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Expert's review of the doctoral dissertation

New perspective on the role of gravity waves in the stratospheric dynamics and variability

submitted by Petr Šácha

The role of small-scale internal gravity waves in the Earth atmosphere is still under discussion, in particular in the stratosphere, although the importance of gravity waves for atmospheric dynamics in general has been recognized nearly 60 years ago. There are several open questions with respect how they are affecting specific dynamical atmospheric features (like the tropical quasi-biennial oscillation, QBO) or the atmospheric composition. One of the main problems is still that gravity waves cannot be fully resolved in general circulation models or climate models and therefore the effects of gravity waves have to be parameterized in an adequate manner.

The doctoral dissertation of Mr Šácha aims to investigate the effects of spatio-temporal distribution of the internal gravity wave activity regarding middle atmosphere dynamics and how it affects the transport of air masses. This work is on the one hand based on theoretical considerations (among others using observations), on the other hand some numerical modelling exercises are carried out.

The presented thesis is based on three peer-reviewed papers (Šácha et al., 2014; 2015; 2016). Obviously these papers have received several positive ratings from external reviewers, indicating the quality of these studies. With respect to the Šácha et al. (2016) which is mentioned in the reference list as a "discussion" paper (Atmos. Chem. Phys. Disc.), it can be assumed that this paper will be finally accepted and published in ACP very soon. (I am the Editor of this manuscript and I know well the positive reviews regarding this paper.)

The doctoral thesis of Petr Šácha is structured as follows: After a short introduction, in Chapter 1 the theoretical background for his work is presented. In Chapter 2 observations of gravity waves are introduced and discussed in detail. In this chapter he is using density profiles derived from Global Positioning System (GPS) utilisation by radio occultation (RO) signals. In the following, enhanced activity of gravity waves is globally analysed

using these satellite-based measurements in Chapter 3. Here Mr. Šácha is concentrating on information received for the region over the North-Eastern Pacific / Eastern Asia, an area which indicate enhanced gravity wave breaking. Finally, the influence of gravity waves on middle atmosphere dynamics, circulation patterns and the transport of air masses is investigated and discussed in Chapter 4. At the end of this thesis an overall summary and a general conclusion is given in the Epilogue.

This doctorate presented by Petr Šácha contains several very interesting outcomes. On the one hand some already known results are confirmed on the other very interesting new findings are presented.

In the beginning of the thesis a nice review of the well-known wave-mean flow interaction theory is presented, including a discussion of some new results published in recent years. Šácha et al. (2014; here Chapter 2) introduced a new approach for the analysis of internal gravity waves (IGW) employing density profiles which are derived from the GPS-RO data. Several tests have been performed and at the end it turned out from his investigations that it seems leading to robust results. A detailed discussion of the advantages and disadvantages of this novel method is given which enables an objective assessment. This approach allows a global investigation of IGW activity. In particular a region with enhanced IGW activity has been identified for the first time (Šácha et al., 2015): In the North-Eastern Pacific / Eastern Asia area seems to be a suitable area for increased gravity wave breaking. Possible sources for this centre of IGW activity are discussed (Chapter 3). Some explanations are given with respect to this extraordinary region and why it was not identified before. How this specific region of particular activity of gravity waves is affecting the dynamics of the middle atmosphere (especially the stratosphere) is discussed in the last chapter of this doctoral thesis (based on Šácha et al., 2016). For this purpose, a mechanistic model system is applied describing atmospheric (dynamical) processes. Possible effects of this specific localised forcing of TGW (here especially the North-Eastern Pacific / Eastern Asia region) are investigated. It turned out that this kind of wave forcing modifies the formation of large-scale planetary waves and therefore affecting the stability of the polar wind vortex and also the zonal mean residual circulation (i.e. the Brewer-Dobson circulation). Furthermore, the impact of zonally asymmetric gravity wave breaking is determined. Some evidence is found that the localised gravity wave drag has a larger dynamic impact than the corresponding zonal symmetric distribution.

Overall, the work of Petr Šácha is well structured and the form of expression is good. This doctoral thesis fulfils all necessary criteria. All necessary information is provided with respect to the scientific background including the state of knowledge. The description of the used methods and tools is very good. In this connection it should be especially emphasized that Petr Šácha used not only different methods of diagnostics but also worked in detail on elicitation of data, the analysis of these data and using a numerical model system for the interpretations of the data. The quality of his scientific results is excellent. The presentation of his outcomes is mostly good, in parts sometimes difficult to understand and hard to follow his conclusions for people who are not experts in the field. Existing literature is quoted adequately and Petr Šácha's results are nicely compared and discussed with respect to results published by others.

Mr Šácha has presented a very nice doctoral dissertation. This thesis impressively documents that Petr Šácha is an excellent scientist and an expert in this field of science. Some of his results will motivate further research, for example with respect to the role of IGW

for the dynamics of the stratosphere or teleconnections between the troposphere, the stratosphere and the middle atmosphere.

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(Prof. Dr. Martin Dameris)