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Interactive Comment

Interactive comment on "Net effect of the QBO in a chemistry climate model" *by* H. J. Punge and M. A. Giorgetta

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The authors thank referee 1 for the comments and careful reading.

Replies to General Comments:

(1)
Brief statement: in the lower stratosphere the feedback of ozone changes to the temperature field is small.

Explanation: It is difficult to determine the relative impact of the ozone feedback on temperature variations. However some conclusions can be drawn from the net effects in these fields, given in Figs. 9a and 12a. In the upper stratosphere, there is a net effect on mid-latitude ozone concentrations, but no net difference in temperature results, hence the feedback does not appear to be important here. In the tropical lower

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stratosphere, the effects of (1) the net difference in the BDC and (2) the feedback of the resulting ozone changes on temperature are in the same direction, so no conclusion can be drawn from the comparison. At polar latitudes, similar patterns in the seasonal net differences (Figs 10 and 13) indicate a connection of temperature and ozone, especially during SON, which may however be due to increased ozone depletion at low temperatures.

(2)
Brief statement: We expect that the residual meridional circulation in the stratopause region, where the SAO exists, is biased in both simulations mostly in the equinox seasons. Biases in this limited region are larger in the QBO simulation, where the SAO is too weak, than in the non-QBO simulation, where the SAO is slightly too strong. We do not expect this issue to bias our analysis of the net effect heavily.

Explanation: The SAO depends strongly on wave mean-flow interaction, in a similar fashion as the QBO, though also meridional advection is important and explains the synchronization with the annual cycle. Hence, the simulation of the SAO in a GCM depends on the ability of the model to simulated wave mean-flow interaction in the SAO region. This wave mean-flow interaction depends again on the sources of upward propagating waves in the equatorial latitudes and the wave filtering in the lower and middle stratosphere. The sources of horizontally resolved waves are equally underestimated in both simulations (the key reason why MAECHAM4 cannot simulate the QBO) while sources of unresolved gravity waves are equally prescribed in both simulations. The filtering effect in the lower and middle stratosphere is essentially missing in our non-QBO simulation because the QBO structure is missing, but present in the QBO simulation, where the QBO is externally enforced by the nudging technique. This difference in the wave filtering in the lower and middle stratosphere results in a stronger wave mean-flow interaction and SAO in the non-QBO simulation than in the QBO simulation. Differences are more obvious in the westerly phases since these are forced by wave mean-flow interaction, while easterly phases also depend on advection. There-

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fore biases of the QBO simulation in the circulation in the tropical stratopause region are mostly expected in the equinox seasons, and the circulation differences between the QBO simulation and the non-QBO simulation in this region are a consequence of the very different filtering of waves in the QBO region (cf. Giorgetta et al, 2006, section 5b and Fig.12). As the focus of four paper is not specifically on the stratopause region, we do not expect this issue to bias our analysis of the net effect heavily.

(3)
Diffusion is not included in the advective terms given in Fig. 6. The numerical diffusion in the model has not been diagnosed separately. Assuming it would balance the net chemical and transport contributions in Fig. 6a, it can be estimated to equal the sum of the blue and black curves in that Figure, hence reaches up to 0.03 ppmV/day. In simulations with a higher vertical resolution, the numerical diffusion will indeed be lower, but more of the turbulent flow will be resolved, which will also produce a net down-gradient transport of trace gases such as ozone, that is then included in the TEM diagnostics. Because this contribution will better represent physical processes, we expect improvements from such simulations. Shorter simulations with the ECHAM5-MESSy model run at high vertical resolution (Lelieveld et al., 2006) showed indeed reduced vertical numerical diffusion compared to the ECHAM4CHEM model, most obvious at the tropopause.

Replies to specific comments:

(1) p. 12117, line 20-21
We will add: "..., especially in the representation of the stratospheric circulation and composition, which can have effects on the troposphere via dynamic or radiative links."

(2) p. 12118, line 5
Vertical resolution is an important but not the only improvement in the ECHAM5-based simulations mentioned. MAECHAM4 at resolution T42L90 does not simulate the QBO, while ECHAM5 does. The ability of ECHAM5 to simulate the QBO results from the

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improvements in the parameterization of tropospheric processes leading to a more energetic spectrum of vertcally propagating equatorial waves. Therefore we think it is relevant to have the "improved" adjective in the statement. Horizontal resolution is beneficial for the representation of the wave forcing. The T42 resolution used in ECHAM5 in fact allows a more realistic QBO than the lower T31 horizontal resolution (cf. Giorgetta et al., 2006, section 6). Of course the high vertical resolution is a prerequisite for the wave mean-flow interaction in ECHAM5 that results in the QBO. We will replace the statement by: "... unlike the ECHAM5 simulations of Giorgetta et al. (2006) and Lelieveld et al., (2007), where the QBO is simulated due to model improvements and a higher vertical resolution."

(3) p. 12121, line 17-18
We will write: "... when there are QBO westerlies in the middle stratosphere." (This relates to the QBO simulation, not to ERA-40)

(4) p. 12123, line 10-12
We remove "... at most levels, indicating that there is a net effect of the QBO" and write instead "... at most levels. This net difference will be discussed in detail in Section 5." Interannual variability is low in the nonQBO experiment and can be inferred from Fig. 12b for the QBO experiment, as sources of variability other than the QBO are unimportant here. It is indeed of similar magnitude as the net effect given in Fig. 12a, but the latter is still significant as is also indicated in Fig. 12a (green lines).

We thank for the technical corrections.

Interactive comment on Atmos. Chem. Phys. Discuss., 8, 12115, 2008.

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