KODYACS

Coupling of Dynamics and Atmospheric Chemistry in the Stratosphere

Dynamical Chemical Interaction in the Stratosphere. Part 1: Dynamics and Transport

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Time Average Effect of the QBO on the Tropical Residual Circulation

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Introduction

The mean meridional circulation of the middle atmosphere is characterized by upwelling in the tropics and downwelling in the high latitudes, specifically in the winter hemisphere. The so-called Brewer Dobson circulation above the tropopause region is driven mainly by dissipation of waves in the mid and high latitude stratosphere and mesosphere. However, within the tropics the quasi-biennial oscillation (QBO) has a strong impact on the local structure in space and time of the mass transport. This impact consists not only in quasi-biennial variations of the residual circulation (v*,w*) and temperature, but also in a QBO average net effect. This work quantifies the average QBO effect on the residual circulation and temperature in the tropics by comparing two experiments with and without a QBO, respectively.

The QBO has two specific properties which imply a QBO averaged net effect on the residual circulation. Firstly the zonal wind in the QBO has a bimodal distribution in zonal wind speed, and secondly the easterly and westerly phases have different levels of maximum duration [Naujokat, 1986]. The easterly phase dominates in the upper levels of the QBO domain while the westerly phase prevails at lower levels. Hence the average of a QBO cycle consists of easterlies and westerlies at upper and lower levels of the QBO domain, respectively. As a consequence the long term average of the secondary meridional circulation of the QBO, which contributes to the general residual circulation, is non-zero as well. Further it follows that the long term average of the observed general circulation in the QBO domain must differ systematically from the long term average obtained from a GCM simulation that does not contain the QBO. The purpose of this work is therefore to quantify this systematic difference by comparison of two experiments which exclude and include, respectively, the QBO. Such an estimate is of interest since GCM experiments often do not include the QBO.

Experiments and Methodology

The following experiments are based on MAECHAM5, the middle atmosphere version of the ECHAM5 GCM. (MA)ECHAM5 is the successor of (MA)ECHAM4 [Roeckner et al., 1996; Manzini et al., 1998].

The GCM resolves the atmosphere from the surface up to 0.01 hPa (ca. 80 km). While the standard middle atmosphere model uses 39 layers (L39), the model simulating the QBO resolves the atmosphere with 90 layers (L90). The horizontal resolution is T42.

Two experiments L39 and L90 are run with climatological boundary conditions for sea surface temperature and sea ice. The control experiment L39 has no QBO, thus corresponds to the majority of GCM experiments concerning the absence of the QBO. Experiment L90 differs from L39 in the improved vertical resolution only. As a result the QBO is generated spontaneously [Giorgetta et al., 2002].

For the following analysis it is useful to separate a variable X within the QBO domain in the following components:

$X(t) = X_c + X_a(t) + X_r(t)$
X_c = climatological annual mean of X
$X_a(t)$ = climatological annual cycle
$X_r(t)$ = residual part

The Xa component is strictly periodic, with a one year period by construction, and contains the annual, semi-annual and higher harmonics. The Xr component includes the QBO variation, the dominant portion of variability in the QBO domain, and other components, either non-periodic or periodic. For the following analysis the Xc components of both experiments are used to define the average QBO effect:

$$X_{cQBO} = X_c(L90) - X_c(L39)$$

References

Giorgetta, M. A., E. Manzini, and E. Roeckner, 2002: Forcing of the quasi-biennial oscillation from a broad spectrum of atmospheric waves. *Geophys. Res. Lett.*, **29**, 10.1029/2002GL014756.

Manzini E., and N. A. McFarlane N.A.,1998: The effect of varying the source spectrum of a gravity wave parameterization in a middle atmosphere general circulation model. J. Geophys. Res., 103, 31523-31539.

Mote, P. W., K. H. Rosenlof, M. E. McIntyre, E. S. Carr, J. C. Gille, J. R. Holton, J. S. Kinnersley, H. C. Pumphrey, J. M. Russel III, and J. W. Waters 1996: An atmospheric tape recorder: The imprint of tropical tropopause temperature on stratospheric water vapor. *J. Geophys. Res.*, **101**, 3989-4006.

Naujokat, B., 1986: An update of the observed quasi-biennial oscillation of the stratospheric winds over the tropics. *J. Atmos. Sci.*, **43,** 1873-1877.

Roeckner, E., K. Arpe, L. Bengtsson, M. Christoph, M. Claussen, L. Dümenil, M. Esch, M. Giorgetta, U. Schlese, U. Schulzweida, 1996: The atmospheric general circulation model ECHAM4: Model description and simulation of present-day climate, MPI Rep., 218, Hamburg, Germany.

Results

The average QBO effects in U and w*, averaged from 10°N to 10°S, are shown in Figure 1 for U and w*. The profile of Uc(L39) (Figure 1a) has one broad minimum (-10 m/s) near 40 hPa without any further structure. The profile Uc(L90), however, shows a maximum (-1 m/s) near 45 hPa and a minimum (-15 m/s) near 17 hPa, as anticipated from the prevalence of QBO easterlies and westerlies in the upper and lower levels of the QBO domain. The difference UcQBO of both profiles (Figure 1b) shows a maximum of +9 m/s near 40 hPa and a minimum of -9 m/s near 20 hPa, both significant at the 95% level.

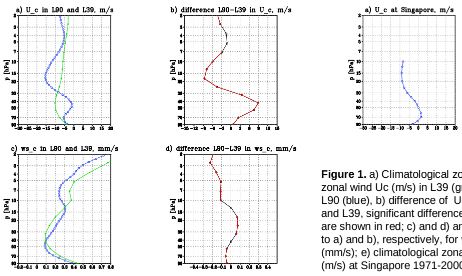

Figure 1. a) Climatological zonal mean zonal wind Uc (m/s) in L39 (green) and L90 (blue), b) difference of Uc in L90 and L39, significant differences (95%) are shown in red; c) and d) analogous to a) and b), respectively, for w*c (mm/s); e) climatological zonal wind uc (m/s) at Singapore 1971-2000.

As a consequence, the long term average of the secondary meridional circulation of the QBO is non-zero as well. The vertical component w*c averaged from 10°N to 10°S is shown in Figures 1c for both experiments. In L90, w*c is reduced (increased) below (above) 40 hPa with respect to w*c in L39 (40 hPa is the position of the maximum in UcQBO). The minimum in w*c is 0.1 mm/s in both experiments, though the levels of the minimum are different: 35 hPa in L39 and 45 hPa in L90.

Comparing the time mean profile in uc at Singapore (Figure 1e) and Uc in the L90 profile (Figure 1a) one finds qualitative agreement in the shape of the profiles, and agreement in the position of the minimum near 15 hPa. The position of the maximum is too high in the simulation. The amplitudes differ to some degree which is explained in part by the local character of the observed wind.

The integral effect of the QBO on the long term mass flux has consequences for the duration spent by upwelling air parcels in the equatorial stratosphere. Figure 2 compares the time series of the annual variation in equatorial specific moisture, the so-called atmospheric tape recorder (ATR) [Mote et al., 1996], averaged from 10°N to 10°S. The ascent of a minimum or maximum from 90 hPa to 10 hPa takes 17 months in experiment L90, in good agreement with the estimates in Mote et al. [1996], but only 12 months in experiment L39, where the QBO is missing entirely.

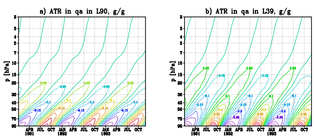

Figure 2. a) Atmospheric tape recorder in specific humidity qa (ppmv) in L90, b) in L39.

Conclusions

The QBO has a net effect on the climatological annual means of variables in the QBO domain. Neglecting the QBO in GCM simulations necessarily results in systematic biases in zonal wind, residual meridional circulation, temperature, and residence time in the lower tropical stratosphere. The QBO and its effects cannot be removed from observed time series by temporal averaging over full QBO cycles. Hence it is necessary to include the QBO in GCM based studies of the tropical stratosphere, either by direct simulation, as used here, or by assimilation as chosen for the KODYACS transient experiments where the QBO evolution is known. Including the QBO specifically improves the upwelling in the tropical lower stratosphere as evident in the simulated atmospheric tape recorder in specific humidity.

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