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Atmospheric Chemistry and Physics Discussions

Interactive comment on "Propagation of gravity waves and its effects on pseudomomentum flux in a sudden stratospheric warming event" *by* In-Sun Song et al.

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General comments

This paper investigates the effect of four-dimensional propagation of gravity waves in time-varying background winds on their properties (pseudomomentum fluxes, wavenumber) during the occurrence of a sudden stratospheric warming. The main motivation is that GW parameterizations implemented in climate models generally neglect these effects (columnar, instantaneous propagation is generally enforced in the GW schemes), and it is important to assess the missing

effects on the redistribution of momentum flux and GW forcing. The authors do not find a big difference between 4D and 2D propagation in terms of latitude-height structure of the total momentum fluxes, but do find a significant difference in terms of the magnitude of the momentum fluxes, with much larger fluxes in the 4D scheme. The effects of curvature on the magnitude of the fluxes seems to be as important as the effect of horizontal wind shear.

The study is well-written and easy to follow, and the results are relevant and timing, aligning with current efforts to better understand GW processes in order to improve their parameterizations in climate models. I have a few, very minor comments, and I believe the paper is basically publishable as is.

- Authors would like to thank the reviewer for reading and evaluating the original manuscript. We have corrected our manuscript according to the reviewer's comments. Please refer to the track-change version of our revised manuscript for figure and line numbers to be mentioned below.

Minor comments

1. Some parts of the introduction seem a succession of references, and sometimes it is difficult to follow/understand the line of argument (e.g., paragraphs in page 2).

   - Following reviewer's comment, some redundant references are excluded and the Introduction is somewhat reduced (see pages 2–3 in the track-change version of the revised manuscript).

2. Page 3, line 8-9. Richter et al (2010) attributed the improvement in the SSW frequency in WACCM to the turbulent mountain stress parameterization (which

improves near-surface winds and planetary wave generation), not to the source-based nonorographic GW scheme.

- Following reviewer's comment, discussion about Richter et al. (2010) is deleted (see lines 18–19 on page 3 of the track-change version of the revised manuscript).

References

Richter, J. H., Sassi, F., and Garcia, R. R.: Toward a physically based gravity wave source parameterization in a general circulation model, J. Atmos. Sci., 67, 136–156, https://doi.org/10.1175/2009JAS3112.1, 2010.

3. Section 3. Why do the authors use both ERA-Interim and MERRA fields, if they basically cover the same altitude range? Why not just one reanalysis?

- We think the overlap of the two reanalysis data can help reduce biases especially in regions where the two reanalyses have quite different structure.
- Each reanalysis has its own reliable altitude range or focuses more on particular altitude range. ERA-Interim reanalysis data are available up to 0.1 hPa for model-level data, but we did not use the ERA-Interim in the mesosphere where effects of spurious Rayleigh damping used instead of nonorographic gravity-wave drag parameterization become large (Fujiwara et al. 2017). In the mesosphere, we used the MERRA2 reanalysis data (together with the NOGAPS-ALPHA) because the Microwave Limb Sounder (MLS) data on the AURA satellite, not used in the ERA-Interim, are assimilated in the MERRA2 (Gelaro et al. 2017). The NOGAPS-ALPHA uses the sounding of the atmosphere using broadband emission radiometry (SABER)

data on the thermosphere ionosphere mesosphere energetics and dynamics (TIMED) satellite in addition to the Aura MLS in the mesosphere (Eckermann et al. 2009).

References

Eckermann, S. D., Hoppel, K. W., Coy, L., McCormack, J. P., Siskind, D. E., Nielsen, K., et al.: High-altitude data assimilation system experiments for the northern summer mesosphere season of 2007, J. Atmos. Solar-Terr. Phys., 71, 531–551, https://doi.org/10.1016/j.jastp.2008.09.036, 2009.

Fujiwara, M., Wright, J. S., Manney, G. L., Gray, L. J., Anstey, J., Birner, T., et al.: Introduction to the SPARC Reanalysis Intercomparison Project (S-RIP) and overview of the reanalysis systems, Atmos. Chem. Phys., 17, 1417–1452, https://doi.org/10.54194/acp-17-1417-2017, 2017.

Gelaro, R., McCarty, W., Suárez, M. J., Todling, R., Molod, A., Takacs, L., et al.: The Modern-Era Retrospective Analysis for Research and Applications, Version 2 (MERRA-2), J. Climate, 30, 5419–5454, https://doi.org/10.1175/JCLI-D-16-0758.1, 2017.

4. Page 10 line 11-12. "Zonal F p s in each OGW ensemble member have locally substantial deviations from the ensemble mean (Fig. 3c) in the major mountain areas". This may be true, but it is not discernible in the figure.

- Following reviewer's comment, Fig. 3 is modified. Note that some panels are removed following the reviewer 2's comments (see page 35 of the track-change version of the revised manuscript).

5. Figure 8. I may be missing something, but how is it possible that the number of GW packets increase with height in the 2D simulation? If I understand correctly, in the 2D case the only process adding wave packets to a given column is wave generation at the source level.

- As reviewer said, GW packets are regularly launched upward at the source levels, but their upward propagation is not uniform in the vertical direciton even in the 2D simulation. The vertical group velocities (c_{gz}) can vary in the vertical direction depending on the background wind and temperature. That is, GW packets can converge (diverge) in the vertical direction when $\partial c_{gz}/\partial z$ $<$ 0 ($\partial c_{gz}/\partial z >$ 0).

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