Review of thesis

submitted at Faculty of Mathematics and Physics, Charles University

☒ Review by supervisor ❑ Review by opponent

❑ Bachelor thesis ☒ Master thesis

Author: Bc. Dominika Hájková
Thesis title: Towards improved orographic gravity wave parameterization in chemistry-climate models.
Study program: Fyzika atmosféry, meteorologie a klimatologie [FAMKP]
Year: 2024

Name of the supervisor: RNDr. Petr Šácha, Ph.D.
Institution: Department of Atmospheric Physics, Faculty of Mathematics and Physics, Charles University
E-mail: petr.sacha@matfyz.cuni.cz

Scientific level of the thesis:
☒ excellent ❑ very good ❑ average ❑ below average ❑ insufficient

Factual errors:
☒ almost none ❑ acceptable number ❑ numerous but non-critical ❑ serious

Results:
☒ original ❑ original & adopted ❑ nontrivial compilation ❑ cited ❑ plagiarized

Extent of the thesis:
❑ large ☒ standard ❑ sufficient ❑ insufficient

Graphical, language & formal level of the thesis:
☒ excellent ❑ very good ❑ average ❑ below average ❑ insufficient

Print errors:
☒ almost none ❑ acceptable number ❑ numerous

Overall level of the thesis:
☒ excellent ❑ very good ❑ average ❑ below average ❑ insufficient

Evaluation and comments by supervisor/opponent:

Internal gravity waves (GWs) in the atmosphere are important drivers of global atmospheric circulation. Due to their small spatial scales, they are usually parameterized in climate models based on numerous underlying simplifications. Moreover, observational constraints for GW parameterizations and their effects are almost completely missing. Given the pronounced effects that GWs have in climate but also weather prediction models, this a critically-important topic of research, with significant and broad implications which can be divided into two categories: 1) our ability to forecast short- and medium- term weather, important for example for disaster-relief planning and crop-planting, and 2) the accurate prediction of weather pattern changes at the scale of decades or longer, information which is needed to plan for the major societal changes expected later this century. Properly understanding and simulating GWs is vital to advancing state-of-the-art modelling over the coming decade and beyond.

In the proposed Diploma thesis "Towards improved orographic gravity wave parameterization in chemistry-climate models.", Bc. Dominika Hájková continues in a systematic research of GWs sourced by the orography that she started in her Bachelor thesis and that will continue during her prospective PhD studies, with the ultimate goal of formulating a novel scheme for parameterization of orographic GWs in climate models. Together with the Appendix, the Diploma thesis spans 69 pages structured in five chapters (including traditional Introduction and Conclusions). The results sections are based partly on the results that have been already published by Bc. Hájková in a Q1 journal and partly on novel results that have a high potential for subsequent publishing. The content of the thesis is described in the following paragraphs.

In the Introduction, Bc. Hájková puts the thesis into a perspective of her former Bc. thesis, motivates the future work and describes the structure of the submitted thesis. In the first chapter "Gravity waves, dynamics and theory of flow over orography", Bc. Hájková gives a nice and concise introduction to the GW theory and selected phenomena emerging for the flow over the obstacle that will be needed for a gross comprehension of the Results section. This part of the thesis has a potential to serve as a teaching material for department's courses concerning waves in the atmosphere.

In the second chapter "GWs in models", Bc. Hájková briefly repeats the basics of the orographic GW parameterization schemes that have been already extensively covered in her Bachelor thesis and derives some classical theoretical formulas that are needed to understand the planetary scale wave-mean flow interaction in the stratosphere. Afterwards, for the sake of space, the author highlights the most important and far-reaching results of her recent publication Hájková and Šácha (2024, CliDyn) and supplements the published results with previously unpublished results demonstrating the robustness of the findings on an ensemble of climate model projections. The main message is unprecedently simple, robust and with far reaching implications - the subjective tuning of orographic GW parameterizations by the modelling centers may result in correct zonal mean model climatologies of basic quantities, but modifies the resolved wave dynamics in the models, projecting harmfully to the model skill of simulating the wave-mean flow interaction affected phenomena like the Brewer-Dobson circulation and Sudden Stratospheric Warmings. The related paper already attracted 3 citations and significant online attention regarding the related metrics (in the 90th percentile of articles from all journals of a similar age) and it was generally incredibly well received in the community.

Finally, in the third chapter " Simulation of a flow over the hill", the author starts a systematic work of examining the features of overflowing of an analytically defined hill, studying how well the resulting drag is captured by the multi-component orographic GW schemes, which include also strongly non-linear components like the near surface drag. For this the author employs a 2D idealistic version of the WRF model, which she first validates on a simple linear case featuring only a freely propagating wave mode. For this case, the author also analytically computes the exact amount of momentum flux propagated upwards. Afterwards, Bc. Hájková repeats the simulation set-up of Doyle et al. (2011, MWR) and performs sensitivity simulations with respect to the shape of the hill, keeping other parameters constant. The resulting drag profiles are then compared with multiple off-line drag estimations, mimicking the functionality of selected existing climate model parameterizations. The results again, strongly point at the role of subjective tunning of the parameterizations for the resulting drag and suggest possible deficiencies in the current handling of the subgrid scale orography by the schemes. Computing these off-line estimates is a very difficult, well-thought and time-consuming effort and I personally consider this part of the thesis to be even more interesting than the already published results that are described in the second chapter.

In the Conclusions, the author sums up the presented results, discusses their uncertainty and gives an outlook for the future work (3D simulations, online parameterization inserted to WRF). Overall, during the work on the thesis, Bc. Dominika Hájková demonstrated her deep understanding of GW dynamics and their parameterizations, excellent physical, mathematical and coding skills, and ability to work independently as well as to cooperate with a group of international experts. The already published paper is a notable contribution to the field of research concerning the role of orographic GWs in climate models and the results from the third chapter are likely to be published in the near future.

All this allows me to unequivocally recommend the submitted Diploma thesis to be accepted with the highest classification possible.

Eventual questions and topics for discussion:

For the discussion, I suggest that Bc. Hájková reminds the audience of all components and processes that are covered in the orography gravity wave parameterization schemes (going far beyond the linear freely propagating modes) and then, I would like to hear from her a detailed outlook of the planned work in this regard.

I do

☒ recommend
❑ not recommend
to accept the thesis as bachelor/master one.

Suggested classification:

☒ excellent ❑ very good ❑ good ❑ insufficient

Place, date & signature: Prague, 4.6. 2024, RNDr. Petr Šácha, Ph.D.

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