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Interactive comment on "Effect of latitudinally displaced gravity wave forcing in the lower stratosphere on the polar vortex stability" *by* Nadja Samtleben et al.

Anonymous Referee #1

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This paper is a sensitivity study about the effect of locally enhanced forcing by gravity waves on the polar vortex. In the mechanistic global circulation model MUAM a longitudinally and vertically confined forcing region is shifted towards lower and higher latitudes in steps of 5deg. The main results are that (1) forcing at higher latitudes has little effect on the stability of the vortex, and (2) forcing at lower latitudes leads to breaking of planetary waves and a slowdown and displacement of the vortex.

This study is very interesting because it contributes to an active field of research that addresses the question how sudden stratospheric warmings (SSWs) are triggered. This topic is of interest to the broad community of atmospheric and climate research because SSWs are known to impact weather and climate at the Earth's surface.

Publication of the paper in Annales Geophysicae is therefore highly recommended.

There is, however, one major issue that should be addressed before publication:
(1a) in the paper the relevance of the work for the understanding of SSWs should be discussed (SSWs are not mentioned at all in the paper)
(1b) it should be qualitatively discussed how the model simulations agree with observations of gravity waves during SSWs

Addressing this issue should however be possible with reasonable effort.

A list of specific and other comments is given in the following.

Specific Comments

1. pg.2, line 2
   jet sources of gravity waves are not limited to frontal systems, and also the reference Plougonven et al. addresses jet sources of gravity waves more generally

2. pg.2, line 5
   for the exponential increase with height constant background conditions have to be assumed and the gravity wave should propagate conservatively

3. pg.2, line 10
   The expression "filtered out" could be misleading in this context. The waves moving into the direction of the wind, but faster, are not necessarily completely removed from the spectrum. Their amplitude growth, however, is hampered by their slow intrinsic phase speed.

4. pg.2, line 10, suggestion:

“For this reason the wind reverses in the mesosphere due to GW breaking, while in the opposite direction to u travelling GWs deposit their momentum (Lindzen, 1981; Holton, 1982).”

$\rightarrow$

“In mesosphere even GWs propagating in the opposite direction to u saturate and deposit their momentum. For this reason the wind reverses in the upper mesosphere/lower thermosphere (Lindzen, 1981; Holton, 1982).”

5. pg.2, line 20/21
   Compared to the enumeration of mountain wave sources, the enumeration of convective regions generating gravity waves is quite short. Suggestion for keeping the balance:

   “Typically, in the stratosphere satellite observations show a characteristic structure of enhanced GW activity in the subtropics that is caused by deep convection over Southeast Asia, America, Africa, or the Maritime Continent in the respective summer season (Jiang et al., 2004; Ern and Preusse, 2012; Wright and Gille, 2011).”

   References:

   Jiang, J. H., B. Wang, K. Goya, K. Hocke, S. D. Eckermann, J. Ma, D. L. Wu, and W. J. Read (2004), Geographical distribution and interseasonal variability of tropical deep convection: UARS MLS observations and analyses, J. Geophys. Res., 109, D03111, doi:10.1029/2003JD003756.

   Ern, M., and P. Preusse (2012), Gravity wave momentum flux spectra observed from satellite in the summertime subtropics: Implications for global modeling, Geophys. Res. Lett., 39, L15810, doi:10.1029/2012GL052659.

   Wright, C. J., and J. C. Gille (2011), HIRDLS observations of gravity wave momentum fluxes over the monsoon regions, J. Geophys. Res., 116, D12103, doi:10.1029/2011JD015725.

6. pg.2, line 22
   Here you write "...objective determination of the GW drag from satellite measurements alone is not possible."

   This is a too strong statement that also does not hold. Estimates based on satellite data exist, however contain large errors.
   In the text following line 22 you give two references and state that GW drag would be derived from superpressure balloons and lidar data.
   However, these two references are used out-of-context!
   The GW drag in these papers is based on model simulations alone. So far GW drag has not been derived from superpressure balloons because these balloons float on a fixed altitude, and vertical gradients cannot be inferred. To my knowledge, GW drag has not been tried from lidar data (please correct me if I am wrong), but I know that GW drag has been derived from radar data. Similar as GW drag derived from satellite, these estimates generally have large errors.

   Therefore I would suggest the following rewording:

   "Reliable estimates of GW drag from observations are generally difficult. There are attempts from satellite (for example, Ern et al., 2014; Ern et al., 2016), or from radar (for example, Reid and Vincent, 1987). Usually, however, uncertainties of these estimates are quite large. From model studies there are indications that GWs can break already in the lower stratosphere (LS), for example Plougonven et al. (2008), or Constantino et al. (2015)."

   References:

   Reid, I. M., and R. A. Vincent (1987), Measurements of mesospheric gravity wave momentum fluxes and mean flow accelerations at Adelaide, Australia, J. Atmos. Terr. Phys., 49, 443-460.

   Ern, M., F. Ploeger, P. Preusse, J. C. Gille, L. J. Gray, S. Kalisch, M. G. Mlynczak, J. M. Russell III, and M. Riese (2014), Interaction of gravity waves

with the QBO: A satellite perspective, J. Geophys. Res. Atmos., 119, 2329-2355, doi:10.1002/2013JD020731.

Ern, M., Trinh, Q. T., Kaufmann, M., Krisch, I., Preusse, P., Ungermann, J., Zhu, Y., Gille, J. C., Mlynczak, M. G., Russell III, J. M., Schwartz, M. J., and Riese, M.: Satellite observations of middle atmosphere gravity wave absolute momentum flux and of its vertical gradient during recent stratospheric warmings, Atmos. Chem. Phys., 16, 9983-10019, https://doi.org/10.5194/acp-16-9983-2016, 2016.

7. pg.3, line 29 — This comment is not relevant for the current paper, but may become relevant for future work.

   On pg.3 line 29 you write that GW potential energy of the MUAM model would be tuned "... based on potential energy data obtained from GPS radio occultation measurements"

   Tuning the model towards GW potential energies observed from GPS may introduce large biases. It has been shown by Rapp et al. (2018) that vertical filtering of GPS soundings for obtaining the gravity wave signal does not remove larger scale structures having short vertical wavelengths, such as inertial instabilities at low and mid latitudes, or Kelvin waves in the tropics (Ern et al., 2008).

   References: Rapp, M., Dornbrack, A., & Preusse, P. (2018). Large midlatitude stratospheric temperature variability caused by inertial instability: A potential source of bias for gravity wave climatologies. Geophysical Research Letters, 45, 10682-10690. https://doi.org/10.1029/2018GL079142

   Ern, M., Preusse, P., Krebsbach, M., Mlynczak, M. G., and Russell III, J. M.: Equatorial wave analysis from SABER and ECMWF temperatures, Atmos. Chem. Phys., 8, 845-869, https://doi.org/10.5194/acp-8-845-2008, 2008.

8. pg.15, line 30
   Gravity wave hotspots do not only occur over mountain ridges. Local hotspots

can also be caused by the GW jet source mechanism. For example, Ern et al., 2016 find enhancements of GW activity that are linked to jet exit regions. Possibly these hotspots are missed by AIRS because of its limitation to gravity waves of very long vertical wavelengths. The proposed follow-up study is therefore a promising way to proceed, but should not be limited to the positions of orographic GW hotspots. Also longitudinally varying positions of jet-related GW sources could be important.

9. General comment for the discussion throughout the paper:
   For midlatitude forcing some of the findings are very similar to the situation during SSWs.
   - vortex slowdown and shift (Fig. 3)
   - stratospheric warming (Fig. 4)
   - changes in the activity of the SPW1

   These similarities should be discussed in more detail and put into the context of SSWs. For example, it has been suggested recently by Albers and Birner (2014) that gravity wave forcing at midlatitudes could be important for the onset of SSWs. Also satellite observations of gravity waves show stronger GW drag at mid or even low latitudes prior to major SSW central dates (Ern et al., 2016). In the same paper strong gravity wave activity and GW drag was seen in the polar vortex during 2011. In this year, however, the vortex was very stable and confined to high latitudes which also confined gravity wave activity to high latitudes, apparently without affecting the stability of the vortex. This supports one of the main findings of your study and should therefore be mentioned.

   Reference:

   Albers, J. R., & Birner, T. (2014). Vortex preconditioning due to planetary and gravity waves prior to sudden stratospheric warmings, J. Atmos. Sci., 71, 4028-4054, doi:10.1175/JAS-D-14-0026.1.

Other Comments

1. pg.2, lline 28/29: Please rewrite the following sentence for better legibility! "This study is focusing on different GW breaking areas in the lower stratosphere along and the effects on the middle atmosphere highly depending on the position."
2. pg.2, line 29: who were concentrating → who were focusing
3. pg.3, line 2
   shifting meridionally the EA/NP hotspot along its fixed longitude range
   →
   shifting meridionally the EA/NP hotspot keeping its longitude range fixed
4. pg.3, line 23: interval, in which → interval in which
5. pg.4, line 3: refer to the mid → referring to the mid
6. pg.4, line 17: reproduce → reproduces
7. pg.5, line 2: observations but the → observations, but the
8. pg.5, line 3: jet filtering some of → jet filtering of some of
9. pg.7, line 4: is shifted toward → that is shifted toward
10. pg.7, line 14: kmat → km at
11. pg.8, line 14: west wind → westerly wind
12. pg.11, line 10: more SPW 1 are excited, → SPW 1 excitation is strengthened,
13. pg.12, line 2: fluxes and its → fluxes and their
14. pg.13, line 3: atmopshere. → atmosphere.

15. pg.14, line 2: west wind → westerly wind
16. pg.15, line 7: additionaly → additionally
17. pg.15, line 30: öeast → least
18. pg.15, line 30: latitudianlly → latitudinally

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