Atmos. Chem. Phys. Discuss.,
doi:10.5194/acp-2017-128-RC1, 2017

Atmospheric Chemistry and Physics Discussions
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Interactive comment on "Satellite Measurements of Stratospheric GravityWaves over the Andes/Drake Passage Region Using a 3D S-Transform Technique" *by* Corwin J. Wright et al.

Anonymous Referee #1

Received and published: 6 April 2017

In this paper, an extension of the Stockwell-transform (S-transform) to three dimensions is introduced (3DST). This method is applied to the 3D distribution of atmospheric temperatures observed by the Atmospheric Infrared Sounder (AIRS) over South America, the Antarctic Peninsula and the Southern Ocean. Wave parameters of atmospheric gravity waves and their distributions are derived, such as temperature amplitudes, horizontal and vertical wavelengths, phase and group speeds, and wave momentum flux.

The distribution of gravity waves in this region is of particular interest because the Andes and the Antarctic Peninsula form two of the strongest hotspots of gravity wave generation by orography. The gravity wave distribution over the mountain ridges is found to be particularly intermittent, in agreement with previous work about gravity waves

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generated by orography in this region. At latitudes between the two hotspots global atmospheric models underestimate the driving of the background winds by atmospheric waves. It has therefore been proposed that gravity waves from the two hotspots could fill this gap by lateral propagation into the circumpolar wind jet. In the current study, it is shown that the distribution of gravity wave group speeds indeed supports this assumption.

The paper is well written and provides new and important information that can help to overcome one of the major deficiencies of global atmospheric models. Therefore it is of interest for most of the readership of Atmos. Chem. Phys.

My main concerns are that there are several limitations of the method, such as uncertainties in the determination of vertical wavelengths and the quite substantial correction of wave amplitudes, as well as a low bias of wave amplitudes near the upper and lower limit of the altitude range. These shortcomings are not relevant for the main findings, but will affect some of the results. This requires a more detailed discussion in parts of the manuscript. In addition, some discussion should be added regarding the relatively low momentum flux over the Drake Passage. More details are given below in the Minor Concerns. Most important points are 12, 19, 21–23, and 25–28. After revision, the paper is recommended for publication in Atmos. Chem. Phys.

Minor Concerns

1. p.1, l.12 — here you write "the largest known GW sources" please be more specific! largest in size of the source region? largest in amplitude?
2. p.1, bottom — Gravity waves are much more important for driving the circulation in the mesosphere. This aspect should also be addressed in the introduction.
3. p.1, l.24 — Reference Butchart et al. (2014) is about the Brewer-Dobson circu-

lation, not about the QBO. Please replace with the more appropriate reference Baldwin et al. (2001).

Baldwin, M. P., et al. (2001), The quasi-biennial oscillation, Rev. Geophys., 39, 179-229.

4. p.1, l.24 — "contribute significantly" is not entirely correct; polar sudden stratospheric warmings are mainly driven by planetary waves. However, gravity waves may contribute to the triggering of sudden stratospheric warmings by preconditioning the polar vortex (Albers and Birner, 2014; Ern et al., 2016).

   Albers, J. R. and Birner, T.: 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, 2014.

   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, doi:10.5194/acp-16-9983-2016, 2016.

5. p.5, l.8 — "...near-perpendicular mountain ranges."
   This is meant relative to the wind direction?

6. p.5, l.23 — In Meyer and Hoffmann (2014) it is mentioned that the AIRS temperature retrieval method is different for daytime and nighttime data, resulting in different noise and different vertical resolution.
   Therefore you should add the information whether you use both daytime and nighttime data?

7. p.7, l.11–15 — I guess that input dimensions equal to powers of two is not the only reason for this interpolation. Probably the most important point is that the

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use of a FFT requires the data to be equispaced. This should be more clearly mentioned.

8. p.7, l.17 — About the removal of exponential increases.
   I do not understand this reasoning! The growing temperature amplitudes are caused by the gravity waves themselves; how, then, can they mask their own temperature perturbations?

9. p.7, l.16–21 — About the removal of exponential increases.
   An exponential increase of wave amplitudes seems not be the general case for your application. As can be seen from your Fig.10, for the whole period considered, zonal momentum flux peaks at 30 km, and then strongly decreases with altitude.

10. p.7, l.16–21 — About the removal of exponential increases.
    Given the two previous points, it is unclear why the exponential scaling is applied. It would make sense if you believe the data at lower altitudes to be more reliable. Still, by scaling one might boost noise at the lowermost altitudes where wave amplitudes should be still comparably small.
    Did you explicitly check whether your method performs better if the exponential scaling is applied?

11. p.7, bottom — Wouldn't it make more sense to switch step 5 and step 6, such that the true height-scaling is restored before a final amplitude correction is made?

12. p.7, about step 5:
    It should be more emphasized that this amplitude correction of as much as a factor of three is quite substantial. This correction could introduce large errors, particularly for momentum flux which requires amplitudes squared.

13. p.9, l.15 — A general correction factor is taken for a whole granule; two questions.

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- Could it happen that the magnitude of correction is dominated by small-amplitude regions? And: Could this magnitude be inappropriate for large-amplitude regions in the same granule, such that biases are introduced?
- Why is the median taken, and not the mean? Is there a strong difference?

14. p.10, Eq.(6) — To avoid confusion, this equation should be written in a different way.
First of all, strictly speaking, division by a vector is not defined in a mathematical sense!
Next, $\omega \rightarrow \widehat{\omega}$
Further, the intrinsic phase velocity vector has the direction of the wave vector (k,l,m):

$$\vec{\widehat{c}}_\varphi = \widehat{\omega}\,\frac{(k,l,m)}{k^2+l^2+m^2}$$

For gravity waves, this vector is perpendicular to the intrinsic group speed vector.

The intrinsic phase speeds in x, y, and z directions are calculated as:

$$\widehat{c}_{\varphi,x} = \widehat{\omega}/k; \quad \widehat{c}_{\varphi,y} = \widehat{\omega}/l; \quad \widehat{c}_{\varphi,z} = \widehat{\omega}/m$$

such that $(\widehat{c}_{\varphi,x}, \widehat{c}_{\varphi,y}, \widehat{c}_{\varphi,z}) \neq \vec{\widehat{c}}_\varphi$ (Lin, 2007). This is also indicated in Fritts and Alexander (2003) by stating “Note that the phase speed is not a vector quantity, although wave phase propagation has a direction given by the vector (k, l, m).”

Yuh-Lang Lin, Mesoscale Dynamics, Cambridge University Press, 2007 ISBN: 9780521808750.

15. p.11, l.16, l.21 — You should clarify about the effect of using 8-bit integers!
As far as I understand, all values T’ are scaled by the same factor to match the range covered by 8-bit unsigned integers.
Does the use of 8-bit unsigned integers have the effect of introducing additional

noise on T'?
You mention an effect of 1.5K. This would mean a doubling of the measurement noise. If this is correct, please add this information.
Would this be a problem for waves of smaller amplitude?

16. p.11, l.25–28 — To which horizontal and vertical scales does the cutoff of "1/15 of the data length" correspond?

17. p.12, l.7 — The "Southern Cone" "...is a geographic region composed of the southernmost areas of South America, south of and around the Tropic of Capricorn." (from Wikipedia). Therefore using this expression for only latitudes south of 40S is not entirely correct.

18. p.12, l.26 — Please clarify!
Wave amplitude in Fig.4b is after applying the aforementioned amplitude correction?

19. p.14, l.13 — Obviously, there are strong limitations of the 3DST in determining vertical wavelengths, and the effects of this limitation should be more clearly mentioned!
There are several questions arising:

    - What is the range of vertical wavelengths available?
    - Does this range depend on altitude?
    - Will the 3DST vertical wavelength limitation or edge truncation result in strongly reduced wave amplitudes and momentum flux close to the upper and lower limits of the altitude range?
    - Is this the reason why in Fig.5 strongest momentum flux is seen in the middle of the altitude range, but considerably weaker at low and high altitudes?
      At low altitudes, this effect is quite striking! At low altitudes T' is relatively strong, but momentum flux is very weak!

20. p.16, l.10 onward / Fig.4j and 4l
Why are ground-based group speed and ground-based phase speed so large in the region around 76W / 47S (colored yellow in Fig.4d)?
In this region horizontal wavelength, vertical wavelength, and propagation angle are almost the same as in the surrounding regions. Therefore I would expect also ground based group speed and phase speed to be similar as in the surroundings. (It is unlikely that variations in the background wind would have this effect.)
Please check whether there is a mistake! In the region around 76W / 47S the propagation angle is close to +180deg, while for the surroundings it is close to -180deg. This is almost the same due to periodicity, but may easily cause problems when processing and interpreting the data.

21. p.17, l.20 onward
At high altitudes, indeed, the reduction of momentum flux may have several reasons. However, at low altitudes it looks like the dominating effect would be the edge-truncation problem of the 3DST because T' is quite high. This should be stated more clearly.

22. p.20, l.12 — If no momentum flux is observed over the Drake Passage, does this mean that the propagation of orographically-generated waves into this region, as indicated by the direction of group velocity, is not a significant effect in the altitude range considered? Or do you think that vertical wavelengths are outside the observable range of AIRS?

23. p.20, l.15 — The finding of only little momentum flux over the Drake Passage could also mean that gravity waves generated by source processes other than orography could have vertical wavelengths outside the detectable range of AIRS or of the 3DST.
In Figs.1d and 3 of Jewtoukoff et al. (2015), absolute momentum flux is in the range 10–20 mPa over the Drake Passage, which is non-negligible. In October

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even ∼30mPa are obtained. Admittedly, the altitudes of these observations are quite low, somewhat below 20km. But there are also satellite observations of 10mPa at 30km (Fig.3c in Ern et al., 2011).

Jewtoukoff, V., Hertzog, A., Plougonven, R., de la Camara, A., and Lott, F.: Comparison of gravity waves in the Southern Hemisphere derived from balloon observations and the ECMWF analyses, J. Atmos. Sci., 72, 3449–3468, doi:10.1175/JAS-D-14-0324.1, 2015.

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.

24. p.23, l.20 — Please clarify!
You write “our results at high altitude”. Are you referring to Hertzog et al. (2012), which is mostly at 20km and lower, while AIRS generally observes at altitudes higher than this.

25. p.23 — Could limitations of the 3DST method introduce biases in the distribution of G?
The apparent loss of amplitude close to the upper and lower limits of the AIRS altitude range could make the momentum flux distribution more uniform, resulting in too low Gini coefficients, whereas in the center of the altitude range the 3DST is performing quite well, and G is less biased.

    Generally, it would be counter-intuitive why G should be much lower at 20–30km than at 40km, because the variability of the distribution should be seeded mainly at the source level.

26. p.29, l.16 — When discussing advantages and disadvantages of the method, you should also mention the limitation of the 3DST in determining amplitudes

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and vertical wavelengths, particularly close to the upper and lower limits of the AIRS altitude range!

27. p.29, l.31 — There is some kind of discrepancy, and you should comment on this! (Similar as 22 and 23)
    You observe wave propagation of orographically-generated waves toward the Drake Passage, but not much momentum flux is seen over the Drake Passage. Do you think that the momentum flux gap is filled at higher altitudes? Or could the waves be outside the sensitivity range of AIRS and the 3DST?

    Further, the absence of momentum flux over the Drake Passage does not necessarily mean that nonorographic wave generation does not take place. Several observations show considerable momentum flux over the Drake Passage (Jewtoukoff et al., 2015; Ern et al., 2011). Possibly, these waves are not visible for the combination of AIRS and 3DST.

28. p.29, l.32, 33 — The following information should be added.
    In addition, wave amplitudes may be underestimated due to limitations of the 3DST.

Other Comments

1. p.3, l.33 (Sections 4.1 and 4), → (Section 4),
2. caption of Fig.1 'S. Ocean' (red). → 'Southern Ocean' (red).
3. p.5, l.16 off-axis → off-nadir axis
4. p.6, l.17 time domain → time (or spatial) domain
   later in the manuscript you generally switch to the spatial domain

5. p.10, l.7 $\frac{\rho}{4\pi} \rightarrow \frac{\rho}{2}$
6. p.12, l.2 other than the largest-amplitude → other than that corresponding to the
7. p.12, l.22 earliest phase fronts of the wave to a near-vertical alignment for later ones.
   →
   earliest phase fronts of the wave (at low altitudes) to a near-vertical alignment for later ones (at high altitudes).
8. p.14, l.11 near westerly → near easterly
9. p.17, l.5 Please check labels for consistency!
   5(a,d,g) → 5(a,b,c)
   Figs 5(b,e,h) → Figs 5(d,e,f)
   5(c,f,i) → 5(g,h,i)
10. p.22, l.20 eastward → westward
11. p.24, caption of Fig.10
    shown is a range of altitudes, please delete "at 35 km"
12. p.27 The final sentence is somehow in disorder, please correct!
    "... along the Drake Passage maps at the 40 km altitude level; the height level is again chosen for consistency with Fig. 5, while the zonal section is selected as being close to the polar jet centre latitude."
    →
    "... along the Drake Passage. For Figs. 13b, e the 40 km height level is again chosen for consistency with Fig. 5, while the zonal section is selected as being close to the polar jet centre latitude."

13. p.28, caption of Fig.13
Please correct; sub-figures are switched and longitude for (c,f) is wrong
"... at (a,d) 70° W against height and latitude; (b,e) 50° S against height and longitude; (c,f) 40 km altitude, mapped."
→
"... at (a,d) 70° W against height and latitude; (b,e) 40 km altitude, mapped; (c,f) 60° S against height and longitude."

14. p.34, l.35 page range of reference Wu and Waters (1996) is missing.

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