Understanding the jet-structured Deep Tropical Ocean Circulation

Insight from idealized numerical simulations

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INTRODUCTION

In the tropical Pacific Ocean, several systems of zonal jets are observed below the thermocline down to the bottom of the ocean (Fig. 1 and 6c)

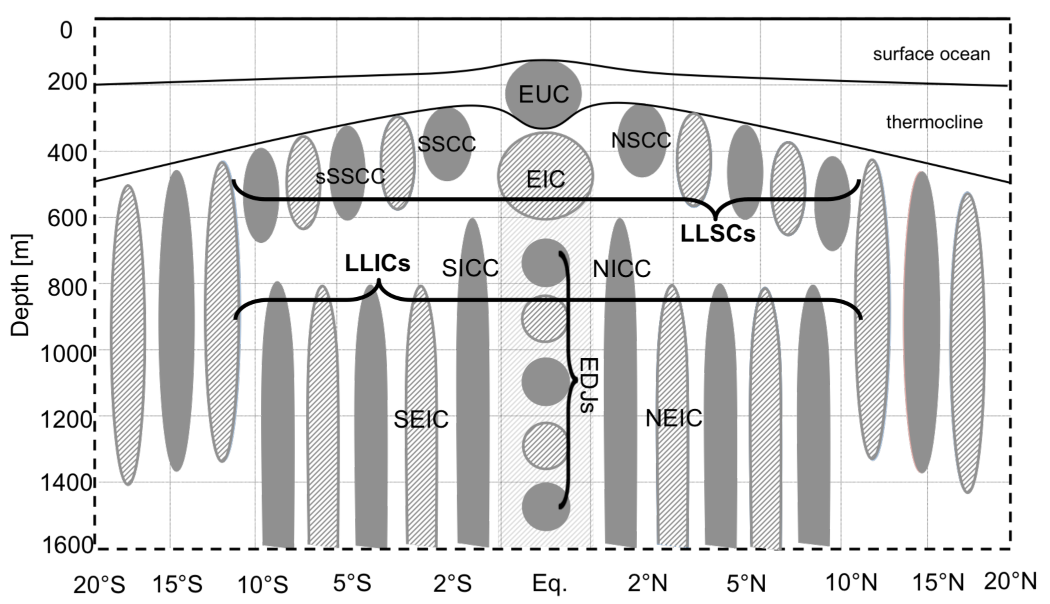
- Vertically-alternating Jets at the Equator (EDJs)
- Meridionally-alternating Jets on each side of the Equator (LLSCs and LLICs)

These jets are misrepresented in Ocean Global Circulation Models (OGCMs) used for climate studies, inducing potential biases on the regional circulation, biogeochemical forcing and other feedbacks.

Possible theoretical mechanisms for the jets formation are:

- Short Equatorial waves destabilization into long waves with high vertical and meridional modes (Hua 2008, Ménesguen 2009, Ascani 2015)
- Inverse turbulent energy cascade (Vallis and Maltrud 1993)

Both mechanisms require that a substantial amount of energy is present at depth. We investigate different wave-like forcings in an idealized numerical model and their ability to transport energy at depth and to create the observed jet-structured tropical circulation.



Main Characteristics

- ~ 3° meridional wavelength for LLSCs and LLICs.
- ~ 350 m vertical wavelength for EDJs
- ~ 2-10 cm/s amplitude, decreasing poleward

Figure 1 : Scheme of equatorial zonal currents found in the tropical oceans. Light grey: eastward jets, Dark grey: westward jets adapted from Menesguen (2019).

MODEL & SET UP

- Idealized numerical simulations are performed using CROCO model (primitive equation solver)
- **Domain** : 140° x 50° x 5000 m with 0.25° horizontal resolution and 40 sigma-levels. Equatorial beta plane approximation.
- **Boundary conditions** :
  - Surface : time- and zonally-periodic wind stress confined in the center of the basin, around the equator.
  $$\tau^y = \tau_0 X(x) Y(y) sin(kx - \omega t)$$
  - Bottom : linear bottom drag to damp wave reflections
  - N-S boundary : sponge layers to damp coastal Kelvin wave
  - E-W boundary : rigid walls to represent idealized coasts
- **Stratification** : Constant N=2.10^{-3}, representative of subthermocline conditions
- **Parameterization** : K-Profile Parameterization based on the gradient Richardson number for vertical mixing.

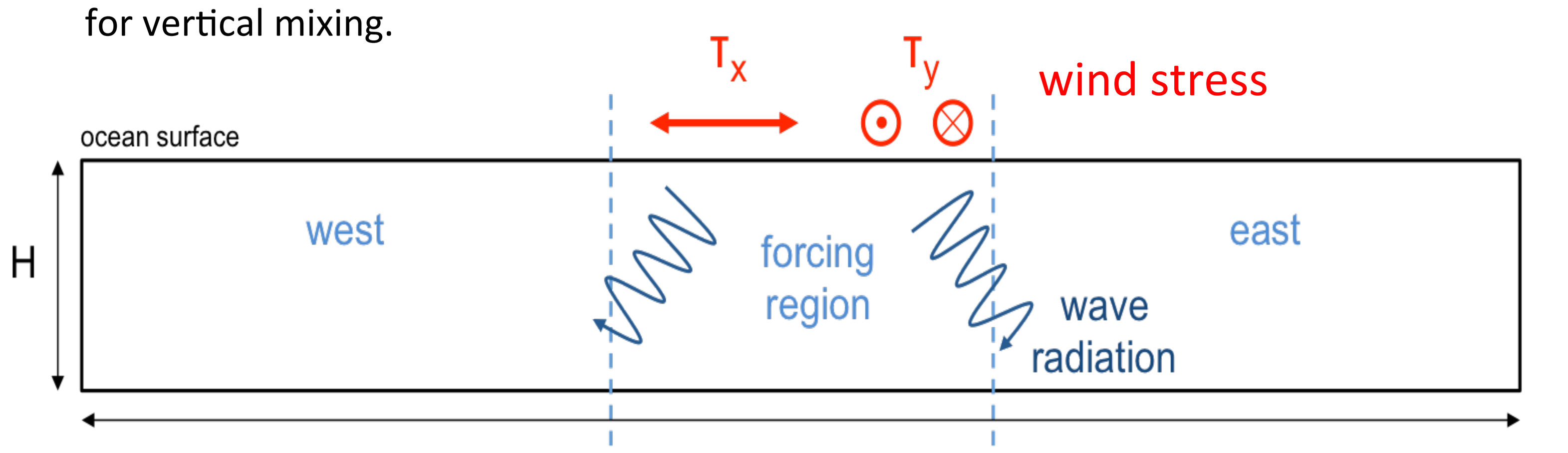


Figure 2 : Model configuration. The ocean is forced in a localized region in the middle of the basin.

RESULTS

A - WAVES & ENERGY PATHWAYS TO DEPTH

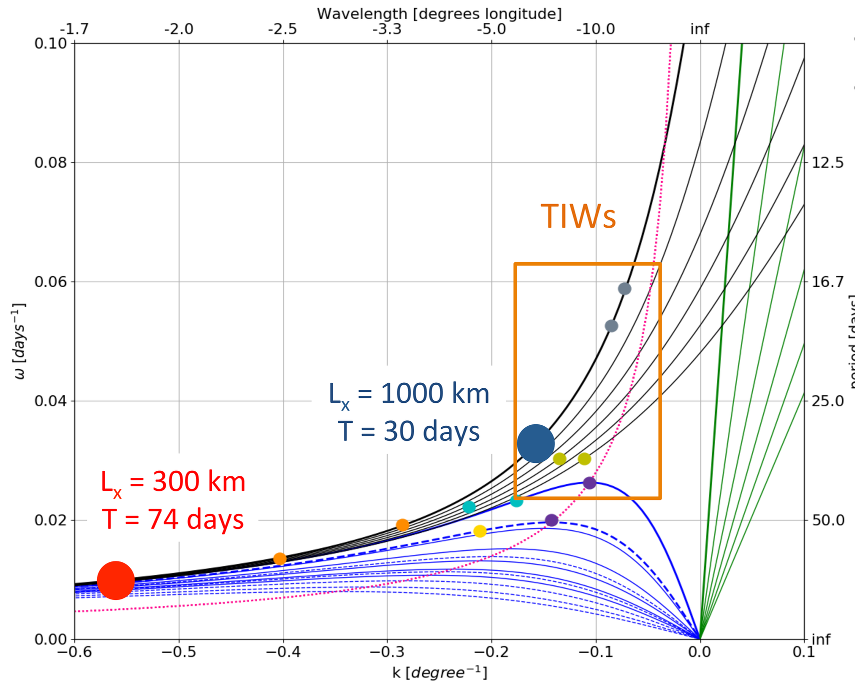


Figure 3 : Equatorial waves dispersion diagram as a function of zonal wavenumber (k) and frequency (w) for different vertical and meridional modes. Green : Kelvin waves, Black : Yanai waves, Blue : Rossby waves.

- Waves transport efficiently energy.
- They are particularly present in the tropical ocean at intra-seasonal time scales (Ascani 2010).

We force our model with different wave-like stress spanning intra-seasonal wave periods.

Period T = 2π/ω	Wavelength L_x = 2π/k
30 days	1000 km
40 days	700 km
50 days	550 km
74 days	300 km
100 days	270 km
180 days	250 km
365 days	180 km

Waves propagation

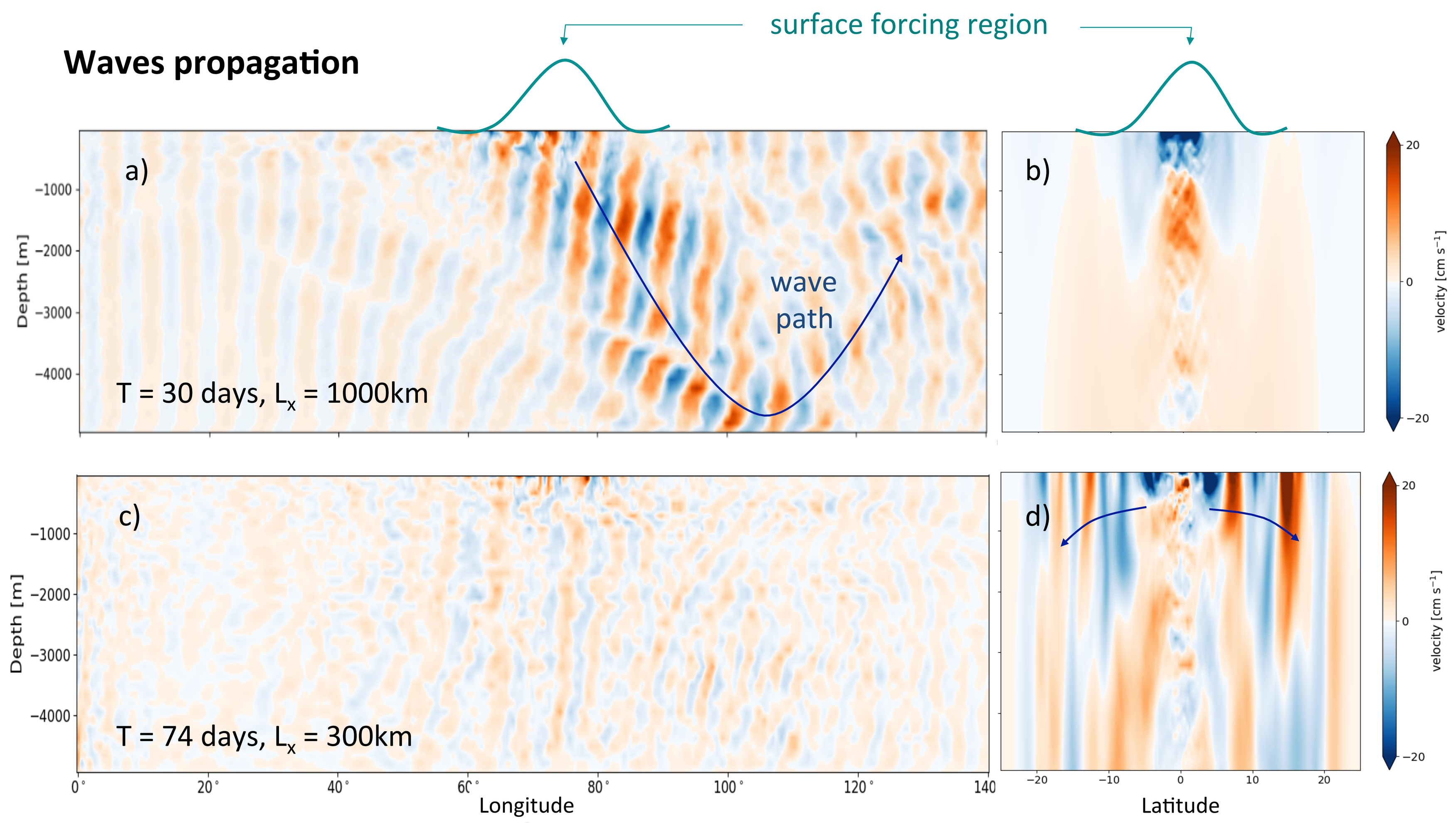


Figure 4 : Snapshots of the meridional velocity after 2 years of simulation for (a-b) T=30 days and L_x=1000 km forcing and (c-d) T=74 days and L_x=300 km forcing (a-c).

The long wavelength (L=1000km) propagates mainly as a single Yanai wave along the equator and is relatively stable (Fig. 4a-b). The shorter wavelength (L=300km) scatters into different meridional modes and is no longer observed as a zonally propagating equatorial wave (Fig. 4c-d).

Kinetic energy dependence to Forcing Frequency-Wavenumber

The total amount of energy transferred to the ocean depends on the frequency and wavenumber forced. Sensitivity study shows that :

- Shorter periods are more efficient to transfer energy to the ocean
- Longer wavelengths are also more efficient to transfer energy
- Combination of both shows an optimum of energy for T=50 days and L_x=500 km.

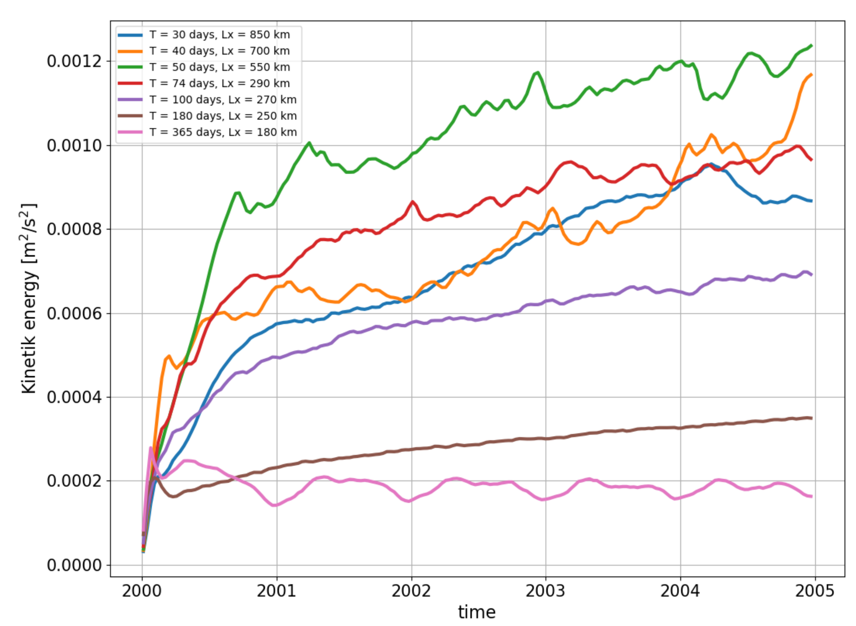


Figure 5 : Time evolution of basin-averaged kinetic energy for each simulation

B – RESULTING MEAN CIRCULATION

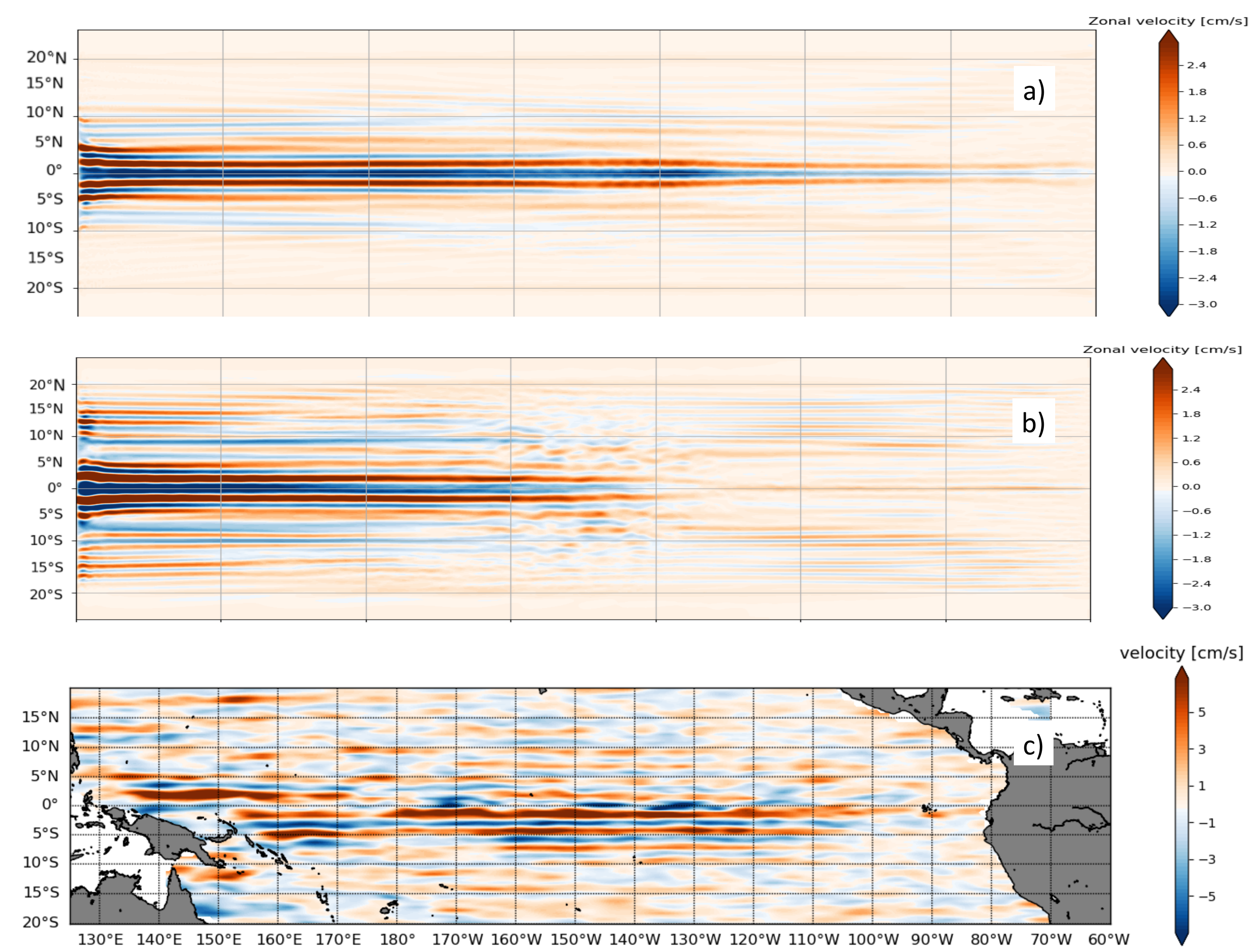


Figure 6 : Comparison of time-averaged zonal velocity over the last 10 years out of 20 for the simulations, integrated between 900 and 1200 m : (a) T=30 days and L = 1000 km and (b) T = 74 days and L= 300 km. (c) time-averaged over 10 years of zonal velocity from Argo float drift integrated between 900 and 1100 m in the Pacific Ocean (adapted from Cravatte et al., 2012) .

The second simulation (Fig. 6b) has a better ability to reproduce observed off-equatorial zonal jets (Fig. 6c) than the first simulation (Fig. 6a). This is compatible with shorter wavelengths being more efficient in transferring energy to higher latitudes by meridional waves radiations (Fig. 4d).

CONCLUSIONS

We have investigated the ability of surface-generated intra-seasonal variability to generate a jet-structured deep tropical circulation from idealized numerical simulations. A sensitivity study to the forcing period and wavelength shows that :

- The ability of the forcing to radiate energy at higher latitudes depends on its period and wavelength.
- The total amount of kinetic energy transferred to the ocean also depends on the forcing period and wavelength.

Both aspects affect the ability of the forcing to reproduce the observed deep circulation with zonal jets of amplitude around 5-10 cm/s and spanning the latitude range from at least 15°S to 15°N. From our limited set of experiments, the forcing with a period of 74 days and a wavelength of 300 km seems the best for reproducing the observed circulation.

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