Impact of Oceanic Scale-Interactions on the Seasonal Modulation of Ocean Dynamics by the Atmosphere

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Ocean Scale Interactions - A Tribute to Bach Lien HUA -, June 23-25, 2013

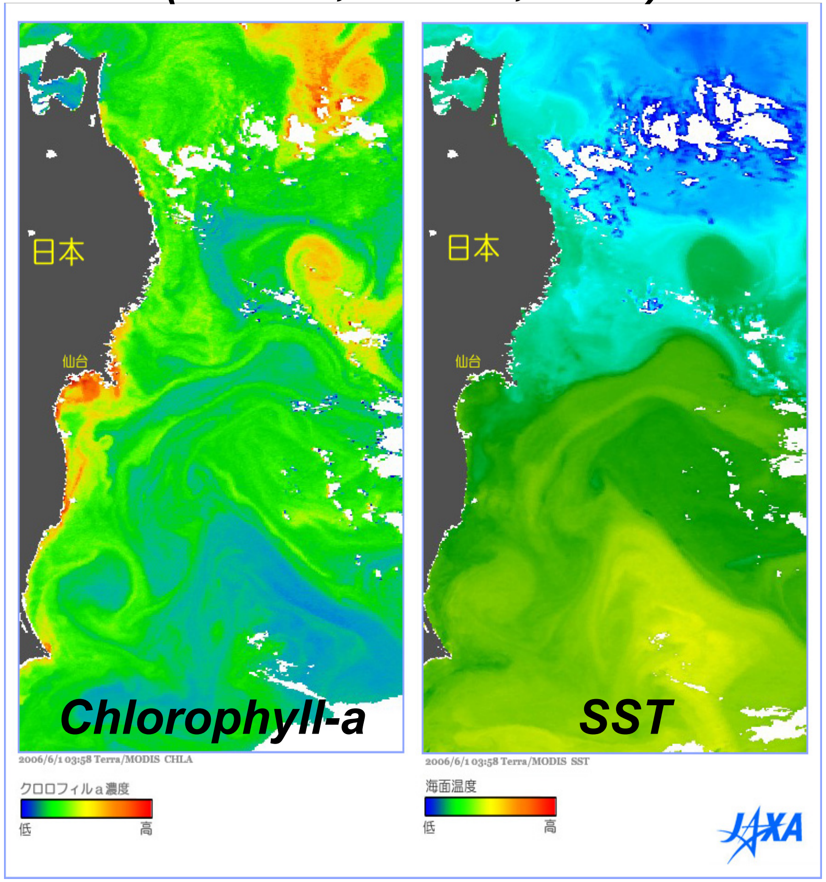
Introduction

Oceanic flow is highly turbulent with a very broad range of scale.
(O(1000km – O(1km)…)
⇒ Energetic Scale Interactions

Satellite Observation
(Ocean Color & SST)
Not only mesoscale (O(100km)) structures but also smaller scales (submesoscales down to O(10km))

Numerical Simulation Studies
Non-negligible contributions of the submesoscales to vertical transports and impact on large-scale ocean properties via nonlinear interactions (Capet et al. 2008; Klein et al. 2008; Lévy et al. 2010).

Satellite observation
(MODIS, June 1, 2006)



MODIS: Moderate Resolution Imaging Spectroradiometer

Introduction

Mensa et al (2013): Seasonality of the submesoscale dynamics in the Gulf Stream region in a 1/48° realistic simulation (compared with that in the coarse (1/12°) resolution simulation)

A seasonal cycle of submesoscale:

Submesoscale mostly present in winter

Dynamics of active submesocales in winter

The mixed layer instabilities (MLIs) mostly due to deepening of the mixed layer (ML), which controls available potential energy.

 # MLI (e.g. Stone, 1970, Boccaletti et al., 2007): Ageostrophic baroclinic instabilities along the density fronts in the ML.

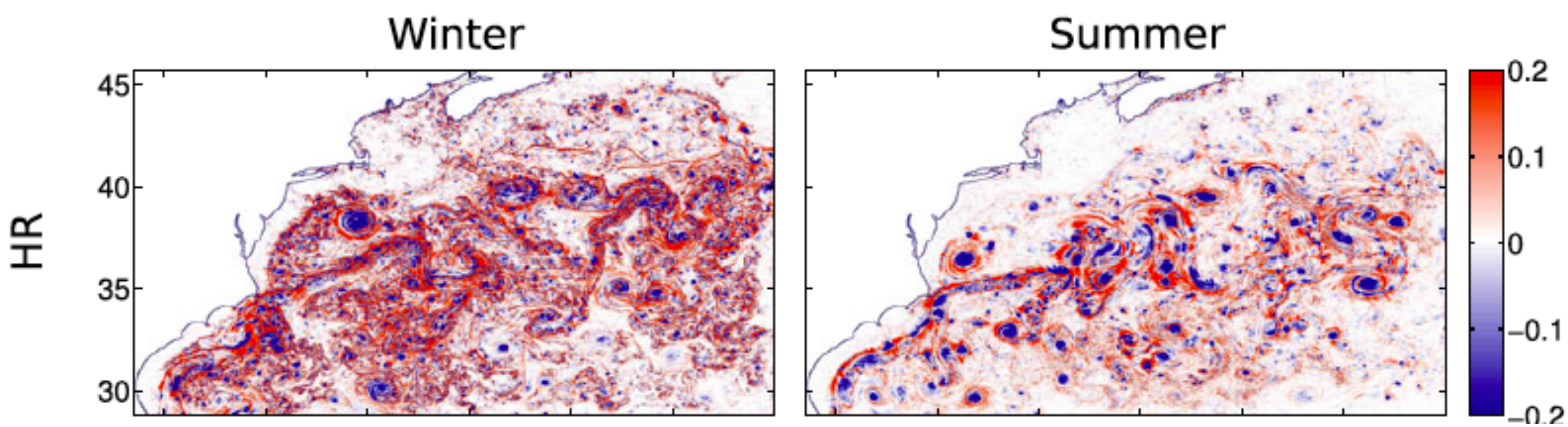


Fig. 14 in Mensa et al.(2013): Okubo–Weiss parameter normalized by f^2 at the surface (5 m)

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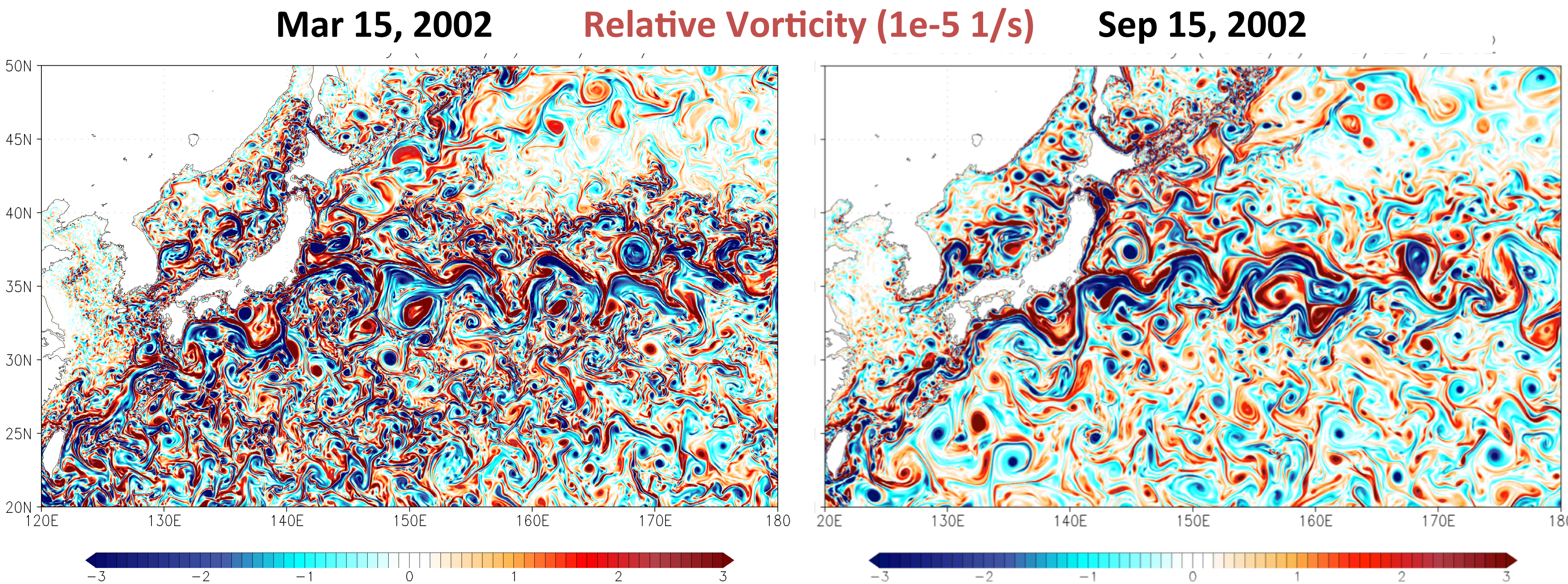
Purpose of this study

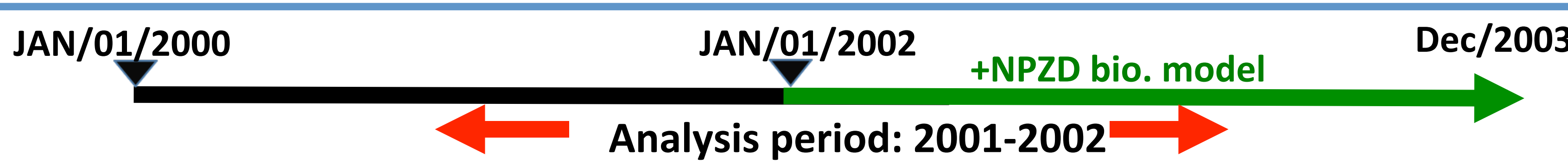
How much of the seasonally-varying submesoscale energy is dissipated or feeds up mesoscale oceanic eddies and larger scales?

Because the nonlinear interactions cover a wide spectral range, a realistic high-resolution numerical simulation of large domain is needed to challenge this study.

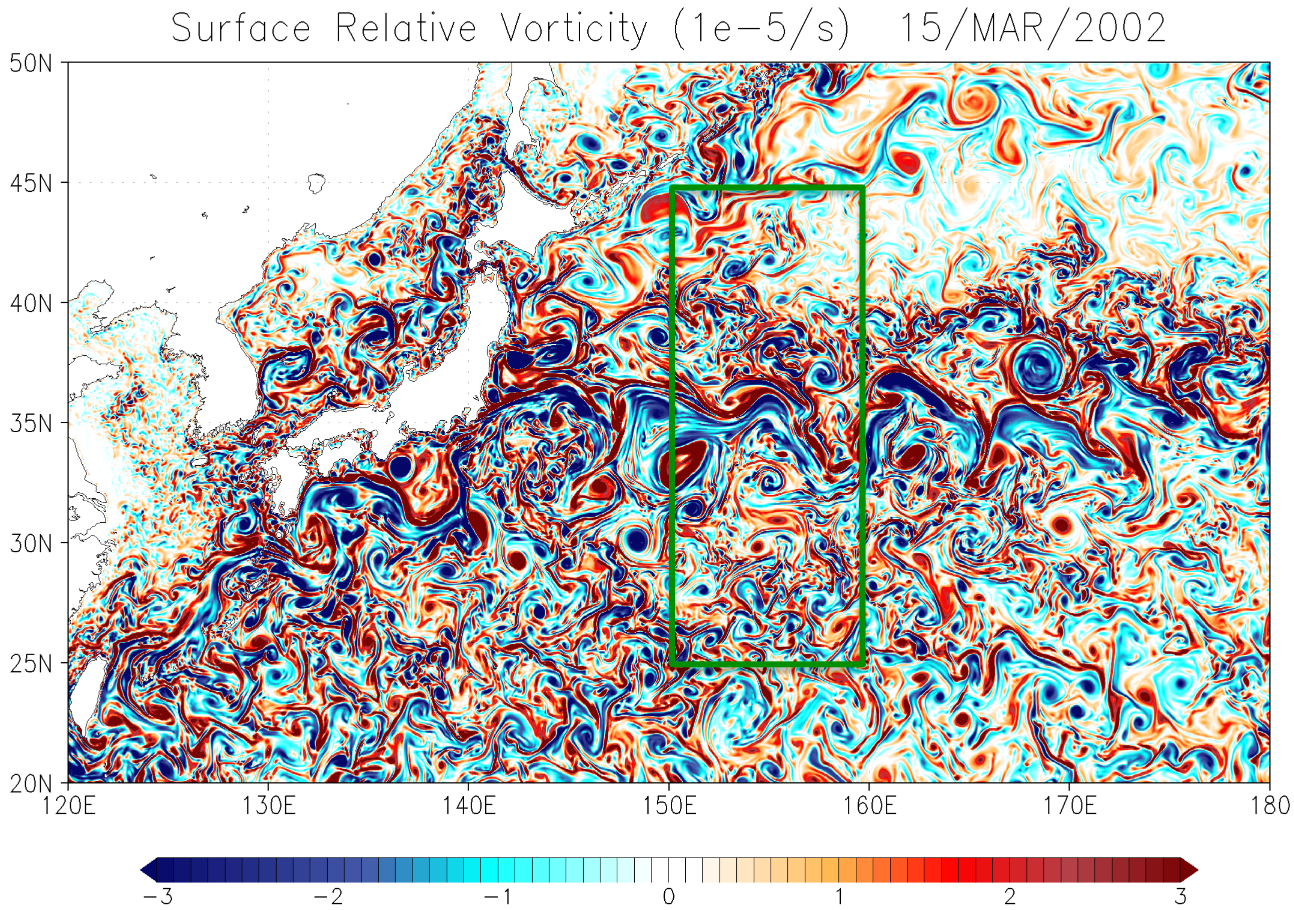
OFES 1/30° North Pacific Simulation



Model: OFES (OGCM for the Earth Simulator based on MOM3, Masumoto et al., 2004)
Domain: North Pacific (20S-68N, 100E-70W)
Resolutions: 1/30° Number of vertical level: 100
Horizontal mixing: Bi-harmonic, **Vertical mixing**: Noh and Kim (1999)
Forcing: 6 hourly reanalysis data of JRA-25(Onogi et al., 2007)
Initial condition: Outputs of 0.1° hindecast simulation on JAN/01/2000

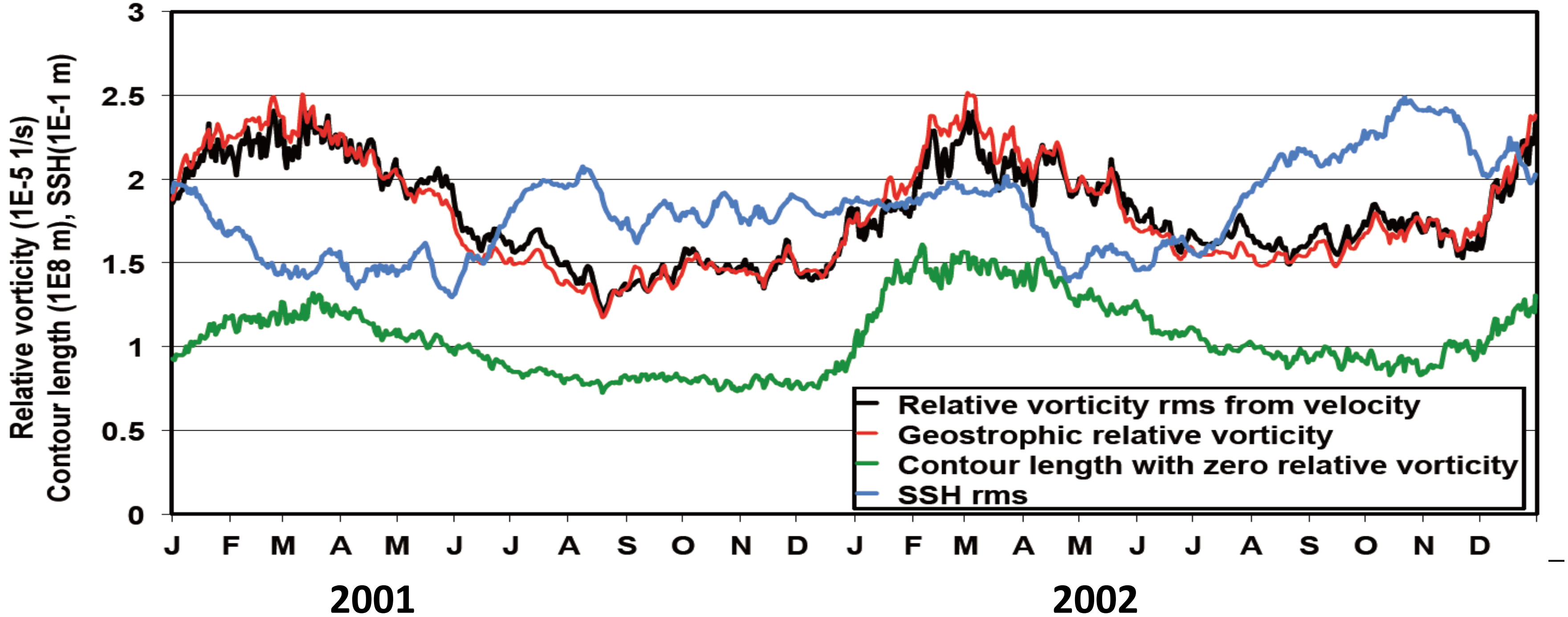


Characteristics of the seasonality and dynamics of submesoscale around the Kuroshio Extension



Analysis Box: 150-160E, 25-45N

Seasonality of submesoscale activity



Magnitude of relative vorticity RMS:

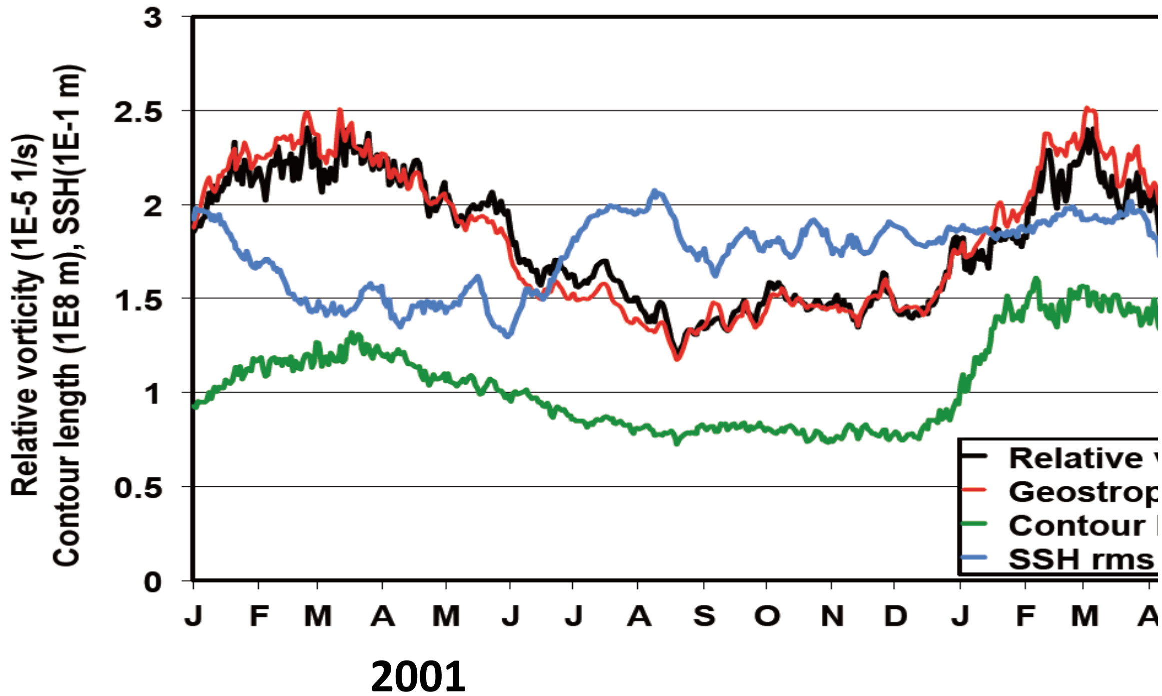
Larger in late winter and smaller in summer (factor 1.5) ⇒ *Seasonality of submesoscale*

Correlation between **relative vorticity RMS** and **length of contour with 0 value**: 0.79

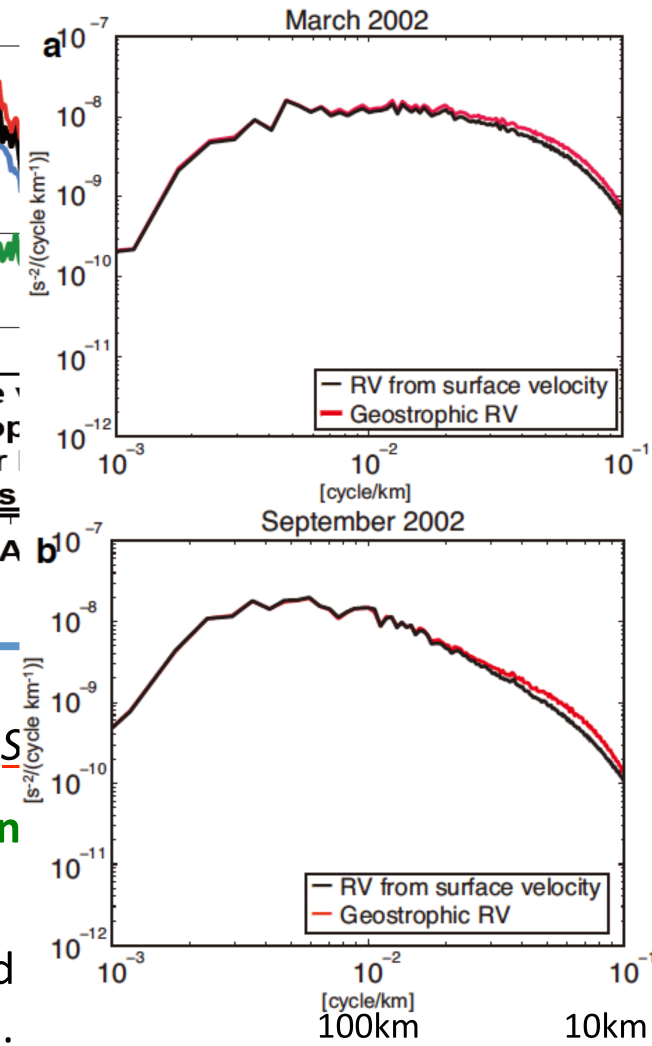
⇒ *Seasonality of submesoscale activity is confirmed.*

High correlation between **relative vorticity from velocity** and **relative vorticity from SSH**(0.97)

Seasonality of submesoscale activity



Relative Vorticity Spectra



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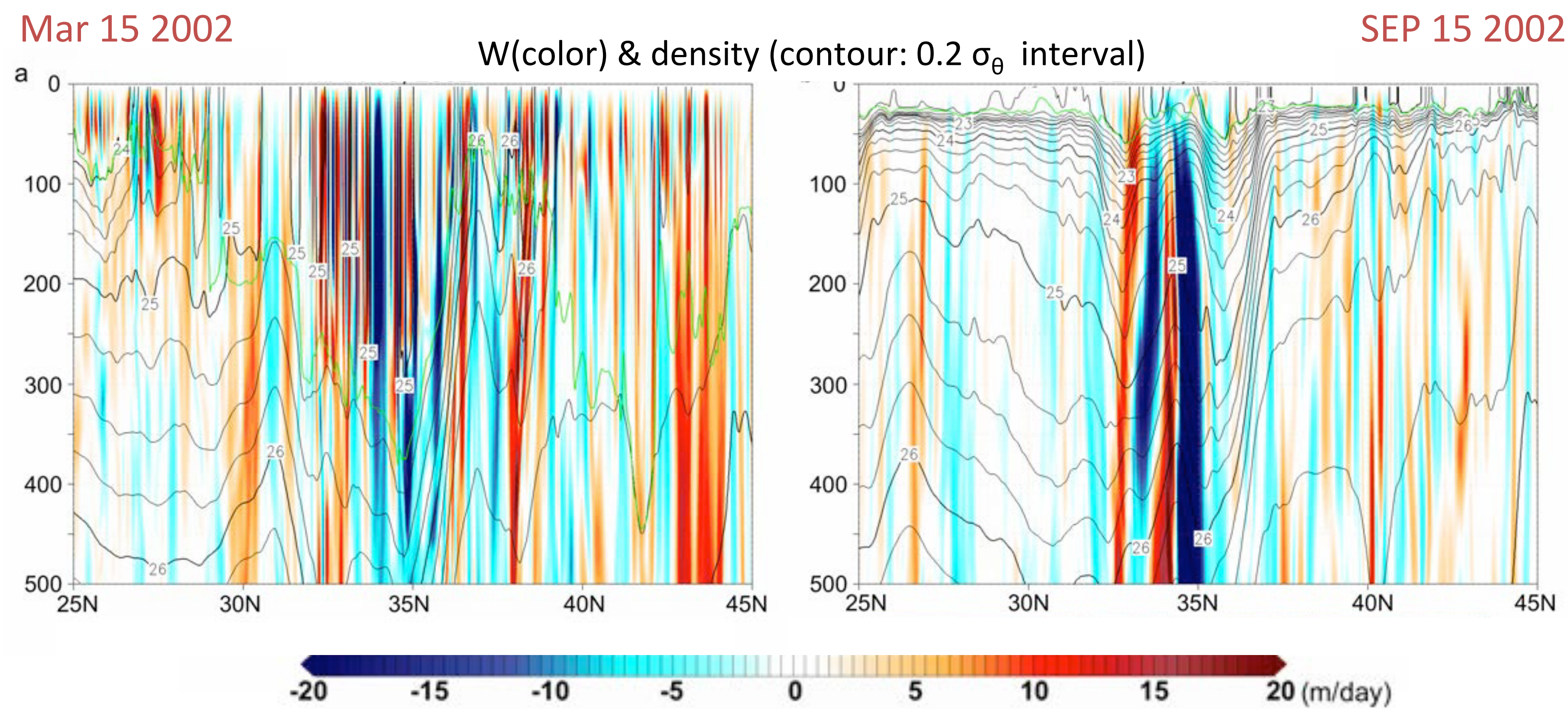
High correlation between **relative vorticity from velocity** and
⇒ The surface flow is statically in geostrophic equilibrium.

High-resolution SSH (will be observed by SWOT and COMPIRA missions in several years) should capture seasonality of submesoscales in various regions.

Vertical motion and density at 155E



March 15 (Late winter)

Large vertical motions (> 10 m/day) with small scale within the ML

Some vertical motions notably extending below the ML

September 15 (Late summer)

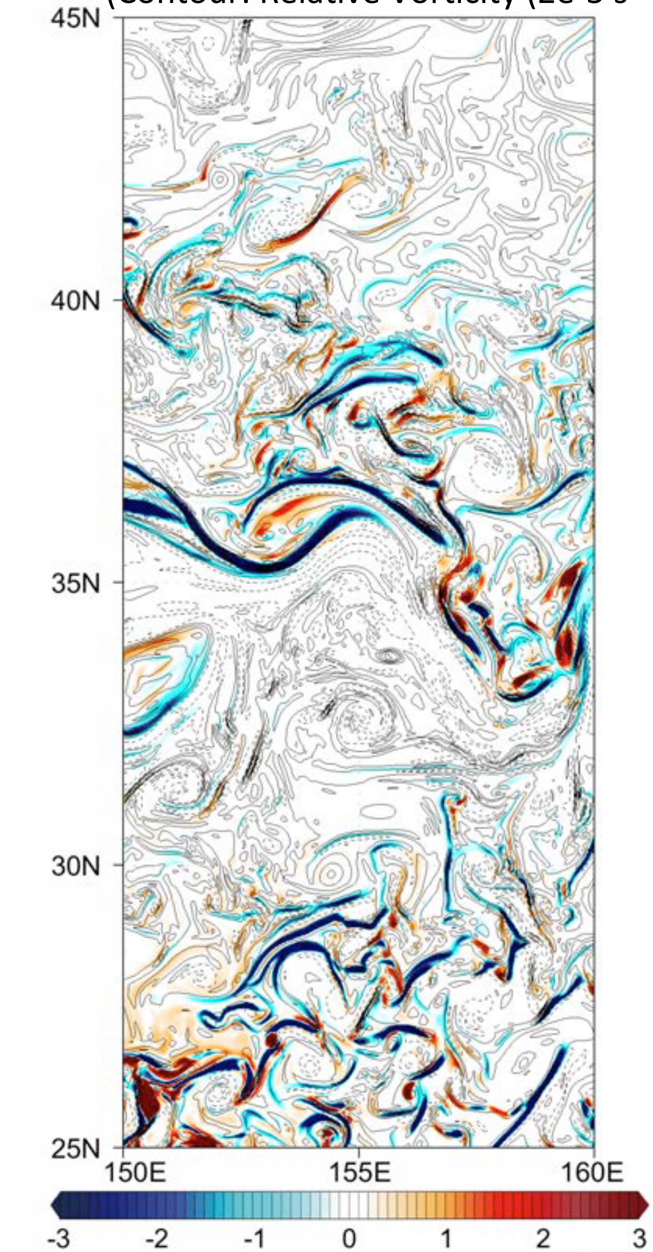
Weak vertical motion (< 5 m/day) within the ML (whose thickness is about 20m).

Large vertical motions (> 5 m/day) below the ML with horizontal scales not as small as in winter.

Symmetric Instability (Ertel Potential Vorticity at 25m)

EPV at 25m on March 15, 2002

(Contour: Relative Vorticity (2e-5 s^{-1} interval))



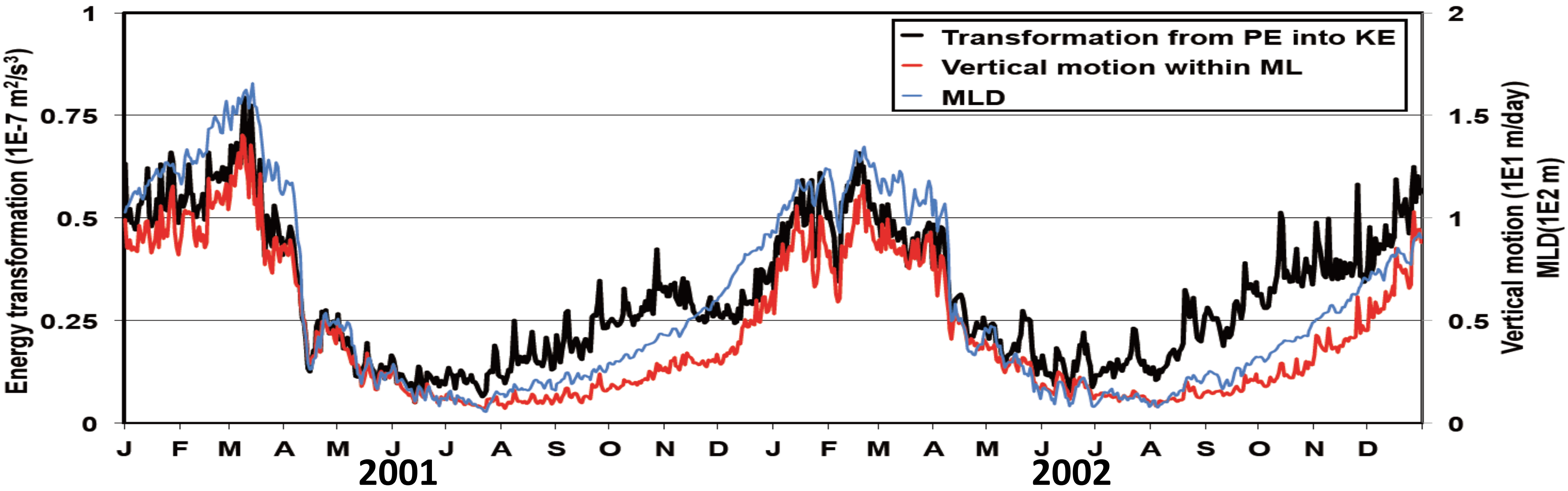
EPV at 25m on March 15 (Late winter)

Large negative EPV (<-2e-9 1/s^{-3}) along relative vorticity contours.

⇒ *Symmetric instability (Hoskins, 1974) along submesoscale fronts*

No symmetric instabilty within the ML in summer (not shown)

Seasonality of vertical motions, PE into KE, and MLD



Vertical motions within the mixed layer and **transformation PE into KE**

Large in winter and small in summer with rapid decay in late winter

High correlation with **Mixed layer depth** : 0.97(**Vertical motions**), 0.92(**PE into KE**)

(consistent with Capet et al., 2008; Mensa et al., 2013)

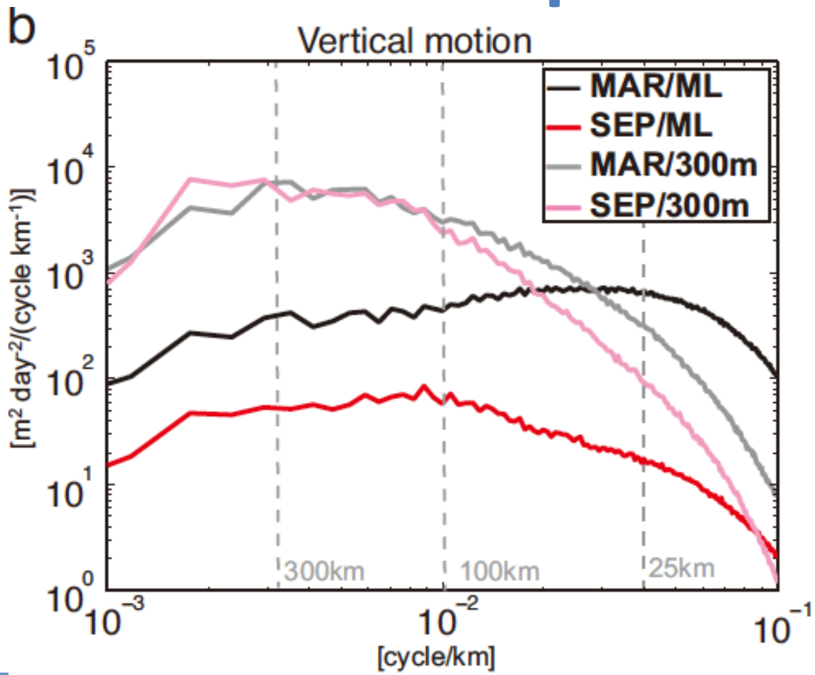
⇒ *Atmosphere variations (influences much on MLD variations) control production of oceanic fine scales.*

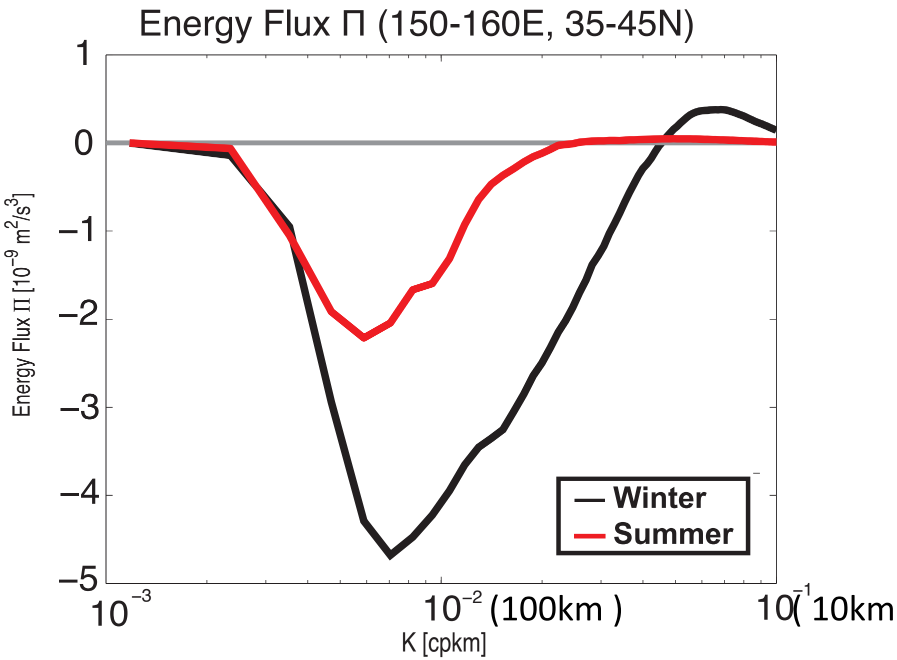
Correlation between these time series and relative vorticity (no rapid decay): 0.7

Submeso/mesoscale fields do not respond to these abrupt variations immediately.

⇒ *Other processes such as the nonlinear scale interactions are at work*

Wavenumber Spectra in 2002 (150-160E, 35-45N)





Spectra of Vertical Motion

- Scales of spectral peak within the ML: ≈ **25 km (MAR)** , **100km (SEP)**

25 km (MAR) is close to the most unstable MLI (Mixed Layer Instability) wavelength.

⇒ Transformation of KE into PE occurs at this fine scale.

- Relatively shallow slope in small scale range at 300m in **MAR** compared with **SEP**

⇒ Large contributions of vertical motions with submesoscales below the ML.

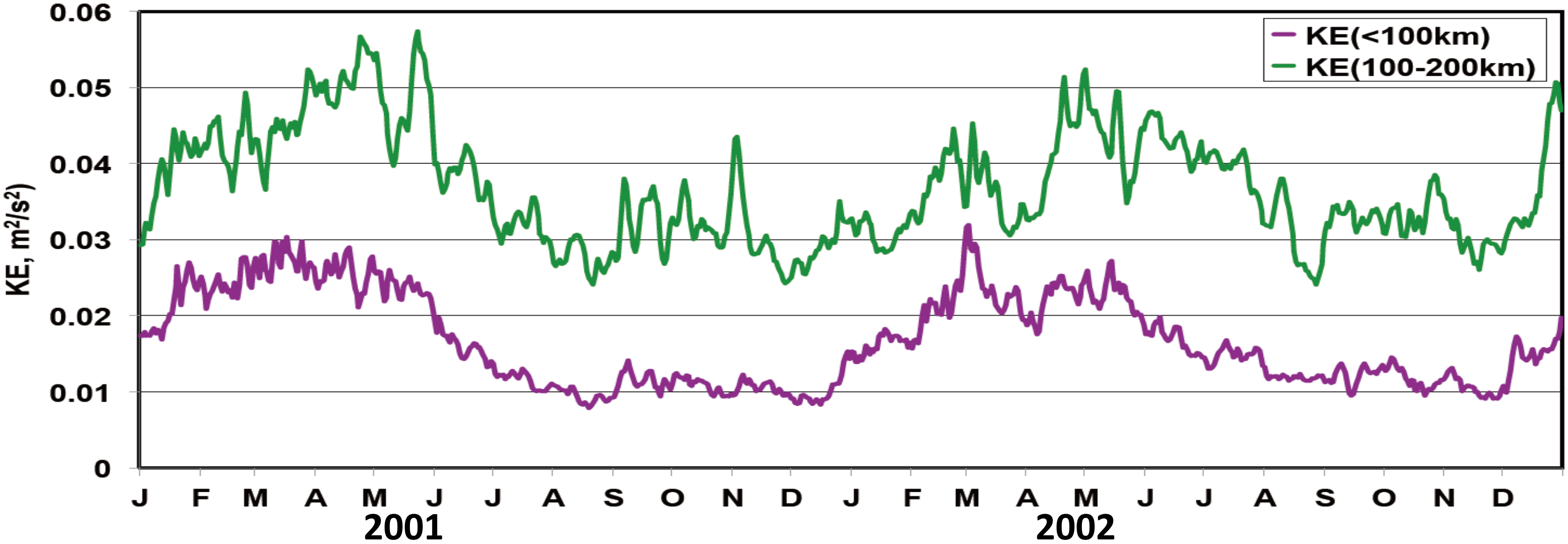
Spectra of Energy Flux between horizontal scales

Large negative values in small scales in winter

⇒ Large inverse KE cascade from small scale in winter, but not in summer.

 # This result highlights significant dynamical impact of small scale on large scale.

Seasonality of Kinetic Energy



KE (<100km), KE(100-200km):

Large in late winter and small in summer – autumn

KE(100-200km) > (by two times) **KE (<100km)**

⇒ Significant seasonal modulation of mesoscale eddies should be induced by atmospheric forcings through an energy pathway involving the transformation of KE into PE at fine scales and an inverse KE cascade towards larger scales.

Conclusions

The 1/30° North Pacific OFES exhibits seasonality of submesoscale activity around the Kuroshio Extension.

1) An efficient energy pathway setup by atmospheric forcing induces a significant seasonal modulation of the mesoscale eddies.

2) The sesonality of submesoscales and its dynamics should be captured by high-resolution SSH (SWOT and COMPIRA missions).

3) The vertical motions with submesoscale penetrating below the ML in winter should contribute much on vertical transport of tracers including biogeochemical materials.