Wind-driven oscillations of cross-equatorial Meridional Overturning Circulations in a numerical ocean model

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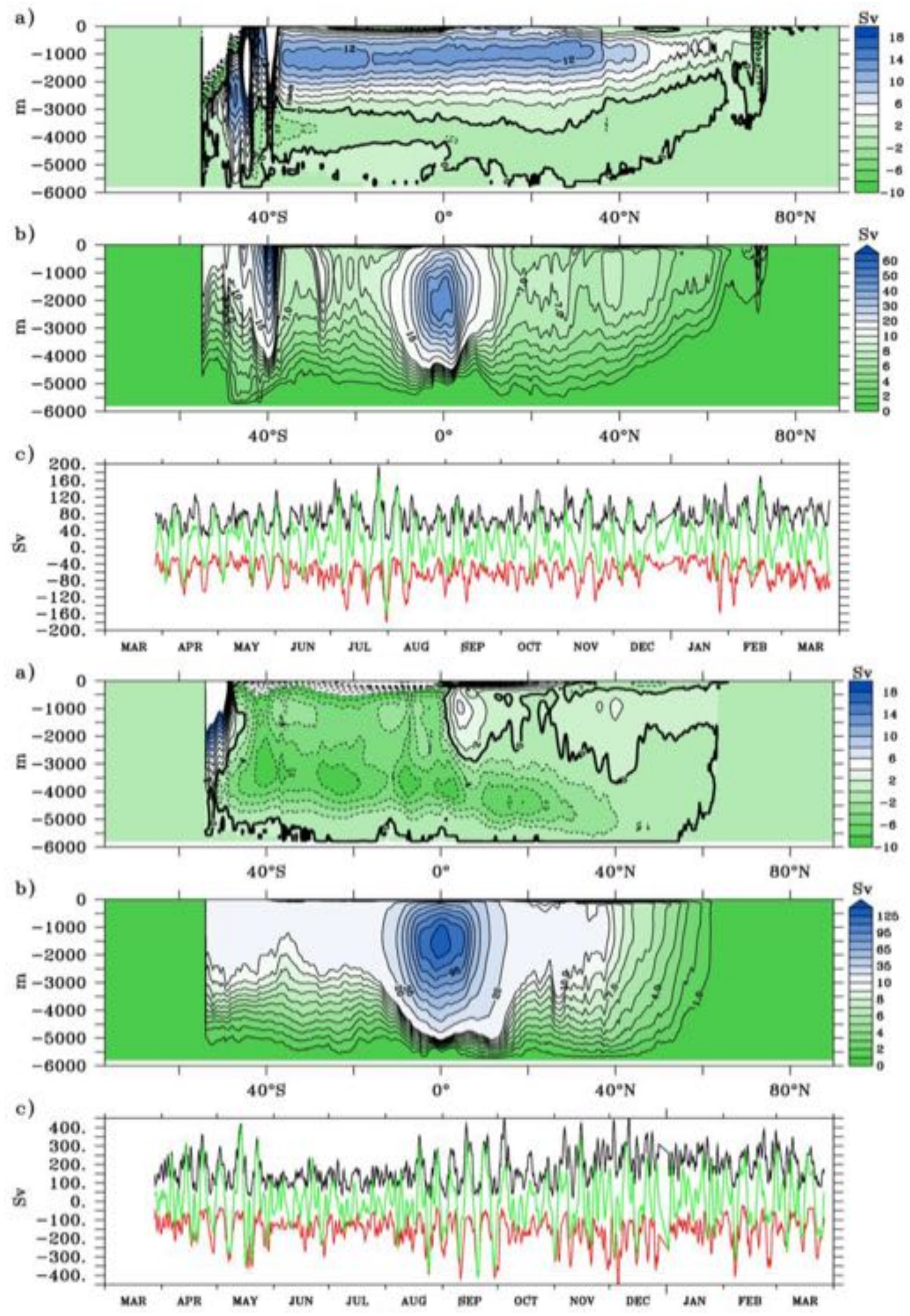
1) Large equatorial MOC variability

Numerical simulations performed with an eddy-permitting global ocean model (NEMO) suggest the existence of large amplitude equatorial oscillations in the Meridional Overturning Circulations (MOCs) in the Atlantic, Pacific (Fig. 1) and Indian (not shown) oceans. Their amplitude is proportional to the width of the ocean basin and is typically ~200 Sv in the Pacific.



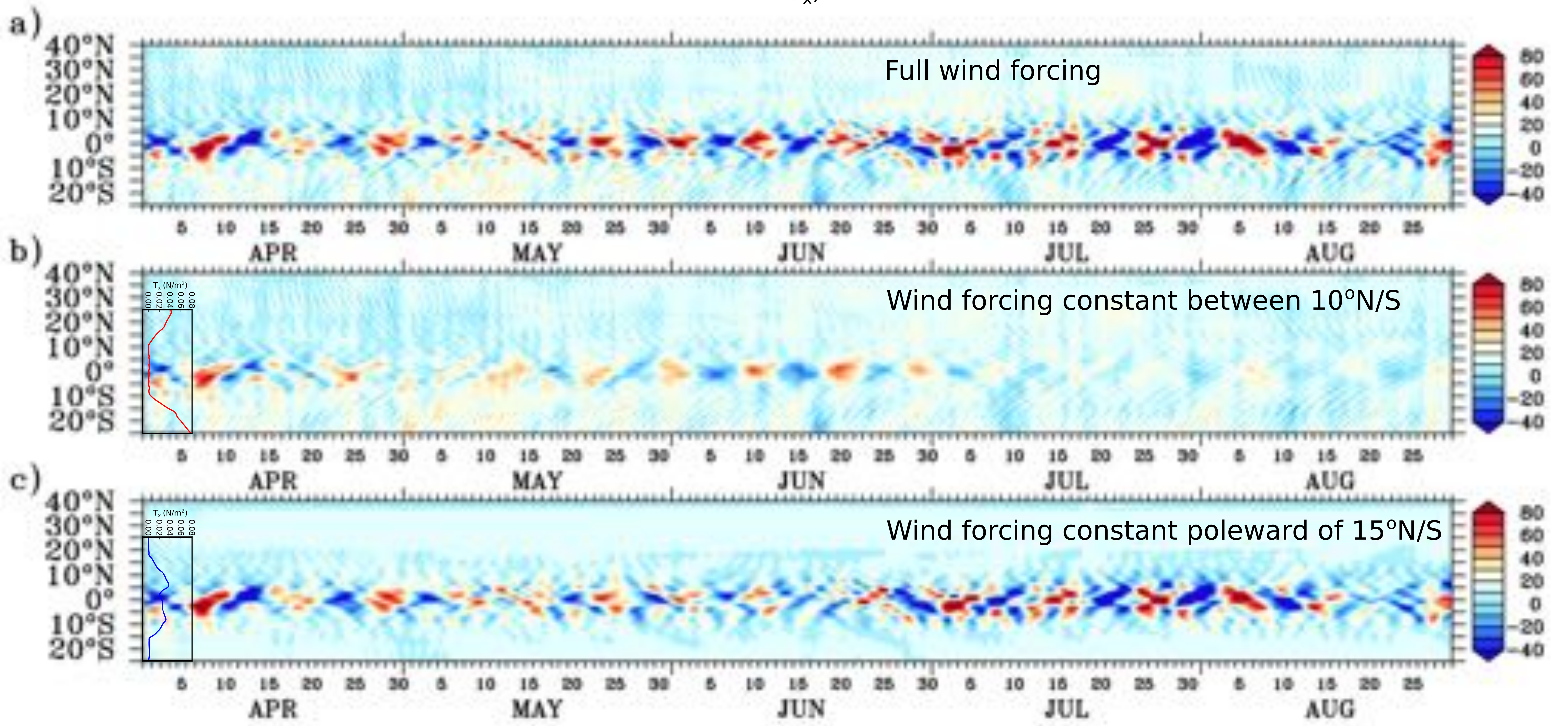
Analysis of an earlier simulation showed pronounced variability of the Atlantic MOC at 26°N arising from equatorward-propagating near-inertial waves (Blaker *et al.* 2012). The effect was manifest in the ageostrophic component of the MOC, and this was subsequently shown to undergo superinertial resonance (Sevellec *et al.* 2013).

Fig. 1: Atlantic (top) and Pacific (bottom) meridional overturning: a) time mean; b) standard deviation; c) time series showing overturning at 1500m depth on the equator (green), and minimum (red) and maximum (black) within the equatorial region 12°N/S, 0-5500m depth

2) Role of wind forcing

The oscillations are a response to the local wind variability. We conducted a series of experiments (Fig. 2), starting from April 1st, in which we fix the wind forcing over parts of the domain. If winds are kept constant within 10° of the equator the large MOC oscillations fade and disappear within a few months. Near-inertial waves formed at higher latitudes can be seen to propagate, crossing the equator. Allowing only the winds local to the equator to vary in time, the large equatorial variability remains, and we lose all the near-inertial waves formed at higher latitudes. The period of the equatorial variability is between 4-10 days.

Fig. 2: Atlantic MOC at 1000m depth (Sv) as a function of latitude and time for simulations with wind forcing: a) fully varying (control); b) held constant between 10°N/S; c) held constant poleward of 15°N/S. For b) and c) a tapering is applied over ~5°. The insets show the standard deviation of τ_x, the zonal wind stress.



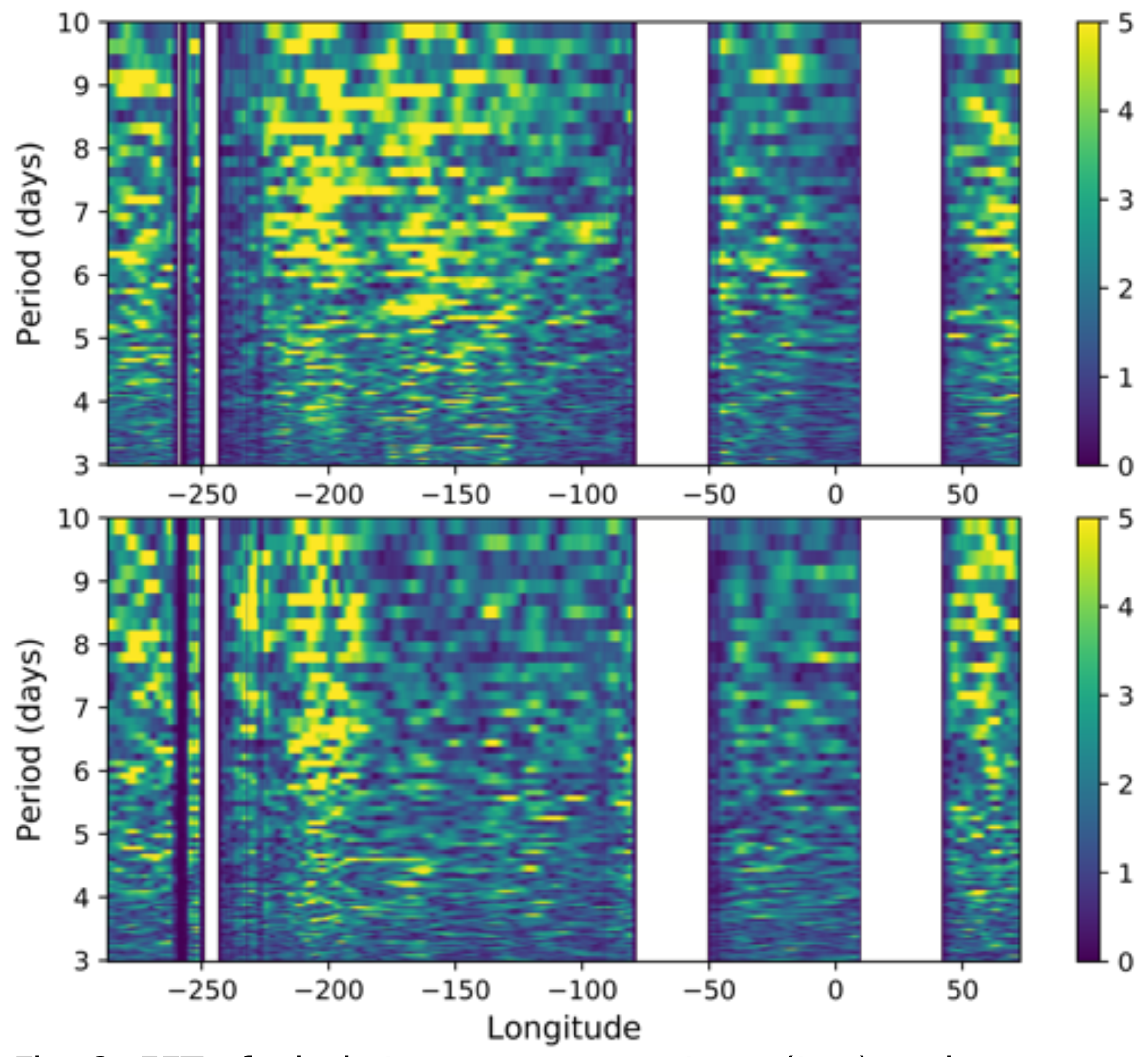


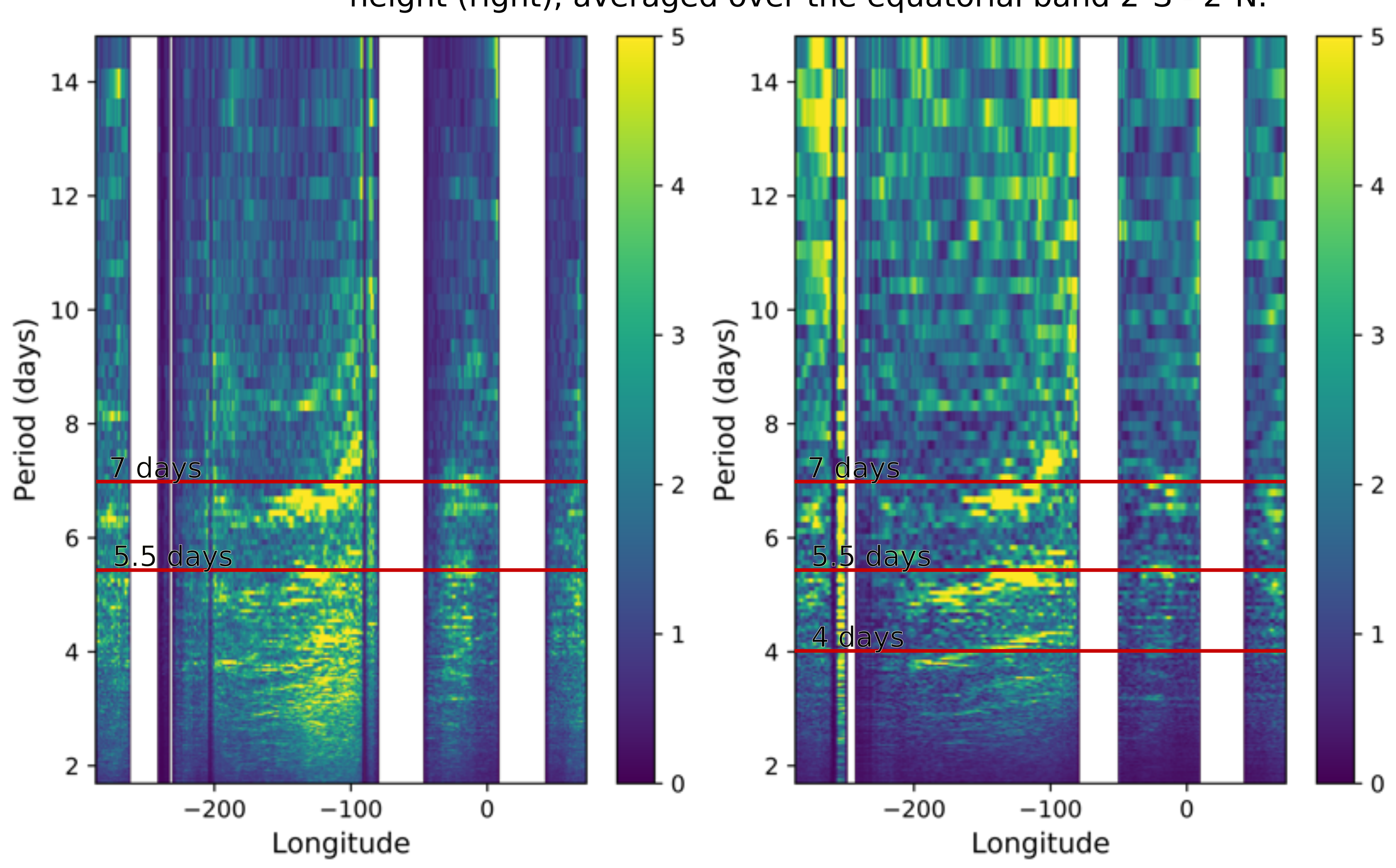
Fig. 3: FFT of wind stress components τ_x (top) and τ_y (bottom), averaged over the equatorial band 2°S - 2°N.

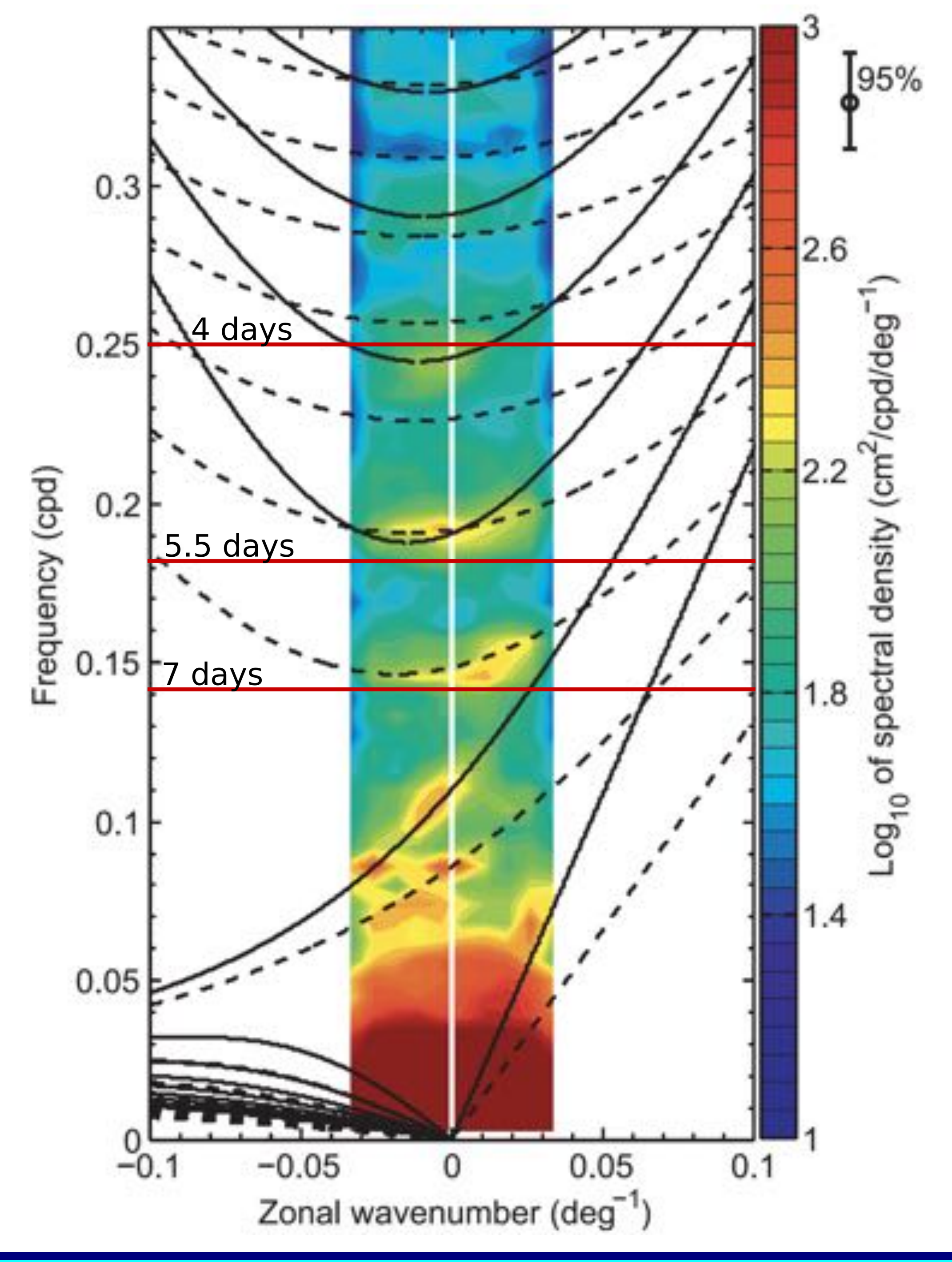
3) Power spectrum analysis

We find no enhanced peaks in the power spectra of the zonal (τ_x) or meridional (τ_y) wind components on the equator to match the periods seen in the MOC (Fig. 3). Understanding how the wind variability forces the MOC oscillations will require further analysis.

FFT analysis of sea surface height (SSH) and vertical velocity (Fig. 4) shows spectral peaks with periods of 5.5 and 7 days. SSH also shows a well defined peak close to 4 days, and possibly higher modes. The peaks are not present at all longitudes, and in the eastern Pacific there appears to be a shift towards slightly longer periods moving from the central Pacific towards the S. American coast.

Fig. 4: FFT of vertical velocity at 2 km depth (left) and sea surface height (right), averaged over the equatorial band 2°S - 2°N.





4) Equatorially trapped inertia-gravity waves

Observations from the TAO/TRITON mooring array in the equatorial Pacific show peaks in the power spectrum of surface dynamic height at periods close to 5.5 and 7 days (Fig. 5, Farrar and Durland 2012). These peaks closely correspond with the theoretical dispersion relations for low baroclinic mode equatorially trapped inertia-gravity waves. The presence of enhanced energy corresponding to higher baroclinic modes is also visible.

As a next step we will further analyse the numerical model output to determine whether the peaks identified in ocean properties (e.g. Fig. 4) arise from equatorially trapped inertia-gravity waves. We will also look to explain the zonal variability, for example identifying whether there is a relationship between this and the forcing fields.

Fig. 5: Reproduced from Farrar and Durland (2012) "Wavenumber-frequency power spectrum of surface dynamic height relative to 500 db, averaged over 5°S-5°N (from TAO/TRITION moorings...). Solid black and dashed black curves are the theoretical dispersion curves for baroclinic modes 1 and 2, respectively."

5) Summary

- Numerical simulations suggest the existence of large amplitude MOC variability in all ocean basins
- We show that these are forced by local wind variability
- FFT analysis of the zonal and meridional wind stress components does not yield clear peaks in the power spectra to match the variability seen in the MOC.
- FFT analysis of the SSH and vertical velocities in the ocean interior yield peaks at periods of 5.5 and 7 days
- We believe that the MOC variability results from excitation of equatorial inertia-gravity waves, for which there is observational evidence of enhanced dynamic height variability in the tropical Pacific (Farrar and Durland 2012)

References

Blaker *et al.* (2012) Large near-inertial oscillations of the Atlantic meridional overturning circulation. Ocean Modelling, 42, 50-56.

Sevellec *et al.* (2013) On the near-inertial resonance of the Atlantic meridional overturning circulation, JPO, 43, 2661-72.

Farrar and Durland (2012) Wavenumber-frequency spectra of inertia-gravity and mixed Rossby-gravity waves in the equatorial Pacific Ocean, JPO, 42, 1859-81.