Review of "Radar observations of winds, waves and tides in the mesosphere and lower thermosphere over South Georgia island (54°S, 36°W) and comparison to WACCM simulations"

General comments

- This manuscript presents comprehensive analysis of horizontal winds observed using the meteor radar deployed at South Georgia island over the Southern Ocean and temperature obtained from the MLS sensor mounted on the AURA satellite in terms of mean flow, tides, planetary waves and gravity waves. In addition, this study compares the analysis results with the climatological WACCM results and suggest directions in which whole atmosphere climate models like WACCM can be improved in the future for better MLT simulations.
- The conventional methodology in retrieving horizontal winds from meteor radar echoes is overcome through the development of a novel technique based on Gaussian weighting approach. This new technique allow for obtaining the smoother wind information as much as possible from meteor radar observations. This study is impressive in that it includes almost every analysis that can be done with meteor radar horizontal winds. Most of descriptions of results are reasonable, but there is an issue that need to be clarified. This issue is related to conclusion of this study and may affect considerably discussions about secondary gravity waves. For this reason, reviewer recommends major revision for consideration of publication to Atmospheric Chemistry and Physics.

Major comments

- One major issue is about inferring the propagation direction of gravity waves derived from the sub-volume gravity-wave variances. Authors said in the paragraph between L490 and L496 that any residual meteor wind perturbation due to this (zonally propagating) gravity wave measured to the east or west of the radar will exhibit larger radial wind perturbations than those measured to the north or south. Therefore, if the variance of the residual perturbations in the zonal direction is larger than the variance in the meridional direction, we can infer that there is a zonal "directional tendency" of GWs towards the zonal direction.
  - First of all, could you confirm the formulations of σ^2_{zon} and σ^2_{mer}? Are they defined by something like the following equations? $\sigma^2_{zon} = \left(\sum_{i=1}^{N} {v'}^2_{ri} \sin^2\theta_i\right)/(N-1)$ and $\sigma^2_{mer} = \left(\sum_{i=1}^{N} {v'}^2_{ri} \cos^2\theta_i\right)/(N-1)$, where ${v'}_{ri}$ is the residual radial (horizontal) wind at each radar echo position, θ_i is the azimuth angle of the radial (horizontal) wind measured clockwise from the North. Here, the residual wind is the result of subtracting radial projection of the hourly zonal and meridional winds from the observed radial winds on the horizontal plane as in

Mitchell and Beldon (2009).

  – If the two formulations are what the authors employed, the directionality obtained based on these equations may give biased estimate of the propagation direction of gravity waves because $\sin^2\theta_i$ ($\cos^2\theta_i$) have the same positive weights for eastward and westward (northward and southward) propagating gravity waves. Figures below show possible situations of the phase progressions for gravity waves around a radar site. On the first panel, upward propagating gravity waves propagate eastward (or northward) relative to the zonal (meridional) mean flow. Radar observation is sensitive to those gravity waves east (north) of the radar, but not sensitive to those waves west (south) of the radar. On the second panel, upward propagating gravity waves propagate westward (southward) relative to the mean flow. Radar observation is sensitive to those gravity waves west (south) of the radar, but not sensitive to waves east (north) of the radar. In other words, radar observations can be sensitive to gravity waves that are generated from the radar site and propagate in radial directions away from the radar. However, for gravity waves passing through the radar site, radar can detect those waves only either east or west (either north or south) of the radar site. In summary, the directionality computed in the manuscript can possibly be biased towards gravity waves generated near the radar site (or downward propagating toward the radar site in case of upward phase propagation).
  – Reviewer wonders if the authors have considered the above-mentioned issue. If the directionality computed is biased towards gravity waves propagating horizontally outward from (or towards) the radar site, the directionality in the present manuscript should be interpreted differently. Correction of the interpretation of the directionality may lead to modification of interpretation of the seasonal variations of the propagation direction of gravity waves and modification of discussion of generation of secondary gravity waves.

Specific comments

- L11: Symbols W1 and W2 are used without appropriate definitions.
- L41: Solomon and Garcia, 1987
- L52: Considering oblique propagation of GWs in parameterizations has a relatively long history, although Kalisch et al. (2014) is relatively recent one. Consider citing some of relevant previous studies: Song and Chun (2008), Hasha et al. (2008), or Choi et al. (2009).
- L53: Current GW parameterizations do neither include secondary GWs nor GWs that originate from the middle atmosphere (upper stratosphere or lower mesosphere) (e.g., Fairlie et al., 1990; Sato and Yoshiki, 2008).

- L220: How large-amplitude Q6DW can be related to small impacts due to southern SSW in September 2019?
- L222: It does not seem reasonable to discuss the Brewer-Dobson circulation (BDC) at the mesopause heights, although the BDC is expected to manage to reach somehow middle mesosphere as inferred from the stream lines shown in Seviour et al. (2012). Besides, results in Murgatroyd and Singleton (1961) were mostly shown below $z = 80$ km.
- Figure 5: How about include labels for zonal and meridional winds in panels (or as panel titles)
- L301: How can we explain the upward propagation of diurnal tides in the high-latitude regions where the Coriolis frequency is larger than diurnal frequency?
- L399: The subsection number should begin from 1.
- L465: 100s ⇒ hundreds
- L532−L537: Secondary gravity waves with concentric-ring shaped phase lines can have meridional components of horizontal propagation even though they are generated by a zonal body force. That being said, logic used to explain the meridional GW propagation tendency seems weak because the major propagation direction of secondary GWs still lies in the sense of the direction of the body force induced by the primary GWs. This part is also related to the major issue raised above.
- L535: stratopause ⇒ mesopause
- L594: WACCM observations ⇒ WACCM
- Section 9: Although authors suggest impacts of secondary GWs as a promising mechanism to improve the MLT simulations of whole atmosphere models based on recent studies (e.g.,Becker and Vadas, 2018), there are also substantial uncertainties regarding impacts of GW generation due to flow imbalance in the upper stratosphere and lower mesosphere. Recommend to mention even briefly potential middle-atmospheric GW sources as mentioned above.

References, not cited in the manuscript

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- Sato, K., and M. Yoshiki, 2008: Gravity wave generation around the polar vortex in the stratosphere revealed by 3-hourly radiosonde observations at Syowa Station. Journal of the Atmospheric Sciences, 65, 3719−3735. https://doi.org/10.1175/2008JAS2539.1
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