SSH wavenumber spectrum in the North Pacific: impact of submesoscales

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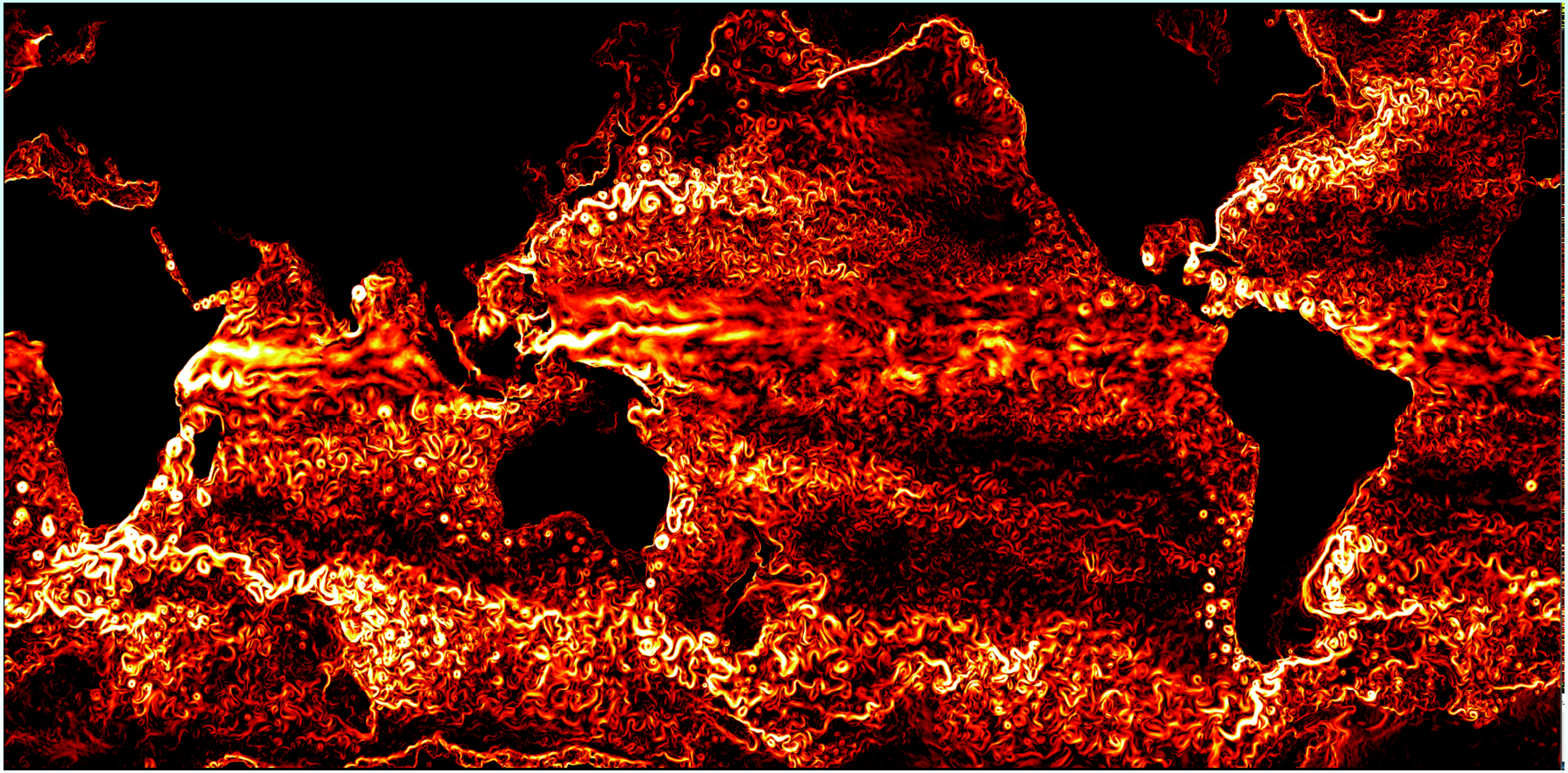
A fully turbulent ocean !

10 years ago, most observations and modelling studies revealed that all the oceans are **crowded with a large number of mesoscale eddies (with 100km scales)**



KE at the ocean surface from an OGCM (1/10th degree) [Courtesy Raf Ferrari]

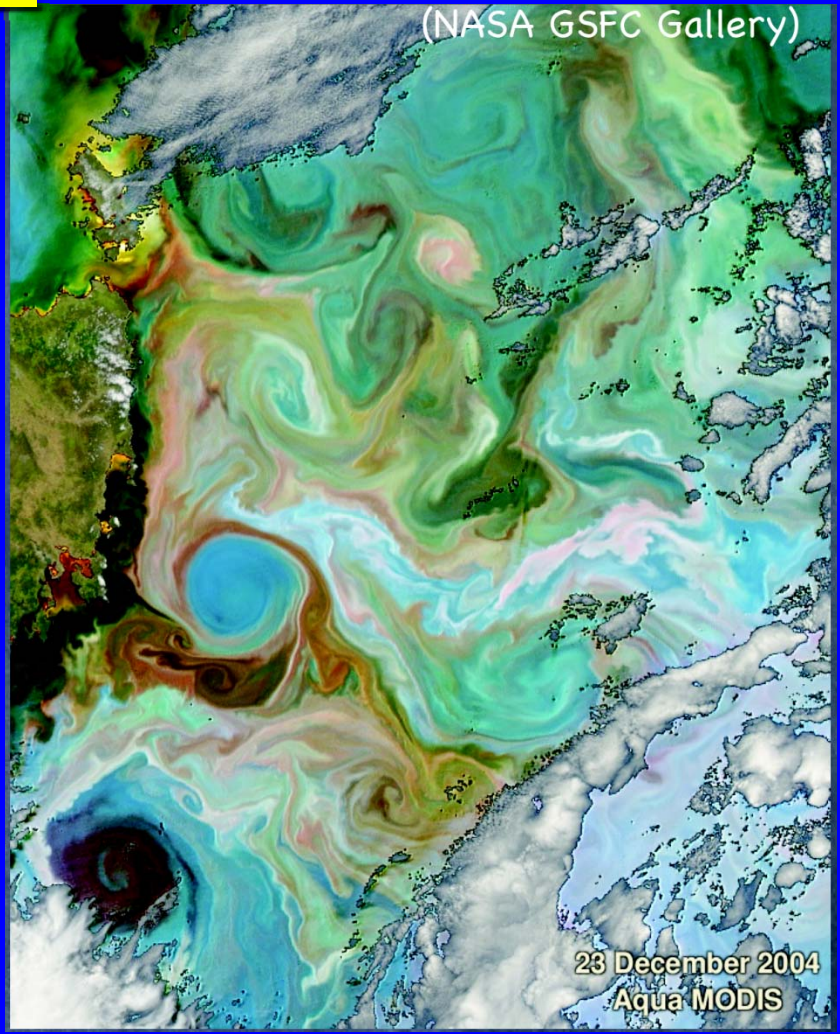
Vision well confirmed by the analysis of conventional altimetry (Chelton et al.)

But these mesoscale eddies strongly interact:

SST and biogeochemical tracers are stirred, leading to a strong production of a large number of smaller scales.

This is observed on HR SST and Ocean color images that reveal at the surface a large number of submesoscales (filaments ~10km)

Unfortunately ...



As a consequence ...

@ ***Submesoscale structures*** (5-50km such as elongated filaments)

These structures were <u>considered</u> (until a few years) to be very weakly energetic <u>with NO impact on the ocean properties.</u>

@ ***Mesoscale eddies*** (100-300km)

assumed to capture most of 3D dynamics
led to a **surface velocity spectrum with a k^{-3} slope (or a SSH spectrum slope in k^{-5})** (properties close to geostrophic turbulence)

But this is not what recent high resolution modelling studies ...

In the last 5 years, several high resolution (1 km) idealized simulations of high EKE ocean turbulence performed in large domain (3000km*2000km) to further understand the dynamical impact of submesoscales ...

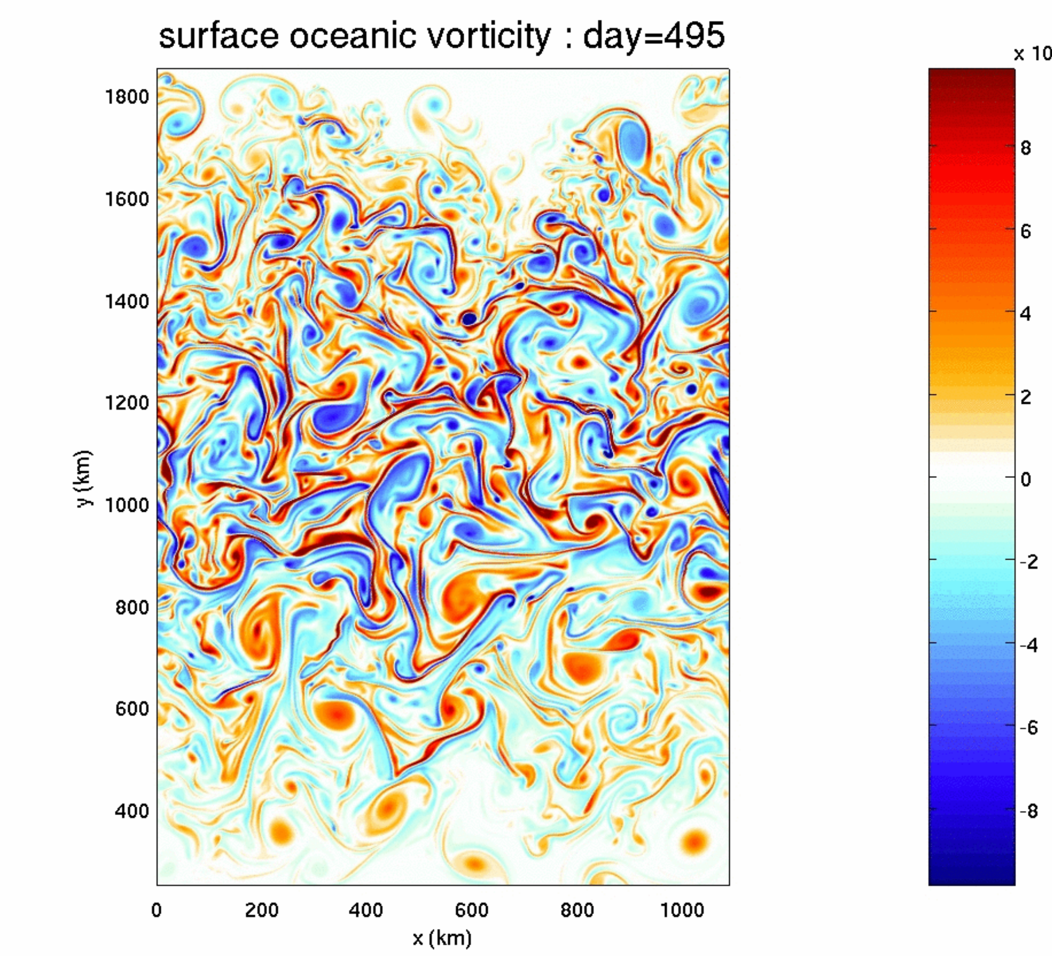
@

Submesoscales with

large vorticity values (-f to 3f)

quickly evolving (=><u>large W</u>)

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



Main results from high resolution idealized studies

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

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

=> ***~50% of the W-field*** *in the first 400m is within submesoscales*

As a consequence they have a strong impact on the larger oceanic scales.

=> ***Total EKE is larger*** *(~x2) when submesoscales taken into account*

=> **Contribution of submesoscales** *to the total meridional heat transport is* ***equivalent to that of mesoscales*** (Levy et al. , 2010)

This impact explains that ***SSH spectrum slope is in*** k^{-4} and NOT in k^{-5} *in the mesoscale and submesoscale range*

SSH slope (k^{-4}) **confirmed in high EKE areas** by the recent reanalysis of the altimeter datasets (Le Traon et al.'08 and Xu and Fu '11)

(from Xu and Fu'11)

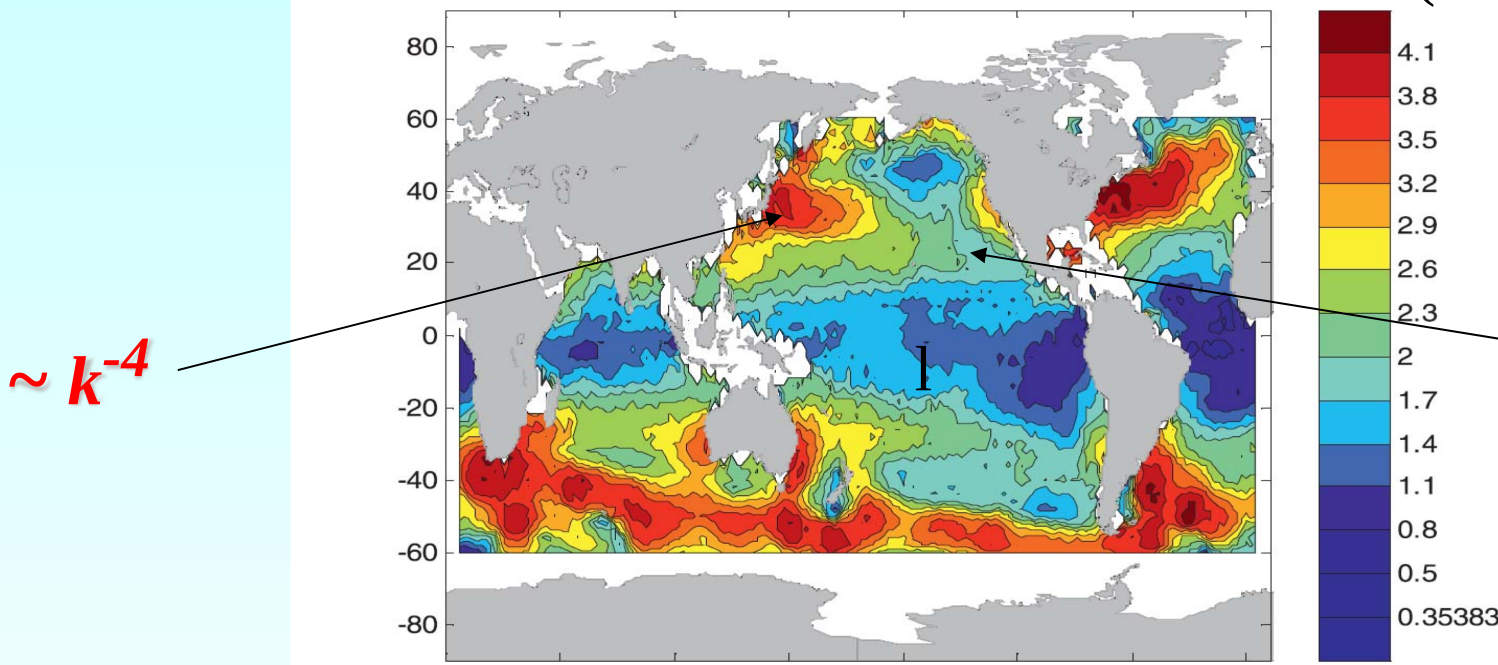


FIG. 2. The global distribution of the spectral slopes of SSH wavenumber spectrum in the wavelength band of 70–250 km estimated from the *Jason-1* altimeter measurements. The sign of the slopes was reversed to make the value positive.

but NOT in low EKE areas (only k^{-2} or k^{-3} slopes) which is quite pulzzing in terms of the mechanisms involved (impact of submesoscales?)?

=>We have recently addressed this question using a HR realistic simulation...

Realistic simulation of the North Pacific with high resolution on the Earth Simulator

@ Performed with the OFES model

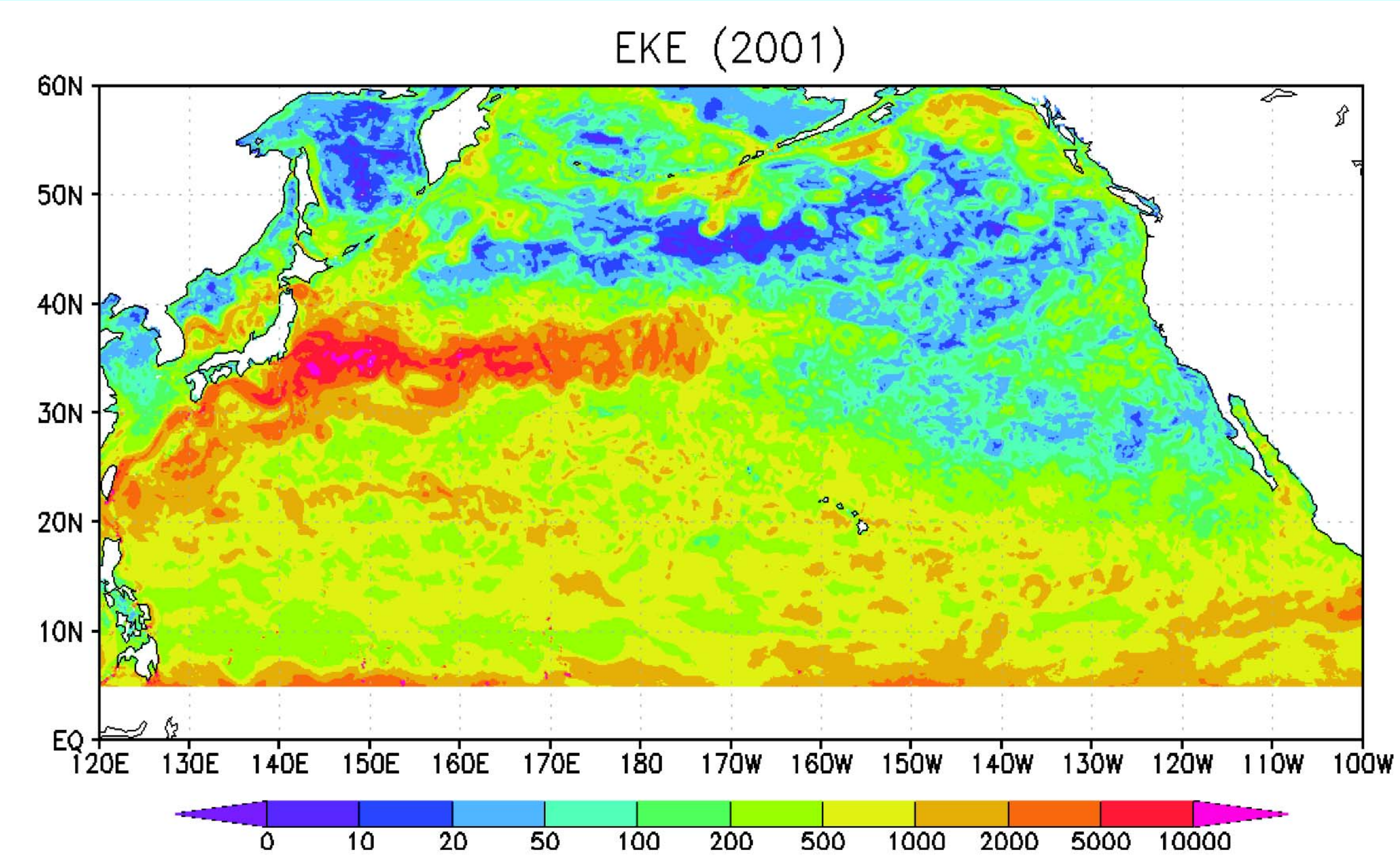
@ Resolution: 1/30th degree, 100 vertical levels

@ Forced by surface wind stress and heat fluxes using 6-hourly Japanese reanalysis (1 degree)

@ No tidal motions

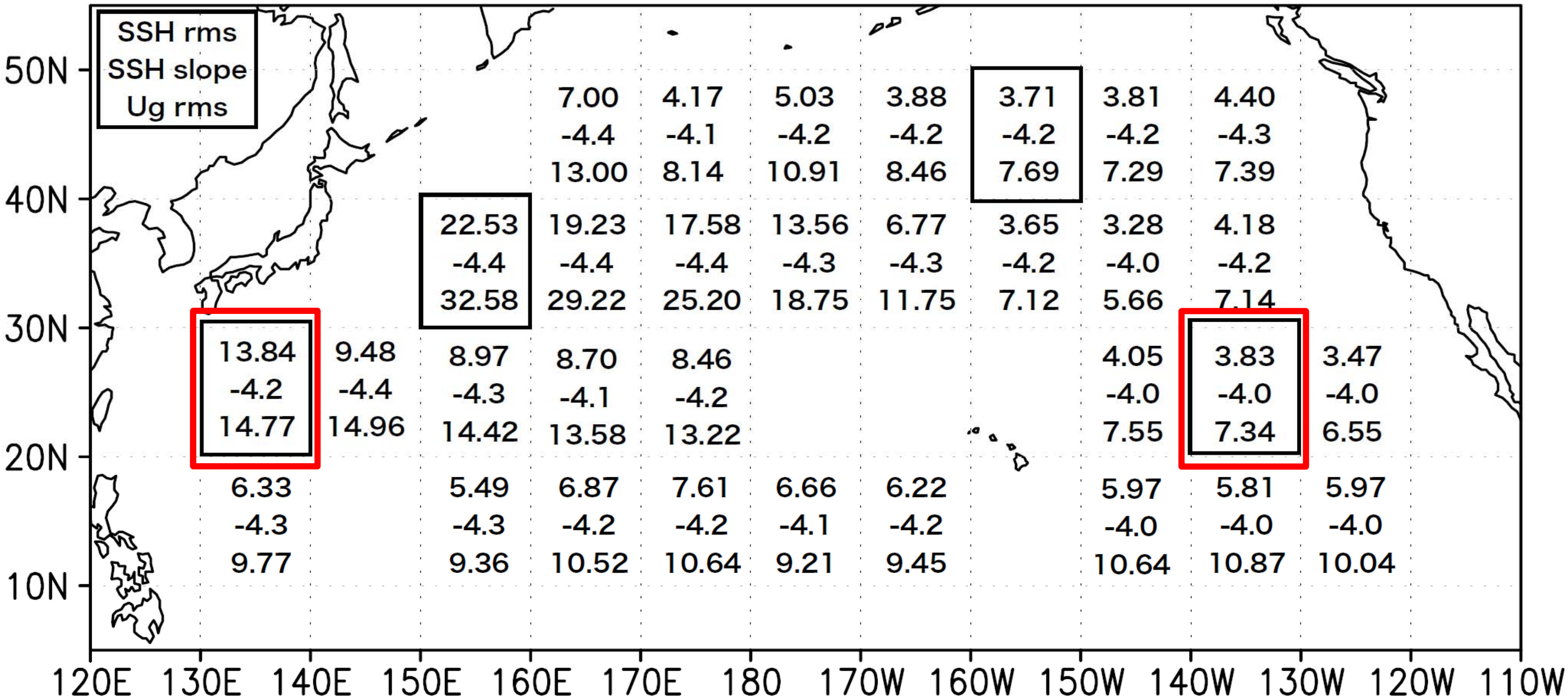
@ Turbulent field in the upper layers in statistical equilibrium in the last ten months of integration

@ Statistical SSH characteristics estimated in 10° x 10° boxes



EKE (2001)
60N
50N
40N
30N
20N
10N
EQ
120E 130E 140E 150E 160E 170E 180 170W 160W 150W 140W 130W 120W 110W 100W
0 10 20 50 100 200 500 1000 2000 5000 10000

Statistical SSH characteristics estimated in 10° x 10° boxes



SSHrms in cm (upper number), **SSH spectrum slope (middle number)** and Urms (lower number) in cm/s.

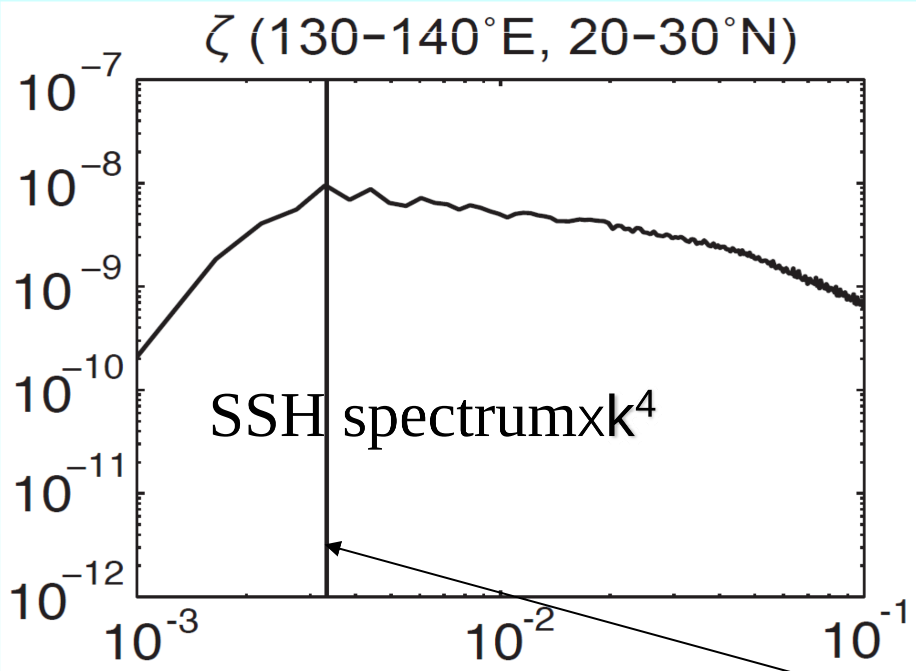
=> **~ k^{-4} SSH spectrum slope not only in high but <u>also in low EKE areas</u>** (which emphasizes the impact of submesoscales on the larger ones)

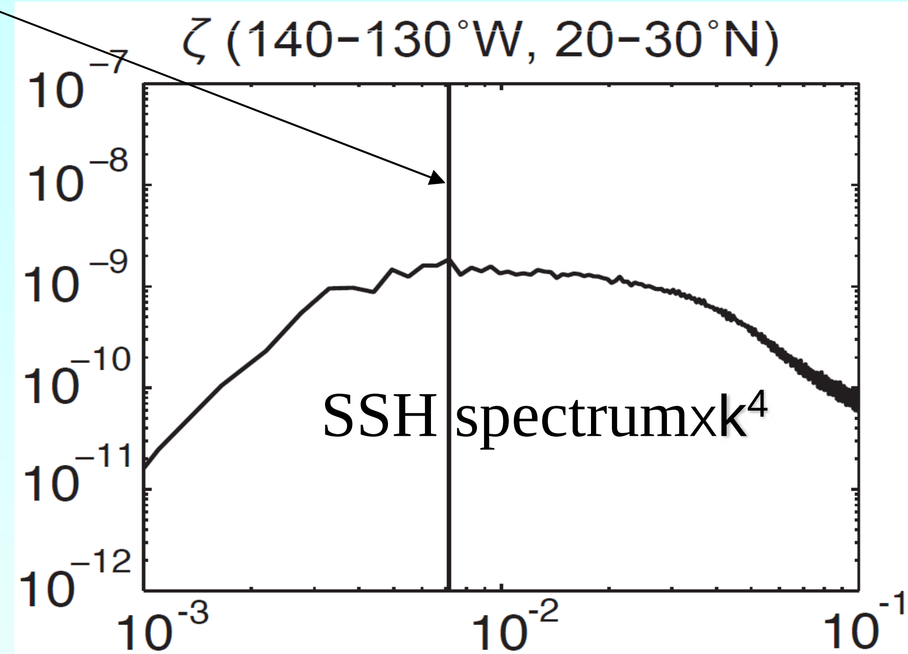
=> however analysis of **SSH spectra reveals some important differences**

High EKE

Low EKE

Lv=~120km





Lv=~280km

Lv is related to the **peak** of the relative vorticity spectrum

=> For **scales < Lv**, SSH spectrum should have a slope **equal to or steeper than k^{-4}**

=> For **scales > Lv**, SSH spectrum should have a slope **shallower than k^{-4}**

Lv is significantly smaller in low EKE areas than in high EKE areas

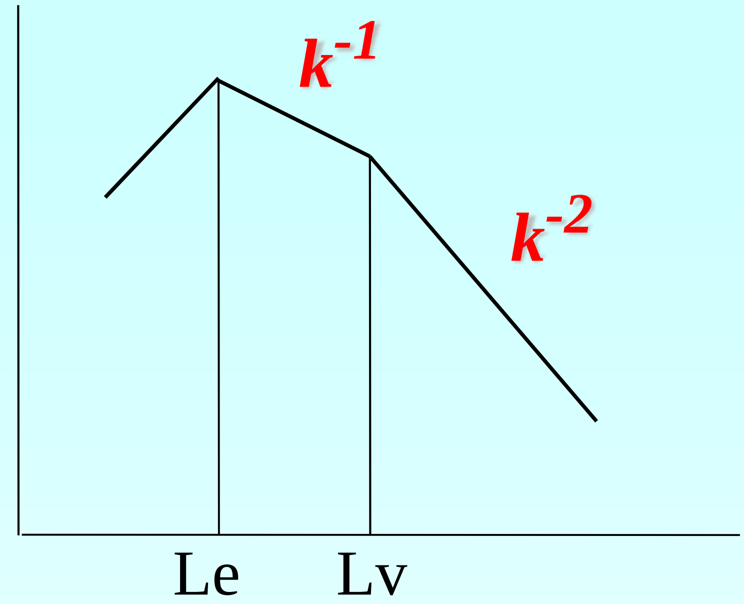
In terms of interpretation of the altimeter datasets ...

@ Since a slope equal or steeper than k^{-4} can only be observed for scales smaller than Lv, such slope will be difficult to emerge from altimeter datasets in low EKE areas if Lv is too close to the lower bound of the spectral window even if the spectral energy is above the noise level.

@ This may explain the results of Xu and Fu'11.

@ Is there in-situ observations in low EKE areas that confirm this explanation ?

For a better **comparison with observations**, let us examine the consequences in terms of **velocity spectrum** (=SSH spectrumxk^2):



@ Lv may differ from Le, the scale of the maximum of U-spectrum.

Lv <Le in low EKE areas.

Lv~ Le in high EKE areas.

@ As a consequence:

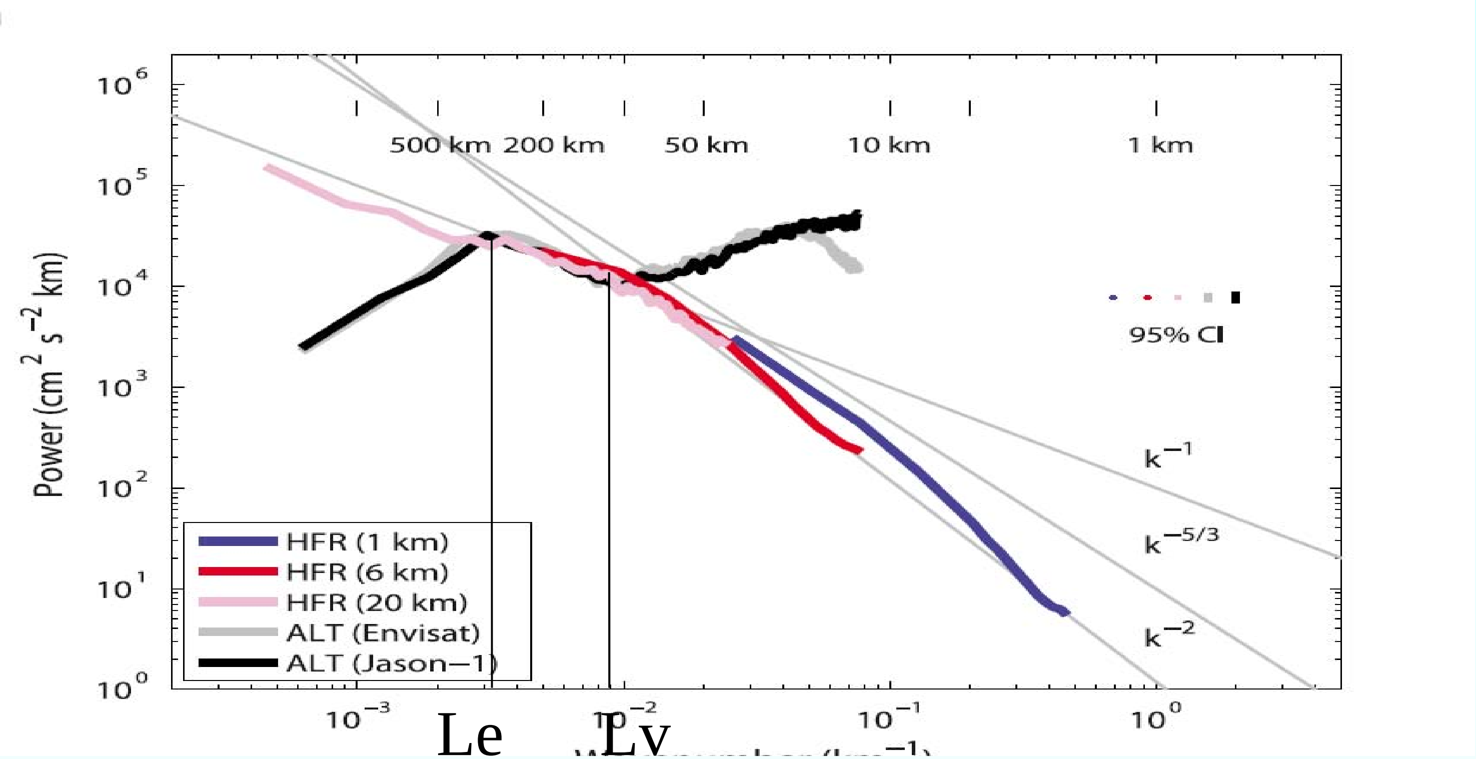
in high EKE areas, a k^{-2} slope should be found for all scales smaller than Le, but

in low EKE areas, a k^{-2} slope should be found for scales smaller than Lv, but a shallower slope should be found between Le and Lv.

(Sasaki and Klein, 2011)

How these results compare with the observations in low EKE areas....

Velocity spectrum from altimetry (black line) and High Frequency Radar observations off the California coast (Kim et al. JGR 2011)



A k^{-2} slope is observed only for scales smaller than Lv~100km (smaller than Le~300km)

Summary

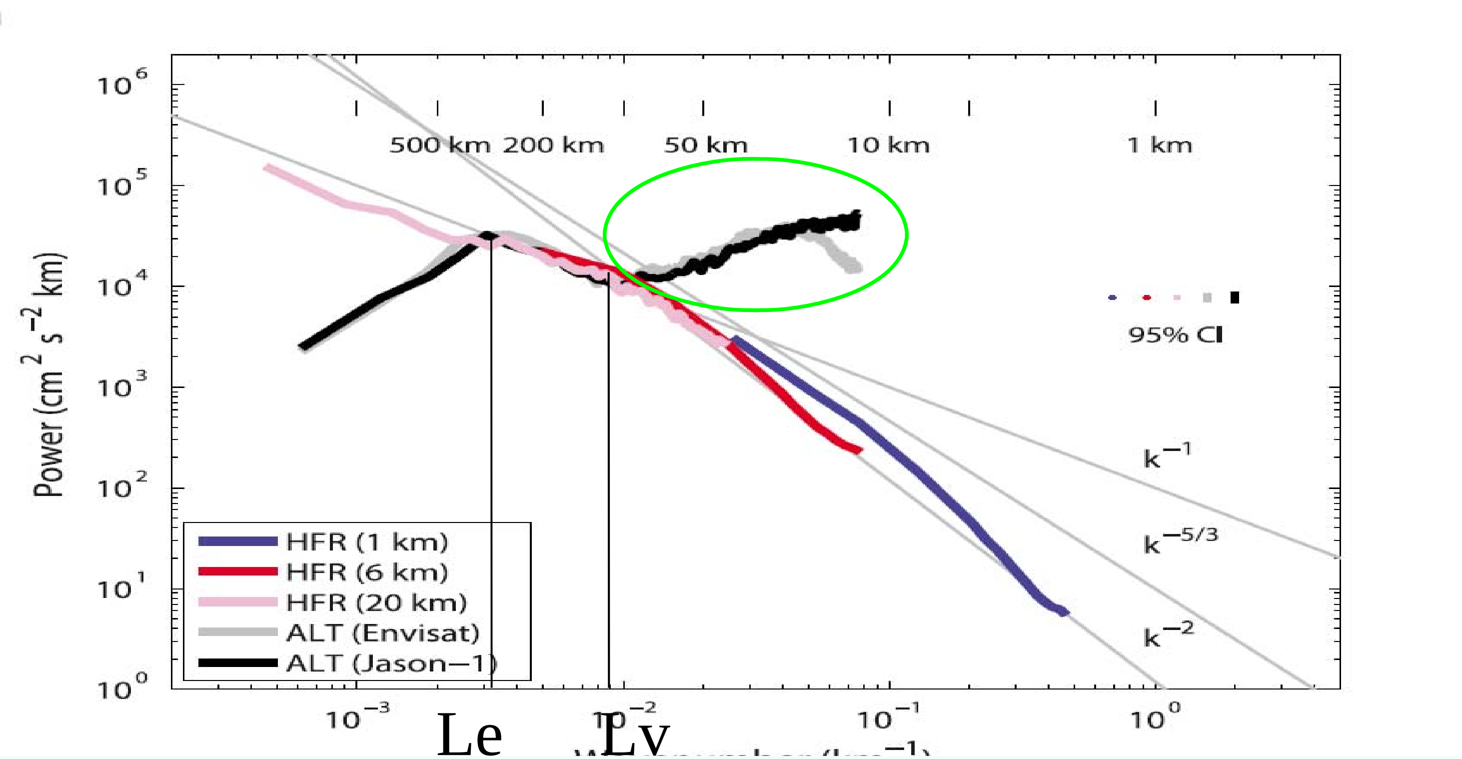
@ If submesoscales have an impact on larger scales, the SSH spectrum should have a k^{-4} slope and not a k^{-5} slope

@ A k^{-4} SSH spectrum slope (k^{-2} velocity spectrum slope) can be observed only for scales smaller than Lv (related to the peak of the relative vorticity spectrum) that may differ from Le (related to the peak of the velocity spectrum) in low EKE areas.

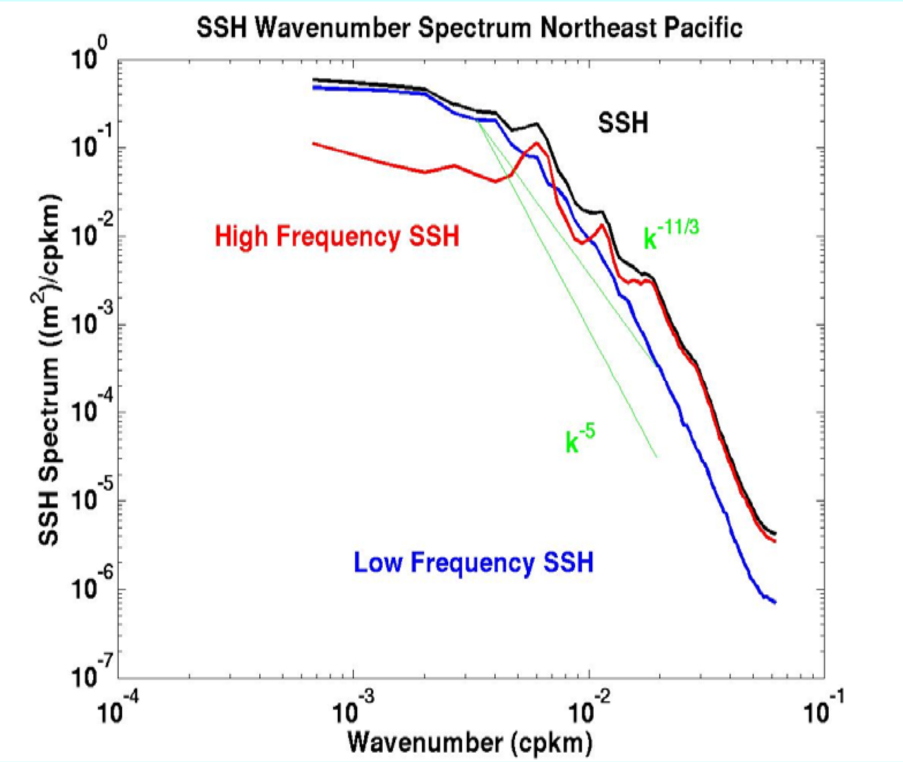
@ In both high and low EKE areas in the NP submesoscales have an impact on the SSH spectrum.

@ Further studies need to be done to better understand the impact of submesoscales on the larger ones in low EKE areas

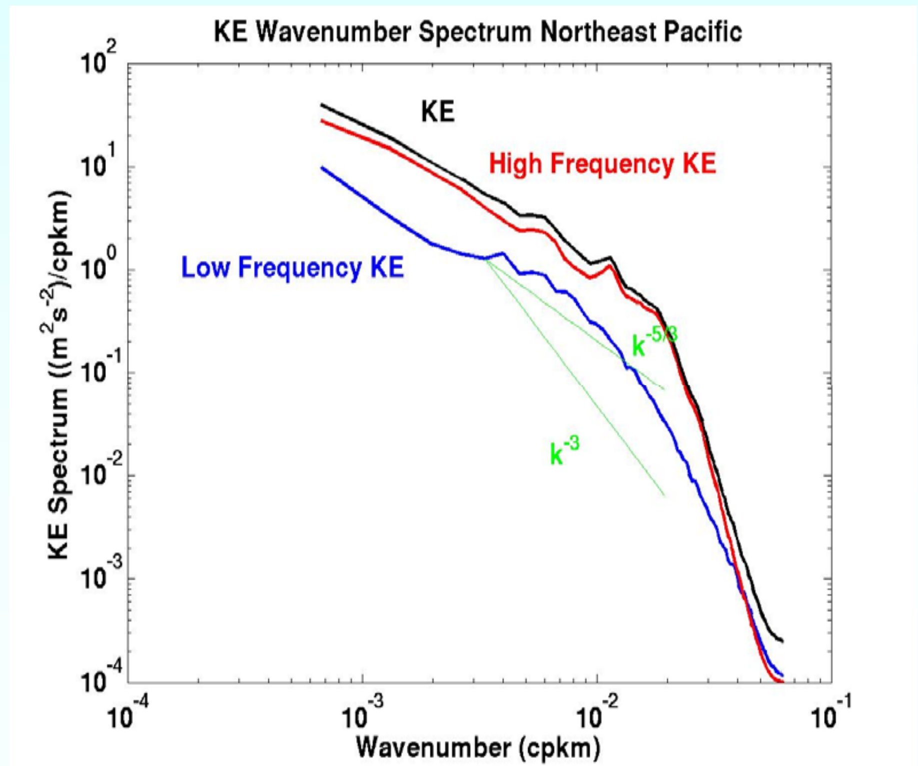
Velocity spectrum from altimetry (black line) and High Frequency Radar Observations (Kim et al. JGR 2011)



A k^{-2} slope is observed only for scales smaller than Lv~100km (< Le~300km)

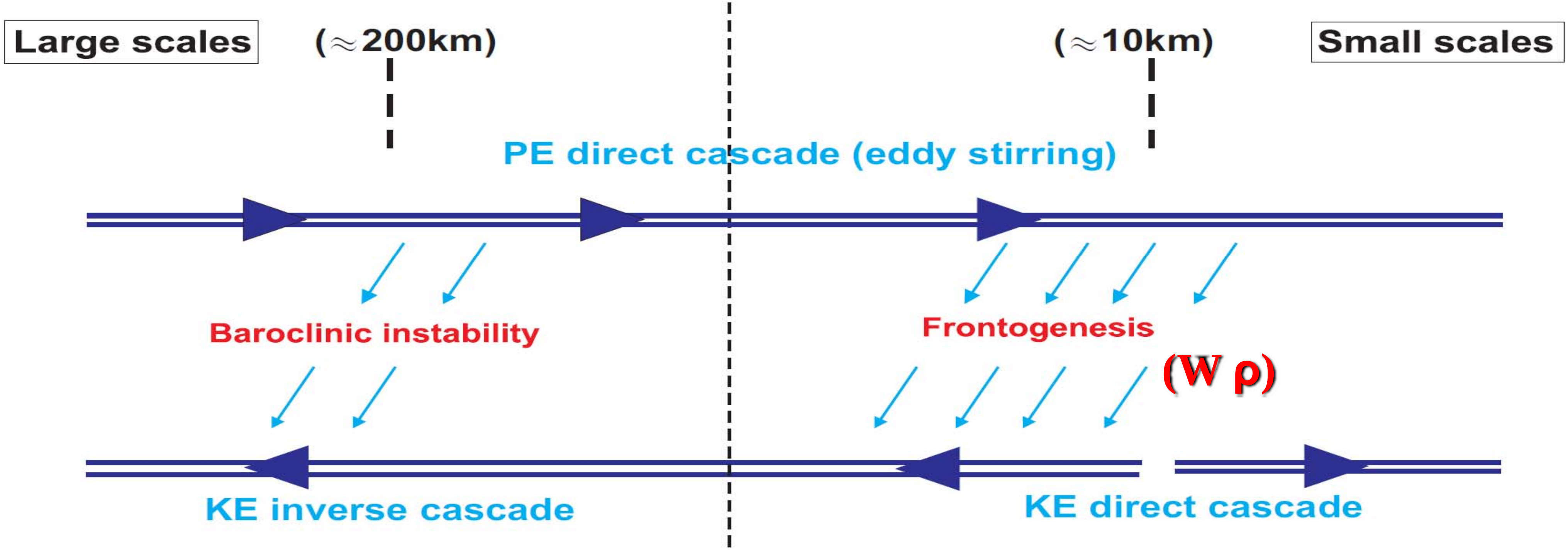


SSH Wavenumber Spectrum Northeast Pacific
SSH
High Frequency SSH
Low Frequency SSH
k-11/3
k-5
SSH Spectrum ((m2)/cpkm)
Wavenumber (cpkm)



KE Wavenumber Spectrum Northeast Pacific
KE
High Frequency KE
Low Frequency KE
k-5/3
k-3
KE Spectrum ((m2s-2)/cpkm)
Wavenumber (cpkm)

... Frontal dynamics at submesoscale modifies the nonlinear interactions over a large spectral range

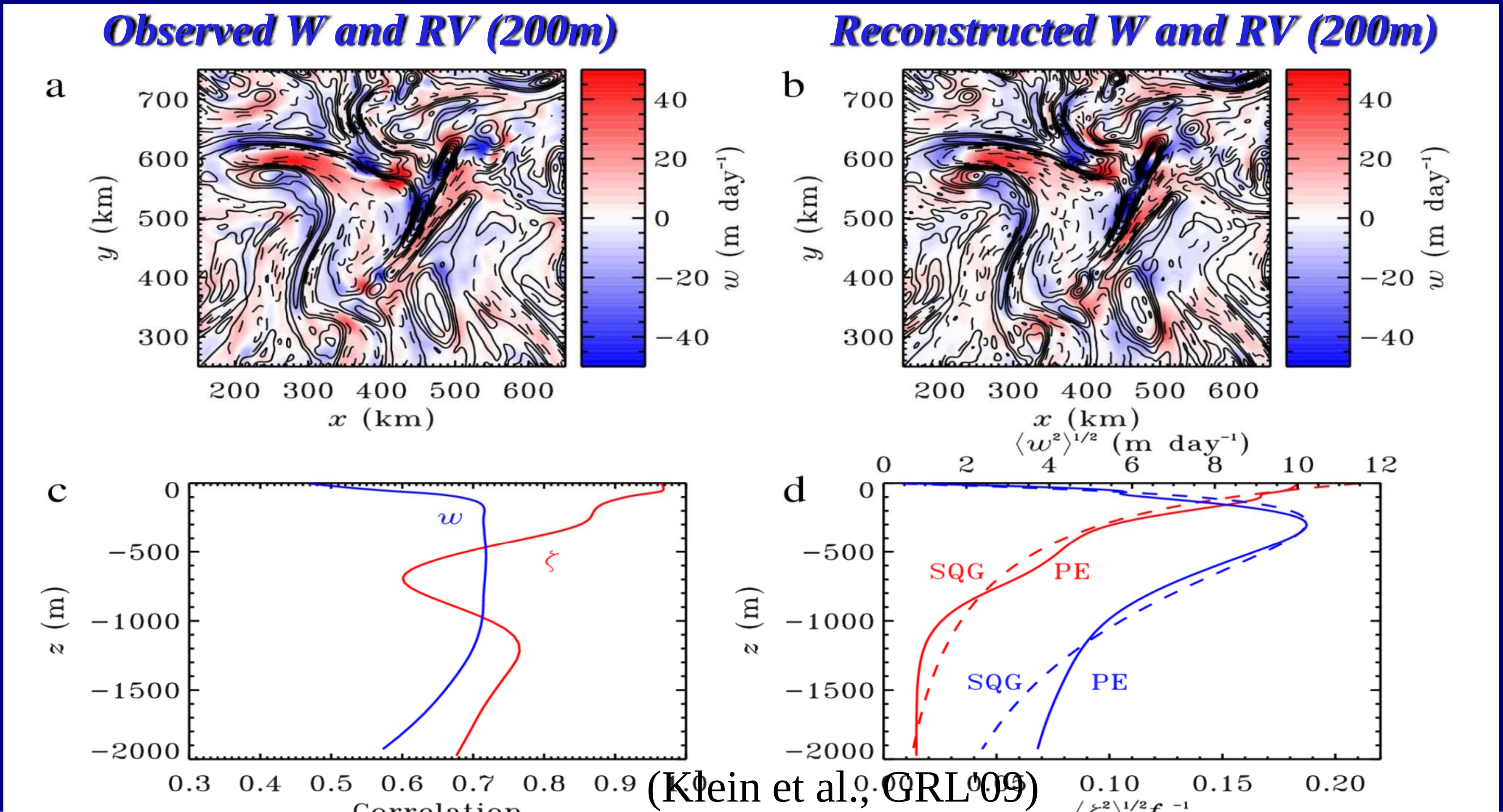


Submesoscales efficiently feed up mesoscale eddies and larger scales
(Capet et al., 2008; Klein et al., 2008)

=> SSH spectrum slope in k^{-4}
in the mesoscale and submesoscale range

Knowledge of HR SSH* and climatological stratification combined with results from theoretical studies should allow to *diagnose* not only the surface currents but also *the 3D motions (including the vertical velocity)* in the first 500m *below the mixed-layer:

=> Access to the horizontal and vertical fluxes of any tracers



(Klein et al., GRL'09)