Last results and perspectives of balanced motions and internal gravity waves: submesoscale impacts in winter

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Outline

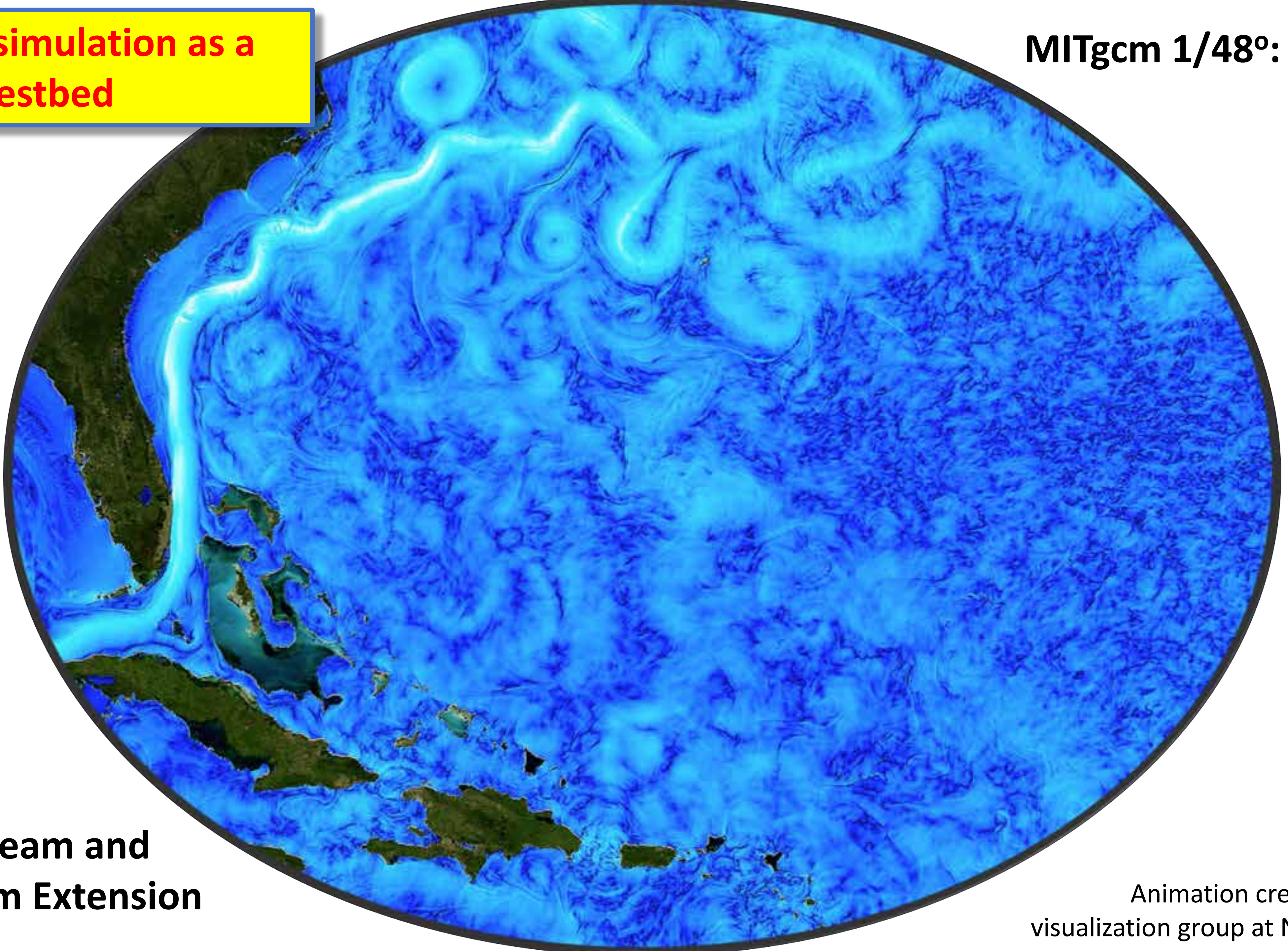
1. Helmholtz decomposition

2. Surface kinetic energy during the wintertime

3. Vertical heat fluxes and submesoscale motions

LLC4320 simulation as a testbed

MITgcm 1/48º: Surface speed



Gulf Stream and Gulf Stream Extension

Animation created by the visualization group at NASA/AMES

Helmholtz decomposition

$$u = -\psi_y + \varphi_x, \qquad v = \psi_x + \varphi_y$$

with ψ the stream function and ϕ the potential. This leads to

$$RV = \zeta = v_x - u_y = \Delta\psi \qquad DIV = -w_z = u_x + v_y = \Delta\varphi$$

In the *ω-k* spectral space, the relation between KE, RV and DIV is:

$$\widehat{KE} = \left|\widehat{RV}\right|^2/k^2 + \left|\widehat{DIV}\right|^2/k^2$$

$\left|\widehat{RV}\right|^2/k^2$ **and** $\left|\widehat{DIV}\right|^2/k^2$ **are called respectively the RV and DIV contributions to KE.**

Motivation is that this decomposition is often used to discriminate IGWs from BMS with DIV part assumed to be mostly explained by IGWs (Buhler et al. 2013; Rocha et al. 2016; Qiu et al. 2017).

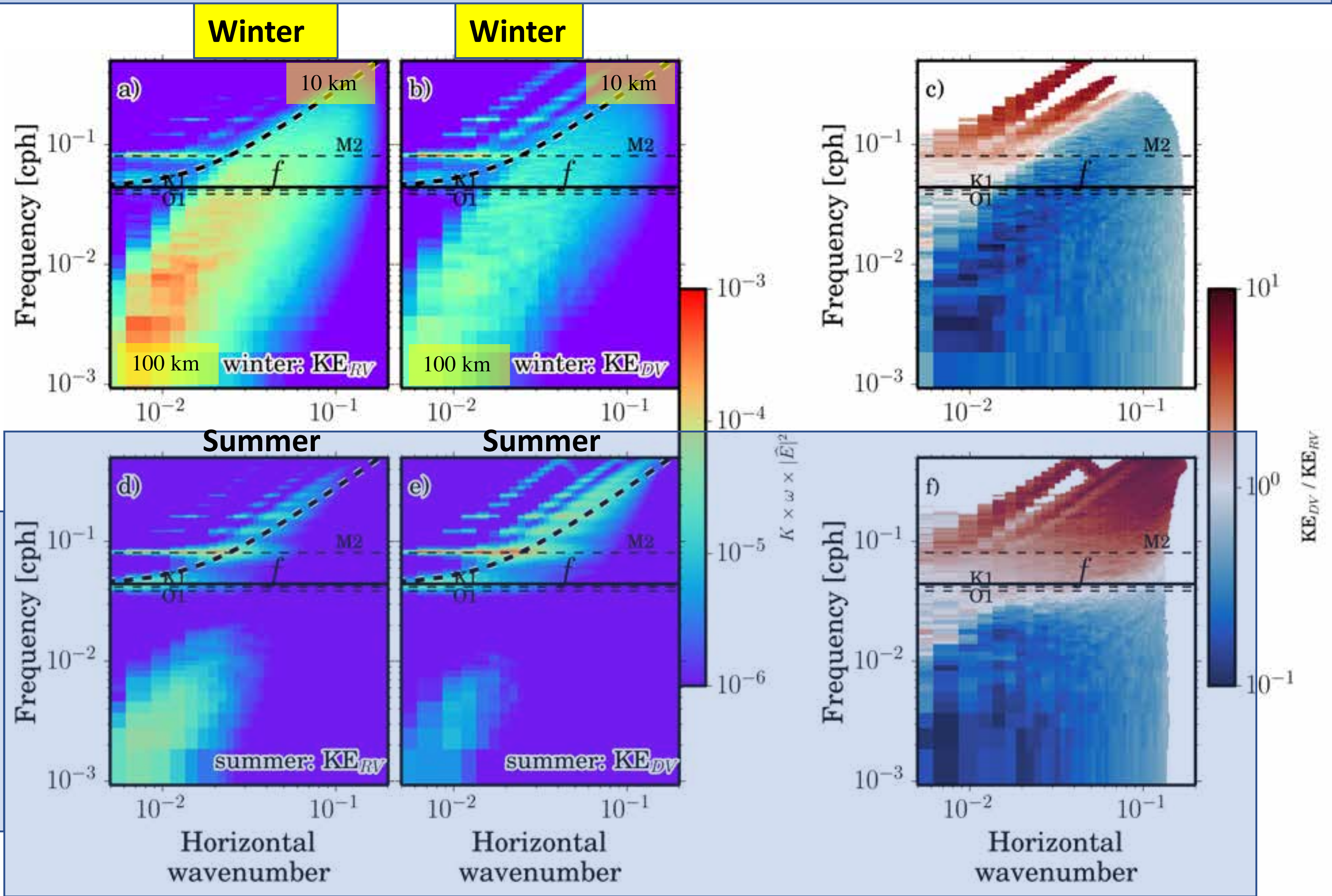
The picture from the *ω-k* spectra is different in winter.

Helmholtz decomposition: Kuroshio Extension
RV and DIV contribution to KE

The winter RV and DIV contributions to KE are dominated by BMs

Submesoscale BMs dominate the divergent part

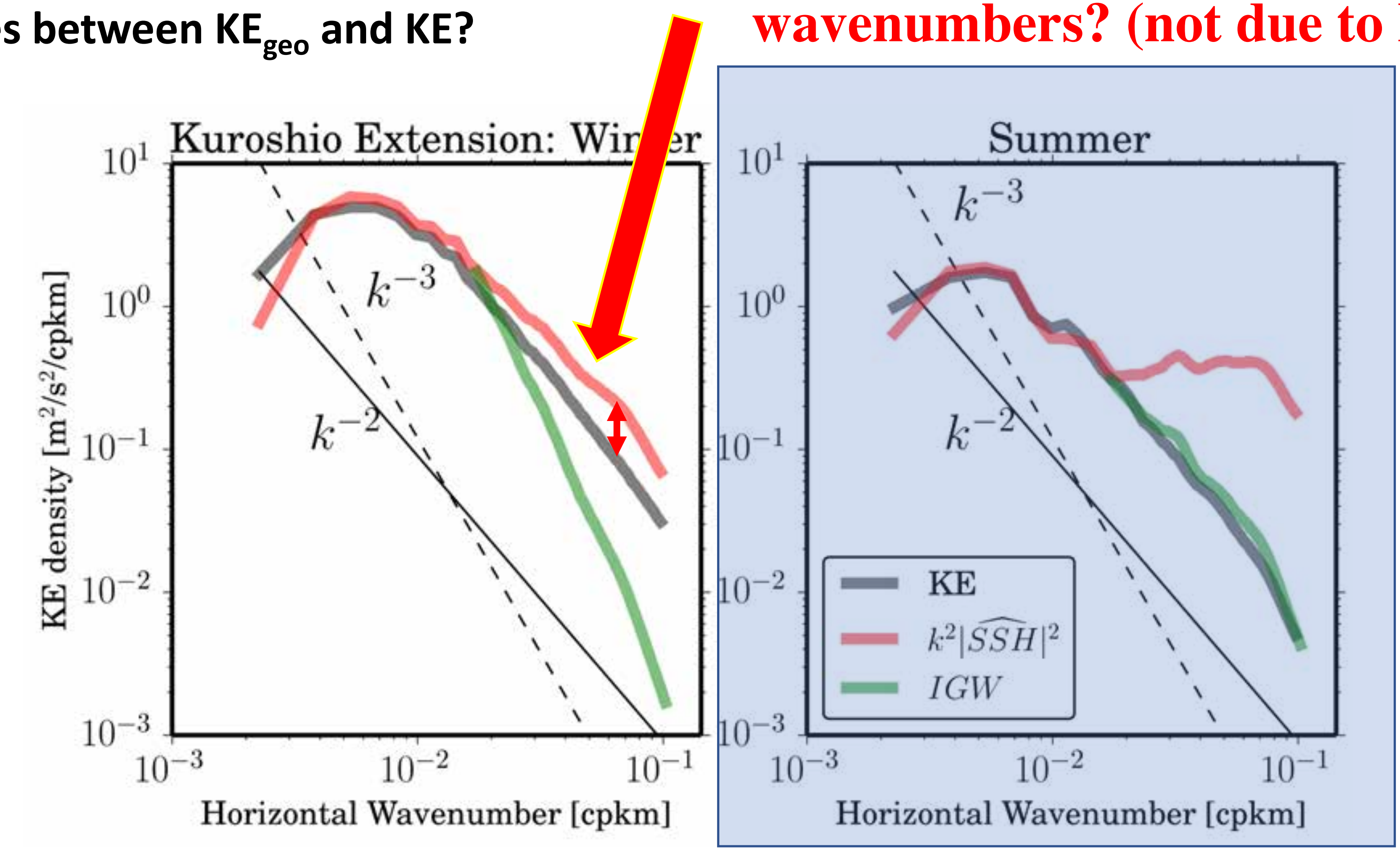
- The summer RV and DIV contributions to KE are dominated by IGWs
  - IGWs dominate the divergent part



Kinetic energy during the wintertime

Now, lets talk about the wintertime and the differences between KE_{geo} and KE?

- **Geostrophic KE is larger than KE at higher wavenumbers? (not due to IGWs!)**



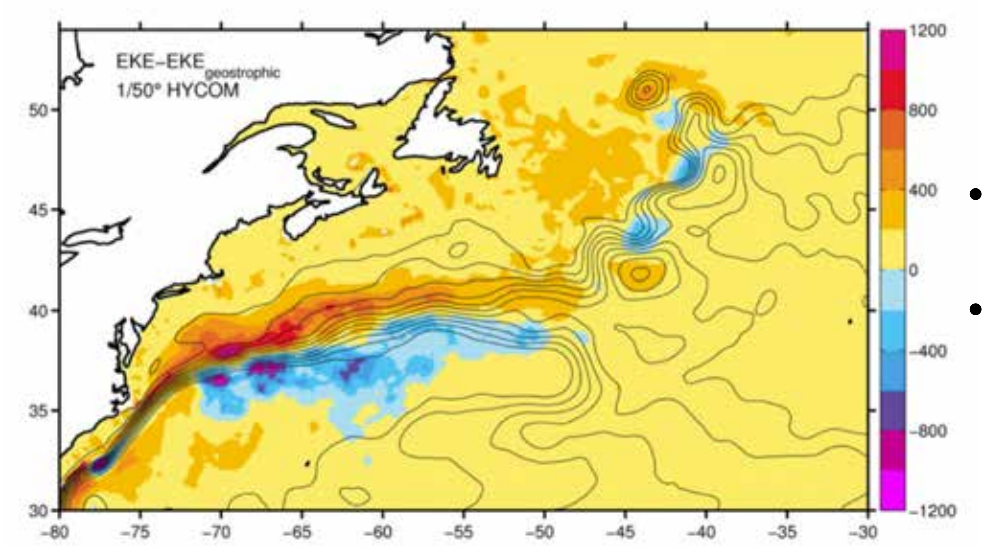
This is due to gradient-wind balance

$$\vec{u} \cdot \nabla \vec{u} + f \hat{k} \times \vec{u} = -g \nabla \eta$$

cyclogeostrophic motions **[O(Ro)]**

Coriolis term **[O(1)]**

pressure term **[O(1)]**



$\Delta = \mathrm{EKE} - \mathrm{EKE}_{geo}$

- $\Delta > 0$ → Cyclonic side
- $\Delta < 0$ → Anticyclonic side

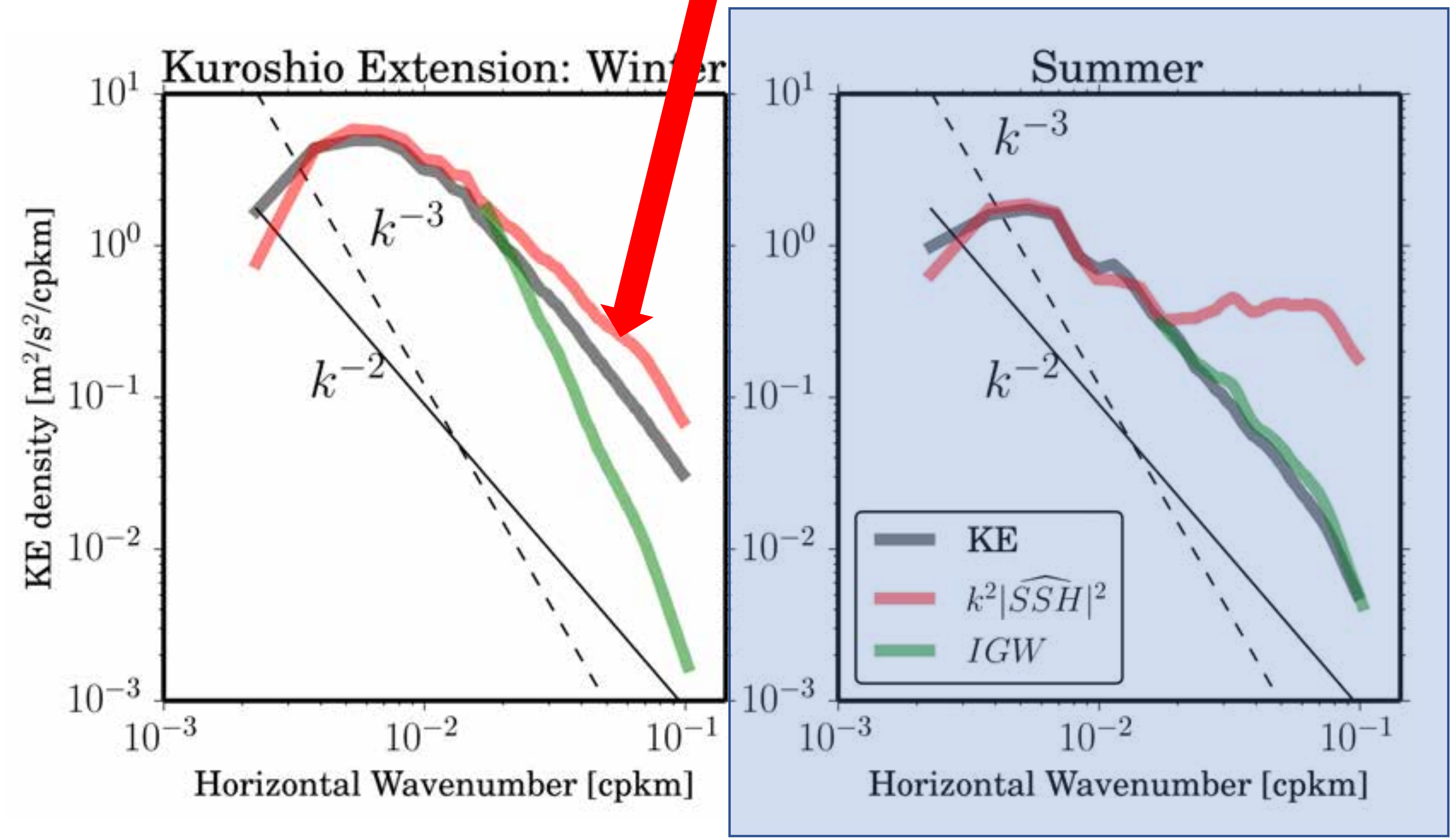
The geostrophic balance overestimates the velocity in cyclonic motions

Chassignet and Xu, 2017

Kinetic energy during the wintertime

Now, lets talk about the wintertime and the differences between SSH and KE?

The differences are explained by the gradient-wind balance:
Cyclonic motions dominate in submesoscales (because Ro ~ 1), leading to KE < KEgeo



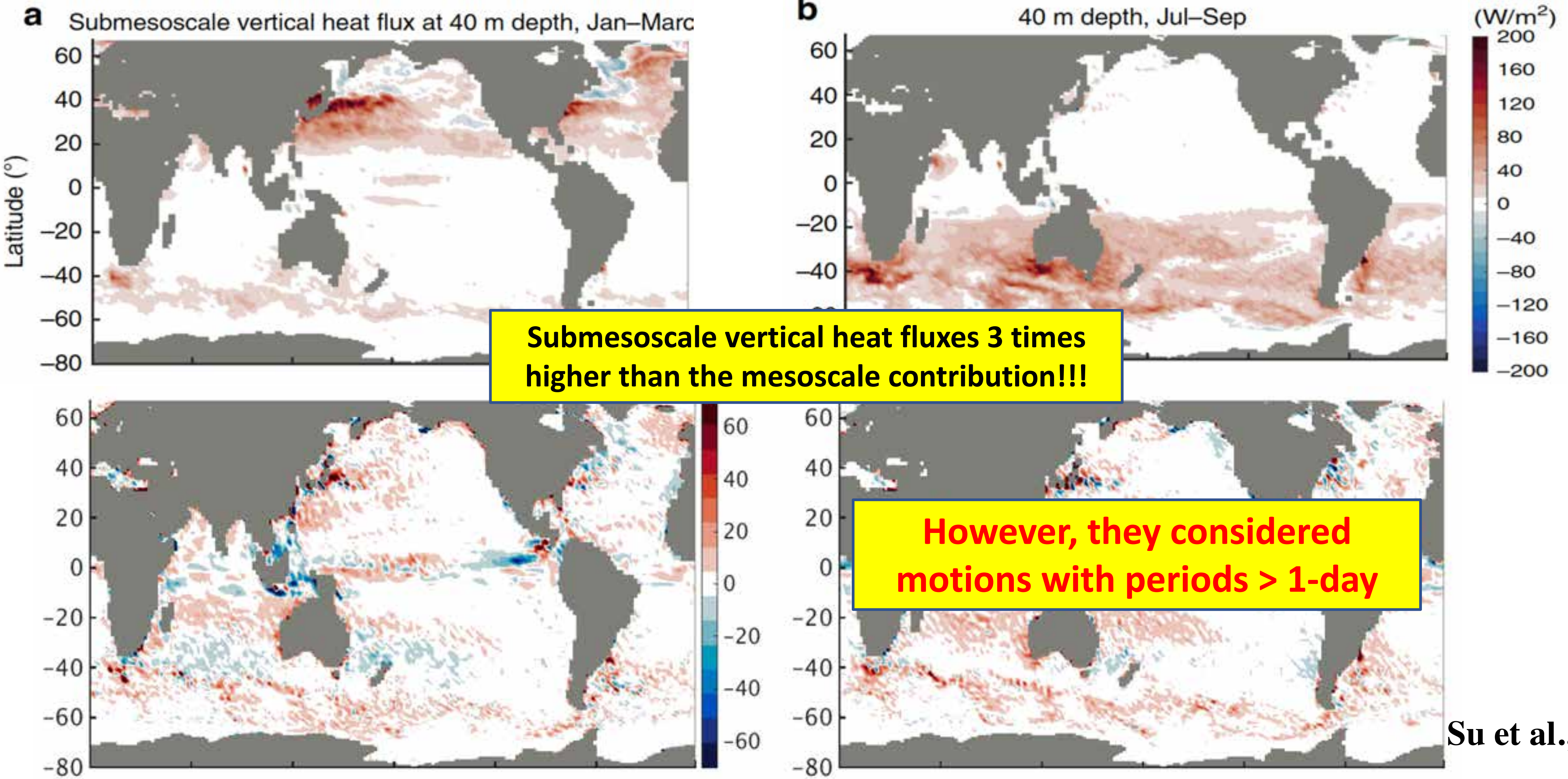
Conclusion

- **The differences between geostrophic KE and total KE in winter is due to submesoscale balanced motions in gradient-wind balance**

- **The differences between geostrophic KE and total KE in summer is due to internal gravity waves (see morning's talk)**

Impact of winter submesoscales on the vertical heat fluxes?

Jan-March, submesoscale daily-average | **Jul-Sep, submesoscale daily-average**



Submesoscale

Mesoscale

Submesoscale vertical heat fluxes 3 times higher than the mesoscale contribution!!!

However, they considered motions with periods > 1-day

Su et al., NC 2018

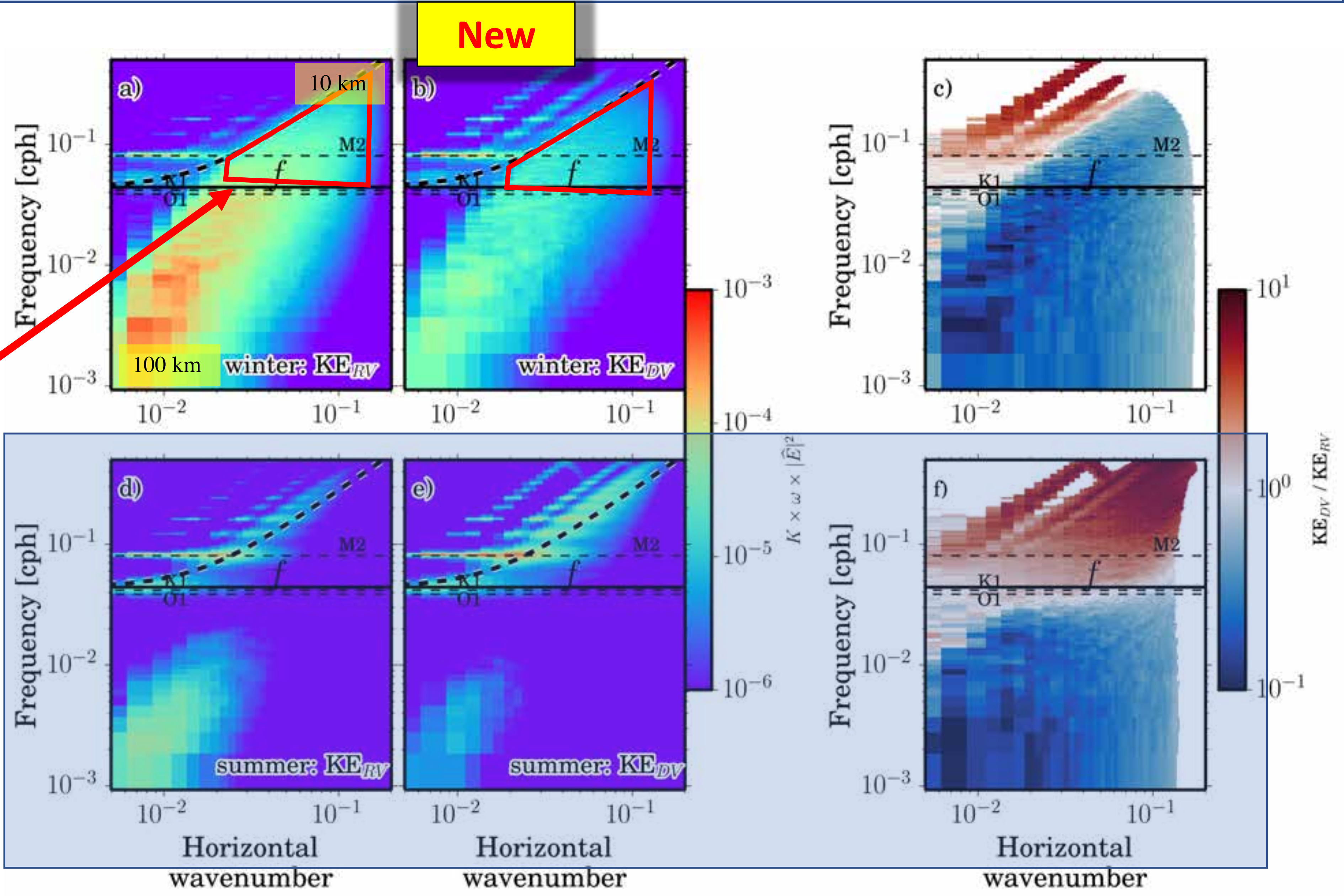
High-frequency balanced motions

RV and DIV contribution to KE

The winter RV and DIV contributions to KE are dominated by BMs

Submesoscales with frequencies higher than *f* are non-negligible (Thomas 2017; see Ed Zaron's talk)

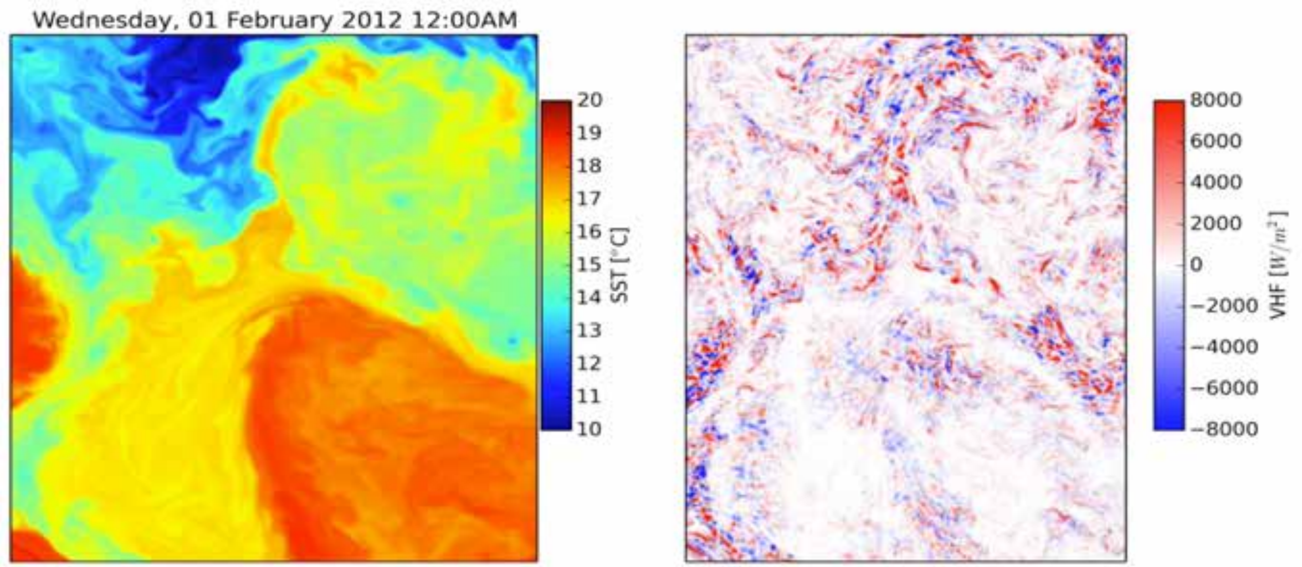
- The summer RV and DIV contributions to KE are dominated by IGWs
  - The third baroclinic mode is intensified in summer



Conclusion

➢ **Submesoscales associated with frequencies higher than f in winter lead to almost double the vertical heat fluxes.**

➢ **Work in progress. Su et al in preparation**



Ratio divergence/rotational in the wavenumber space

- **Winter:** The spectral slope of the RV contribution in winter is k^{-2}, as expected (Rocha et al. 2016; Qiu et al. 2017)

- **Summer:** Whereas RV contribution to KE explains most of the KE for large scales (> 70 km), **DIV contribution mostly explains KE for smaller scales (< 50 km)**

Ratio

$$\frac{|\widehat{DIV}|^2(k)}{|\widehat{RV}|^2(k)} = \frac{\omega^2}{f^2} = 1 + Rd^2k^2$$

Thus, the ratio increases as k^2.