Atmos. Chem. Phys. Discuss., 15, C2606–C2615, 2015
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Atmospheric Chemistry and Physics
Discussions

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.

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Received and published: 15 May 2015

The authors are very grateful to the anonymous reviewer for all of their helpful comments and suggestions. The comments are fair, reasonable and contribute to the improvement of the paper.

1 Major Comment

Reviewer's Comment: I have found that the authors provide convincing arguments that the broad longitudinal enhancement of gravity wave activity is likely to be associated with a nearly uniform gravity-wave source at 60°S. In particular, I think that it is quite unlikely that the Andes and Antarctic Peninsula could generate waves with horizontal wavelengths much longer than 350 km, and thus significantly contribute to the gravity-wave activity enhancement east of 20E. On the other hand, I am less convinced by the authors claim (in particular around p3185 l13-26; p3199, l9-16; p3200 last paragraph and p3201 first paragraph) that Figure 4 supports that this broad gravity-wave source is likely to be a local stratospheric source (either secondary generation from primary mountain waves or stratospheric jet adjustment or instabilities). I have mainly two reservations:

- first, the fact that Figure 4 shows that Ep peaks around 20-35 km in August above the Austral Ocean (letting apart the orographic waves at 60W) may result from an observational effect associated with the GPS-RO dataset. As shown on Figure 3, the zonal wind increases from the tropopoause to 35 km at 60°S in August, which will result in an increase of the vertical wavelength of westward propagating gravity waves. Some of these waves may thus be invisible in the GPS-RO dataset below 20km (vertical wavelength less than twice the GPS-RO vertical resolution, i.e., 2.8km), but become more and more resolved as the wind increases above. O'Sullivan and Dunkerton (1995) for instance show that waves generated around the tropospheric jet have vertical wavelengths of a few kilometers. The maps on Figure 2 are furthermore much reminiscent of the spiral structure of the Southern Hemisphere storm track with less activity over the Pacific Ocean (see, e.g., Hoskins and Hodges (2005)), so that this broad gravity-wave feature may actually be associated with non-orographic waves generated in the tropopsphere.

  Authors' Response: Agreed. We have updated the article such that we discuss this effect in our description of Figure 4 in Section 2.3 and the main discussion in Section 5. We include relevant references to O'Sullivan and Dunkerton (1995) and Hoskins and Hodges (2005) as suggested.

Reviewer's Comment: then, it is written in the article that the quantity displayed on Figure 4 (and Figure 3) has been normalized, but this normalization has not been explicited. Raw $E - p$ is not density weighted (cf. Eq. (3)), so that it is expected to increase as exp(z/H) for linear waves, with H the density-scaled height. Is the normalization used by the authors supposed to counterbalance this increase? Otherwise, one can not deduce from the peak of E_p at 30 km on Figure 4 that it is associated with a local source: it may rather be the altitude where gravity waves generated below deposit most of their momentum. I therefore strongly suggest that the authors present a explicitly density-weighted version of Figure 4, so that one will be able to assess where the waves observed above the oceans are primarily generated.

Authors' Response: For each height level in Figures 3 and 4, E_p is normalised such that the lowest value is equal to 0 and the highest value is equal to 1. This normalisation identifies the relative intensity of E_p in the panel at each height level and removes any exponential increase with decreasing pressure. This is the same normalisation as was used by Wright and Gille (2011, their Figure 4). This normalisation approach already accounts for decreasing density. We have updated the description of the normalisation to make this clearer.

2 Minor Comments

- **p.3178, l.25:** ***Reviewer's Comment:*** (and p3179, l2): Actually, waves with $\lambda_H < 2 \times 270$ km are unlikely to be detected (Nyquist wavelength).

  Authors' Response: We do not agree, see Kursinski et al. (1997, Section 2.5).

  Nyquist-sampling limitations only apply to the vertical profile. The horizontal resolution of each data point in the vertical profile is determined by an integral along the line-of-sight and is not Nyquist-sampled. An alternative discussion of the horizontal resolution of a limb-sounding instrument using a line-of-sight integral method can be found in Preusse et al. (2002, 2009).

- **p.3179, l.2-7:** ***Reviewer's Comment:*** It is recalled here that most of the orographic waves generated above the Andes or by the Antarctic Peninsula have “westward oriented horizontal wavenumber vectors”, while the “COSMIC occultations in this region tend to be preferentially aligned towards the north-south axis”. I would like that the authors further develop this point, and in particular discuss how it could affect the sensitivity of the measurements to wave disturbances. One issue that strikes me for instance is that the HIRDLS soundings are performed in a direction almost perpendicular to the GPS occultations in this region. I thus wonder what is the meaning of the comparisons performed in section 4: how can both techniques be sensitive to the same waves there? Which technique is the best suited to obaserve zonally propagating waves in this region? And what is the validity of λ_H derived from the GPS RO there?

  Authors' Response: We do not claim that HIRDLS and COSMIC are sensitive to exactly the same waves, although their observational filters should be similar. As mentioned in Section 1, the COSMIC horizontal line of sight (LOS) resolution is ~270 km. The average theoretical horizontal resolution along the axis joining the profile-pairs used in Section 4 is $\sim 2 \times \Delta r = 20\,km.$ A sensible value for the HIRDLS LOS resolution is ~300 km (e.g. Presse et al., 2009 and citations therein). The HIRDLS along-track resolution is twice the inter-profile spacing, up to $\sim 2 \times \Delta r = 160$ or 240 km (there are generally two values of Δr for HIRDLS, see Appendix A). If a wave in this region has a true absolute horizontal wavelength greater than ~300 km, it should be detected by both COS-

MIC and HIRDLS, regardless of orientation. There is a very large overlap in the observational filters of both instruments, and the two are broadly comparable in the horizontal domain. We acknowledge that differences may arise in special cases where wavefronts are aligned favourably for one instrument such that it may resolve a wave with $\lambda_H < 300$ km when the other instrument may not. We are confident however that differences arising from this effect are not significant in the general case and do not undermine our comparison in Section 4. The north-south GPS-RO LOS orientation is favourable for the detection of zonally propagating waves with true absolute horizontal wavelength slightly shorter than 270 km (see also later response below).

- **p.3181-3182, l.29-5:** ***Reviewer's Comment:*** I also observe on Figure 2 that one does not observe a continuous decrease of E_p as one goes farther East in the "leeward" region of increased E_p. This seems to be in contradiction that most of these waves are of orographic origin. On the other hand, your discussion here seems to make the implicit assumption that the waves were generated above the mountains and "have long dwell times".

  Authors' Response: We do not claim that most of the waves in the long leeward distribution of increased E_p are of orographic origin. Sato et al. (2012) suggested that some of this feature could be explained by the leeward advection of mountain waves from the southern Andes and Antarctic Peninsula. Their ray-tracing analysis suggested however that the increased E_p eastward of around 20°E is not likely to be explained by this mechanism. The term "long dwell times" refers to the relatively low vertical group velocity of low-frequency inertia-gravity waves relative to their high-frequency counterparts (Fritts and Alexander, 2003). These waves "dwell" longer in the atmosphere, increasing their likelihood of detection by a pseudo-random sampling technique such as GPS-RO. The vertical and horizontal observational filters of GPS-RO (roughly $5 < \lambda_Z < 15$ km and

  $\lambda_H > 270$ km) favour detection of these low-frequency waves.

- **p.3183, l.28-29:** ***Reviewer's Comment:*** You may recall here to which altitude range does this 2500 km horizontal propagation distance correspond?

  Authors' Response: This horizontal propagation distance is traversed whilst the simulated waves ascend from the ground to 40 km. The horizontal propagation distance approximate since Sato et al. launched a number of waves that traversed different distances for different launch angles and latitudes.

- **p.3184, l.6-9:** ***Reviewer's Comment:*** This is actually somewhat striking that the Antarctic Peninsula does not show up very clearly in your dataset, while it has been recognized as a major hotspot by several previous studies. Could you discuss whether this could be an effect of the RO orientation at high latitudes, or if it is due to the vertical wavelength range in which the GPS RO are most sensitive?

  Authors' Response: The Antarctic Peninsula shows up as a major hot spot in our results, as is evident in Figure 10c. This paragraph in question relates to the lack of a symmetric meridional focussing effect so clear as was observed over the Andes in Figure 3, not the lack of waves over the Antarctic Peninsula itself.

- **p.3187, l.1:** ***Reviewer's Comment:*** p3187, l1: Is this normalization really needed?

  Authors' Response: Yes this normalisation is absolutely necessary. Otherwise it is not possible to set one consistent threshold value for $C_{\max}$ to be applied to every profile. We have re-written the description of this section of the Wave-ID method description in response to another reviewer, and we hope that the reasoning behind each step is clearer.

- **p.3188, l.2:** ***Reviewer's Comment:*** p3188 l2: unless I have missed something, this 1 K lower and 10 K upper limits appear here for the first time without real justification. Do you use the lower limit to avoid including noise in your analysis? Why do you need an upper limit? How sensitive are your results if you change these limits?

  Authors' Response: The estimated accuracy of COSMIC GPS-RO temperature profiles is generally ∼1 K or better (e.g. Tsuda et al., 2011 and citations therein). It is very unlikely therefore that we can reliably disassociate waves with amplitude $T' < 1$ K with noise related to the RO retrieval or improper background temperature removal. We take $T' > 1$ K as a reasonable lower limit. Resolved gravity waves of these scales with amplitudes $T' > 10$ K are rare in satellite data. We believe amplitudes this large in the level 2 COSMIC retrieval are more likely to be spikes related to error or miscalibration in the retrieval than real gravity waves. Furthermore, such large amplitudes fall well outside the 95^{th} percentile of the amplitude distributions in Figure 9. It is for this reason that we set the upper limit to $T' < 10$ K.

- **p.3189, l.20:** ***Reviewer's Comment:*** I would add ""detected by the wave 1D method" between "waves" and "themselves".

  Authors' Response: Agreed, changed.

- **p.3190, l.2-8:** ***Reviewer's Comment:*** Both sentences have very similar meaning.

  Authors' Response: Agreed, though there is a subtle but important difference. The fact that the peak of the distribution shifts implies large amplitude, highly intermittent waves in the vicinity of the peak. The fact that the rest of the distribution does not move implies that the rest of the distribution is made up of waves which are not as intermittent. We have rephrased the paragraph to highlight this difference.

- **p.3191, l.17:** ***Reviewer's Comment:*** typo: $3 < T'$

  Authors' Response: Corrected.

- **p.3194, l.20:** ***Reviewer's Comment:*** See remarks p.3179 l.2-7: Is the RO orientation not too problematic here, as the waves are expected to be mostly zonally propagating?

  Authors' Response: The phase-fronts of zonally propagating waves will be aligned roughly parallel to the north-south axis. This means that the horizontal wavelength in the north-south direction can be very long. This favours detection by COSMIC occultations with north-south alignment, since we require $\lambda_H > 270$ km in the line-of-sight. The estimation of λ_H used in Section 4 is the component of λ_H projected along the axis joining the two profiles in a profile-pair. This axis is often roughly perpendicular to the line-of-sight. The cross-beam resolution of GPS-RO is ∼1.4 km (Kursinski et al., 1997), so we can even (theoretically, see Appendix A) resolve zonally propagating waves with very short horizontal wavelength components in the east-west direction. In summary, the orientation of RO profiles here is actually favourable to the detection of zonally propagating waves.

- **Figure 11** ***Reviewer's Comment:*** could you label the longitudes on this plot? Why are you limiting these maps to the South America sector?

  Authors' Response: We assume the reviewer means Figure 10. The longitudes are labelled on panel (f) of Figure 10. Each map has the same geographical extent, and the addition of repeated longitude labels on each panel leads to significant visual clutter which detracts from easy interpretation of the results.

In addition to the changes requested by the reviewers, we have also made some small changes to the structure of the abstract, introduction and conclusions, with the aim of providing a better scientific context for the work undertaken.

3 References

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