

Transient Changes in the Brewer-Dobson circulation Associated with ENSO



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Motivation

Numerous studies have shown that warm ENSO (El Niño) events are able to modify the Brewer Dobson (BD) circulation in middle and high latitudes. The anomalous upward propagation and dissipation of planetary waves at middle latitudes during strong warm ENSO events force the acceleration of the BD circulation in the middle and upper stratosphere towards the North Pole resulting in a warmer polar stratosphere and a weaker polar vortex (Sassi et al., 2004; Manzini et al., 2006; Garcia-Herrera et al., 2006).

We use NCAR's Whole Atmosphere Community Climate Model WACCM3 to show that warm ENSO events may affect the BD circulation not only at middle and high latitudes but also in the tropical lower stratosphere. We study here the mechanisms involved and compare them with those that accelerate the BD circulation under GHGs increases.

Model and Simulations

WACCM3 (Garcia et al., 2007) is a fully interactive Chemistry Climate Model (CCM) that spans the altitude range 0-140 km. It is based on the Community Atmosphere Model CAM, version 3, and incorporates most of the physical and chemical processes required to model the middle atmosphere, including the mesosphere and lower thermosphere. The simulations used here were part of the CCM Validation activity of the SPARC project.

REF1: A four-member ensemble simulation from 1950 to 2003 run at horizontal resolution 4°x5° (lat vs lon), Sea Surface Temperatures and loadings of greenhouse gases and halogen species are prescribed from observations. There is no QBO in the model, either internally generated or externally prescribed. Chemical effects of volcanic aerosols are included but not their radiative effects and the 11-yr solar cycle irradiance variability is parameterized in terms of observed f10.7 radio flux.

REF2: This is a prognostic three-member ensemble run from 1975 to 2050 where GHGs and halogen abundances are prescribed following A1b scenario of IPCC and WMO. SSTs are specified from a run made with CAM3 coupled with a full ocean model.

ENSO composites

The strongest ENSO events during the period 1950-2003 have been composited using the REF1 simulation according to the monthly values of the Niño 3.4 index (N3.4) whenever this index exceeds 1 standard deviation. A total of 10 events were selected, all of them peaking in late fall or early winter. The strong ENSO observed in summer 1988 was not chosen as it has an anomalous phase with respect to the seasonal cycle.

The monthly mean ensemble series from REF1 simulations were treated before being composited to eliminate the seasonal cycle and remove linear trends. Short period fluctuations (2-3 months) were smoothed.

The composites are shown here averaged from month 1 to month 4 (month 0 is the month with the largest N3.4 value for each ENSO event), as the anomalous warming observed in the tropical troposphere after any strong warm ENSO event maximizes in WACCM3 during months 2 and 3.

Results

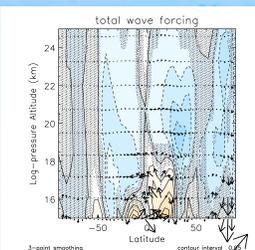


Figure 1. Warm ENSO composite (month 1 - month 4 average) of (arrows) TEM meridional circulation anomalies and (contours) zonal mean acceleration anomalies. Solid (dashed) lines for positive (negative) anomalies. Non stippled areas denote the 95% significant values following a Monte Carlo test.

Figure 1a shows the anomalies in the residual circulation (arrows) during strong ENSO events. The largest anomalies in vertical upwelling are observed in the lowermost stratosphere around the Equator slightly shifted towards the Northern Hemisphere as for that of the two branches of the BD circulation. The contours display the anomalies in wave forcing that are actually driving the residual circulation anomalies.

The downward control principle (DCP; Haynes et al., 1991) estimates the tropical average of the vertical velocity in terms of parameterized and resolved waves, Eq. (1) (Randel et al., 2002). This expression predicts that the tropical upwelling at a certain height is due only to the wave dissipation that occurs in the Tropics above it. Results are shown in Figure 2.

$$\langle \bar{w}^* \rangle(z) = \frac{1}{\rho(z)} \int_z^{\infty} \frac{\rho a \cos \phi \left[(\rho a \cos^2 \phi)^{-1} \nabla \cdot \mathbf{F}(\phi, z') + \mathbf{X} \right]}{\bar{m}_\phi} dz' \times \left(\sin \phi_{\text{top}}^* \right)^{-1} \quad (1)$$

where $\bar{m} = a \cos \phi (\bar{u} + \Omega a \cos \phi)$

z is log pressure altitude, a is the Earth's radius, ϕ is the latitude, m is the zonal-mean meridional gradient of angular momentum, and \mathbf{X} denotes the zonal force due to unresolved waves. We average Eq. (1) between 26°S and 26°N to avoid closed contours of zonal-mean angular momentum nearer the Equator.

The agreement between the actual $\langle w^* \rangle$ computed by the model and the one obtained through the DCP is very good (solid and dashed blue curves in Fig. 2). However, when the parameterized waves are not taken into account (dashed red curve) the agreement is much poorer, specially in the lowermost stratosphere. There, in fact, the resolved waves act to decrease the vertical upwelling and the parameterized gravity wave forcing is what explains the actual acceleration in the BD circulation. This result is supported by the resolved and parameterized wave forcings shown in Fig.3. Positive anomalies in EP flux divergence are seen in the lower tropical stratosphere (Fig. 3a), which are responsible for the negative contribution of the resolved waves to the tropical upwelling there (red curve). The contribution of the parameterized wave forcing comes mainly from the NH subtropics.

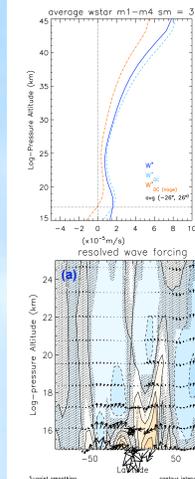


Figure 2. (Left), Warm ENSO composite of the TEM vertical velocity averaged over the tropical region (22 S-22 N) from month 1 to month 4. The solid blue line denotes the actual value calculated from the model; the dashed blue line is the DCP estimate from Eq. (1). The dashed-dotted red curve is the DCP estimate excluding the contribution, \mathbf{X} , of parameterized waves.

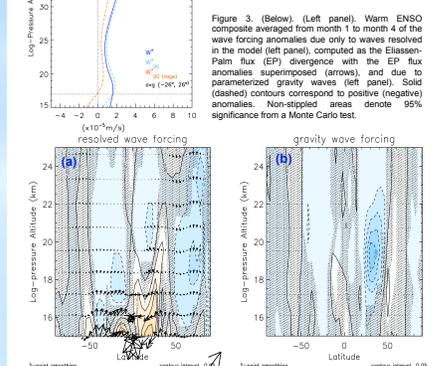


Figure 3. (Below) (Left panel), Warm ENSO composite averaged from month 1 to month 4 of the wave forcing anomalies due to waves resolved in the model (left panel), computed as the Eliassen-Palm flux (EP) divergence with the EP flux anomalies superimposed (arrows), and due to parameterized gravity waves (right panel). Solid (dashed) contours correspond to positive (negative) anomalies. Non-stippled areas denote 95% significance from a Monte Carlo test.

Is the mechanism analogous to that operating under increase in GHGs?

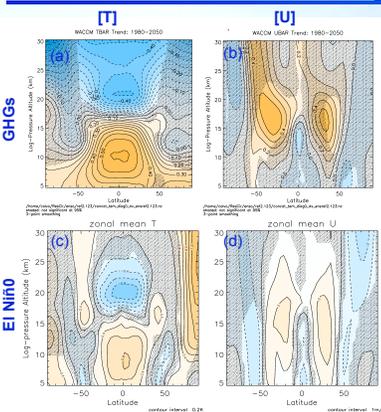


Figure 4. (Upper panels) Annual trends of zonal-mean temperature (left) and zonal wind (right) for the period 1980-2050 in the REF2 simulation. (Bottom panels) Warm ENSO composites averaged from month 1 to month 4 of the zonal mean temperature (left) and zonal wind (right) anomalies. Solid (dashed) contours denote positive (negative) trends or anomalies. Non-stippled areas are 95% significant. Upper panels from Garcia and Randel (2008).

Increasing GHG concentrations also accelerate the BD circulation in the tropical lower stratosphere (e.g. Butchart et al., 2006). Garcia and Randel (2008) suggested that, in WACCM3, this appeared to be due to enhanced wave propagation and dissipation in the tropical lower stratosphere due to changes in the zonal-mean zonal wind structure in the UTLS region (which is geostrophic balance with changes in the zonal-mean temperature structure; Fig. 4a and b). These zonal wind and temperature change patterns are similar to those generated by ENSO (Fig. 4c and d); nevertheless, in the ENSO case, there is reduced dissipation of resolved waves in WACCM.

Garcia and Randel (2008) also showed that in WACCM3 only the dissipation of resolved waves played a significant role in forcing the BD circulation in the lowermost stratosphere (below 20 km), the contribution of gravity waves being much smaller. This is shown by the dashed curves in Fig 5 computed through the DCP following Eq. (1) as in Fig 2. Figure 6 shows the forcing due to resolved waves and gravity waves (as in Fig.3). Above 17-18 km the resolved and parameterized forcing from the ENSO and GHG cases (Figs. 3 and 6) look quite similar. However, below 17-18 km, large differences are observed in the tropical upwelling due to the resolved forcing (dashed red curve in Fig. 5). Positive EP flux divergence anomalies are observed along the tropical region during El Niño events (Fig. 3a) decelerating the BD circulation in this area (dashed red curve in Fig. 2), while the opposite is seen in the GHGs case. Thus, the role of the gravity waves becomes crucial in the ENSO case to explain the observed acceleration of the BD circulation in the lowermost tropical stratosphere.

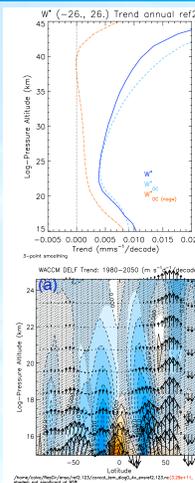


Figure 5. (Left) As figure 3 for the annual trends computed for the REF2 simulation (1980-2050).

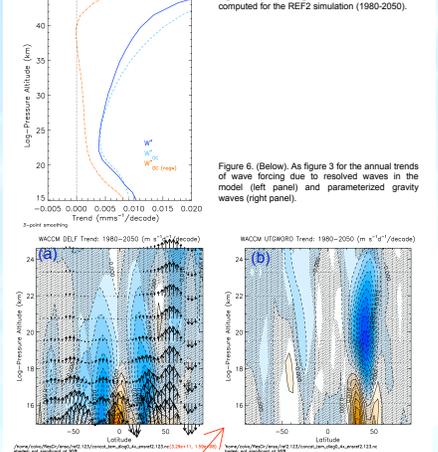


Figure 6. (Below) As figure 3 for the annual trends of wave forcing due to resolved waves in the model (left panel) and parameterized gravity waves (right panel).

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