On the fluctuations of eddy fluxes simulated in a 1/10º OGCM

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1. Introduction

OGCMs have finite resolution and are based on Reynolds equations. For tracer b, the equation takes the form of $\partial\bar{b}/\partial t + \nabla\cdot\bar{F} = \bar{Q}$, where $F = ub$, u is velocity vector, and Q indicates source and sink of b. $\overline{()}$ represents an average over unresolved temporal and spatial scales. Fluctuations of eddy fluxes are deviations from mean flux, i.e., $F' = F - \bar{F}$. Even though the mean of the fluctuation vanishes, the fluctuation F' can affect low frequency variations and even the mean oceanic state. Most of previous studies have devoted to the mean eddy flux $\overline{u'b'}$ that contributes to $\bar{F}$. We concentrate on the divergence of F'. As a first step towards a stochastic parameterization of $\nabla\cdot F'$, we study the basic features of fluctuation divergence using a MPI-OM simulation at 1/10º horizontal resolution.

2. Data and simulations

Fluctuations are studied using hourly data from the STORM NCEP simulation with the 1/10º MPI-OM model (TP6ML80) for January-February-March and July-August-September of the year 2005. Since the fluctuations in the tropical oceans have large spatial scales, no matter whether they are generated by winds or by internal instability processes, experiments with MPI-OM at 0.4º resolution (TP04L40) are also considered. We drive MPI-OM TP04L40 with 6 hourly (TP04L40_ori) and 10-day smoothed wind forcing (TP04L40_smth) to quantify the contribution from the wind-induced near-inertial waves. To ensure reaching a quasi-equilibrium for meso-scale processes, all the experiments restart from a spin-up phase and integrate for 57 years from 1948-2005.

3. Geographical distribution and typical magnitude

Fluctuation F' is not a negligible term, its divergence is even one order of magnitude larger than the mean eddy flux divergence in tropics and most of the subtropics. The strongest fluctuations are in the subtropical regions from 30ºS-40ºN. There are also large values in regions with strong currents, such as Gulf Stream, Kuroshio, and ACC.

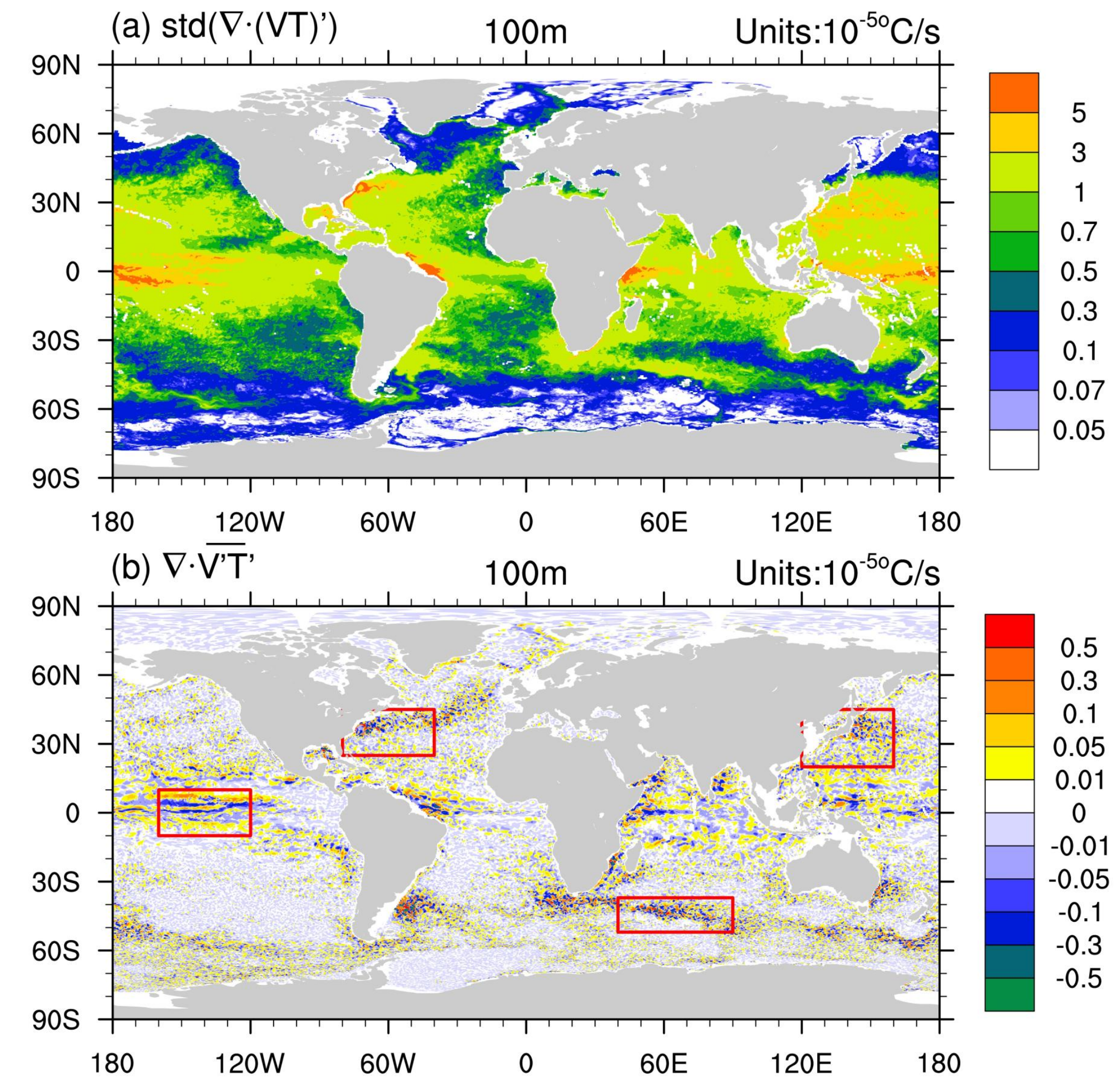

Fig.1 (a) Standard deviation of fluctuation divergence and (b) mean eddy heat flux divergence at 100m. The red boxes delineate 4 specific regions (ACC, tropics, Gulf Stream, and Kuroshio) for spectrum analysis in Fig. 4.

4. Seasonality and its cause

- Outside eddy active regions, stronger fluctuation divergence occurs in winter (Fig. 2a). This is caused by the seasonality of the wind forcing (Fig. 2b).
- In eddy active regions, summer fluctuation divergences are slightly stronger than winter ones (Fig. 2a). It relates to the seasonality of eddy intensity (Fig. 2c-d).

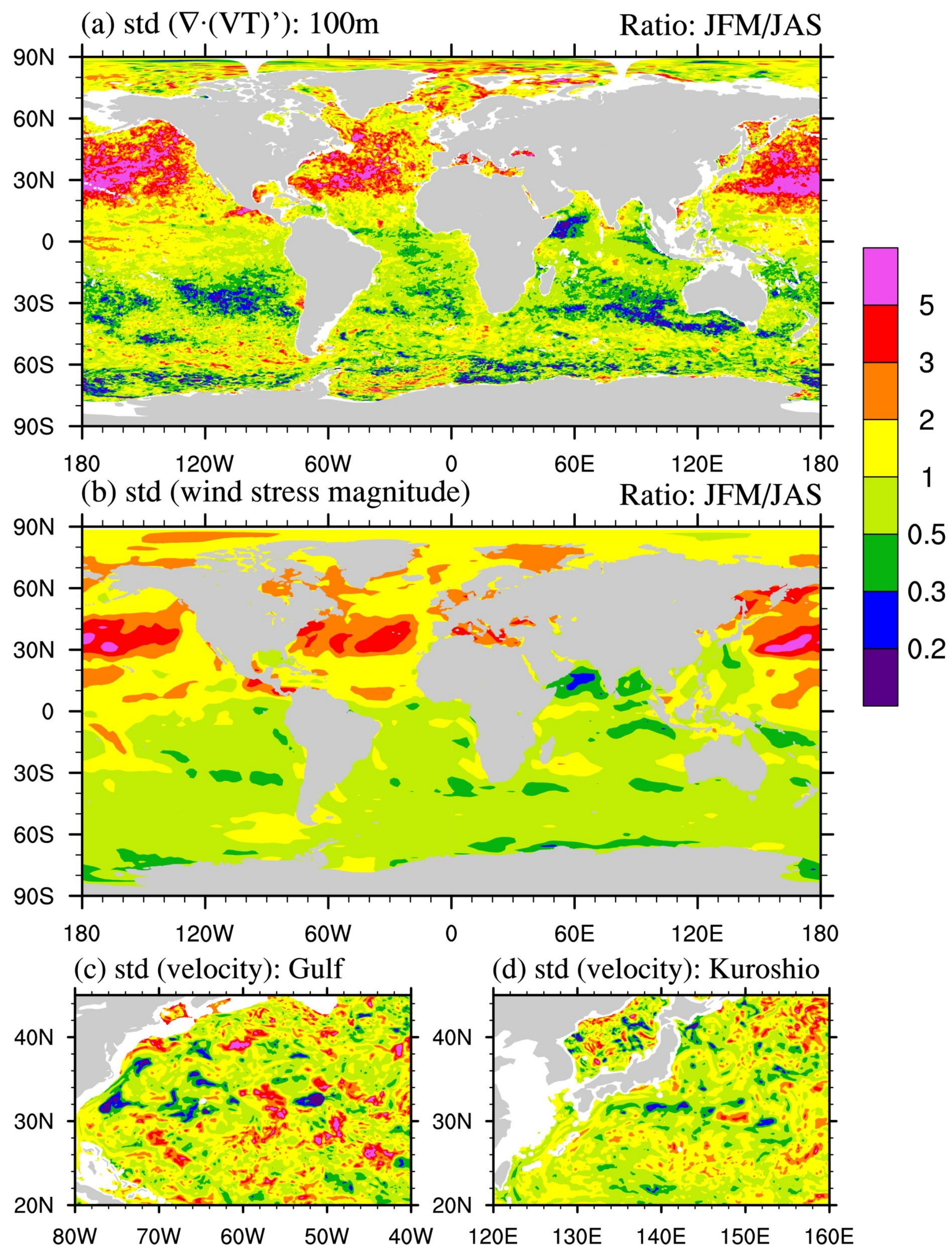

Fig.2 Ratio between JFM & JAS in standard deviation of fluctuation divergence (a), wind stress magnitude (b), and velocity speed in Gulf Stream (c) and in Kuroshio (d).

5. Basic spatial & temporal characteristics

Larger spatial scales are found in tropics (~500km), mainly on the zonal direction, which is coherent with the characteristics of tropical instability waves. Meridional scales are dominant in eddy active regions, which imply meridional heat transport induced by eddies.

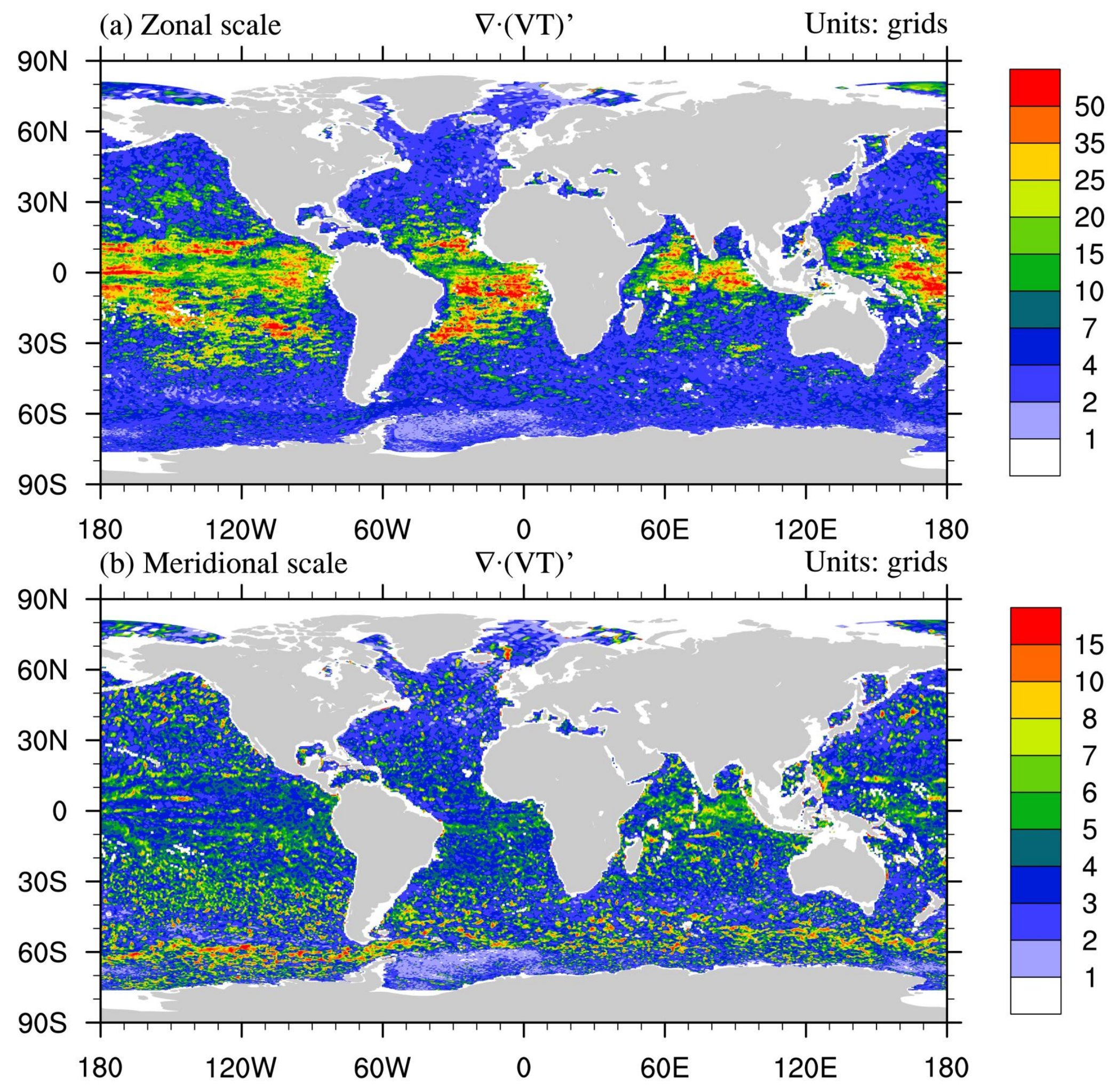

Fig. 3 Spatial scale of fluctuation divergence, defined as the number of grid cells at which the spatial correlation drops below 0.1.

Near inertial waves are active both in strong and weak current regions. Low frequency variabilities of about 20-40 days are found in strong current regions. It suggests that meso-scale eddies are dominating in regions with strong current at mid-high latitudes and tropical instability waves are active in tropics.

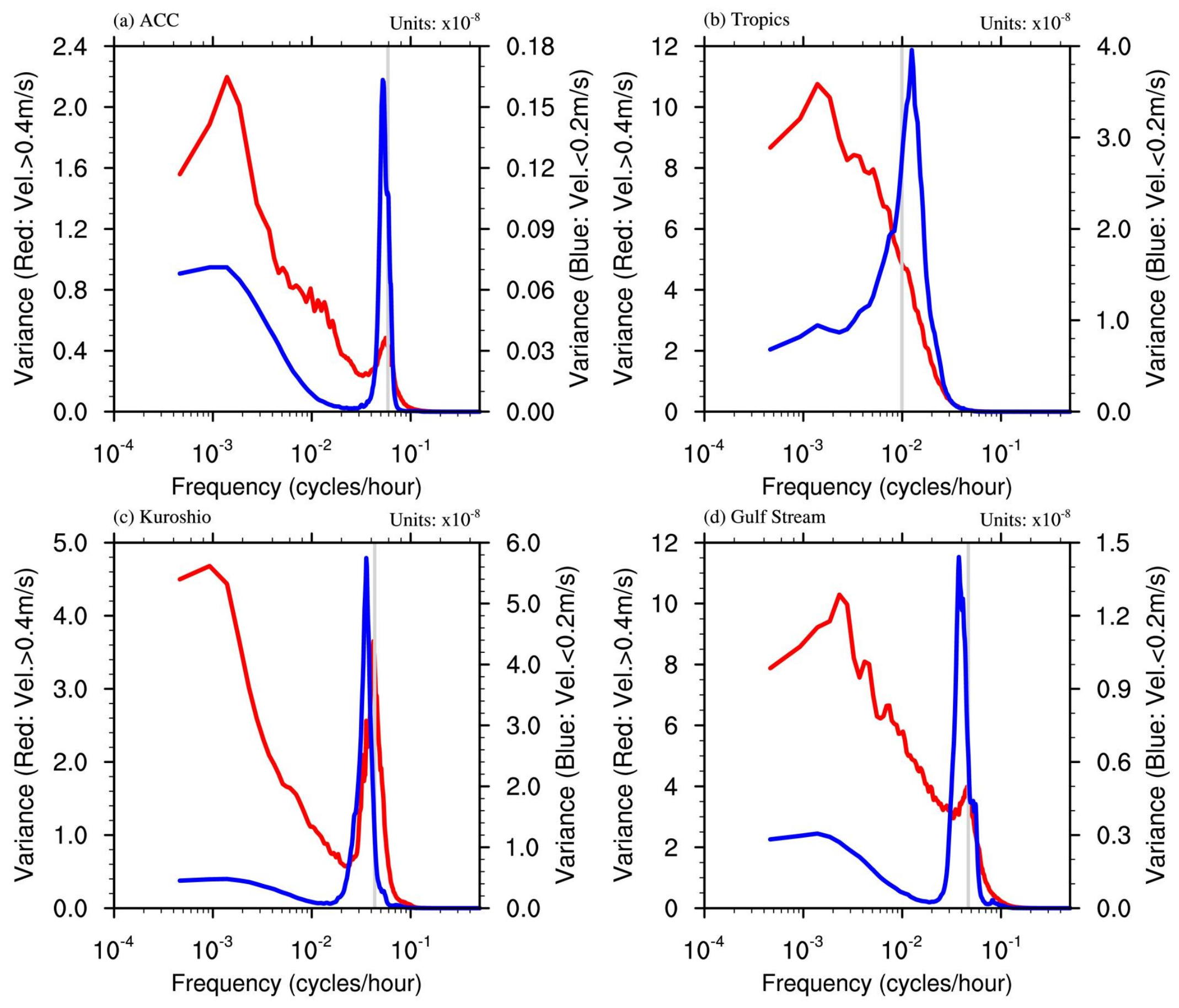

Fig. 4 Regional mean spectrum of fluctuation divergence at grids with strong currents (red line, velocity>0.4m/s) and weak currents (blue line, velocity<0.2m/s). The grey lines mark mean inertial frequency in weak current regions. The locations of the 4 specific regions are shown in Fig. 1b.

6. Possible mechanisms responsible for fluctuations

At mid- and high-latitudes, meso-scale eddies and near-inertial waves have distinctly different time scales. By recalculating the standard deviations of fluctuation divergence using daily data, the wave contribution in the extratropics can be excluded. We find that in the extratropical ocean:

- Fluctuations originate from near-inertial waves almost everywhere outside the regions with strong currents such as Gulf Stream, Kuroshio and ACC.
- More than 70% of the fluctuations result from meso-scale eddy activities in regions with strong currents.

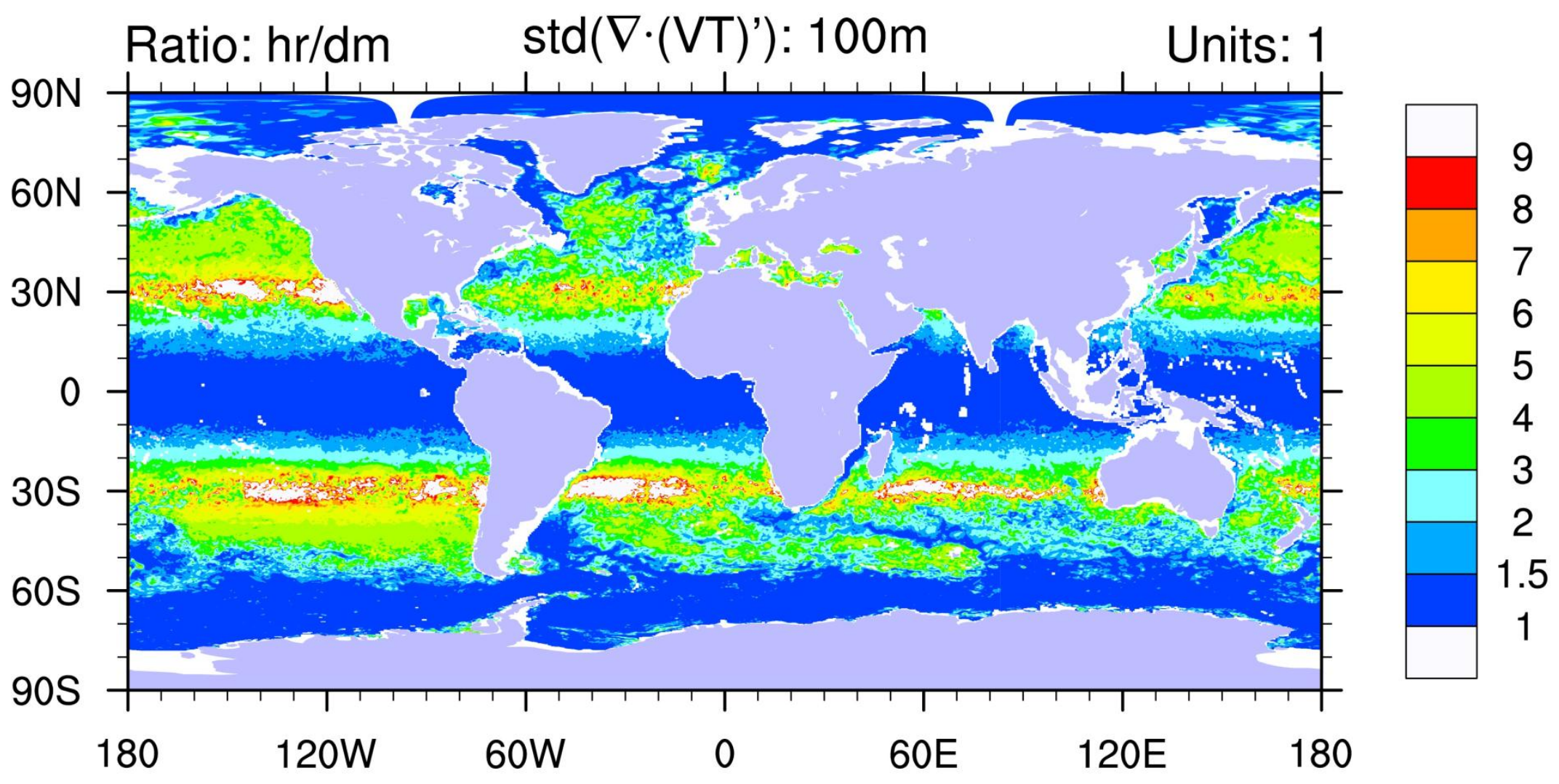

Fig. 5 Ratio of standard deviation of fluctuation divergence obtained from hourly data to that obtained from daily data.

Assuming that tropical and subtropical fluctuations can be simulated by MPI-OM at 0.4º resolution, experiments with 6 hourly wind forcing and with 10-day smoothed wind forcing are used to investigate the extent to which wind-induced near-inertial waves contribute to fluctuations. We find that in the tropical ocean:

- Wind-induced near-inertial waves account 50% of the standard deviation of the fluctuation divergence.
- The other 50% result presumably from instabilities of the equatorial current system.

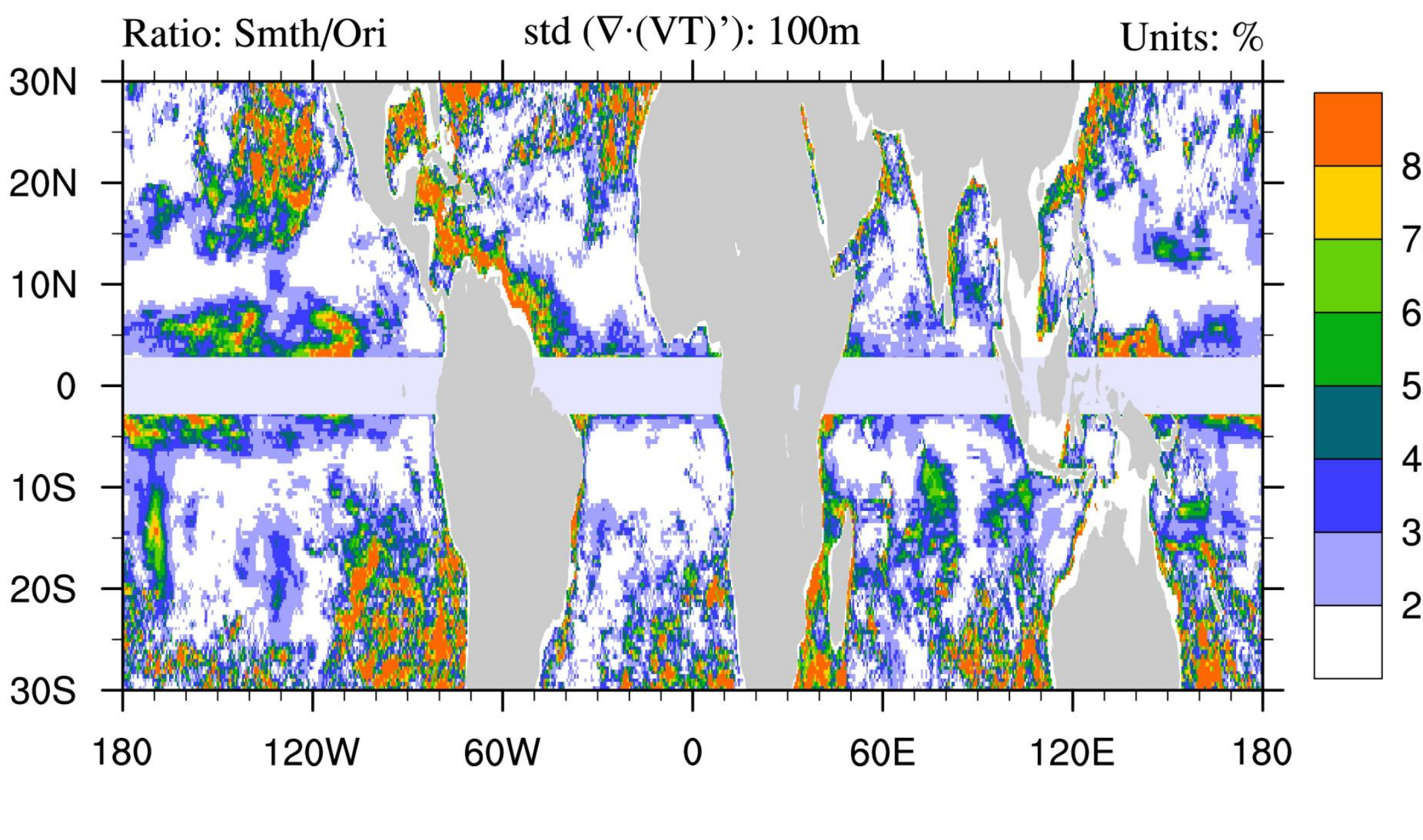

Fig. 6 Percentage of standard deviation of fluctuation divergence simulated by MPI-OM TP04L40 with 10-day smoothed wind forcing (TP04L40_smth) to that simulated by MPI-OM TP04L40 with 6 hourly wind forcing (TP04L40_ori). The equatorial region from 3ºS-3ºN is left out because 10 day smoothing mainly exclude near-inertial waves from 3º poleward.

7. Conclusion

1) Fluctuation F' is not a negligible term, its divergence is even one order magnitude larger than mean eddy flux divergence.
2) Fluctuations are stronger in winter than in summer in the subtropical and mid-latitude oceans due to the seasonality in the wind stress forcing there. In regions with strong currents, it is the other way around due to the seasonality in eddy activities.
3) Three possible generation mechanisms are responsible for fluctuations:
   a) Near inertial waves are active globally with large values in subtropics.
   b) Meso-scale eddies are dominating in the regions with strong current at mid-high latitudes.
   c) Tropical instability waves contribute more than 50% of fluctuation divergence between 6ºS-6ºN.

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