Review of EGUsphere-2025-939 “Climatology, long-term variability and trend of resolved gravity wave drag in the stratosphere revealed by ERA 5” by Z. Procházková , R. Zajíček, and P. Šácha

Overview

The authors aim at giving a comprehensive overview of the climatology of gravity wave (GW) induced drag in the stratosphere. For this, 44 years of ERA 5 reanalysis data are investigated using a methodology first presented in Kruse et al. [2022] but adapted to weaker assumptions increasing the validity of this approach. Furthermore, they use a scale separation approach that has not yet been applied to the analysis of GWs in model data.

Using this toolbox, the authors present seasonal climatologies for zonal and meridional GW drag in the stratosphere as well as detailed climatologies of the usual GW hotspots, such as the southern Andes and Himalaya, giving insight into the variability and vertical structure of GW drag. Finally, the trend of GW drag throughout the investigated period is shown and the influence of other dynamical processes, such as the NAO, ENSO, solar activity, and the QBO, on GW drag is quantified.

In general, the paper is very well written and the scientific statements are well supported by the methodology and figures. At times, the text might need some smaller revision and some figures could be improved in visual presentation. Since a climatology of GW drag and a trend analysis is unprecedented, my verdict of the article is that it is well worth publishing in Weather and Climate after a minor revision.

General comments

1. Your analysis takes into account regional differences by your separation into ”GW hotspots”. Since your analyzed period is quite long, it would be awesome if you could also investigate the differences in your GW hotspots of the northern hemisphere in terms of variability between SSW and non-SSW years. In particular, I would be interested in the Himalaya region, as it is hypothesized that strong GW activity in this region might precondition the vortex before an SSW. A climatology of the SSW vs non-SSW periods in this region might shed some light into the role of the Himalaya. Did you have a look into this? For me, it’s not necessary to include it in this publication if it’s more work than I imagine, however, it would be an interesting point for a short follow up study.

Specific comments

- l16: ‘...phenomenon in the terrestrial atmosphere...’ GWs are not limited to the terrestrial atmosphere but are also present on other planets with an atmosphere (e.g. on Mars)
- l35f: ‘..., which cannot be to date derived from global-scale observations.’ rephrase this sentence. I think you mean that there are nor current observations that allow for this derivation. However, it could be understood as that the methodologies for extracting the GW parameters do not yet exist, which would be wrong [cf. Hindley et al., 2020, Lear et al., 2024, Rhode et al., 2024].
- l63: When mentioning ERA 5.1, it would be helpful to explain why you are using it. I.e., half a sentence on what ERA 5.1 improves upon compared to ERA 5.
- l111-113: ‘A perfect match between vertical velocity and horizontal velocity perturbations cannot be expected, as polarization relations indicate that gravity waves with shorter horizontal wavelengths tend to project onto horizontal wind perturbations and vice-versa.’ This sentence is not clear to me and should be rephrased. Do you mean that shorter waves have higher ratio of vertical to horizontal wind amplitudes (which would be the case from the polarization relations) or is it about a direction change (as implied by the word ‘projection’)?

- 179 & Fig. 5: ‘Additionally, we see the...’ this is barely visible. The figure is definitely too small to see all the features well. Consider making it wider. You could gain some width be dropping the y ticks on the middle an right panels, as they are the same(?). Please also add a period axis as top axis for the plots, which would make figuring out the features much easier than counting the dotted lines from left to right. The red line is barely visible.
  This figure would probably benefit from showing only 2 columns but wider panels.
- Fig. 6: Consider adding a running mean and limit the y axis to Jan-Jan. West America is not visible at all, maybe the visibility could be improved by adding transparency to the high resolution data shown here and a solid-colored running mean (e.g. 7 days).
- Fig. 7 & 8: Why are you using transparency in panel f? Is this for color blindness? If so, make sure that Fig. 6 is also accessible for color blind people.
- ‘A possible reason for this can be that the horizontal scales and background flow of the Himalaya hotspot favor sourcing of longer orographic GW modes that propagate mostly vertically.’ This could be misunderstood as ”GWs with longer horizontal wavelengths propagate mostly vertical” which would be false in general. I think, you mean something like: In the Himalaya region, the longer horizontal GWs seem to show faster vertical propagation. The reason for this, however remains unclear (do they also have longer vertical wavelengths? why is this only the case in the Himalaya region? are the winds different here than in other orographic GW regions?). Please rephrase in a way that states what you mean more clearly.

Technical comments

- l18: ‘...GWs exist **at** and...’
- l21: ‘on a leading order’ → ***at*** *leading order*
- l46, 48: consider adding Lear et al. [2024] to the listed citations.
- l66: drop ‘the’ in ‘using the linear interpolation’
- l68: drop ‘the’ in ‘above the 10 hPa’
- l71: Consider changing ‘. The details of the filtering are described in the following subsection.’ to *as described in Sec. 2.1*
- l131: Consider dropping ‘the years’.
- l160: Add a comma: ‘In their work**,** the meridional...’
- l167: Maybe: ‘The zonal mean meridional drag component has by more than a half smaller magnitude...’ → *The magnitude of the zonal mean meridional drag component is by a factor of more than 2 smaller than the zonal component.*?
- l189f: ‘For Southern Andes, based on the definition of the hotspot, two opposite yearly cycles can be derived.’ is not too clear. Maybe something like: *For the Southern Andes regions (as shown in Fig. 1), two opposing yearly cycles can be derived.’*
- l193: ‘overlaying’ → *overlapping*
- l200: ‘maximum **is** not’
- l217: ‘which is **asymmetrical** around’
- l218: ‘The probability distributions in Fig. 9 for two cut-off ranges also reveal’ is not clear, please rephrase. E.g.: *he probability distributions for different scale-separation cut offs in Fig. 9 also reveal.*
- l268: Maybe: ‘The last column...’ → *The* ***rightmost*** *column...*?
- l292: ‘...ozone **depletion** and recovery...’
- l322 & 327: *drag* instead of ‘drags’
- l339: no brackets around citation
- l353: ‘...GW field**s**...’
- l354: ‘dedicated **to** this effort’
- l358: Maybe *globally observe local GW parameters and induced GW drag*

References

N. P. Hindley, C. J. Wright, L. Hoffmann, T. Moffat-Griffin, and N. J. Mitchell. An 18-year climatology of directional stratospheric gravity wave momentum flux from 3-D satellite observations. *Geophys. Res. Lett.*, 47(22):e2020GL089557, NOV 28 2020. ISSN 0094-8276. doi: 10.1029/2020GL089557.

C. G. Kruse, M. J. Alexander, L. Hoffmann, A. van Niekerk, I. Polichtchouk, J. Bacmeister, L. Holt, R. Plougonven, P. Sacha, C. Wright, K. Sato, R. Shibuya, S. Gisinger, M. Ern, C. Meyer, , and O. Stein. Observed and modeled mountain waves from the surface to the mesosphere near the Drake Passage. *J. Atmos. Sci.*, pages 909–932, 2022. doi: 10.1175/JAS-D-21-0252.1.

E. J. Lear, C. J. Wright, N. P. Hindley, I. Polichtchouk, and L. Hoffmann. Comparing gravity waves in a kilometer-scale run of the ifs to airs satellite observations and era5. *Journal of Geophysical Research: Atmospheres*, 129(11):e2023JD040097, 2024. doi: https://doi.org/10.1029/2023JD040097. URL `https://agupubs.onlinelibrary.wiley.com/doi/abs/10.1029/2023JD040097`. e2023JD040097 2023JD040097.

S. Rhode, P. Preusse, J. Ungermann, I. Polichtchouk, K. Sato, S. Watanabe, M. Ern, K. Nogai, B.-M. Sinnhuber, and M. Riese. Global scale gravity wave analysis methodology for the ESA Earth Explorer 11 candidate CAIRT. *Atmos. Meas. Tech.*, 17:5785–5819, 2024. doi: 10.5194/amt-17-5785-2024. URL `https://amt.copernicus.org/articles/17/5785/2024/`.