Net Impact of the QBO in a Chemistry Climate Model

Introduction

The quasi-biennial oscillation (QBO) [e.g., Baldwin 2001] can be included in simulations with the chemistry-climate model MAECHAM4-CHEM by nudging of zonal wind in the equatorial stratosphere towards observed winds [Giorgetta 1999].

Modelled QBO signals in temperature and ozone mixing ratios are discussed.

Comparison to an analogous QBO-free experiment allows the identification of the net effects of the QBO on dynamic variables as well as on trace gas concentrations. The net differences in the climatological mean fields of wind, temperature, mass stream function, water vapor and ozone are shown.

Some of the underlying mechanisms in dynamics, transport and chemistry are presented.

The analyzed QBO net effect provides an estimate for the climatological net bias in QBO-free models.

Conclusions

Nudging of zonal wind in the equatorial stratosphere leads to a realistic representation of the QBO and its effects in a chemistry climate model.

The **QBO signal in ozone** is confirmed to be affected by the **QBO in nitrogen oxides** NO_x.

Comparison of a nudged run to a un-nudged run in a model with no internal QBO reveals significant **differences also in the long term mean** of zonal wind, the meridional circulation, temperature and trace gases, termed the **net effect of the QBO**.

Differences in the time mean zonal wind field lead to a cold-warm pattern in equatorial temperatures. The tropical **tropopause is warmer by 2-3 K in the QBO run**, causing water vapor concentrations to be higher by about 10% in the lower stratosphere.

The net effect on the mean meridional circulation is diagnosed from the mass stream function. It causes net effects on trace gases of up to **5% in O_3 and 15% in NO_x**. Interestingly, the higher NO_x in the upper stratosphere does not affect ozone concentrations significantly.

Our findings underline the importance of a representation of the QBO in models.

Experiment design

- Middle-atmosphere general circulation model MAECHAM4
- Spectral resolution T30 and 39 layers, of which 16 lie between 130 and 1 hPa
- MAECHAM4 is fully coupled to the complex chemistry module CHEM [Manzini 2003]

Two experiments were performed for the CCMVal model validation project [Eyring 2005]. Sea Surface temperatures are taken from the HadISST1 data set, and trace gas concentrations are those selected for CCMVal REF1.

(QBO) 1980-1999, zonal wind is nudged towards radiosonde observations at Singapore to produce a QBO, volcanic aerosol and 11-year solar forcing are included

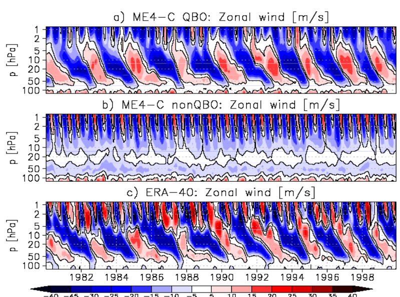
(noQBO) 1980-1999, none of the additional forcings in **(QBO)**

QBO in the model

Zonal wind:

(QBO): good agreement with ERA-40, SAO slightly underestimated

(noQBO): little variability, SAO stronger

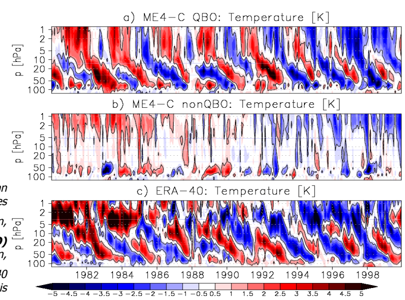


*Equatorial zonal mean zonal wind, (top) in the **(QBO)** run, (center) the **(noQBO)** run, and (bottom) the ERA-40 reanalysis*

Temperature:

(QBO): good agreement with ERA-40, differences in upper stratosphere

(noQBO): Impact of ENSO in the lower stratosphere, cooling trend as in QBO & ERA-40



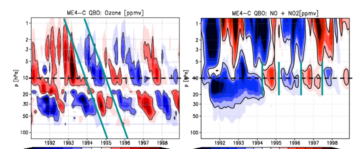
*Equatorial zonal mean temperature anomalies (top) in the **(QBO)** run, (center) the **(noQBO)** run, and (bottom) the ERA-40 reanalysis*

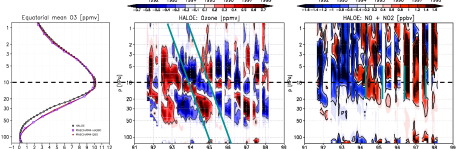
Ozone:

(QBO): Modelled concentrations are in good agreement with HALOE satellite observations. Equatorial ozone is affected

-directly by the vertical transport anomaly due to the SMC: enhanced upwelling causes O_3 increase (decrease) above (below) the level of maximum O_3 mixing ratio, weakened upwelling has the reverse effect. This explains the existence of a phase reversal in the O_3 signal.

-indirectly by the upwelling on tracers that impact its depletion, notably NO_x. The SMC causes NO_x anomalies at 10 hPa, which modulate the O_3 loss, causing a downward shift of the phase reversal to about 15 hPa [Chipperfield 1994].

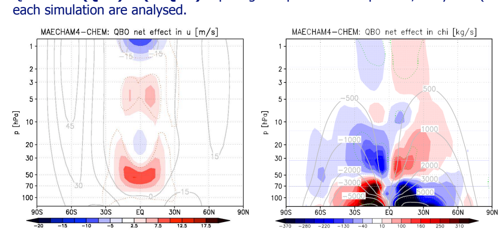




*Left: Equatorial ozone profile, Center: Zonal mean ozone anomalies 1991-1999 in (top) model **(QBO)** run and (bottom) HALOE observations. Right: Anomalies of NO $+NO_2$ for the same period.*

Net effect

Compute annual climatological averages of fields & compute difference between QBO- and non-QBO runs: **(QBO) – (noQBO)**. Sparing the post-volcanic periods, 15 years (≈ 6 QBO cycles) of each simulation are analysed.



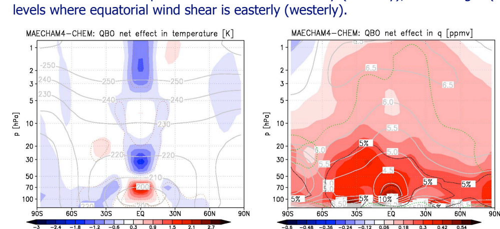
*Shading: difference **(QBO) - (noQBO)**; Greycontours: mean for **(QBO)**; Dotted contours: 2σ significant (Student's t-test)*

Zonal wind:

More westerly winds in **(QBO)** in the lower stratosphere, 4 layer pattern in the tropics (West-East-West-East)

Mass stream function:

Circulation is weaker below and stronger above net westerly wind jets: Net Pole (Equator) ward flow at levels where equatorial winds are net easterly (westerly), net stronger (weaker) ascent at levels where equatorial wind shear is easterly (westerly).



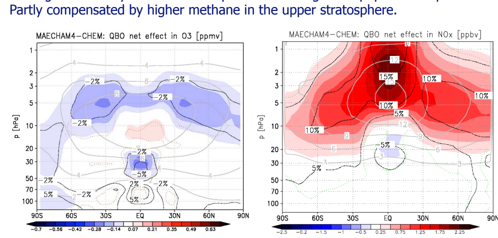
*Shading: difference **(QBO) – (noQBO)**; Grey contours: mean for **(QBO)**; Dotted contours: 2σ significant (Student's t-test) Right panel: solid lines indicate relative difference (%).*

Temperature:

Net equatorial cooling (warming) at levels where wind shear is easterly (westerly) in the **(QBO)** run, reversal in subtropics. Cooling tendency at poles in respective summer and spring seasons.

Water vapor:

Net higher humidity in lower stratosphere due to higher tropopause temperature in the **(QBO)** run. Partly compensated by higher methane in the upper stratosphere.



*Shading: difference **(QBO) – (noQBO)**; Grey contours: mean for **(QBO)**; Dotted contours: 2σ significant (Student's t-test); Solid lines indicate relative difference (%).*

Ozone:

Below the maximum at 10 hPa, lower (higher) where there is net stronger (weaker) upwelling at the Equator, lower at mid-latitudes in the upper stratosphere. Polar signals correlate with temperatures.

Nitrogen oxides ($NO_x = NO + NO_2 + NO_3 + 0.5\ N_2O_5$)**:**

Net higher in the upper tropical stratosphere by up to 15%, 10% at mid-latitudes.

References

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SCOUT-O3

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