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Atmospheric Chemistry and Physics Discussions

Interactive comment on "Characteristics of gravity waves resolved by ECMWF" *by* P. Preusse et al.

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We highly thank the reviewer for pointing out a larger number of references with relevance for this study. Including these references in the study will strengthen the case of the paper.

The reviewer has two major points:

1. The reviewer requests that we more clearly separate between features relevant for the real world and such that are represented in a distorted manner in ECMWF, i.e. for which we show that ECMWF misrepresents reality.

We will emphasize in the new version that all features shown are features of the ECMWF model. In particular, we will add for each source process which we discuss some sentences, to which degree this source process may be represented realisticly

in ECMWF.

There are two reasons why GWs may not be well represented. The first reason is that the resolution of the model is not sufficient. The second reason is that source processes are not adequately represented in the GCM or do not feedback to the dynamical core.

Regarding resolution: It is evident that the model can only represent processes and associated GWs which are larger than the spatial and temporal resolution of the model. This excludes parts of the mountain waves as well as some convective processes. Larger scale mountain waves, on the other hand, should be well represented.

There are also processes which are represented in ECMWF but for which the resolution still may be important. For instance, the question whether GWs from spontaneous imbalance are realistically represented is more difficult to answer. Previous investigations showed that the horizontal wavelengths of the excited GWs depend on the model resolution. Whether the scales generated by ECMWF are realistic, is beyond the means of this study. However, this study demonstrates clearly that these waves are very important for the total momentum in the vortex regions. Also our study hints at a source process in the high-latitude tropopause region. Again we can show that this source process produces a major part of the GW momentum resolved by ECMWF.

In the cases of spontaneous imbalance and high-latitude tropopause region we have evidence that they are important in ECMWF. In both cases measurements indicate comparable GWMF in the investigated regions. We therefore may assume that they are likely important also in reality. However, whether the spectral features are well compatible we have insufficient evidence. In this case the absence of contradicting evidence is not yet proof for realism.

Finally, we can clearly show that some source processes connected to convection are missing. As discussed below that does not mean that the source processes represented in ECMWF would not occur in nature.

We think our paper is an important step forward, because it a) gives guidance which source processes need to be addressed in more detail, b) provides tools for the interpretation of these data and c) in case that realism could be shown, this would validate ECMWF as a mean for extrapolating locally understood processes to the global scale.

2. Further references to relevant literature are requested.

We highly appreciate the reviewer's suggestions and will include them in the discussion of the text. They document that already a larger number of studies used ECMWF data for scientific interpretation and hence support the importance of better understanding these data.

Specific comments:

p11964, par2

We want to distinguish between the parametrization of Charron and Manzini (2002), where waves have wave vectors orthogonal to the background flow, and waves from spontaneous imbalance, for which wave vectors may point at least in part in the direction of the flow. We will rewrite this paragraph to clarify and include further references suggested by the reviewer.

P11965, L15

We will update the resolution to the last value available before resubmission and include the precise date for this resolution.

P11966, l6-7; and l25.

We will include the suggested references in the discussion.

Figure 4

Marking the discussed regions was explicitly requested by reviewer 2. We think these marks are indeed helpful for following the discussion and therefore we would like to

retain the ellipses.

p11979 Reduce discussion, because this is not a real process

The nature of tropical waves in reality is debated. There is evidence for different processes and for different scales. In particular, there is also evidence that those long waves found in ECMWF may exist in nature (cf. the quoted radar measurements). What is not realistic is the dominance of these waves.

The vertical wavelength depends on the Doppler shift by the background winds. Therefore a dominant vertical wavelength does not exist. For instance, the vertical wavelength changes and will approach zero when the waves are filtered by the QBO (e.g. Ern et al., 2014). The backward rays are stopped because a critical layer is reached from above. This means that in the region of excitation these waves have short vertical wavelength. This again is compatible with radar measurements. Therefore the second argument is not true: the waves considered here have shorter vertical wavelengths in the excitation region. We will add this point in the discussion.

Concluding: the discrepancy to nature is not the fact that the described forcing mechanism does not exist in reality, but a) that it may be overestimated in ECMWF and more important b) that other types of wave sources exciting GWs of a few hundred kilometer are missing. As requested by the reviewer in his/her major comment we will discuss for the individual processes which facts are realistic and which are not.

P11984, L1-2 Importance of the factor $(1 - f^2/\omega^2)$ and Figure 7

Reviewer 2 requests to delete figure 7. Accordingly we will also erase the related text from the manuscript.

p11985 Relative importance of shear and convection

We find in our investigations

- that many wave sources are obviously related to convection (cf. Figure 3 and 5)
- that, assuming convection as the source, almost all waves are from the tropopause region (Figure 6), and
- no evidence for an alternative source process

The tropopause region is characterized by strong wind shear and accordingly low Richardson number. Therefore we conclude that apparently processes associated with convection are generating GWs on top of the convection in the region of strongest wind shear. Based on six hourly data we cannot precisely analyze such processes. Further, this is beyond the scope of our paper.

We will try to clarify this point in the revised version of the paper.

P11990 The intensity of the updrafts depends on the resolution of the model

We agree with the reviewer that only very high resolution models can fully capture the updrafts of a deep convective system. However, the updrafts in ECMWF are exceptionally weak even for a model of this resolution. For instance, typhoon simulations with the MM5 and the WRF model (e.g. Kim et al., 2009) show updrafts of the order of 10m/s at the same horizontal resolution as that of ECMWF. We will modify the paragraph.

p11990 Do you mean seasonal prediction?

We will use "seasonal prediction"

p11983 Discussion on intermittency of mountain waves

We will include the references of Plougonven et al. (2013) and Hertzog et al. (2012) in this discussion.

References

Charron, M. and Manzini, E.: Gravity waves from fronts: Parameterization and middle atmosphere response in a general circulation model, J. Atmos. Sci., 59, 923–941, 2002.

Ern, M., Ploeger, F., Preusse, P., Gille, J. C., Gray, L. J., Kalisch, S., Mlynczak, M. G., Russell III, J. M., and Riese, M.: Interaction of gravity waves with the QBO: A satellite perspective, J. Geophys. Res. Atmos., 119, 2329–2355, doi:10.1002/2013JD020731, 2014.

Hertzog, A., Alexander, M. J., and Plougonven, R.: On the Intermittency of Gravity Wave Momentum Flux in the Stratosphere, J. Atmos. Sci., 69, 3433–3448, doi:10.1175/JAS-D-12-09.1, 2012.

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Plougonven, R., Hertzog, A., and Guez, L.: Gravity waves over Antarctica and the Southern Ocean: consistent momentum fluxes in mesoscale simulations and stratospheric balloon observations, Quart. J. Roy. Meteorol. Soc., 139, 101–118, doi:10.1002/qj.1965, 2013.

Interactive comment on Atmos. Chem. Phys. Discuss., 14, 11961, 2014.