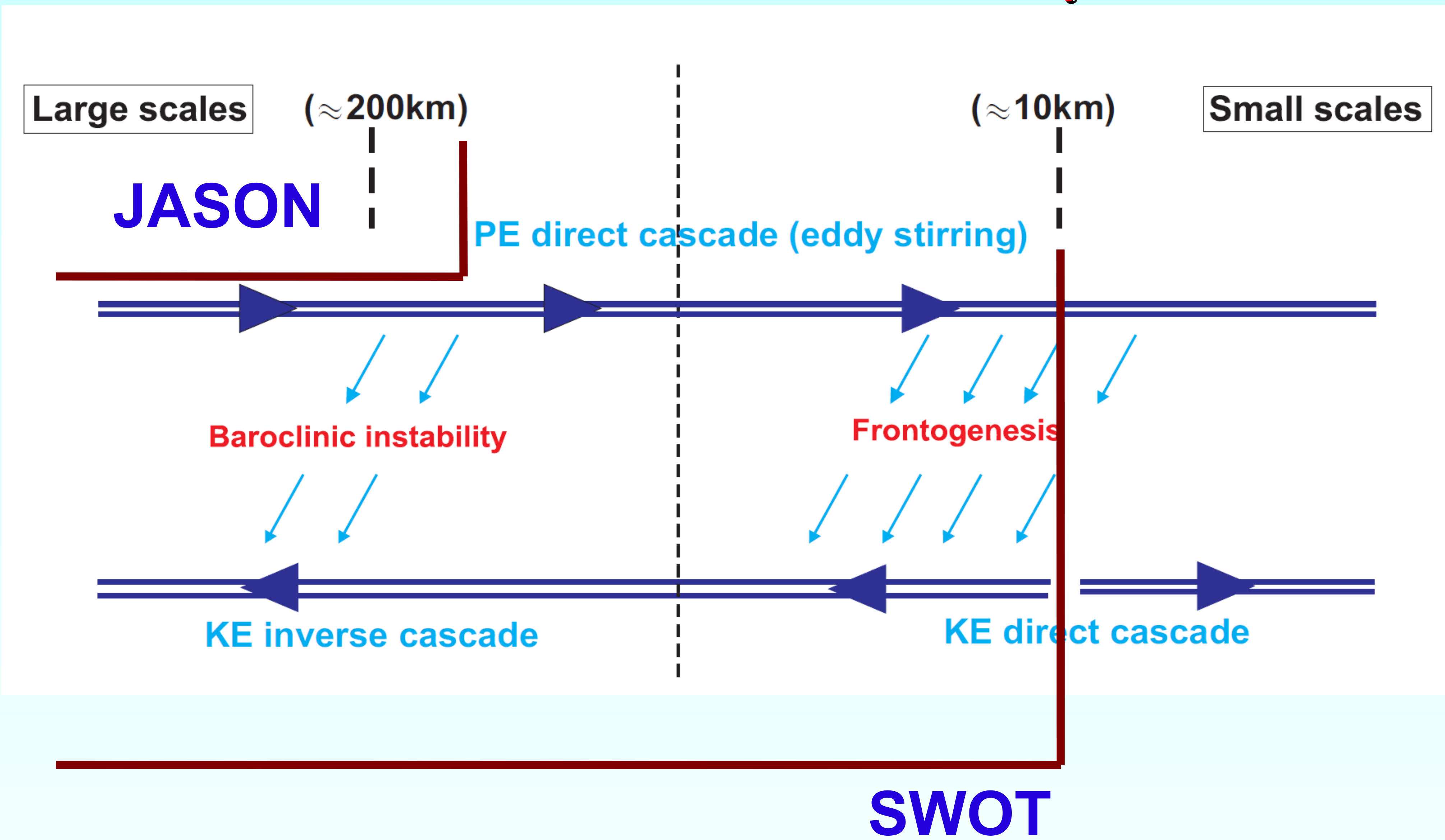
Reconstructed W from SSH



Contours : relative vorticity

Source : P. Klein (IFREMER)

SWOT/ conventional altimetry



Conclusion

=> ***New challenges:***

Future *satellite altimeters have to capture SSH submesocale patterns (with space scales between 50 km and 10km and time scales as small as 2 days (instead of only mesoscales (100km and 10 days)) !*

Their space resolution should be ~1km and their noise level about 1cm !

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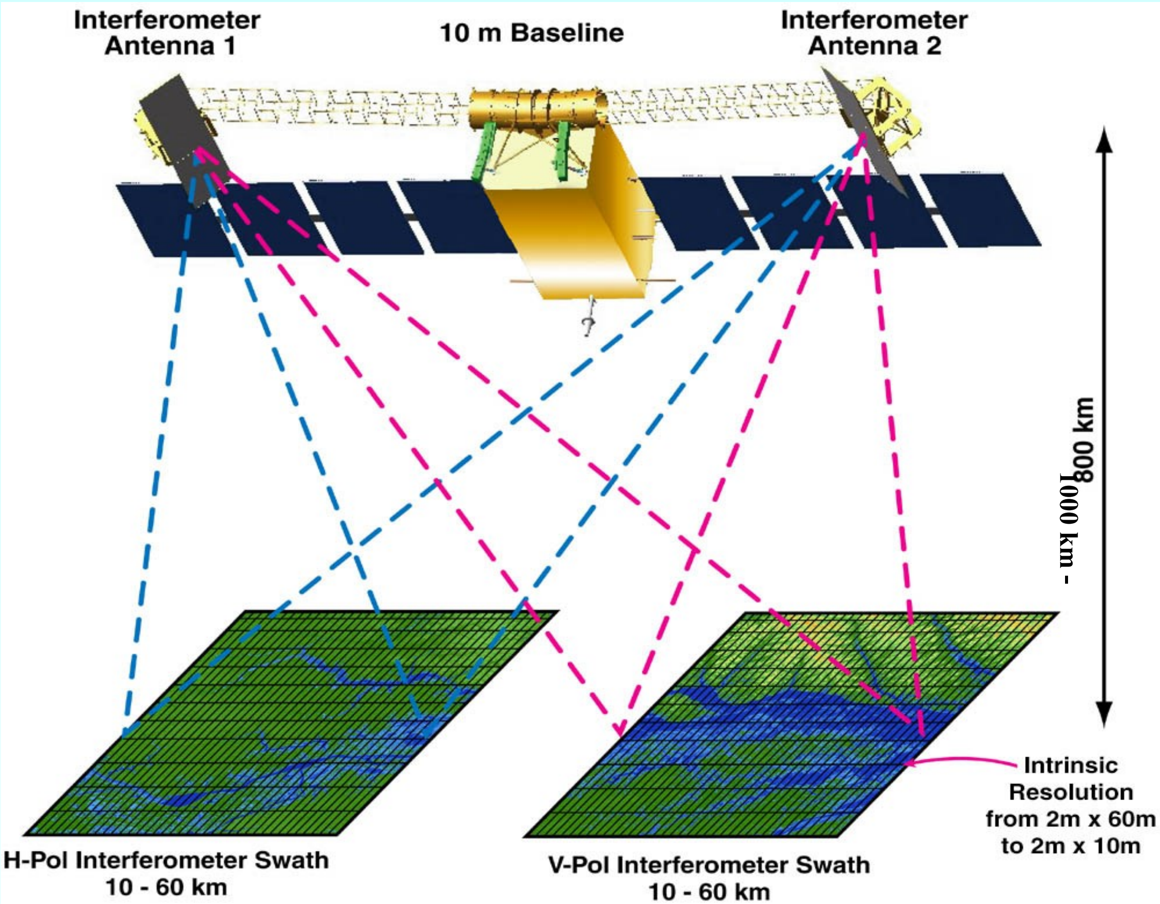
=> ***Further new challenges:***

1) Still need of a constellation of altimeters (and not only one) including new and conventional ones !

2) How to combine these new altimeter observations with other satellite data (SST, Ocean color, SAR, ...) !

SWOT : Radar Interferometer



Ka band interferometer penetrates clouds and relies on small canopy openings to penetrate to underlying water surfaces (openings of only 20% are sufficient).

Two Ka-band SAR antennae at opposite ends of a **10 m boom**

Both antennae transmit and receive the emitted radar pulses along both sides of the orbital track.

Look angles are limited to 4.5° to reduce the baseline roll-error.

Provides a **120 km wide swath**.

Specular scatter : water bodies scatter more strongly than land.

Interferometric SAR processing of the returned pulses yields a **5 m alongtrack resolution**

Crosstrack resolution is 10 m in far swath to 70 m in near swath,

Elevation precision is ± 50 cm.

Data averaging over areas less than 1 km^2 increases the ocean **height precision** to less than **± 1 cm**.

Launch : 2019!