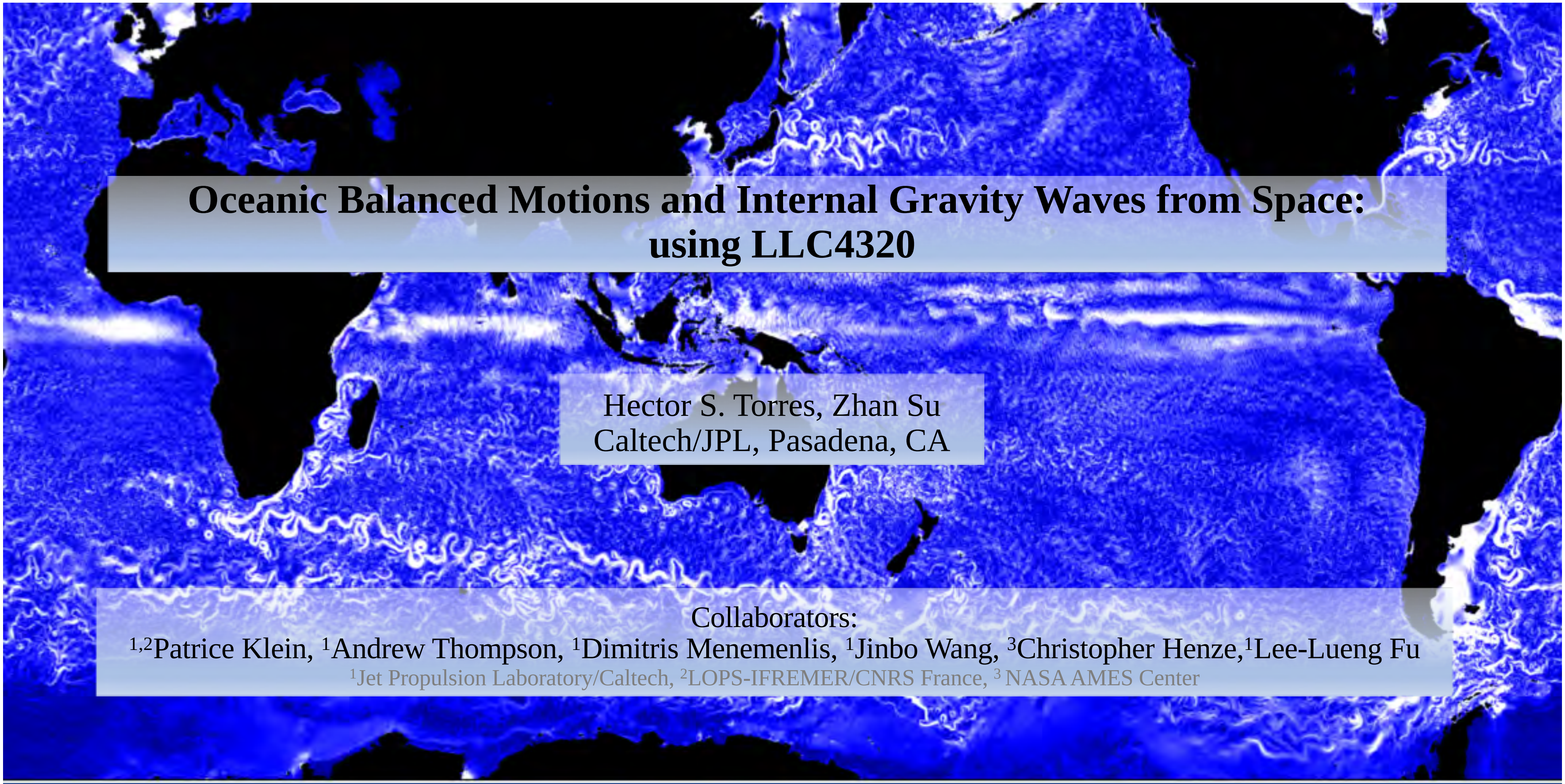

Oceanic Balanced Motions and Internal Gravity Waves from Space: using LLC4320

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Collaborators:
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Jet Propulsion Laboratory
California Institute of Technology

Balanced motions: Meso/sub-mesoscale motions

Mesoscale balanced motions:

- Mesoscale eddies (50 – 200 km)
- Impact on **horizontal** fluxes of heat and momentum

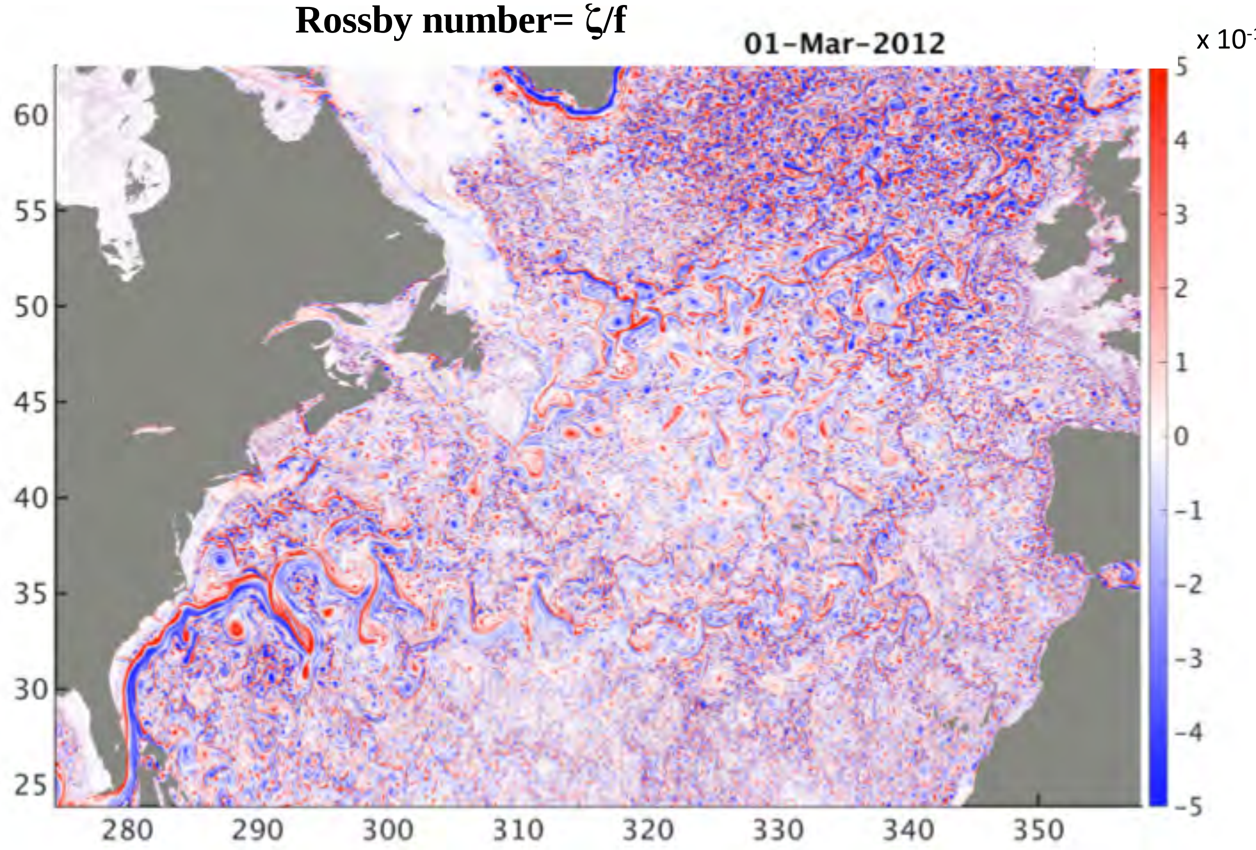
Submesoscale balanced motions:

- Frontal structures and smaller eddies (1 – 50 km)
- Impact on **vertical** fluxes of heat and momentum

Submesoscale motions (1—50 km) have strong vertical velocities lead to vertical exchanges between the upper and interior ocean

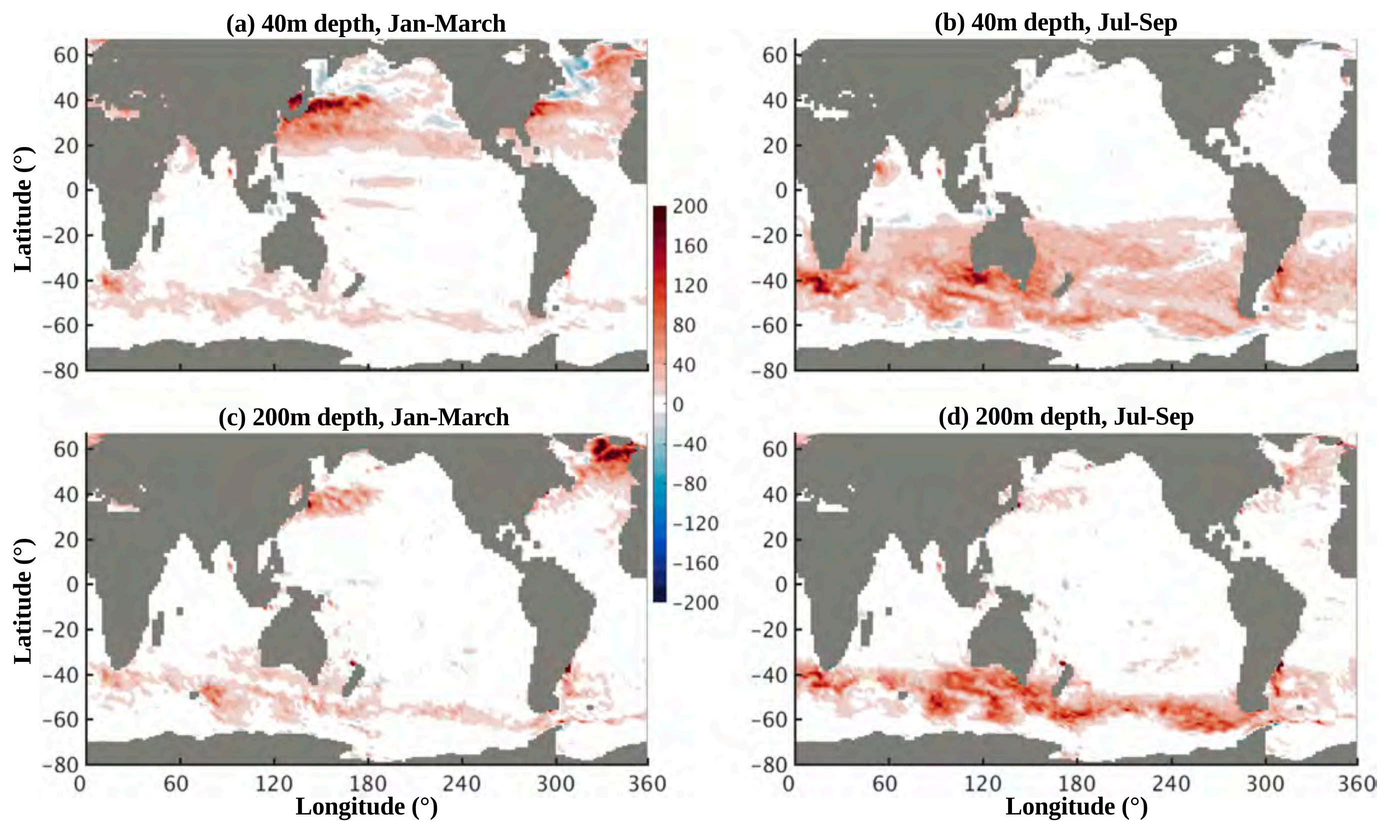
Where and when?

Rossby number= ζ/f



LLC4320 simulation

Submesoscale motions lead to upward vertical heat fluxes, up to 100 W/m²
--> air-sea interactions

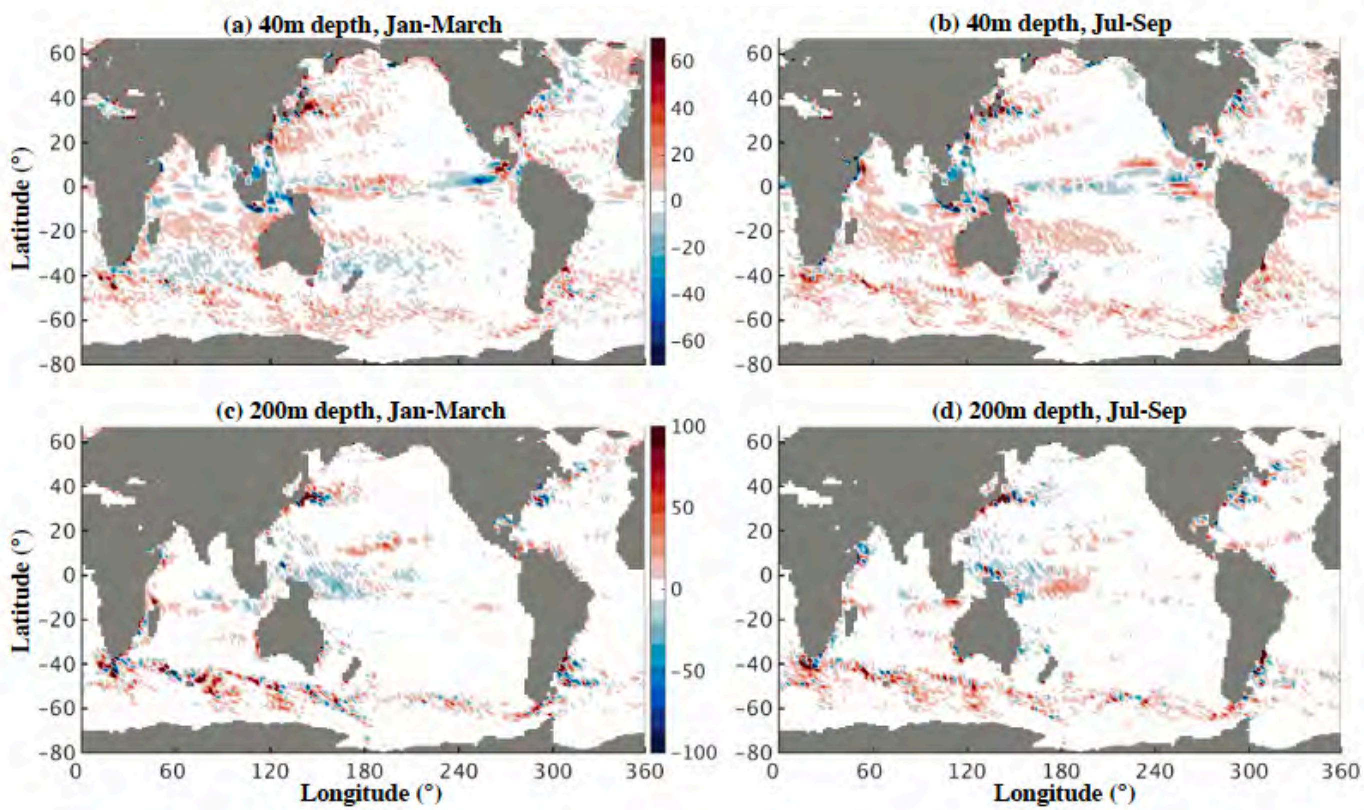


Up-gradient vertical heat fluxes and not down-gradient vertical heat fluxes

Global maps of the vertical heat fluxes in the **submesoscale band [10 – 50 km]** (W/m²). **20-100 W/m².**

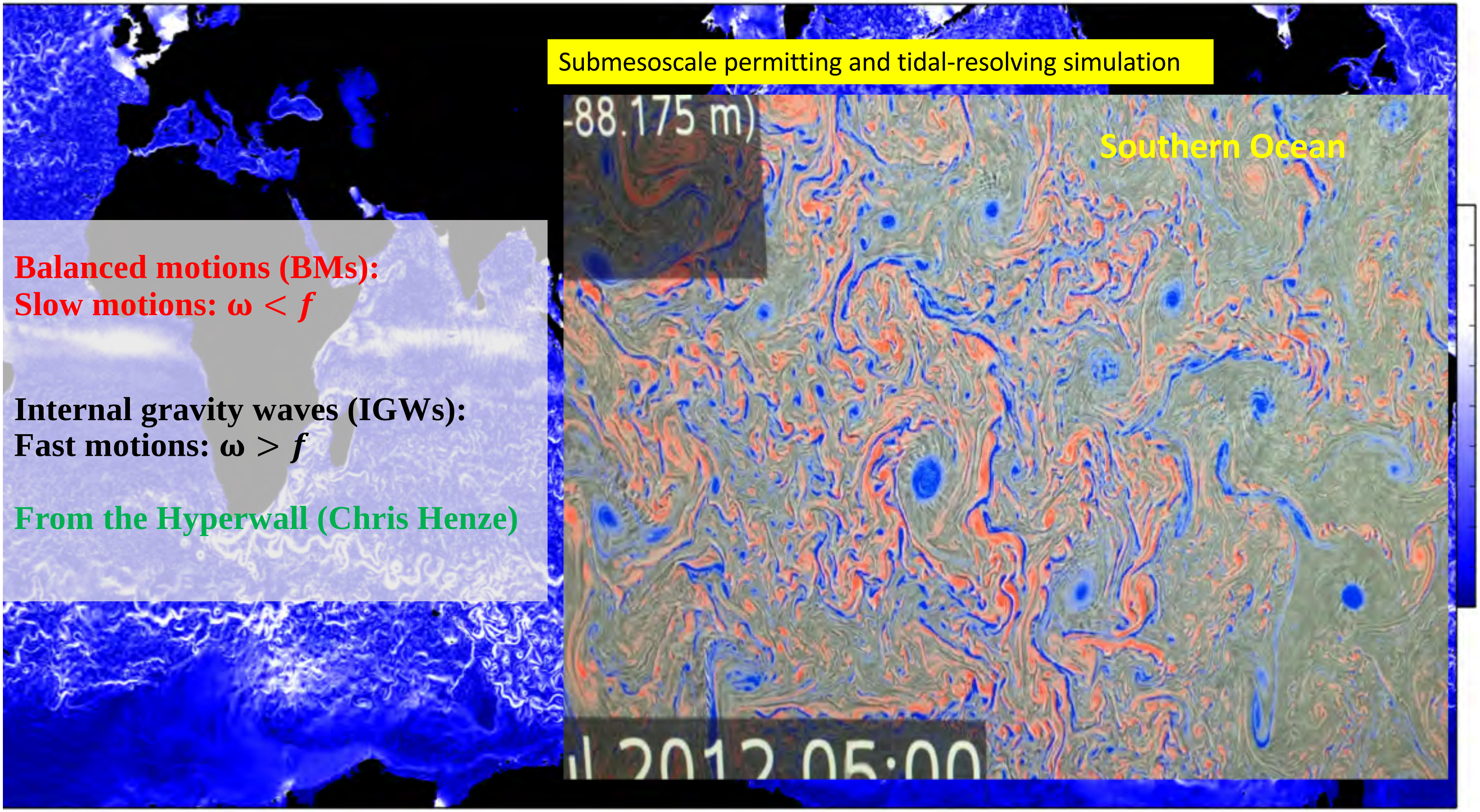
Su et al. 2017,
Nature communications,
under review

Mesoscale eddies have a weak impact on the vertical heat fluxes



3 times smaller than the submesoscale part!

Global maps of the vertical heat fluxes in the **mesoscale band [50 – 100 km]** (W/m²).



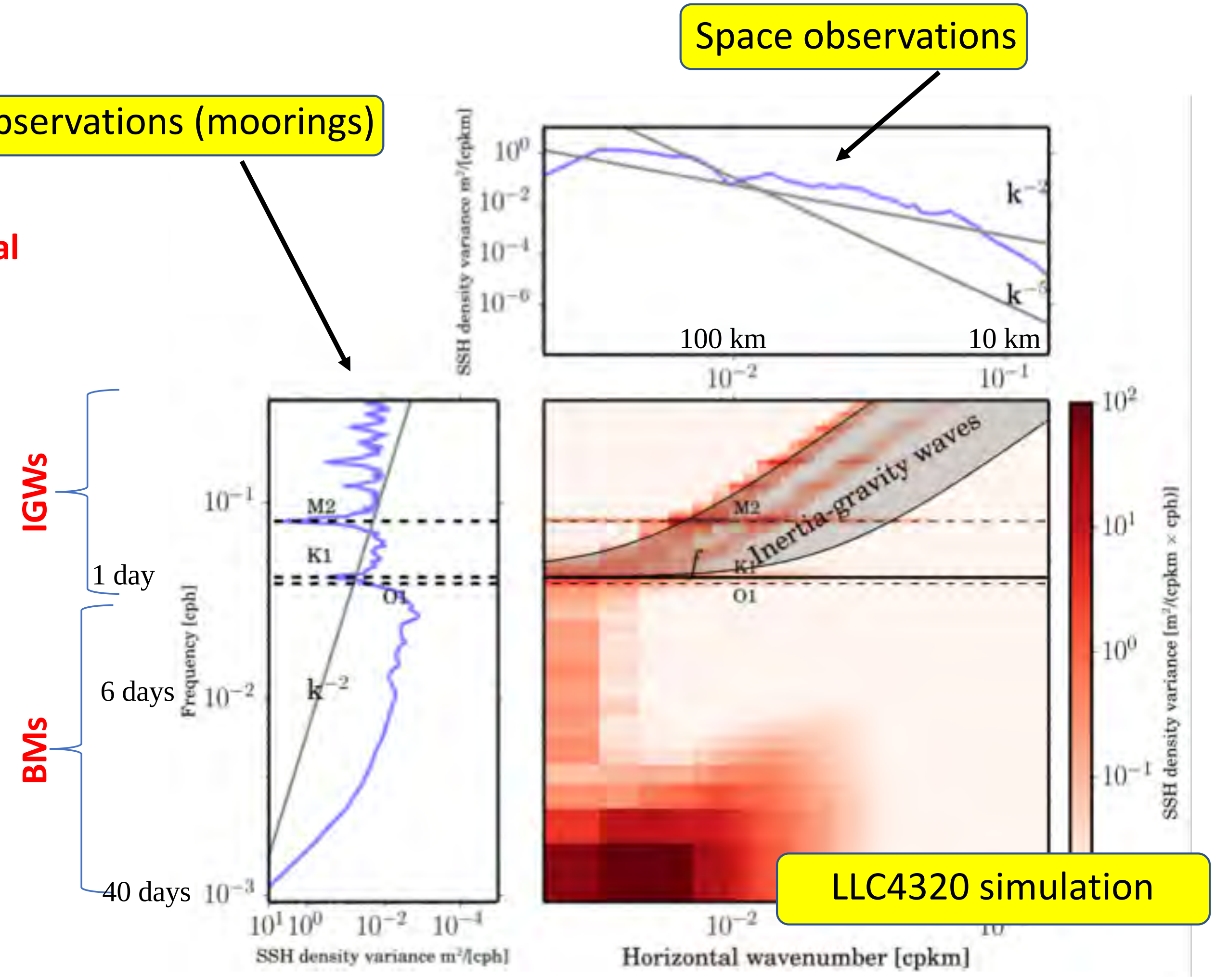
Submesoscale permitting and tidal-resolving simulation
-88.175 m)
Southern Ocean
Balanced motions (BMs):
Slow motions: ω < f
Internal gravity waves (IGWs):
Fast motions: ω > f
From the Hyperwall (Chris Henze)
l 2012 05:00

How to discriminate BMs from IGWs: frequency-wavenumber spectrum

- **Frequency-wavenumber spectrum (numerical simulations):**

  Continuity for BMs
  - Indicating strong nonlinear interactions

  Dispersion relation curves following **discrete beams for IGWs**
  - Indicating weak nonlinear interactions



Need to monitor these two classes of motions in the global ocean because of their different impacts on the energy budget

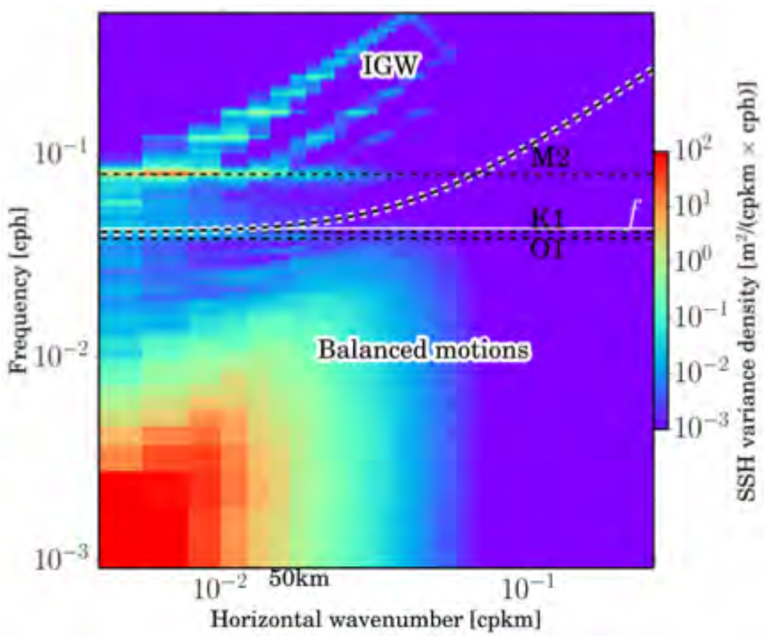
Our project is to better understand the respective signature of BMs and IGWs on the different oceanic fields observable from space: SSH, KE, SST, SSS

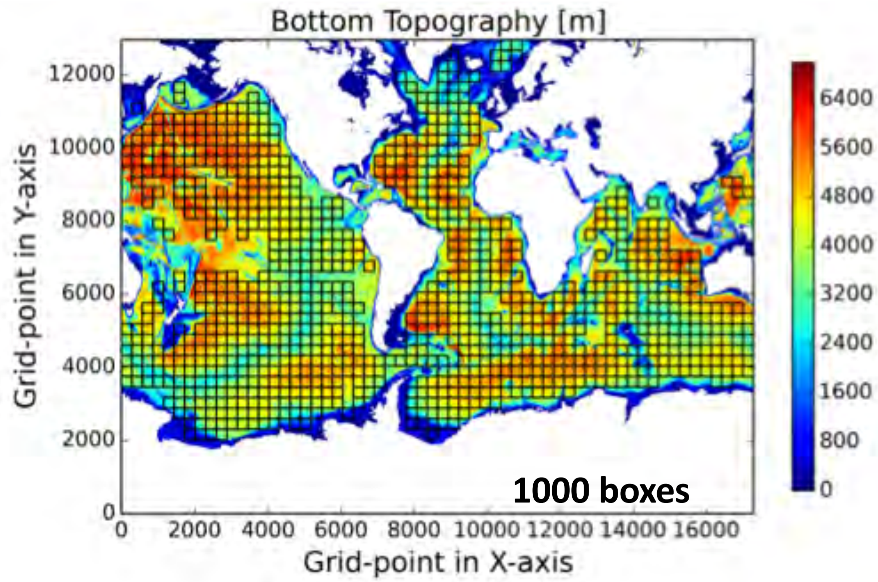
How to discriminate these two classes of motions in high-resolution observations?

Using frequency-wavenumber spectrum to partition IGWs and BMs

We can define the ratio, R, between the variance associated with BMs and that associated with IGWs (using the dispersion relation curve for the highest baroclinic mode to partition the two classes of motion)

$$R = BMs/IGWs$$





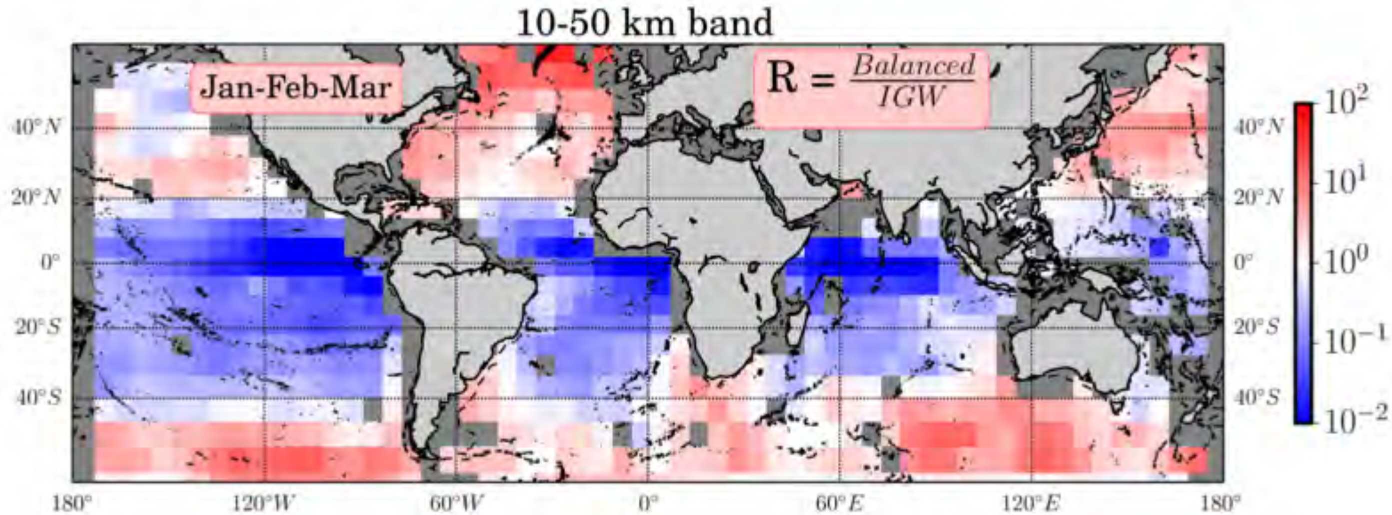
This has been done for SSH, KE, relative vorticity (RV), divergence (DIV), SST, and sea surface salinity (SSS)

Two scale ranges are considered:

- 10 – 50 km (from Su et al. 2017)
- 50 – 100 km

12,000 frequency-wavenumber spectra computed

Global maps of R value, $R = \frac{BMs}{IGWs}$, example



For a given spatial-scale band and a given variable

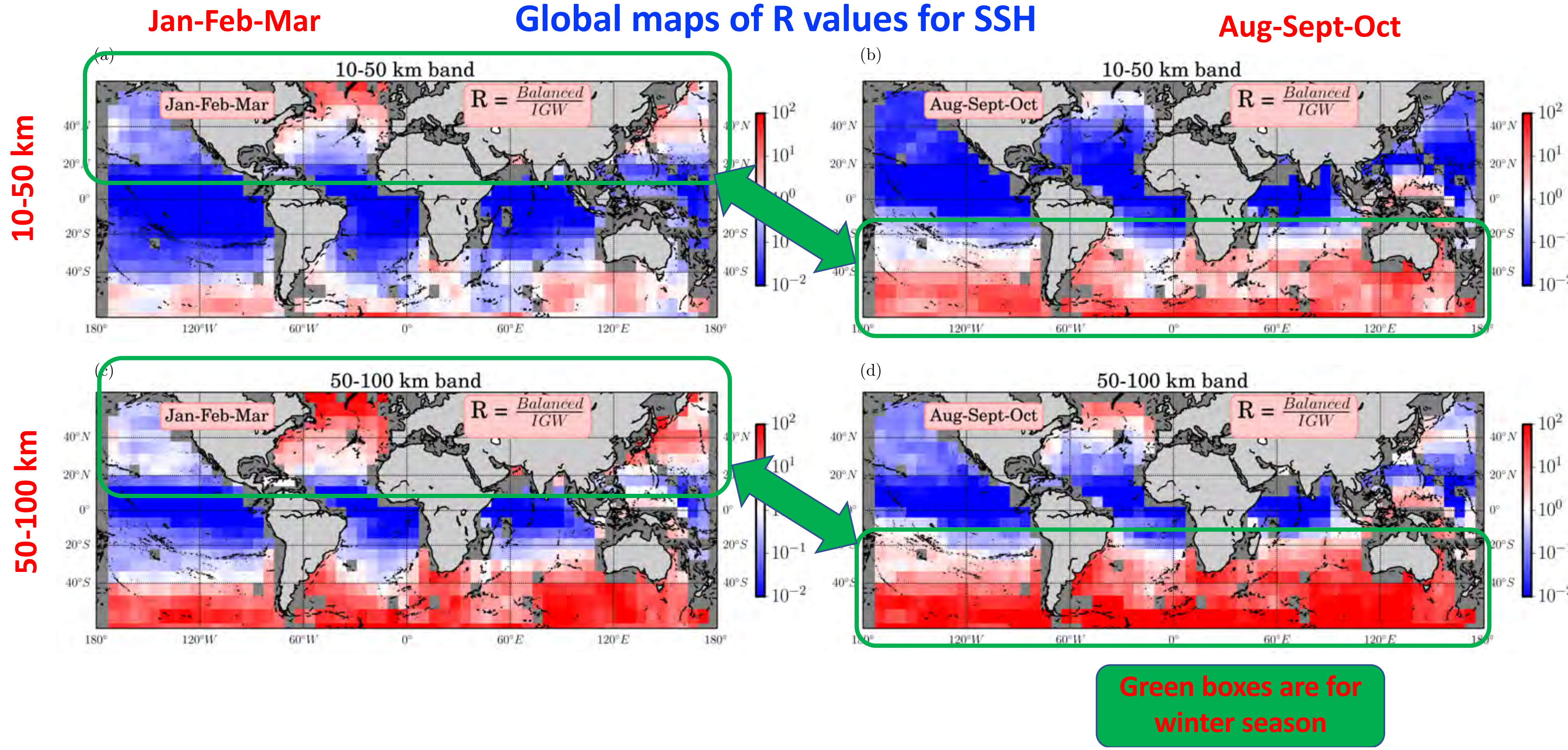
R > 1 **means that the variability of the flow is explained by BMs**

R = 1 means that is difficult to distinguish

R < 1 **means that the variability of the flow is explained by IGWs**

Differences between Northern and Southern Hemispheres: Northern Hemisphere more affected by IGWs in the 10—50km band

Global maps of R values for SSH

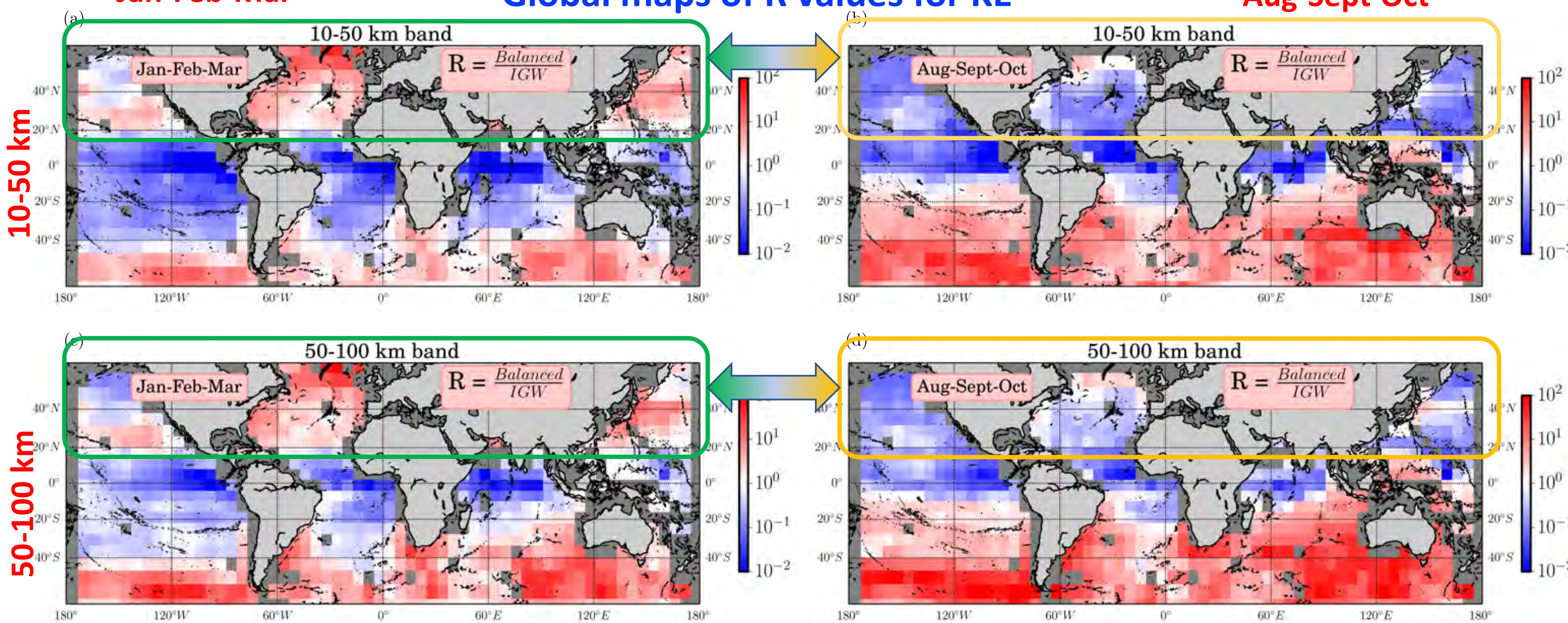


Differences between summer and winter: Strong seasonality in each Hemisphere, with IGWs more dominant in summer and BMs in winter

Jan-Feb-Mar

Global maps of R values for KE

Aug-Sept-Oct



Green boxes are for JFM

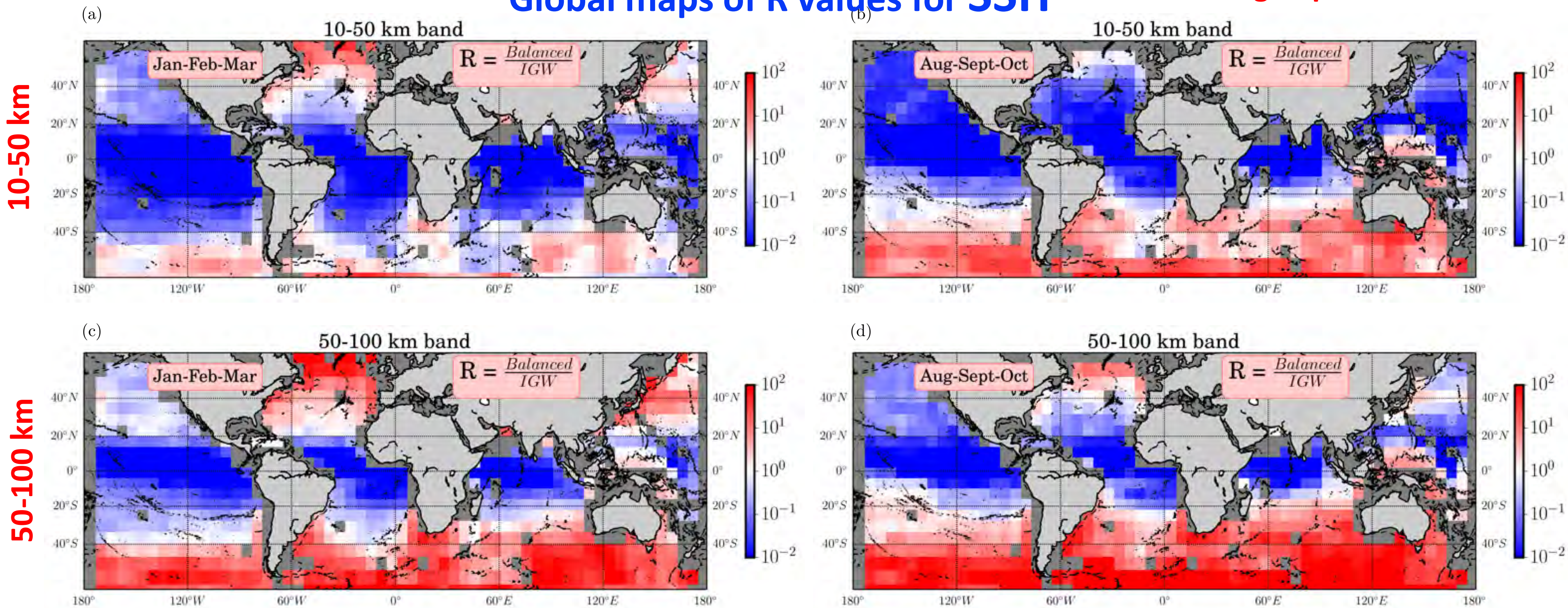
Yellow boxes are for ASO

Differences between SSH and KE: IGWs have impact on both fields with larger contrast for SSH

Jan-Feb-Mar

Global maps of R values for SSH

Aug-Sept-Oct



Differences between SSH and KE: IGWs have impact on both fields with larger contrast for SSH

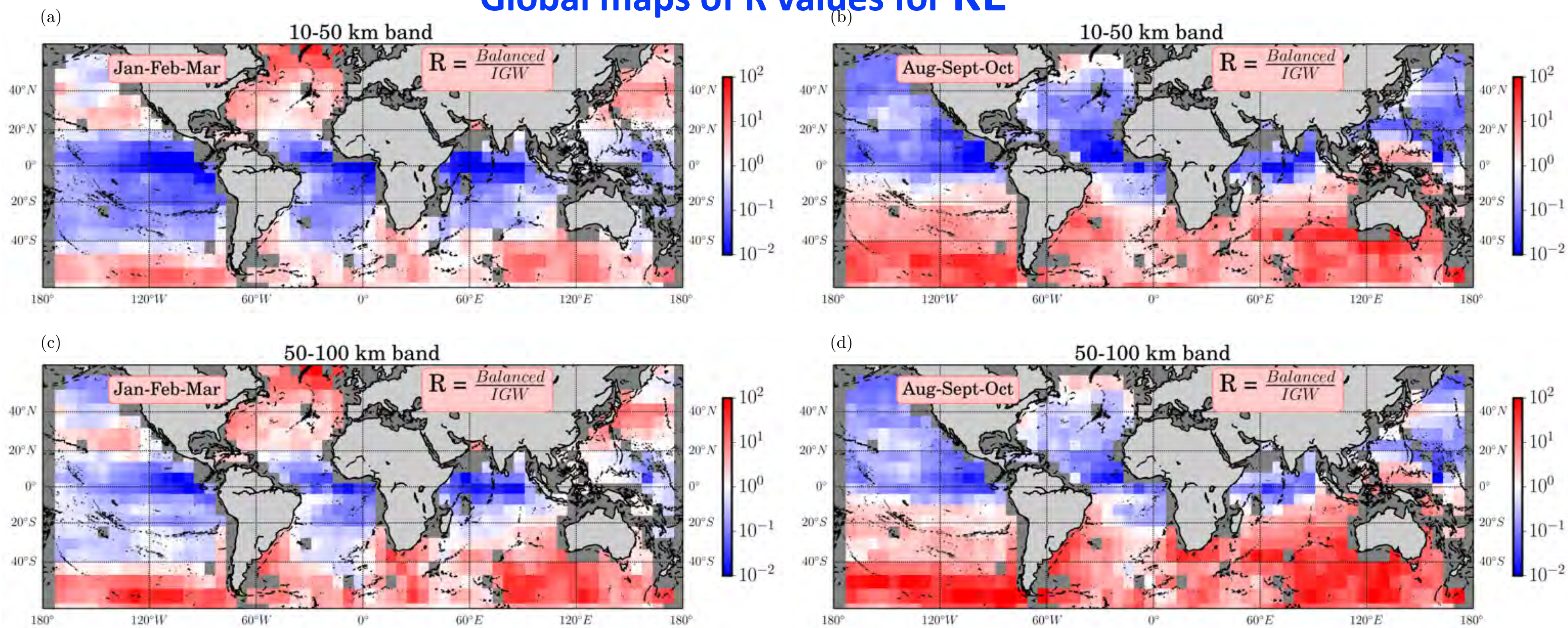
Jan-Feb-Mar

Global maps of R values for KE

Aug-Sept-Oct

10-50 km

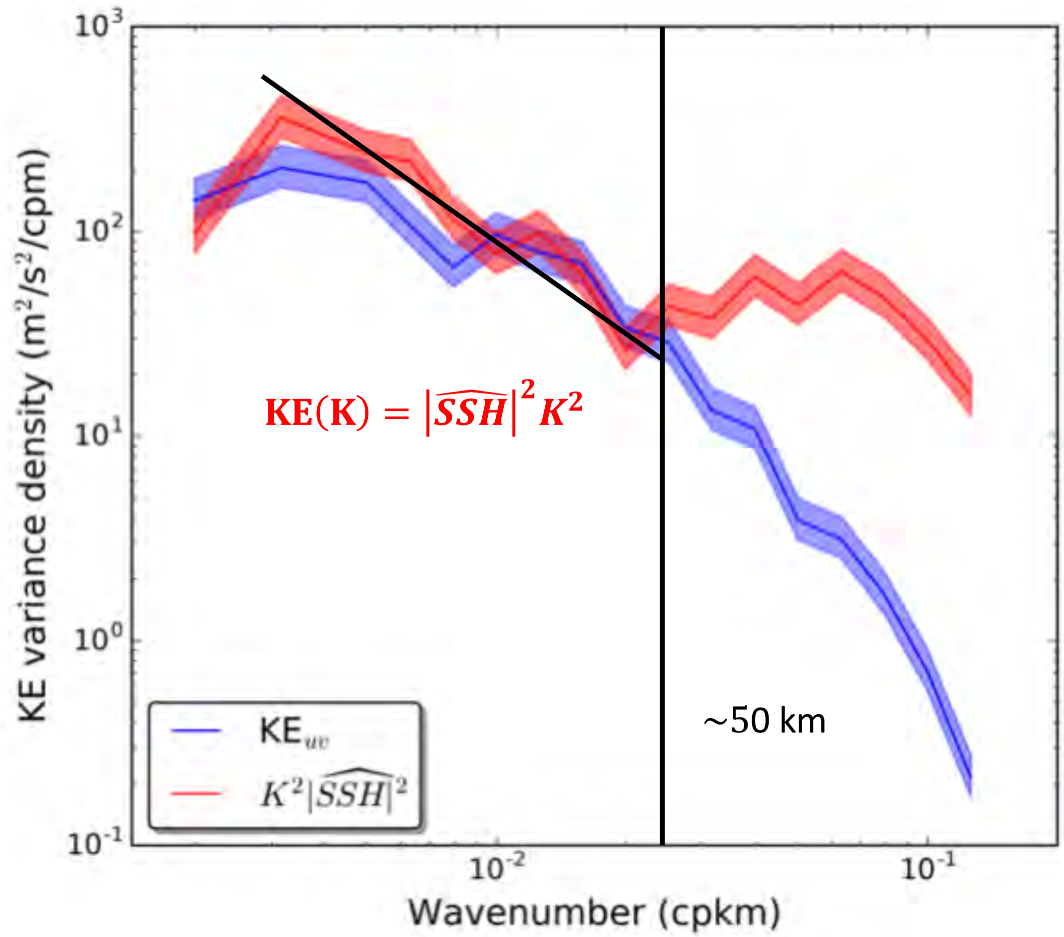
50-100 km



KE spectra deduced from surface motions and that deduced from SSH

For BMs (> 50 km), the relation between Potential Energy (PE) and Kinetic Energy (KE) in spectral space is (assuming geostrophic balance and isotropy)

$$\mathbf{KE(K)} = \left|\widehat{SSH}\right|^2 K^2$$



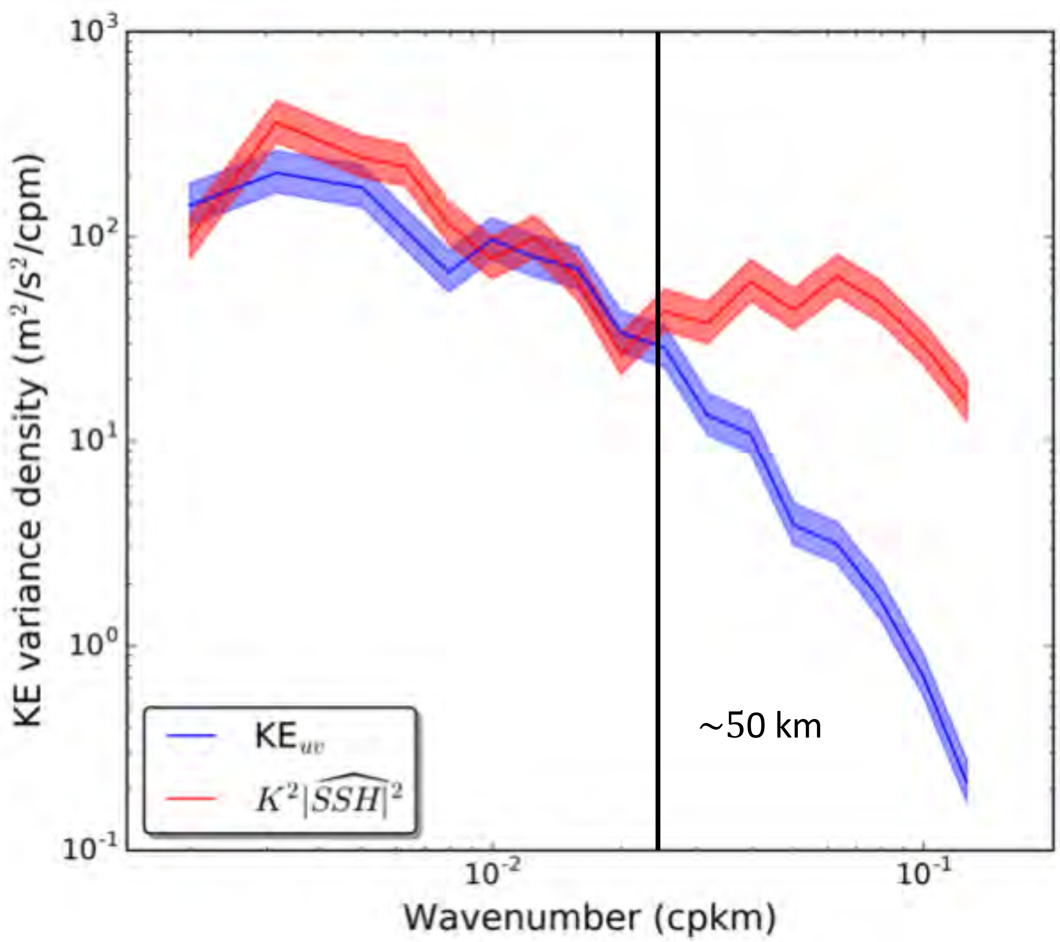
Region: California Current
Season: summer

KE spectra deduced from surface motions and that deduced from SSH

- For scales smaller than 50 km, **the spectral slope for $K^2|\widehat{SSH}|^2$ becoming much shallower**

If KE departs from this relation, it means a loss of balance

=> This discontinuity of the SSH spectral slope is not observed in HR simulations without tides (Chasssignet and Xu, JPO 2017)



Region: California Current
Season: summer

KE spectra deduced from surface motions and that deduced from SSH

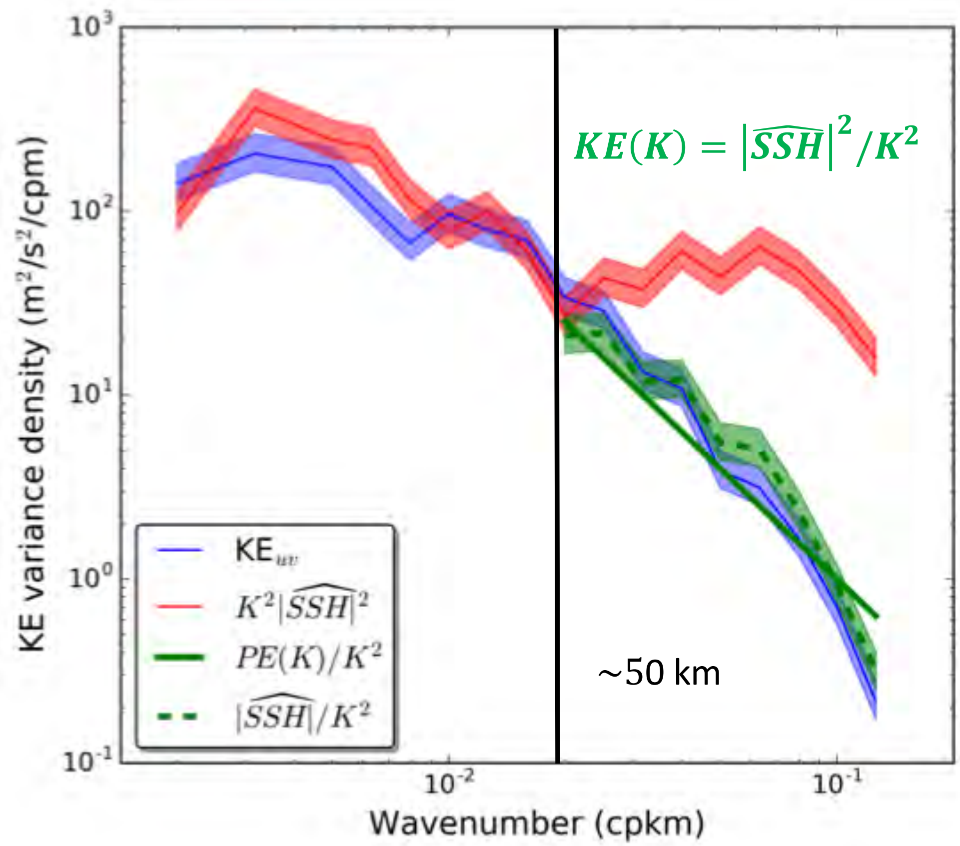
For BMs (< 50 km), $\cancel{\mathbf{KE(K)} = \left|\widehat{SSH}\right|^2 K^2}$

Based on the linearized shallow water model (Gill, 1982),

$$KE(K) = \left|\widehat{SSH}\right|^2 / K^2$$

Here we use SSH like proxy of PE

The significant discontinuity in the PE spectral slope thus characterize the IGW impact on SSH and therefore the loss of balance in this scale band, 10 –50 km



Region: California Current
Season: summer

Summary

I. Differences between Northern and Southern Hemispheres: **Northern Hemisphere is more affected by IGWs than Southern Hemisphere, with these discrepancies mostly pronounced during summer for the 10 - 50 km.**

II. Differences between summer and winter: **The seasonality concerns all regions but emphasized in the Northern Hemisphere. Its strongest amplitude is observed in low EKE regions, mostly in the 10 - 50 km.**

III. Differences between SSH and KE: **Regions of the KE field where R $\leq$ 1, the SSH field often displays even much smaller values (R $\ll$ 1). In the Northern Hemisphere, such differences are mostly in the 10-50 km band.**

IV. Impact of BMs and IGWs on SST and SSS: **SST and SSS in the 10 - 100 km band are not affected at all by IGWs.**

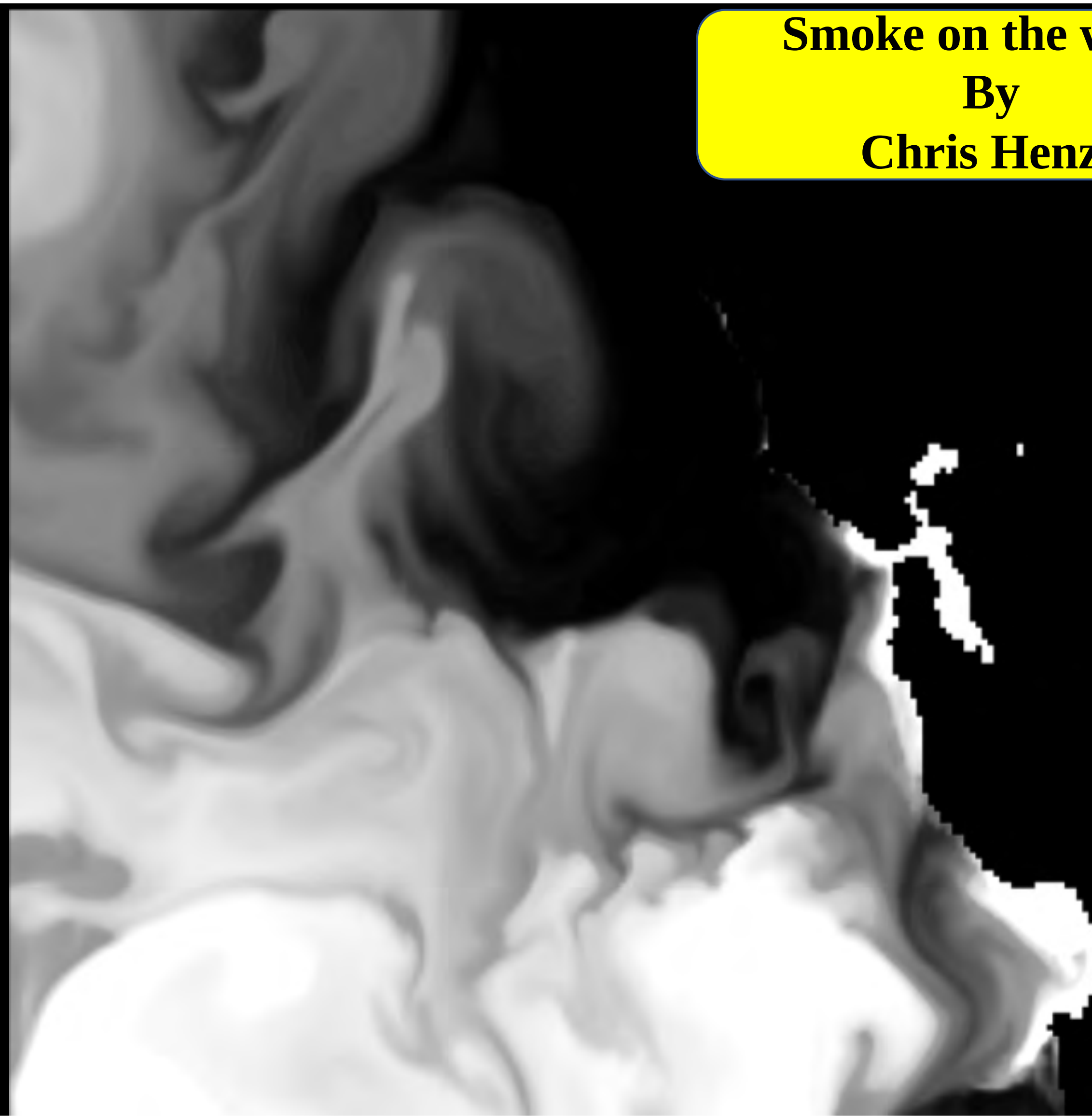
Need to monitor these two classes of motions in the global ocean because of their different impacts on the energy budget

Image credit: NASA

One way to address this need is exploiting the synergy of existing and future satellite observations

- Conventional altimetry (existing JASON I-III)
- SWOT (to be launched in 2021)
- DopplerScatt (project in progress)
- SST (MUR)
- Sea surface salinity (SMAP)

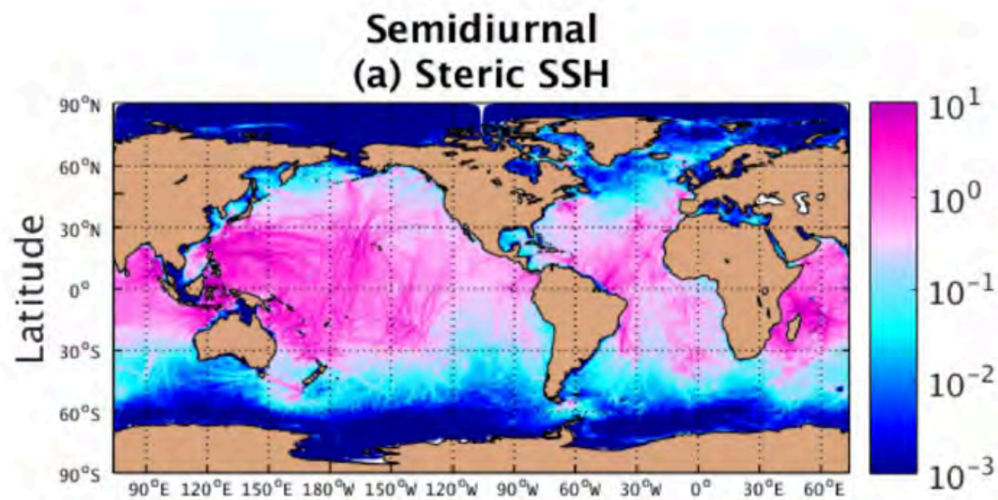
Thank you,

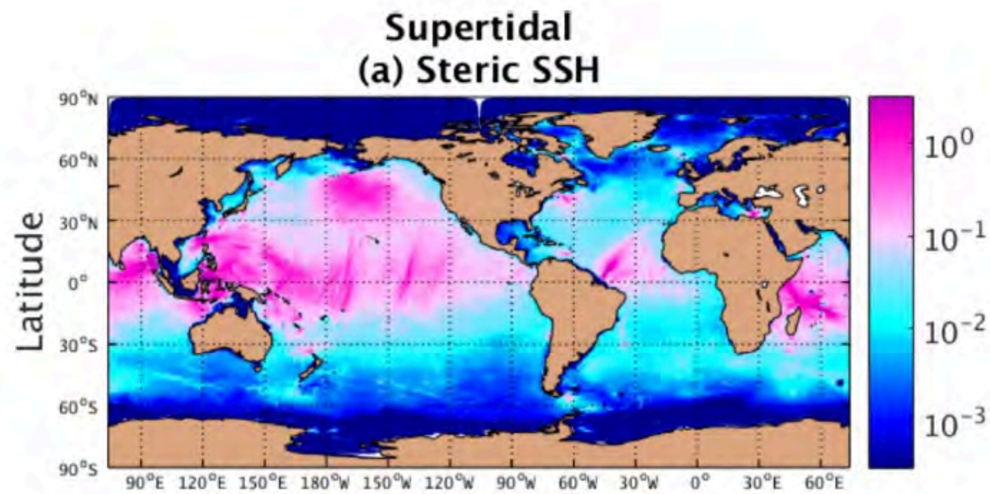


Smoke on the water
By
Chris Henze

Differences between Northern and Southern Hemispheres

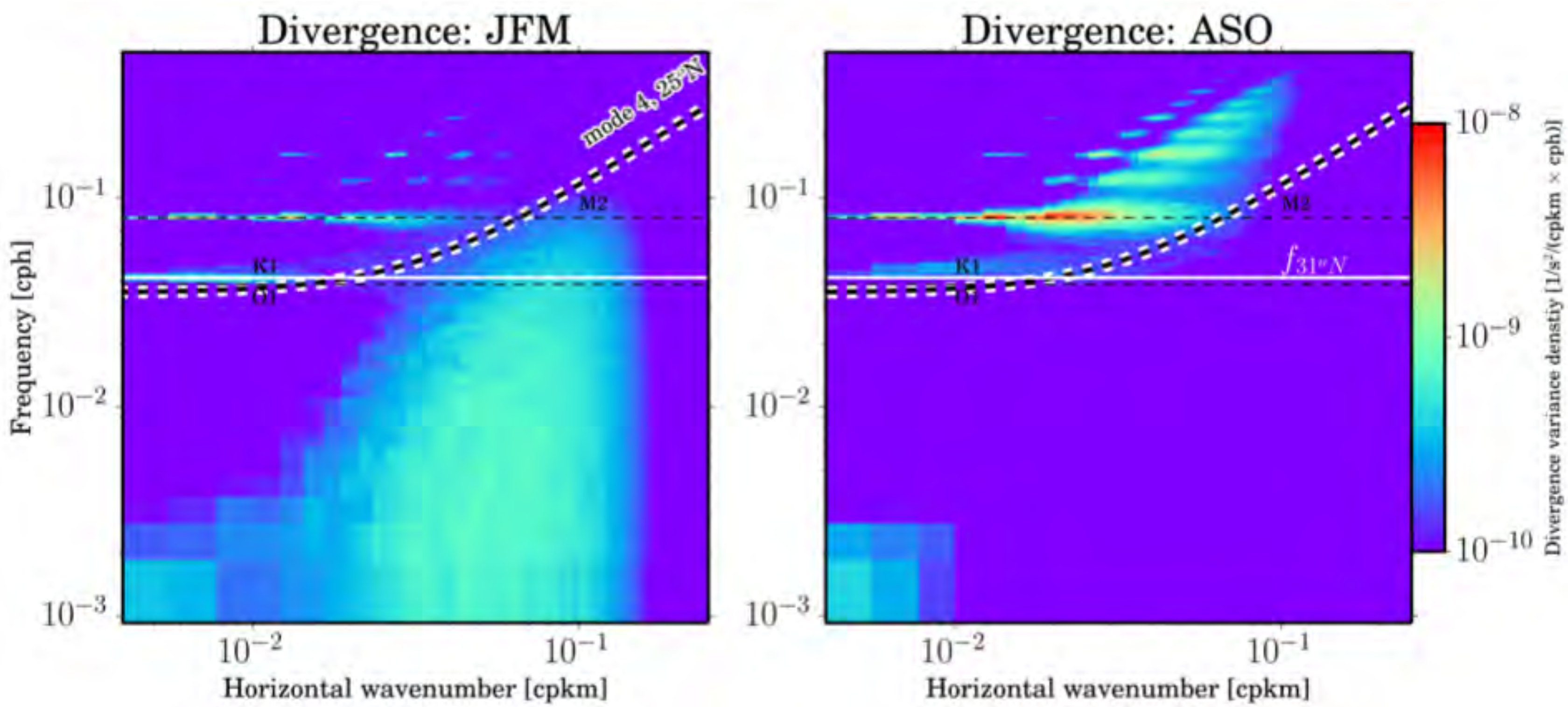
- Energy associated with internal tides (Savage et al. 2017):
  - Mostly energetic in the latitude band between 30° S and 30° N
  - Outside this band internal tides are still energetic in the Northern Hemisphere
  - Also, super-tidal motions are more energetics in the Northern Hemisphere





In the upper oceanic layer: asymmetric seasonal variability of BMs and IGWs

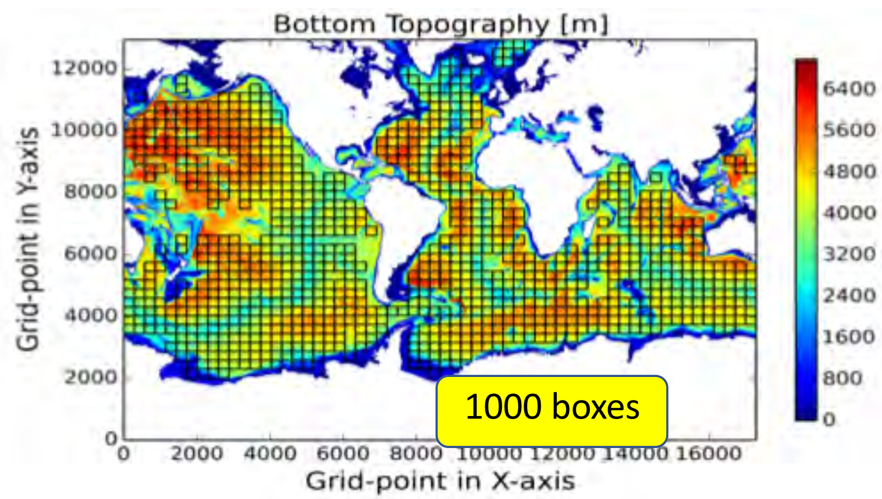
Kuroshio Extension: 6º x 6º box

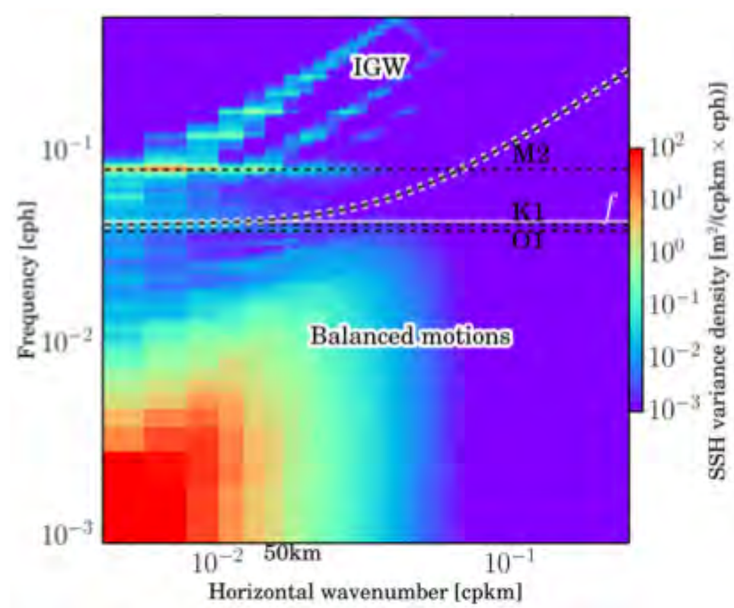


Frequency-Wavenumber spectrum of divergence, Kuroshio Extension

Estimation of **R** in the global ocean: small boxes

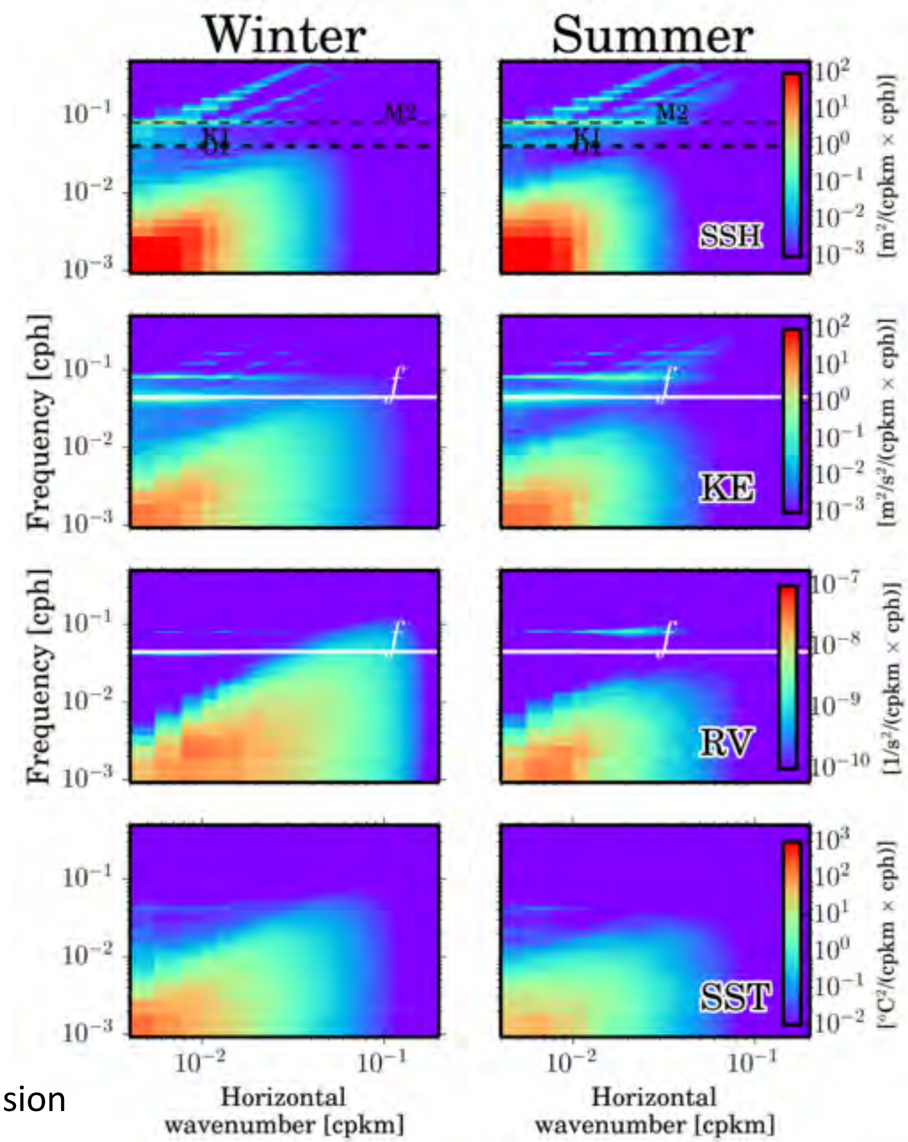
- ~6º x ~6º grid points
- Temporal coverage: 90 days
- Two seasons:
  - Jan.-Feb.-Mar.
  - Aug.-Sept.-Oct.
- The frequency-wavenumber spectrum was computed for a given variable in each box: (1000 boxes x 2 seasons x 6 variables = 12,000 frequency-wavenumber spectrum)
- Solving a classical Sturm-Liouville problem produced the ***n*** Rossby radii of deformation and therefore the ***n*** dispersion relation





Signature of BMs and IGWs on different oceanic quantities

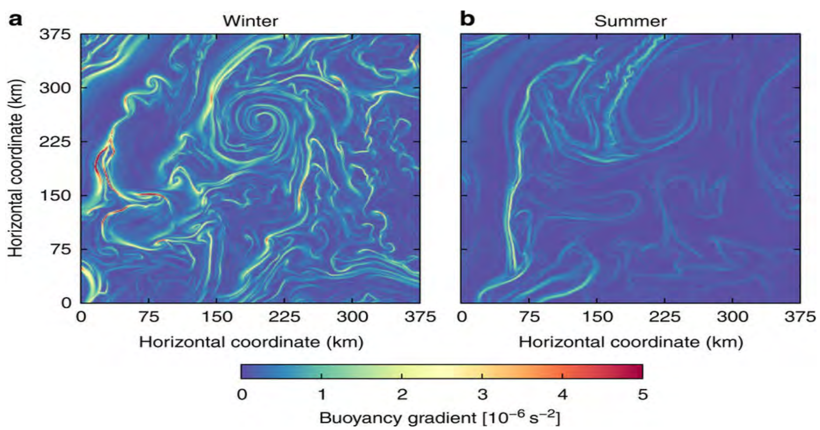
- Strong impact of IGWs on SSH and KE
- Negligible impacts of IGWs on RV and SST
- BMs more energetic in winter
- Amplification of higher baroclinic modes in summer explain a large part of the IGW seasonality



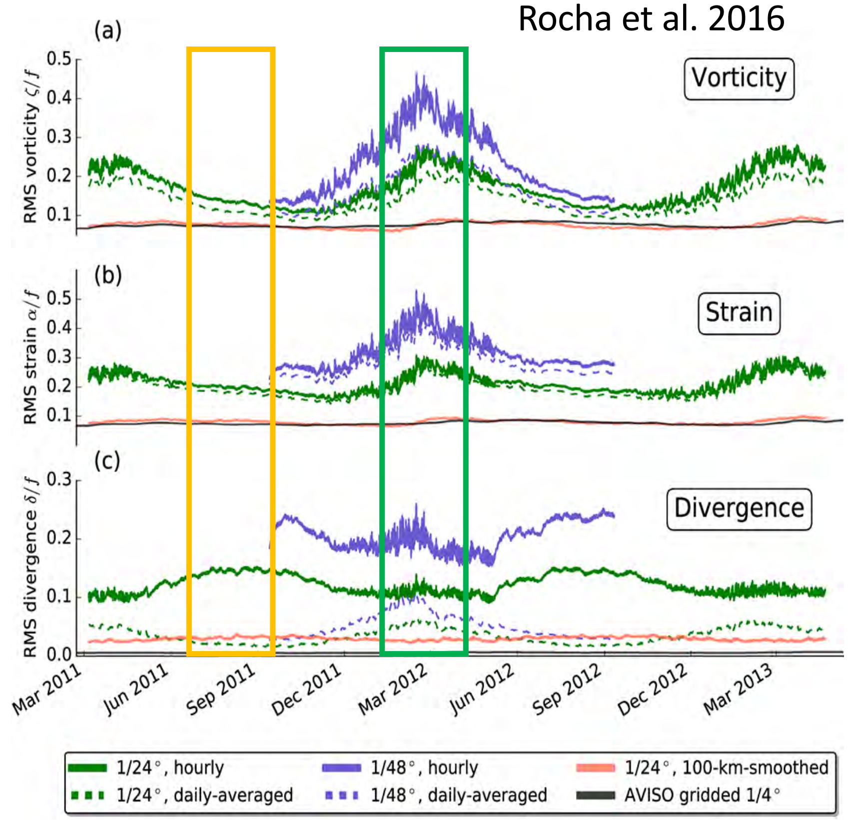
Kuroshio Extension

Upper oceanic layer: seasonality of BMs and IGWs

Callies et al. 2015



Rocha et al. 2016



- **Strong dissymmetric seasonality of BMs and IGWs**
  - August to October: IGWs dominate the variance of the flow
  - January to April: BMs dominate the variance of the flow

My project:

Before examining how to exploit the synergy of using these different satellite observations, we need to better know the respective signature of BMs and IGWs on the different oceanic fields observable from space

How to discriminate these two classes of motions in high-resolution observations?

Results

I. Differences between Northern and Southern Hemispheres: **Northern Hemisphere is more affected by IGWs than Southern Hemisphere, with these discrepancies mostly pronounced during summer for the 10 - 50 km.**

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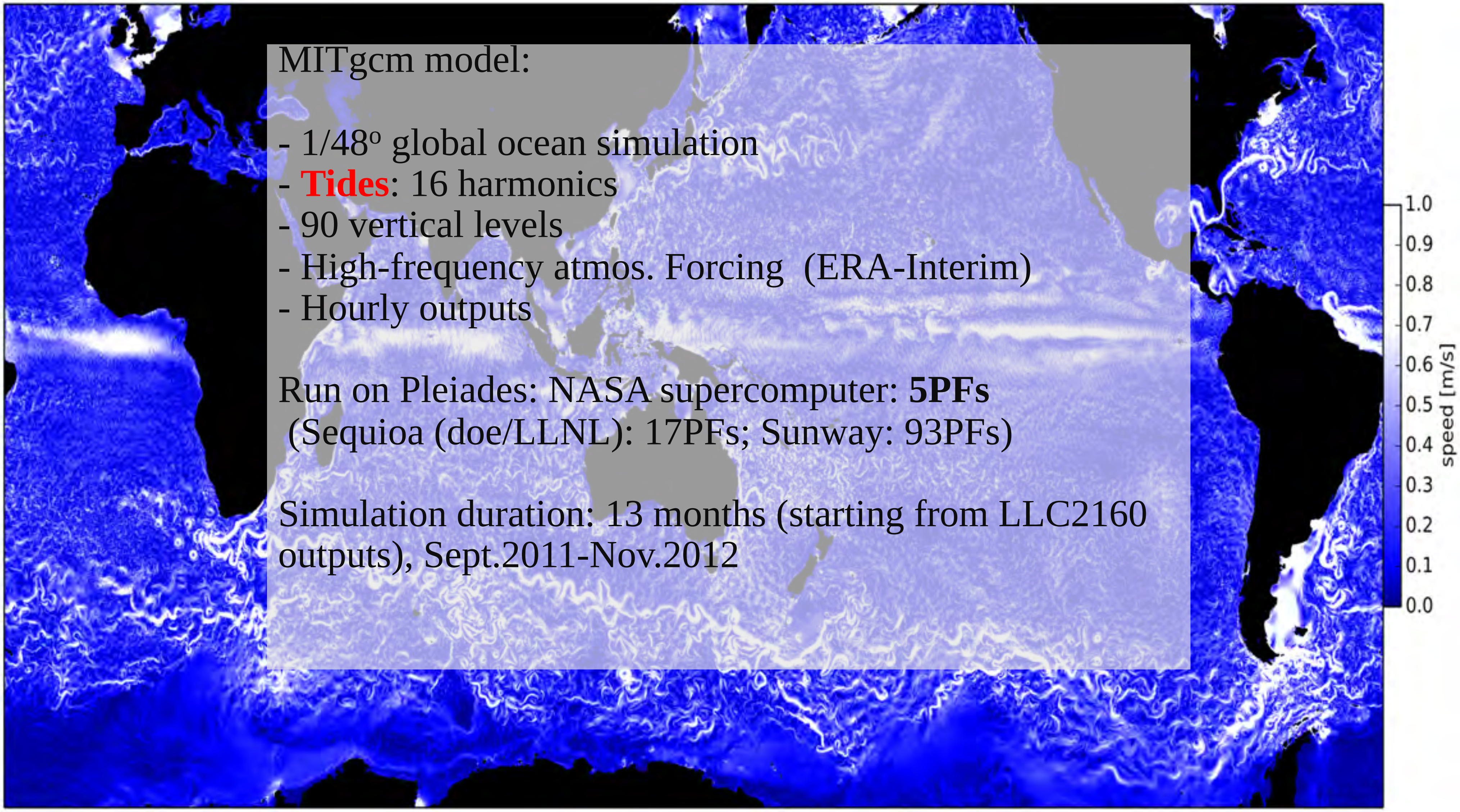
IV. Impact of BMs and IGWs on SST and SSS: **SST and SSS in the 10 - 100 km band are not affected at all by IGWs.**

MITgcm model:

- 1/48° global ocean simulation
- **Tides**: 16 harmonics
- 90 vertical levels
- High-frequency atmos. Forcing (ERA-Interim)
- Hourly outputs

Run on Pleiades: NASA supercomputer: **5PFs**
(Sequioa (doe/LLNL): 17PFs; Sunway: 93PFs)

Simulation duration: 13 months (starting from LLC2160 outputs), Sept.2011-Nov.2012



Comparison with in-situ observations:

Moorings and Gliders data (Rocha et al. 2016a,b; Savage et al. 2017a,b, Drushka et al. 2017; Viglione et al. 2017; …)

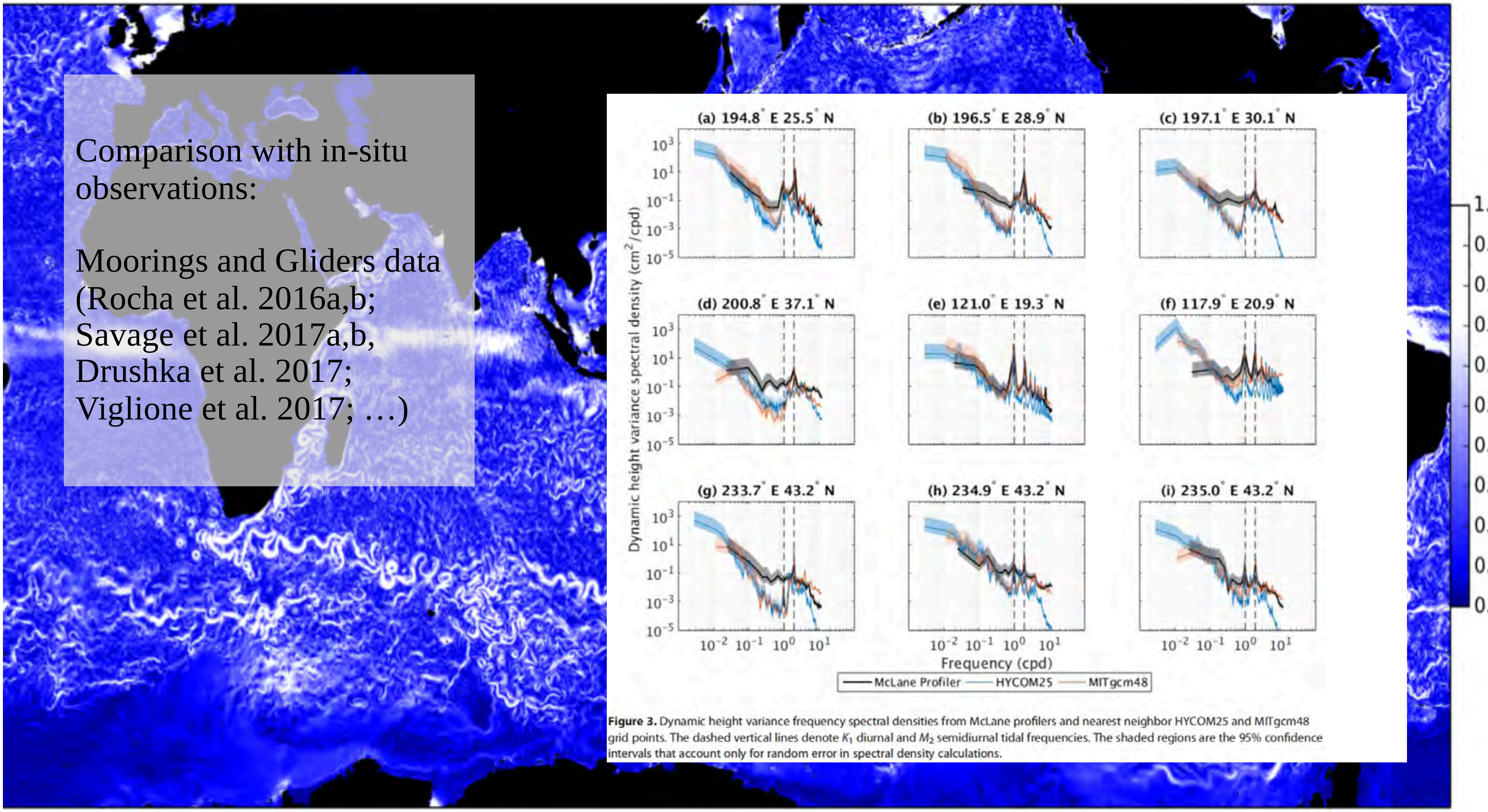


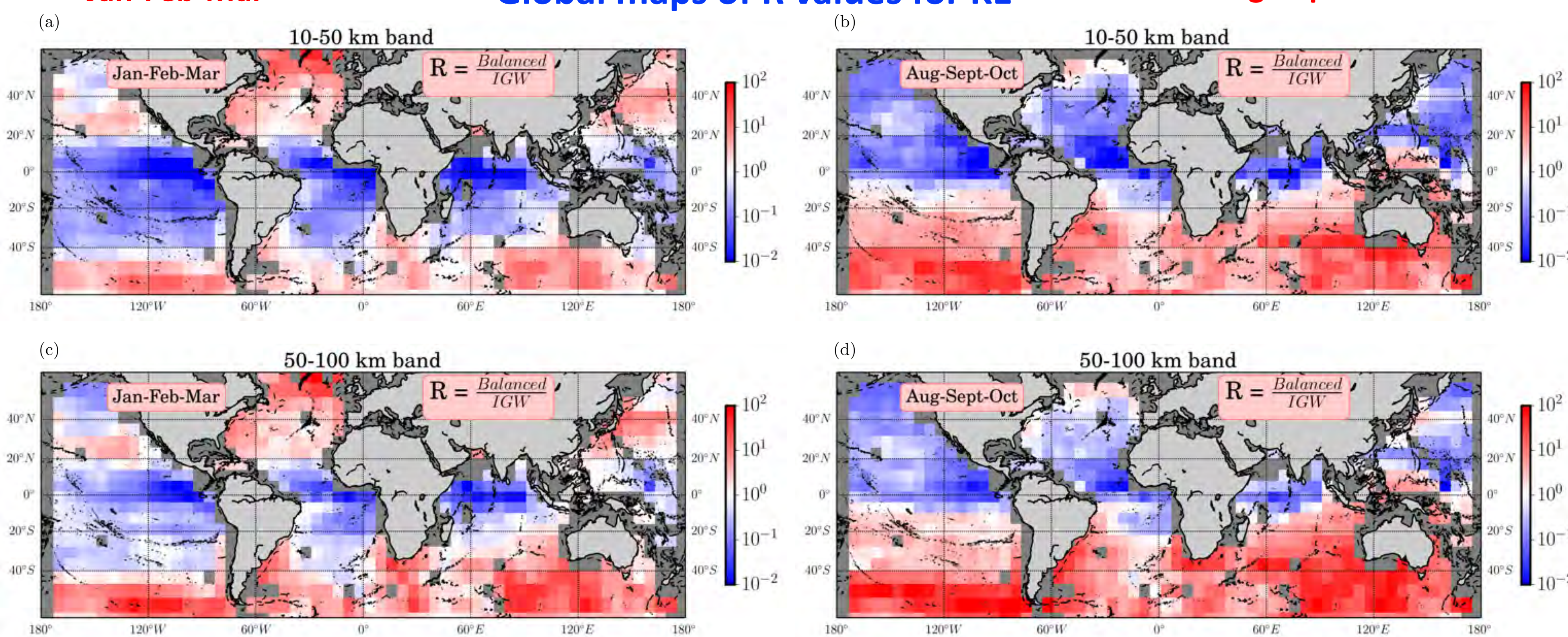
Figure 3. Dynamic height variance frequency spectral densities from McLane profilers and nearest neighbor HYCOM25 and MITgcm48 grid points. The dashed vertical lines denote K_1 diurnal and M_2 semidiurnal tidal frequencies. The shaded regions are the 95% confidence intervals that account only for random error in spectral density calculations.

Differences between KE and RV: BM are more dominant in the RV field compare to KE in both Hemispheres, but only for the period Aug-Sept-Oct

Jan-Feb-Mar | **Global maps of R values for KE** | **Aug-Sept-Oct**

10-50 km

50-100 km

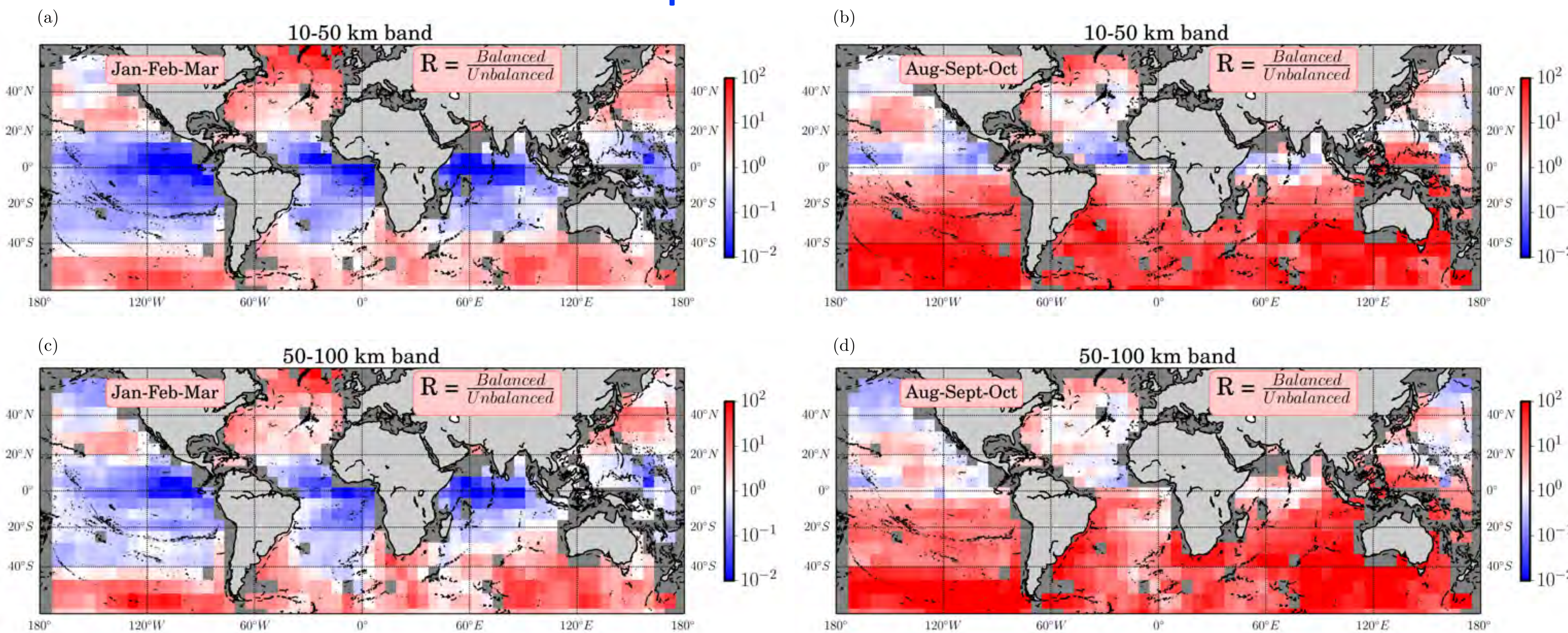


Differences between KE and RV: BM are more dominant in the RV field compare to KE in both Hemispheres, but only for the period of Aug-Sept-Oct

Jan-Feb-Mar **Global maps of R values for RV** **Aug-Sept-Oct**

10-50 km

50-100 km



No impact of IGWs on SST and SSS

Global maps of R values for SST

Jan-Feb-Mar

Aug-Sept-Oct