The M_2 internal tide simulated by a 1/10° OGCM

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1. Introduction

- The state-of-the-art parameterization of mixing leaves 70% of the generated internal tides unspecified. This part is related to low modes, whose dissipation provides a substantial amount of mixing energy. So far, our knowledge about these waves is still limited.
- Concurrent simulation of the ocean circulation and tides is crucial for studying these low-mode internal tides, since satellite altimeters provide only integrated properties.
- **In this study, we aim to identify the low-mode wavelengths, their large-scale characteristics and various factors that affect them, using the 1/10° STORMTIDE model that is based on the MPIOM and has been proved to have skill in simulating the M_2 internal tide** (Müller et all, 2012)**.**

2. Methods

To comprehend simulated internal tides, the STORMTIDE wavelengths are compared with those of the Sturm-Liouville and the WKB-simplified eigenvalue problems.

1) STORMTIDE simulation

Wavelengths $L_{ST,m}$ (m=1,2 mode number) derived from wavenumber spectra $S(k,l)$ and $S(K)$ using simulated M_2 baroclinic tidal velocities for overlapping 15°x15° boxes, with k, l and $K^2 = k^2 + l^2$ being the zonal, meridional and horizontal wavenumbers, respectively

2) Sturm-Liouville eigenvalue problem

Numerically solving the eigenvalue problem for the same boxes without taking eddies and circulation into account, but using simulated box-averaged stratification N to obtain wavelengths $L_{SL,m}$, a function of N via eigenvalues and of the Coriolis parameter f

3) WKB-simplified eigenvalue problem

Simplifying the eigenvalue problem using the WKB approximation to avoid numerical solutions, and to derive wavelengths $L_{WKB,m}$ directly using the vertical integral of N

3. Results

3.1 Wavenumber spectra

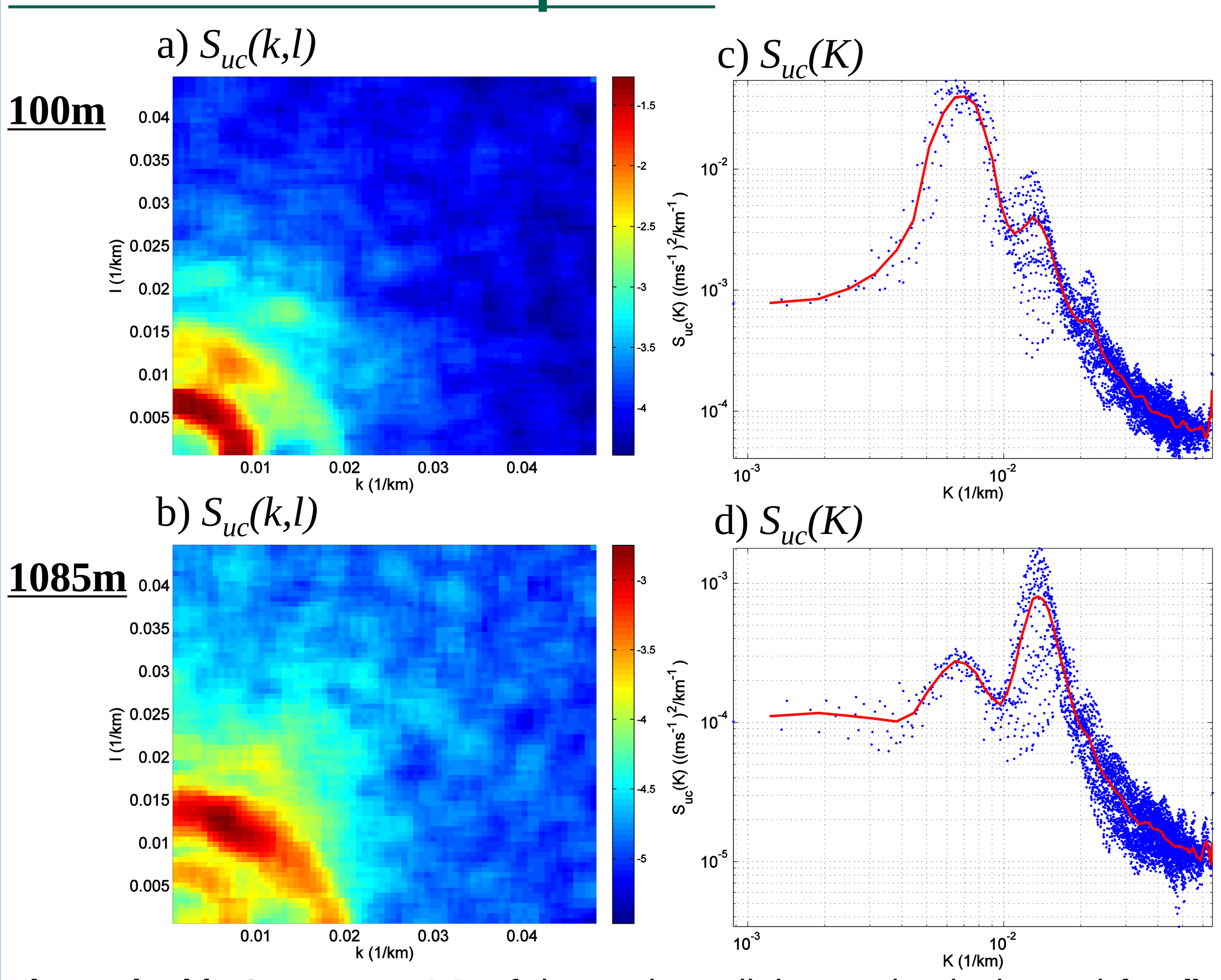

Fig. 1: (a, b): Spectra $S_{uc}(k,l)$ of the M_2 baroclinic zonal velocity and (c, d): their corresponding $S_{uc}(K)$ at 100 m and 1085 m, for the box centered at (192.5E, 22.55N). Red lines are bin-averages of the blue dots, considering in total 100 consecutive intervals for the resolved wavenumber range.

- Two spectral peaks at both depths, the first one around 150 km and the second around 65 km (Fig. 1)
- Both peaks located at the same scales throughout the water column, with the first one being stronger in the top ocean and the second one at around 1000 m, and corresponding to mode 1 and 2, respectively (Fig. 2)

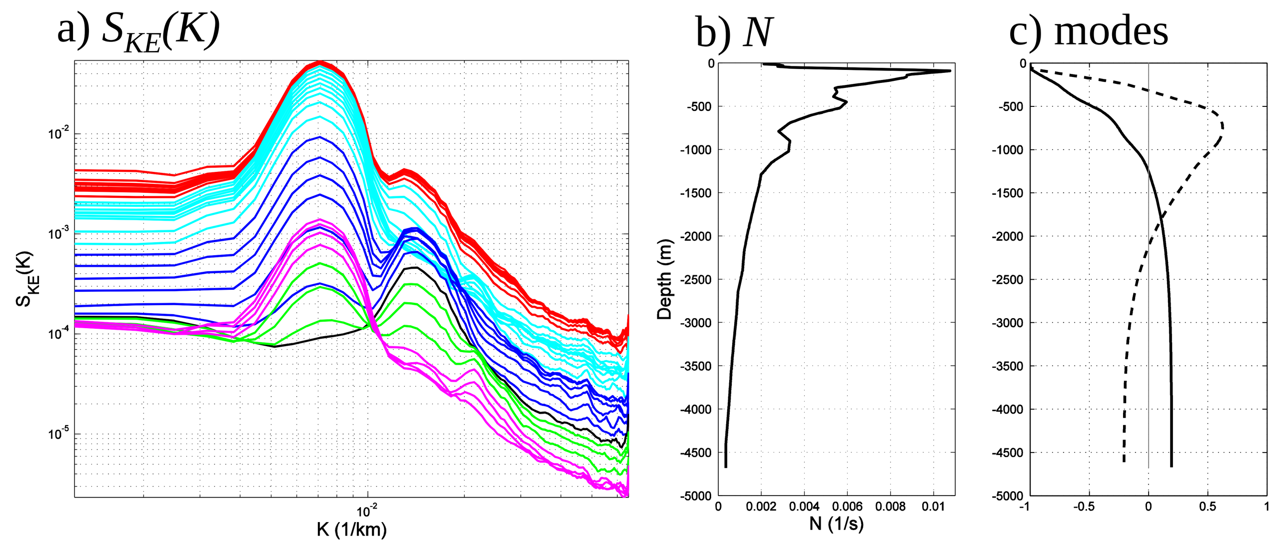

Fig. 2:
***(a):** Spectra of the kinetic energy, in the same box as in Fig. 1, for the top 100 m (red), 122-485 m (cyan), 560-1085 m (blue), 1220 m (black), 1365-1700 m (green) and 1885-2525 m (magenta).*
***(c):** Vertical structures of mode 1 (solid) and 2 (dashed) of the kinetic energy, by solving the Sturm-Liouville eigenvalue problem with stratification in (b).*

3.2 STORMTIDE wavelengths

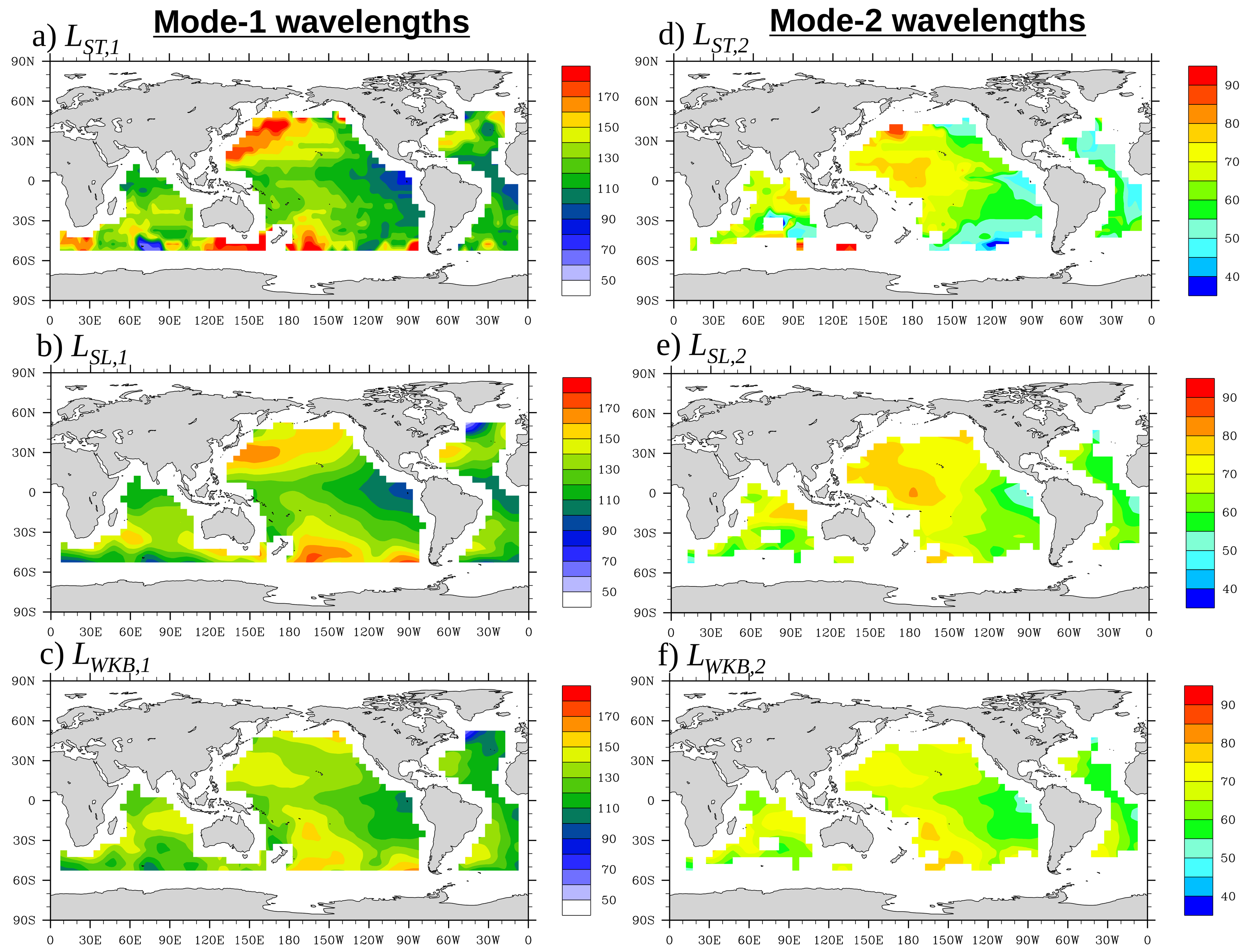

Fig. 3:
***Left panels:** Mode-1 wavelengths in km, simulated by the STORMTIDE model (100 m) (a), derived by solving the Sturm-Liouville (b) and the WKB-simplified (c) eigenvalue problems.*
***Right panels:** Mode-2 wavelengths in km (1085 m), same structure as in the left panels.*
***Neglecting** regions poleward 53° N/S due to flat spectra caused by strong eddy activities.*

- $L_{ST,1}$ mainly in the range of 100-150 km and $L_{ST,2}$ of 45-75 km
- Large-scale features of the STORMTIDE wavelengths also captured by the two eigenvalue problems:
  - A zonal asymmetry, more dominant for mode 2 than for mode 1, expected from the dependence on N
  - A general poleward increase of mode-1 wavelengths, expected from the dependence on f
  - Combined role of N and f for mode-1 wavelengths, while N solely controlling mode-2 wavelengths

3.3 Linear waves?

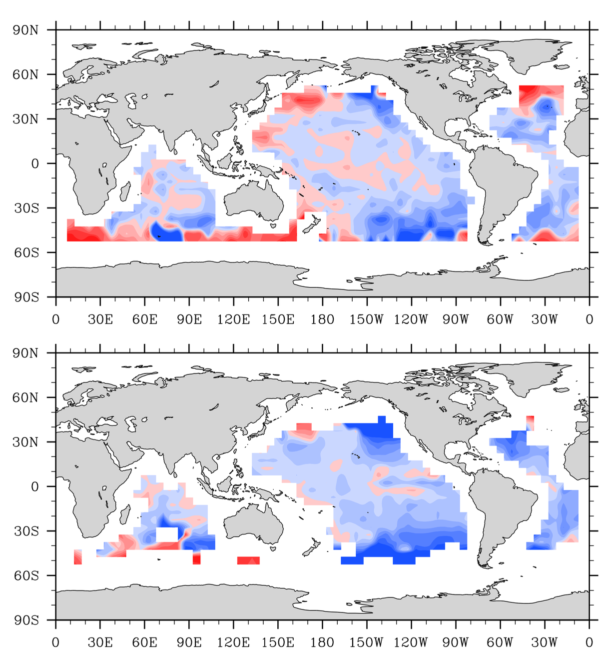

Fig. 4: Differences (%) between $L_{ST,m}$ and $L_{SL,m}$ (m=1,2), normalized by $L_{ST,m}$, for mode 1 (top) and mode 2 (bottom).

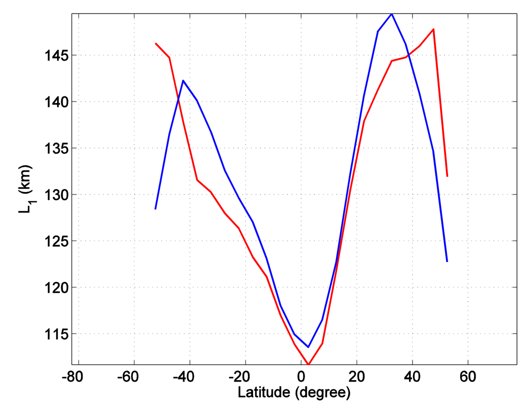

Fig. 5: Zonal mean of $L_{ST,1}$ (red) and $L_{SL,1}$ (blue).

- In the tropical and subtropical regions, essentially linear waves generated in the STORMTIDE model (Fig. 4)
- Systematically larger $L_{ST,1}$ than $L_{SL,1}$ in these regions (Fig. 5), likely caused by refractions via the large-scale increase of stratification toward the equator
- In strong-current and high-latitude regions, larger differences indicating strong non-linear wave-current interactions (Fig. 4)

4. Conclusions

- $L_{ST,1}$ range within 100-150 km, while $L_{ST,2}$ within 45-75 km.
- $L_{ST,1}$ are determined jointly by local stratification N and the Coriolis parameter f, whereas $L_{ST,2}$ are dominantly determined by N only.
- In the tropical and subtropical regions, to a first approximation, the STORMTIDE internal tides are linear waves. The small differences between $L_{ST,1}$ and $L_{SL,1}$ are systematic, likely resulting from refractions of remotely generated waves by the equatorward increase of N.
- In the Kuroshio, Gulf Stream and their extensions, and in high-latitude regions, larger differences are observed, indicating strong non-linear wave-current interactions there.

References:

- Li, Z., J.-S. von Storch, M. Müller, 2014: The M_2 internal tide simulated by a 1/10° OGCM, *submitted*
- Müller, M., J. Y. Cherniawsky, M. G. G. Foreman, and J.-S. von Storch, 2012: Global M_2 internal tide and its seasonal variability from high resolution ocean circulation and tide modeling. *Geophys. Res. Lett.*, 39, L19607