R e p l y

To the interactive comment on “Experiments on sensitivity of meridional circulation and ozone flux to parameterizations of orographic gravity waves and QBO phases in a general circulation model of the middle atmosphere” by A. V. Koval et al. Anonymous Referee #2

We would like to thank the reviewer #2 for useful comments. Our replies are given in bold font below.

This paper uses a simple model to look at the influence of orographic gravity waves (OGWs), and the QBO phase, on the stratospheric circulation and, therefore, on ozone fluxes in the middle atmosphere. The use of simple models to study the effects of a single physical process can be very useful. Indeed, there are a number of comprehensive General Circulation Models (GCMs) which still do not include internally generated QBOs, and the necessity of Earth System models performing climate change simulations to be built on a GCM which does simulate a QBO could be a conclusion of this paper.

However, the analysis in this paper is quite simple - OGWs and the QBO have an influence on the simulated vertical velocity and this has a direct impact on the vertical flux of ozone. The impact of the QBO on the residual circulation is well known (Baldwin et al., 2001: The quasi-biennial oscillation). The impacts of planetary wave drag, orographic wave drag, and non-orographic wave drag, on the stratospheric meridional circulation have been studied and quantified for several GCMs (Butchart et al., 2006: Simulations of anthropogenic change in the strength of the Brewer–Dobson circulation; Butchart et al., 2011: Multimodel climate and variability of the stratosphere). Indeed, the idea that, unless the mean winds are altered, changes in OGW will be compensated for (and cancelled out) by changes in planetary waves has been suggested (Cohen et al., 2013: Compensation between resolved and unresolved wave driving in the Stratosphere: Implications for downward control; Cohen et al., 2014: What drives the Brewer-Dobson Circulation?) such that the impact of OGW described in this paper may not even be realised in GCMs.

We know these studies. Our model involves planetary waves (PWs), and we analyzed interactions between PWs and OGW in our previous papers. PWs play important role in our present simulations, but we concentrate on descriptions of other atmospheric characteristics. However, we added citations listed above into the introduction. About compensation of OGW effects by planetary waves, such compensation can be local. Due to differences in PW and OGW propagation, if these waves are compensated at some altitude, they will be not compensated at some altitudes above. We analyze meridional circulation up to lower thermosphere (altitudes about 150 km).

The effect of transport on ozone is also not the whole story, as ozone concentrations will depend on local sources and sinks as well as fluxes. A method to split these two effects in chemistry-climate models has also already been considered (Garny et al., 2011: Attribution of ozone changes to dynamical and chemical processes in CCMs and CTMs). As such, I feel that this paper adds little to our current scientific understanding. More in depth analysis of the effects of OGW and the QBO needs to be included, and proper reference should be made to the existing literature.

Yes, this is true for chemistry-climate models simulating climate and seasonal changes. Although, mechanistic GCMs with prescribed semiempirical ozone and QBO distributions could be useful for diagnostics of existing meridional circulation and ozone fluxes during intervals of a few days at low and middle latitudes in the lower stratosphere and troposphere, where ozone production is not high (see Garny et al., 2011). Moreover, such diagnostics sometimes could give better results, because empirical ozone and QBO models

could be closer to the reality, than fully simulated numerical results. Such statement is added to the paper. An interesting obtained feature (which we did not find in the literature) is substantial OGW and QBO influence on the local ozone fluxes superimposed the Brewer-Dobson circulation at high and middle latitudes of winter hemisphere. The deeper analysis of these effects is subject to future publications in other journals, as GMD gives generally technical descriptions of numerical models and experiments with them.

Further, it is not clear why OGW has been focused on, and not planetary waves and non-orographic gravity waves also.

Our GCM includes non-orographic GW parameterization and calculates PWs. We described and analyzed them in our previous publications. In the present numerical experiments we changed only OGW parameterization and showed model outputs. Our main aim was to give technical descriptions allowing to everybody to use our parameterizations and reproduce the experiments asking the model code from us.

In general, the use of English in this paper needs improving. I would recommend that any revisions be proof read by a native English speaker before submission.

English was checked by a professional translator.

MINOR COMMENTS Section 2.1: The ozone distribution used in MUAM is compared to Randel and Wu (2005). How does this compare to the newer AC&C/SPARC ozone (Cionni et al., 2011: C1759 Ozone database in support of CMIP5 simulations: results and corresponding radiative forcing) and BDBP ozone (Hassler et al., 2008: Technical Note: A new global database of trace gases and aerosols from multiple sources of high vertical resolution measurements; Hassler et al., 2009: A vertically resolved, monthly mean, ozone database from 1979 to 2100 for constraining global climate model simulations) climatologies?

We compared the used ozone distributions with listed above models. Agreement is good. We added the references.

Section 4.1: If differences greater than 0.1m/s are significant (at the 95% level), it would be useful to include the 0.1m/s contour in Figure 2. Further, you refer to differences as a percentage of the total meridional velocity. It might be useful to add additional panels to this Figure, plotting these percentages.

In fact, contours +/- 0.15 m/s exist in Figure 2. You can trust to everything inside these contours. Usually, the percentages plots are nonrealistic in the regions of small velocity magnitudes, and are not informative.

Section 4.1: Add more detail on the physical reasons why the patterns in Figures 3(b) and 3(c) (and also Figures 4(b) and 4(c)) look so similar.

The only similar physical reasons are larger drag of eastward circulation by OGWs and by equatorial jets during the easterly QBO phases. However, spatial distributions of these drags are different and this similarity could be occasional. We added this explanation to the text.

VERY MINOR COMMENTS AND TYPOGRAPHICAL ERRORS
Equation 1: Two different Greek symbols are used for latitude. Please use one or the other.
Fixed.

Section 4.1: Figures should be referred to in numerical order. Currently Figure 2 is referenced before Figure 1.

Figure 1 is first introduced in Section 2.1.

Equation 5: Need to define rho_i.

Rho as density is defined in Eq. (2).

N. M. Gavrilov, A. V. Koval, A. I. Pogoreltsev, E. N. Savenkova