The role of the Quasi-Biennial Oscillation in the inter-annual variability of the circulation and water vapour distribution

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KODYACS

Kopplung von **Dy**namik und **A**tmosphärischer **C**hemie in der **S**tratosphäre

Introduction

The quasi-biennial oscillation (QBO) in the stratospheric equatorial zonal wind is an outstanding dynamical phenomenon(reviewed in Baldwin et al., 2001). Its secondary residual circulation and related temperature variations can affect transport of atmospheric trace constituents, as for instance water vapour, methane and ozone, as well as chemistry. The QBO therefore must be considered in any attempt to understand the observed inter-annual variability of the circulation and composition of the stratosphere (Steinbrecht, 2003).

The KODYACS project aims at a better understanding of the observed climate and chemistry variability in the past four decades of 1960 to 2000. For this purpose the MAECHAM4-CHEM chemistry-climate model (Steil et al., 2003; Manzini et al., 2003) has been employed in a transient experiment including the major external forcings of the atmosphere in the 1960-2000 period. These include SST and ice (Hadley Centre), major volcanic eruptions (Agung, El Chichon, Pinatubo), the 11-year cycle of the solar irradiation, the CO2 mixing ratio, and emissions of specific chemicals. In addition the QBO is assimilated from observed zonal wind profiles because of its known effects on tracers in the stratosphere and the difficulties to simulate the QBO in atmospheric GCMs.

This study investigates the properties of the quasi-biennial oscillation (QBO) and correlations between the QBO and other fields in the transient coupled chemistry-climate simulation of the period 1960 to 2000 and in a climatological atmosphere only simulation over 30 years. The data used for the assimilation of the QBO in the transient simulation are the analysed zonal wind profiles of Canton Island, Gan and Singapore (Labitzke et al., 2002). The models employed for these experiments are the MAECHAM4-CHEM chemistry climate model (Steil et al., 2003; Manzini et al., 2003), which assimilates the zonal wind in the QBO domain by linear relaxation, and the MAECHAM5 GCM at high vertical resolution, which allows the direct simulation of the QBO (Giorgetta et al., 2002), respectively.

The QBO in observations, and in the MAECHAM4-CHEM and MAECHAM5-L90 models

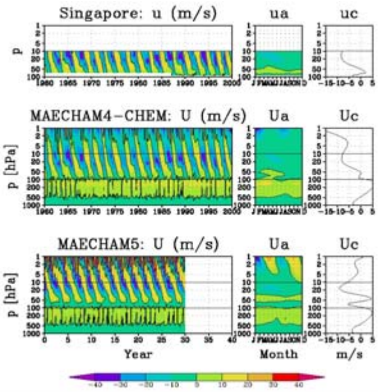


Figure 1. Top row: Equatorial zonal wind u (left), its annual cycle ua (middle) and annual mean uc (right) in observations of the period 1960-2000, Middle row: Zonal mean zonal wind U, annual cycle Ua and mean Uc in the transient MAECHAM4-CHEM experiment for 1960-2000. Bottom row: U, Ua, and Uc for a 30 year MAECHAM5 experiment with simulated QBO.

Figure 1 shows a comparison of the QBOs in observations, in the transient experiment, and in the climatological experiment. The MAECHAM4-CHEM model cannot simulate its own QBO. Therefore the QBO is assimilated by a liear relaxation technique (nudging) based on analysed equatorial wind profiles. The resulting QBO strongly resembles the observed QBO. However, the QBO causes a reduction of the available gravity wave drag at the stratopause level, which explains the poor SAO. The QBO simulated for climato-logical boundary conditions is more regular than in observations. Its amplitude is weaker than observed below 50 hPa, but stronger near 5 hPa. This model shows a strong SAO.

Variance of U' at the the equator

The temporal variance of the equatorial monthly zonal wind residuals U'(t)=U(t)-(clim.annual cycle of U(t)) maximizes at 10 to 20 hPa, which is in the core of the QBO domain. Therefore U'(20hPa) is used as QBO index for the correlation analyses.

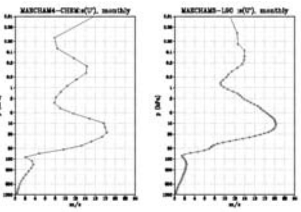
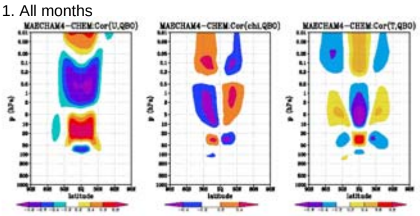


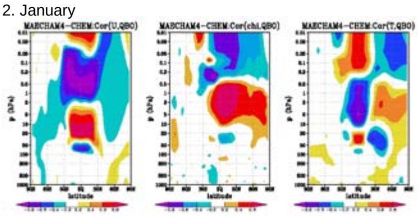
Figure 2. Variance of the monthly residual time series o fthe zonal mean zonal wind U' at the equator in MAECHAM4-CHEM (left) and MAECHAM5-L90 (right).

Correlation of the QBO and U, stream function, and T in MAECHAM4-CHEM

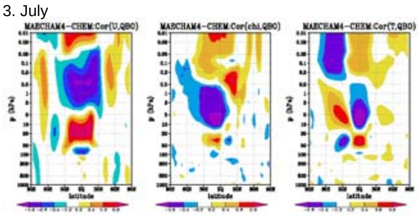
1. All months



2. January

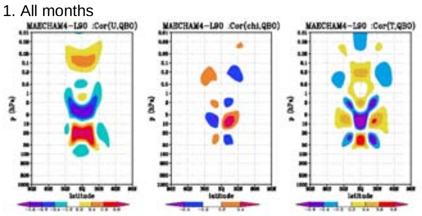


3. July

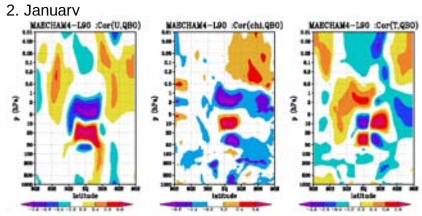


Correlation of the QBO and U, stream function, and T in MAECHAM5_L90

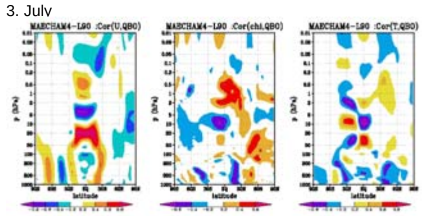
1. All months



2. Januarv



3. Julv



Summary

The transient experiment shows a realistic QBO compared to observations. The same holds for a QBO simulated directly in a GCM with high vertical resolution.

The zonal wind, the streamfunction and the temperature show qualitatively similar patterns in the stratosphere, which are symmetric with respect to the equator if all months are considered, but are asymmetric in solstice conditions, especially in the boreal winter, when the QBO interferes mostly with the northern hemisphere. The transient experiment tends to produce larger correlation scales, specifically in the vertical dimension in the upper stratosphere and mesosphere, where the SAO is too weak and the vertical resolution is poor compared to the ECHAM5-L90 experiment.

Both experiment produce a similar correlation pattern between the QBO and the lower stratosphere moisture.

Correlation of the QBO and stratospheric water vapour

Water vapor enters the stratosphere in the tropics, with highest mixing ratios in the northern subtropics during summer monsoon, and lowest mixing ratios at the equator in borela winter. This imprint in moisture on the lifting air masses in the equatorial stratosphere is known as atmospheric tape recorder (ATR). The QBO can interfere in two ways with the ATR: (1) by its modulation of the tropical residual circulation, and (2) by the modulation of the entry temperatures for water vapor (Giorgetta and Bengtsson, 1999). The resulting interference is nontrivial due to the transience of the phase relationship of the QBO and the annual cycle.

The moisture level at 50 hPa in the transient chemistry climate model is generally higher and more variable (volcano and ENSO effects) than in the atmosphere only experiment, except for the very dry and stable Southern hemisphere vortex in the former experiment (Figure 3). The correlation between the QBO and the residual monthly zonal mean moisture shows negative values of typically –0.2 to –0.3 in a layer above the tropopause, in both experiments (Figure 4).

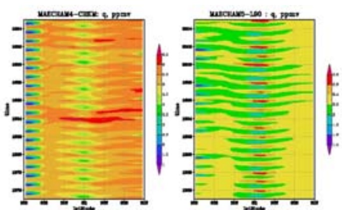


Figure 3. 20 year time series of the zonal mean moisture at 50 hPa in MAECHAM4-CHEM (left) and MAECHAM5-L90 (right).

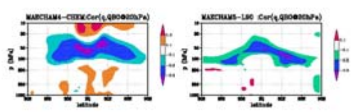


Figure 4. Correlation of the QBO at 20 hPa and the residual zonal mean moisture over 40 years in MAECHAM4-CHEM (left) and 30 years in MAECHAM5-L90 (right).

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