

# 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

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This paper describes numerical experiments using the MUAM general circulation model assessing the combined effects of observationally prescribed tropical stratosphere variability (e.g. QBO) and a newly developed orographic gravity wave parameterisation on (NH) wintertime stratosphere and mesosphere circulation and diagnosed vertical fluxes of ozone.

This paper covers material which has been extensively researched over the last 30 years. As such, it really requires substantial novelty in science or the development of a new innovative model to be publishable. Regrettably this paper has neither novel science nor new physics. Furthermore, as outlined below, major questions are raised concerning both experimental design and the level of appropriate analysis. For these reasons this reviewer cannot recommend publication.

## Major comments

- Experimental setup appears flawed: why examine for changes in circulation from parameterised orographic wave forcing under QBO east and west? Large scale resolved waves, using Holton-Tan arguments I can understand, but not parameterised waves constrained to 'propagate' vertically. If there is a hypothesis which is being tested for it is not apparent in the paper.
- There is a substantial literature on orographic wave parameterisation and associated circulation impacts. It is not evident what new material this paper is adding to the literature.
- Significance testing needs to be undertaken throughout. Furthermore, it is not apparent how long the integrations are for the different experiments. Long integrations would be needed to peg back dynamical noise levels, especially in the upper mesosphere (c.f. figure 2). My impression from the figures (esp. figs 2b, 2c) is that the simulations are (too) short.
- The paper does not offer sufficient analysis to describe/understand circulation features. Strangely, there is no plot showing where the orographic wave forcing is occurring. This would be especially relevant for diagnosing the driver of the summertime mesospheric circulation (and change). Presumably, orographic waves are filtered by the stratospheric easterlies found during the southern summer? Further diagnostics including zonal wind, temperature and resolved forcing should be assessed in the paper at the very least.
- The diagnosis of 'ozone' fluxes is too simplistic here. Only vertical fluxes are assessed and there is no assessment of source changes due to circulation based temperature changes. One of the reason for the inclusion for orographic GWD schemes back in the 1980s was the alleviation of the cold pole bias in GCMs. This was especially relevant for ozone studies at the time, which are significantly affected by temperature effects (e.g. heterogeneous ozone destruction).

- It has not been shown how the inclusion of QBO and OGW effects has improved the model (MUAM) climate and variability as is purported in the text.
- The text would benefit from proofreading for language and grammar.

**Other comments:**

(Line 12) "Earth's"

(P5648, l17) this paragraph is little vague: please cite what climatological fields you are referring too and specifically which parameterisations are being referred to. Perhaps too the first sentence could be rephrased to something like, 'A defining characteristic of the tropical stratosphere variability is the QBO.'

(P5648,l22) once defined, QBO should be used rather than quasi biennial oscillation.

(P5648, l23) Do the authors actually want to make this statement? How would an inaccurate modelling of the troposphere affect resolved waves originating from the troposphere and impacting the stratosphere (and the associated Brewer-Dobson circulation). What impact will such (tropospheric) biases have on the fluxes of parameterised orographic waves across the tropopause? All important questions for this study.

(P5648, l25) "troposphere-stratosphere" to" stratosphere"

(P5649, eq 1) can the authors please explicitly state what the relaxation parameter is as a function of latitude and height, rather than the Mathworks reference. Are higher altitudes relaxed more strongly than lower ones, i.e. following characteristic thermal relaxation timescales? Or does the stated 5 days relaxation time apply at all heights?

(P5649, l6) What is the reference for the Met office data? Presumably it is reanalysis data?

(P5649, l25) The authors define the QBO phase between 30-35km. How might this choice impact their subsequent analysis? Is it the optimum height for diagnosing potential tropical impacts on high latitude variability? As the authors rightly point out, other studies diagnose lower heights in observations (e.g. Holton & Tan, 1980). Presumably (different) models may diagnose high-latitude sensitivity to the QBO at different heights. The authors allude to this in the following paragraph but do not comment the consequences to the subsequent interpretation of their results. Comments?

(P5650, l24) "...atmospheric variables..."

(P5650, l27) "...exchange of energy and momentum between..."

(P5650, section 2.3) Perhaps too much theory is taken from Gavrilov and Koval, 2013. The authors should simply repeat only those parts relevant to the present study and point to the reference, for a fuller treatment.

(P5651, eq 2) What is the parameter  $\alpha$ ? Normally meridional velocity is represented by  $v$  and zonal velocity by  $u$ . So maybe use  $u'w'$  etc in equation 2

(P5651, l9) remove second "of"

(P5651, l24) "... $f$  is the Coriolis parameter..."

(P5653, l8) "...lower..."

(P5653, l14) remove 'angle', i.e. "...resolution of two minutes along..."

(P5653, l17) Please rephrase first sentence; it does not read well.

(P5653, l24) "In the simulations...and employed a timestep of 450 s. Model data was output every 4 hours"

(P5654, l1) "Simulations were spun up from rest and with..."

(P5654, l3) The authors should check whether writing in the third person plural (i.e. we) is encouraged or whether writing in the passive tense is preferred by the journal.

(P5654, l8) What was the 'prognostic equation' used? Please specify.

(P5654, l15) suggest replacing "...simulating the changes..." to "...to look for..." or "...to examine for..."

(P5654, l21) It is suggested that the last two sentences, beginning "The differences in..." be removed as they are self-evident following the preceding sentence.

(P5655, l6) Can the authors add statements of significance to this statement, thanks. Presumably as reference is being made to the (relatively small) circulation features in figure 2a, there would be reduced significance (i.e. perhaps consistent with our ideas of the residual mean circulation at these heights but not apparent here, say, using a Student-T test?).

(P5655, l9) "ascent"