**Atmospheric
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Interactive comment on "The southern stratospheric gravity-wave hot spot: individual waves and their momentum fluxes measured by COSMIC GPS-RO" *by* N. P. Hindley et al.

Anonymous Referee #2

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General Remarks

In the article by Hindley et al. GPS radio occultations are used to study the distribution of gravity waves at high southern latitudes during austral winter. For this purpose gravity wave potential energy Ep and momentum flux are derived. Furthermore, a method is introduced to identify gravity waves in temperature altitude profiles.

The main goal of the paper is to relate the observed distribution of waves to different source processes. This is an important issue because recent modeling work has revealed a lack of wave forcing around 60S.

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Indication is found for meridional propagation of mountain waves into the Drake Passage, while waves seen further leeward over the Southern Ocean apparently have non-orographic sources, such as storms and fronts or geostrophic adjustment.

The paper is well written, and novel and interesting results are presented. It is therefore recommended for publication in ACP after addressing the two major and several minor comments, as detailed below.

Major Comments

(**MC1**) More discussion is needed regarding the vertical wavelength limitations of the analysis method. Otherwise it cannot be decided whether features of the gravity wave distribution are caused by the analysis technique, or whether they are an effect of gravity wave propagation. This concern is addressed in more detail in the specific comments, particularly in specific comment 7.

(**MC2**) Horizontal separations of altitude profiles as short as 10–20 km are used for determining horizontal wavelengths. This is quite short and will lead to random effects. This may explain some of the differences between HIRDLS and COSMIC in Fig. 10.
Fig. 10 should be revised by using longer horizontal separations.
See also specific comments 16, 17 and 21.

Specific Comments

1. p.3175, l.4: For completeness, the earlier reference Eckermann and Preusse (1999) should be included:

Eckermann, S. D., and Preusse, P.: Global measurements of strato-spheric mountain waves from space, Science, 286, 1534—1537, doi:10.1126/science.286.5444.1534, 1999.

2. p.3179, l.26: It should be pointed out more clearly that at this stage of calculating Ep the blue dashed curve in Fig. 6 applies, and a certain contribution of $\lambda_z > 10$ km is still contained in T'. This is important because later, when discussing Fig. 3, it is claimed that meridional propagation of gravity waves would be seen. Assuming a sharp cutoff at λ_z=10km, mountain waves would become invisible if the background wind U parallel to the wave vector exceeds ∼30 m/s. For mountain waves: $\lambda_z \approx 2\pi U/N$ (Eckermann and Preusse, 1999, Eq. 1)

3. p.3180, ll.15ff: It is unclear why the gravity wave distribution consisting of more or less randomly distributed temperature fluctuations should be affected by removing coherent planetary scale waves with s=1 or s=2. Please explain!

4. p.3180, ll.23/24: Why should a 10km window further reduce contributions of planetary waves?
   If T' at a fixed altitude is affected by planetary waves, this planetary wave contribution will enter Ep, independent of the size of the window. Further reduction of planetary waves can only be achieved by separately removing the offset in every 10km window. This is however not mentioned.
   Please either explain or delete this sentence.

5. p.3181, ll.28ff: The reduced sensitivity for gravity waves directly over the mountain ridges is not only an effect of the GPS RO observation technique. The data analysis technique plays also an important role!
   Depending on the strength of the background wind, vertical wavelengths of mountain waves can be quite long. These long λ_z waves should be contained in the GPS RO temperature altitude profiles and can therefore be detected. Also other

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limb observations with similar observational filter show maximum gravity wave variances over the mountains (for example, Yan et al., 2010).

Yan, X., Arnold, N., and Remedios, J.: Global observations of gravity waves from High Resolution Dynamics Limb Sounder temperature measurements: A yearlong record of temperature amplitude and vertical wavelength, J. Geophys. Res., 115, D10113, doi:10.1029/2008JD011511, 2010.

Possibly, the vertical wavelength limitation in your study to only short λ_z reduces the sensitivity to mountain waves, and may in some regions favor waves from sources other than orography.

It should therefore be mentioned that increased Ep over the Southern Ocean could be just an effect of the analysis technique that is limited to short λ_z waves.

6. p.3182, l.9: please omit "significant"; up to 10% is not a large fraction.

7. p.3183, ll.13ff / discussion of Fig. 3:
The background wind in the southern polar jet can be quite strong. It is up to 80 m/s in Fig. 3, and it changes a lot from 40S/22km and 20 m/s to 55S/40km and 70 m/s. Therefore it could be doubted that mountain waves are captured by your analysis over the whole range of altitudes and latitudes considered. A discussion of observational effects related to the vertical wavelength range of your analysis should therefore be included in the manuscript. In addition, previous work that supports your findings should be mentioned.
Please find below a suggested roadmap for this additional discussion:

- $\lambda_z \approx 2\pi U/N$ (Eckermann and Preusse, 1999, Eq. 1): therefore it might be doubted that mountain waves are captured by your analysis for background winds stronger than 40–50 m/s, taking into account the limited vertical wavelength coverage
- Still, your analysis will capture mountain waves for even stronger background winds because the background wind vector and the wave vector

of the gravity waves will not be exactly parallel (for example, Alexander and Teitelbaum, 2011)

Alexander, M. J., and Teitelbaum, H.: Three-dimensional properties of Andes mountain waves observed by satellite: A case study, J. Geophys. Res., 116, D23110, doi:10.1029/2011JD016151, 2011.

- This is further supported by vertical wavelength observations in the southern polar jet from analyses with larger vertical wavelength coverage. On zonal average, these estimates are in the range 10–13 km (for example, Yan et al., 2010; Ern et al., 2011)

Ern, M., Preusse, P., Gille, J. C., Hepplewhite, C. L., Mlynczak, M. G., Russell III, J. M., and Riese, M.: Implications for atmospheric dynamics derived from global observations of gravity wave momentum flux in stratosphere and mesosphere, J. Geophys. Res., 116, D19107, doi:10.1029/2011JD015821, 2011.

- Therefore the slanted vertical column of enhanced E_p in Fig. 3 could be due to mountain waves and could indicate meridional propagation

- Similar effects have been observed before in other regions, for example Jiang et al., 2004; Ern et al., 2013

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

Ern, M., Preusse, P., Kalisch, S., Kaufmann, M., and Riese, M.: Role of gravity waves in the forcing of quasi two-day waves in the mesosphere: An observational study, J. Geophys. Res. Atmos., 118, 3467—3485, doi:10.1029/2012JD018208, 2013.

8. p.3184, ll.11-14: Which latitudes are considered for the zonal cross-section?

The range is given in the figure caption, but should also be given here.

9. p.3187, ll.18/19: "at least 60% of the root-sum-squared energy of the profile"
   Is this correct? Shouldn't it read "at least 60% of the spectral amplitude..."?
   Please check!

10. p.3187, ll.17ff: Does a squared spectral amplitude threshold of 0.36 / spectral
    amplitude threshold of 0.6 imply that at a given altitude usually only one wave
    is selected? Or are multiple selections possible? This information should be
    included in the manuscript.

11. pp.3187/8: The following should be mentioned:
    It is assumed that the vertical wavelength does not change much with altitude,
    which may no longer hold for gravity waves in the real atmosphere if the width of
    the wavelet gets too large.
    In particular, long vertical wavelength waves will therefore be selected with lower
    probability. This may explain the slight mismatch between the histogram in Fig. 6
    and the "permitted" range of vertical wavelengths given by the black curve.

12. p.3189, l.23 and elsewhere
    The statement "profiles that did not contain a wave" is too strong, given the lim-
    itations of the analysis method. Perhaps replace with "profiles with no wave de-
    tected".

13. p.3190, l.15: sector C has quite large longitudinal extent
    It would be good to add a sector C', ≈1/3 of the longitude extent of C, thereby
    focusing more on the vicinity of the Drake Passage where "primary mountain
    waves" should cause even higher intermittency.

14. Fig.9: In this figure both the number of waves and the number of profiles are indi-
    cated below the histograms. Calculating the ratio of these numbers, the fraction

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of profiles containing an identified wave is around 80%. This is in discrepancy with the number of 25-40% mentioned on p.3188, l.5.
Please check and clarify!

15. p.3193, l.8: Please mention that k_h has previously been determined by McDonald (2012) and by Faber et al. (2013) using pairs of COSMIC radio occultations.

   McDonald, A. J.: Gravity wave occurrence statistics derived from paired COSMIC/FORMOSAT3 observations, J. Geophys. Res., 117, D15106, doi:10.1029/2011JD016715, 2012.

   Faber, A., Llamedo, P., Schmidt, T., de la Torre, A., and Wickert, J.: On the determination of gravity wave momentum flux from GPS radio occultation data, Atmos. Meas. Tech., 6, 3169—3180, doi:10.5194/amt-6-3169-2013, 2013.

16. p.3193, ll.22/23ff: Horizontal separations as short as 10–20 km are probably too short to reliably determine k_h.
   Estimated horizontal wavelengths of 1000 km for gravity waves are quite common in satellite data, as seen in your Fig. 10. For 10–20 km horizontal separation the phase difference between two profiles would be $360°/(50...100) \approx 4°...7°$.
   I doubt that the determination of vertical phases is that accurate!
   The use of small separations will therefore introduce a strong random component, resulting in too large phase differences on average and, hence, underestimation of horizontal wavelengths.

   This may also explain some of the differences between COSMIC and HIRDLS horizontal wavelengths in Fig. 10.

   Therefore I recommend to revise Fig. 10 using only longer horizontal separations for COSMIC.

   I leave it to the authors which range of horizontal separations is suitable, keeping in mind that separations should not be too long, and sufficient statistics is needed for the horizontal distributions in Fig. 10.

Possible consequences of too short separations should be briefly mentioned already on p.3193. The discussion on pp.3196/7 should be adapted accordingly.

17. p.3193, ll.22/23ff: Horizontal separations as short as 10–20 km may result in unphysically short horizontal wavelengths. Are these values used for Fig. 10, or are they filtered out before?

18. p.3195, l.4: an illustration of this geometry can be found in Preusse et al. (2009).

    Preusse, P., Schroeder, S., Hoffmann, L., Ern, M., Friedl-Vallon, F., Ungermann, J., Oelhaf, H., Fischer, H., and Riese, M.: New perspectives on gravity wave remote sensing by spaceborne infrared limb imaging, Atmos. Meas. Tech., 2, 299—311, doi:10.5194/amt-2-299-2009, 2009.

19. p.3195, ll.11–13: It is not clear that this estimate of momentum flux is necessarily a lower bound.
    Your analysis technique focuses on strong wave events, causing an increase of Ep by a factor of 3–5 in Fig. 7. This might overcompensate the low-bias in k_h and the restriction to low λ_z values introduced by the analysis technique.
    Suggestion: omit the final sentence in Sect. 4.1.

20. p.3195, ll.20/21: Theoretically, COSMIC and HIRDLS should be sensitive to about the same part of the gravity wave spectrum (Preusse et al., 2008, Sect. 5).

    Preusse, P., Eckermann, S. D., and Ern, M.: Transparency of the atmosphere to short horizontal wavelength gravity waves, J. Geophys. Res., 113, D24104, doi:10.1029/2007JD009682, 2008.

21. p.3196, ll.16ff: Possibly, differences in the geographical distribution of λ_H are caused by the short horizontal separations used for COSMIC.
    This should be checked. See also specific comments 16 and 17.

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22. p.3197, l.8: slightly lower → considerably lower
    (the horizontal wavelength scale differs by about a factor of two!)

23. p.3197, l.25: This is not an effect inherent in the HIRDLS observations. HIRDLS and GPS RO observational filters should be similar. Suggestion:
    since HIRDLS generally resolves → since our HIRDLS analysis generally resolves

Typos etc.

1. p.3176, l.28: pairs → pairs of

2. p.3181, l.20: the the → the

3. p.3192, l.17: can → can be

4. p.3199, l.22: hypotheses → hypothesis

5. p.3208, l.2: occultaions → occultations

Interactive comment on Atmos. Chem. Phys. Discuss., 15, 3173, 2015.