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Atmospheric Chemistry and Physics Discussions

Interactive comment on "Comparative study between ground-based observations and NAVGEM-HA reanalysis data in the MLT region" *by* Gunter Stober et al.

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Reply to Reviewer:

General comments: This study shows comparisons of MLT dynamics between the ground-based observations and the new reanalysis data which covers the mesosphere. The new analysis technique which could overcome the data gap and uneven sampling in the observation is well introduced, although a setting of the vertical retrieval kernel should be carefully discussed. The authors clearly describe the good performance of NAVGEM-HA reanalysis data in terms of climatology and the short-term response to the sudden stratospheric warming. The possible mechanisms for the short-term

response of the semi-diurnal tides are also well discussed in Section 5. Since this paper shows many attractive observational/simulated results, the time-lag and/or the time scale of the short-term response of the semi-diurnal tides, in my opinion, should be a little more described in Section 4, which might be helpful for the discussion of the above mechanisms. In addition, the discussion section could be shortened by moving some sentences/paragraphs to the other sections. So, I would recommend publication of this paper only with some minor revisions described below.

General reply: We thank the reviewer for his constructive and helpful comments about the submitted manuscript. We revised the manuscript according to his suggestions. However, as the second reviewer recommended a more extensive revision, the changes to the manuscript are in some paragraphs substantial. A point by point reply to each raised comment is given below.

Comment: 1. Page 4, line 18: It would be better to replace the sentence "The Rayleigh backscatter is...under the assumption of hydrostatic equilibrium" by a new one; "The temperature is calculated under the assumption of hydrostatic equilibrium from the Rayleigh backscatter which is proportional to the atmospheric air density."

Reply: (Page: 5 line: 3) We changed the sentence as suggested.

Comment: 2. Page 4, line 22: "only down to"→"only above" ??

Reply: (Page: 5 line: 6) We followed the suggestion.

Comment: 3. Page 4, line 29: please delete "?".

Reply: (Page: 5 line: 14) There was a reference missing due to a mistake in the latex file. We cited Kuhl et la., 2013.

Comment: 4. Page 5, line 28: What is the advantage of the ASF compared with a wavelet technique such as S transform (Stockwell et al., 1996)?

Reply: (Page: 7 line: 29-) We added a short paragraph discussing the pro and cons of both techniques. The ASF technique aims, similar to the S-transform \citep{Stockwell:1996}, to infer spectral information of intermittent signals. However, the S-transform is based on wavelet techniques and, thus, takes all the pros and cons of these methods. The main benefits of the ASF are given in the error, the possibility to use unevenly sampled time series with data gaps and most importantly to apply individual constraints (in this study vertical wavelengths) to each fitted frequency component. Both methods should yield similar results for model data sets that obey the requirements mentioned above.

Comment: 5. The benefits of the ASF and a part of the discussion for the vertical kernel described in Section 5.1 would be better to be moved in Section 2 to shorten Section 5.

Reply: (Page: 7 line: 21-28) We moved parts of section 5.1 to the ASF section and linked the new paragraph to this discussion.

Comment: 6. Page 6, lines 1-12: Please insert two references about gravity waves in MLT regions: Chen et al. (2013) to (Page 6, line 9), which shows a case study of observed gravity waves with the vertical wavelength of 22âĹij23 km. Shibuya et al. (2017) to (Page 6,line 6). which shows a case study of gravity waves with the wave periods of quasi-12h (The climatological study of the above cases is discussed in Chen et al., 2016, JGR and Shibuya and Sato, 2019, ACP, respectively, which I think need not to be introduced here).

Reply: (Page: 7 line: 13-16) We added a short discussion of the first two publications into the paragraph. Both publications are interesting and highly relevant for this study. As the rather long vertical and horizontal wavelength, which are reported in both papers at such high latitudes brings new issues to the debate on how to separate a tide from a gravity wave at the polar regions. Further, considering She et al., 2016, who outlined that tidal waves satisfy the polarization relation for gravity waves.

Comment: 7. Page 7, lines 22: The altitudes of the wind reversal are quite different

from the observations and the reanalysis data, which should be mention in the main text. The altitude of the wind reversal is quite important for the breaking condition of the upward propagating gravity waves.

Reply: (Page: 7 line: 13-16) We added some sentences explicitly pointing at these differences at their relevance for gravity wave propagation and breaking. On the other side, we have to mention that NAVGEM-HA winds and temperature fields are in much better agreement with the observation than many other GCM's perform at these altitudes. Even gravity wave resolving models seem to have difficulties to reproduce the observations in such details. Maybe such comparisons should become a benchmark to validate and cross-compare in climatological sense free-running GCM's, reanalysis data sets and meteorological analysis (e.g. NAVGEM-HA).

Comment: 8. Page 8, lines 9: Why is the amplitude of the semi-diurnal tides in reanalysis data overestimated above the altitude of 90 km? I'm afraid that this point is not discussed in Section 5.

Reply: (Page: 5 line: 18-28) We added a paragraph outlining the issue with the altitudes above 90 km. After removing the sponge layer from NAVGEM-HA and converting the geopotential altitudes to geodetic altitudes using WGS84 the uppermost trustworthy altitude is 92 km during winter and 90 km during summer. In fact, tidal amplitudes should not be interpreted beyond these altitudes. Our regridding up to 94 km led to an extrapolation of the tidal amplitudes, which was further enhanced due to the vertical regularization of the ASF. This is now clearly stated in the manuscript.

Comment: 9. Page 10, in Figure 3: Please add the explanation to the representation of a tidal phase (p12?).

Reply: (Figures 3,4,5,6,7 and 9,10) We added an explanation of the labels to the figure caption.

Comment: 10. Page 10, line 9: Please mark the central date of the sudden stratospheric warming in the figures after Fig. 6.

Reply: (Figures 3,4,5,6,7,8 and 9,10,11,12,13) We indicated the onset of the SSW for each figure using the definition from McCormack et al., 2017. The onset is given by a black vertical line.

Comment: 11. Page 10, line 12: Why does the data gap in the observation at Andenes exist near the central date of SSW? Is this related to the SSW?

Reply: The Andenes MR radar had a technical problem and was off for some days. This happens frequently. Mostly due to the icing of the antennas or strong winds, which significantly degrades the VSWR and triggers a shut-down of the transmitter. Whether this was related to the SSW is beyond our knowledge.

Comment: 12. Page 11, line 6 (CRITICAL): Please mention the time-lag between the central date of the SSW and the amplification of the semidiurnal tide both in the observation and the reanalysis data in Figs 6, 7, 9 and 10, respectively.

Reply: We agree to the reviewer that the time-lag between the SSW and the onset of the enhancement of the semidiurnal tide is important. We are already preparing another study with more events to systematically look at this pattern and time scales. However, as the vertical propagation of the semidiurnal tide is mostly affected by the local(regional) air packages in the column around our measurement locations, the classical definition of a central day of an SSW seems to be not appropriate to measure the time-lag (e.g. the zonal wind reversal at 60°N). For different latitudes, the zonal wind and the zonal wind reversal depend on the polar vortex position and its evolution, thus, we have to find another definition to measure the time lag. If we define the max of the zonal wind reversal at a given latitude at 70 km altitude as central day, the time-lag is about 1-3 days. It takes 1 day for the onset of the tide amplification and 2-3 days to reach the maximum amplitude. If we use the standard definition of the central day at 10 hPa and at 60°N, the time lag is between 3-6 days at Andenes and 2-3 days at Juliusruh. Thus, the discussion of time delays and a potentially new definition of the central

day at local coordinates would require a more detailed study, which is in preparation.

Comment: 13. Page 12, line 4: In Figure 8, the SW2 tidal amplitude seems to decrease after the central date of SSW below the altitude of 85 km? Such a decrease is not dominant in each localized point in NAVGEM-HA in Figs. 6 and 7. Why is this found only in the zonal mean?

Reply: We were not aware of this feature so far. A detailed analysis is beyond the scope of the paper. However, there are two aspects that are relevant and need to be further disentangled. As shown in the appendix, there occur short and sudden enhancement of non-migrating tides before and after the SSW event (SW1, SW3), which might just be an artifact due to aliasing or a real excitation of both non-migrating tides modes. The local diagnostic only reveals a superposition of the migrating and non-migrating modes and, thus, depending on the phase behavior and the longitude of the observations, they might pick up only the positive interference of all tidal modes. The second aspect is the planetary waves and how the SSW affects the polar vortex. In the case of the SSW 2010, the polar vortex was clearly displaced to the European sector (see publications of Kodera et al., 2016), which is the sector of our observations. As a result, the local diagnostic can look rather different with respect to the zonal mean. The planetary wave also has an effect on the amplitude of the tides can grow with altitude. Depending on the PW structure of wave numbers 1,2 and 3 the vertical propagation of tides is affected.

Comment: 14. Page 21, line 21-24: Please move the sentence "Atmospheric..." to Introduction.

Reply: (Page:3 line:17-29) We moved the sentence to the introduction.

Comment: 15. Page 22, line 4-9: For the discussion of the amplification of the tides after the SSW, the time-lag of the amplification should be one of the key components. For example, the time-lag might be related to the vertical group velocity of the tides which propagate from the source region. Did the previous study discuss such a time-lag in their proposed mechanism?

Reply: We thank the reviewer for making this comment. The vertical propagation of the tides is indeed a key element and, thus, the time lag between the SSW and the enhancement at least not in the context of the lunar tide. Only Forbes and Zhang (2012) mentioned the time delay between the central day and the semidiurnal tide amplification, which they then attributed to a lunar tide. However, given the dramatic change in the vertical wavelength of the semidiurnal tide from 50-60 km before the SSW to 200-300 km during a back after 3-5 days to 50/60 km indicates already that the vertical group speed is essential. We currently working on a more detailed analysis using a more extended dataset of NAVGEM-HA and observations. We now put more emphasis on this aspect throughout the manuscript. However, a more detailed study is in preparation for more data and events.

Comment: 16. Page 22, line 24: Moreoverr→Moverover.

Reply: (Page: 25 line:22) Done.

Comment: References: Chen, C., Chu, X., McDonald, A. J., Vadas, S. L., Yu, Z., Fong, W., and Lu, X.: Inertia gravity waves in Antarctica: A case study using simultaneous lidar and radar measurements at McMurdo/Scott Base (77.8âŮęS, 166.7âŮęE). Journal of Geo-physical Research: Atmospheres, 118(7), 2794-2808, 2013. Shibuya, R., Sato, K., Tsutsumi, M., Sato, T., Tomikawa,Y.,Nishimura, K., and Kohma, M.: Quasi-12 h inertia–gravity waves in the lower meso-sphere observed by the PANSY radar at Syowa Station (39.6_ E, 69.0_ S), Atmos. Chem. Phys., 17, 6455–6476, 2017

Reply: We thank the reviewer for providing these additional references and included them at the suggested paragraph in the manuscript.

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