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Geoscientific Model Development Discussions

Interactive comment on "Interaction of Small-Scale Gravity Waves with the Terdiurnal Solar Tide in the Mesosphere and Lower Thermosphere" *by* Friederike Lilienthal et al.

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Dear anonymous Referee3,

we wish to thank you very much for your valuable comments and ideas to help improve our mauscript. Below, we are addressing each of your comments.

1. This is a well-written manuscript, but this reviewer is confused about what the paper's focus was supposed to be, and what it turned out to be. Also, the gravity wave spectra used for the numerical experiments did not seem to be rooted in any clearly articulated or compelling physical reasoning.

We are sorry for the confusion and, based on your review, we conclude that the title of the manuscript needs to be adjusted in order to better represent its content: “Variability of gravity wave effects on the zonal mean circulation and migrating terdiurnal tide as studied with the Middle and Upper Atmosphere Model (MUAM2019) using a whole atmosphere nonlinear gravity wave scheme”.

We disagree with the reviewer concerning the gravity wave spectra used for the numerical experiments. The whole atmosphere gravity wave (GW) parameterization has been initially developed in the work by Yiğit et al. (2008), in which various spectral shapes have been tested. However, when the whole atmosphere GW scheme has been implemented into a GCM in the work by Yiğit et al. (2009), we have validated the GW source spectrum and found out that the utilized empirical source spectrum successfully reproduce the large-scale structure of the middle atmosphere dynamics. The chosen momentum flux values are comparable to the observed GW activity in the lower atmosphere. Therefore we use the original GW spectrum as the reference source spectrum with which we have experimented in our current study. While observations provide a better coverage of GW activity nowadays, there are still a certain degree of uncertainties/errors in the observed fluxes. Here we have performed a systematic way of sensitivity tests with the GW spectrum to find out to what properties of the GW spectrum the atmosphere responds. Of course, the uncertainty or variability in the GW source activity is very relevant to the question of GW interactions with the terdiurnal tide: Variation in GW source activity will influence GW effects at higher altitudes, which can impact the terdiurnal tide. A more accurate representation of GW processes in the mesosphere and lower thermosphere can improve our understanding of tidal-GW interactions. Overall, our study of sensitivity tests based on modified GW spectra and the study of GW-terdiurnal interactions are well connected.

2. In the Introduction, please explain what new science that the current paper provides in the context of what is already provided in Lilienthal et al. (2018) and Lilienthal and Jacobi (2019). The titles of those papers sound like they cover the same topics as the

current paper.

The previous papers by Lilienthal et al. (2018) and Lilienthal and Jacobi (2019) mainly focus on the variety and relative importance of forcing mechanisms of the terdiurnal tide. The present manuscript, however, aims to outline the importance of the GW parameterization used, not only with respect to tides but also its impact on the zonal mean circulation. Here, for the first time, we study the GW-TDT interactions with a state-of-the-art whole atmosphere GW parameterization, which gives us a more confident basis to study the influence of GWs on the TDT as the new GW scheme realistically propagates the subgrid-scale GWs through mesosphere into the thermosphere. To highlight this issue, and according to Referee2, we will also include further discussion of the nonlinear whole atmosphere parameterization according to Yiğit et al. (2008) compared to the earlier used linear Lindzen-type scheme and compare with other measurements and models.

3. In the Introduction, it is stated that a "significant amount of work has been conducted on the relation between GWs, DTs, and SDTs", but then the authors go on to quote some rather old papers by Miyahara and Forbes (1991) and Manson et al. (2002) in the context of providing examples of the "vast majority of the studies" (that) "focus on the MLT region in the context of GW-tide interactions". Are there not more current and comprehensive works focusing on GW-DT and GW-SDT interactions to quote?

We will add further and more recent publications, here.

4. This paper spends a lot of its time and effort on the zonal mean circulation and thermal structure, whereas according to the build-up in the Introduction, and the title of the paper, this work ought to be more focused on GW-TDT interactions. Maybe the title needs to be changed.

We have expanded the discussion on the TDT and also adjusted the title of the manuscript to reflect the content of the paper (see comment above).

5. The changes in GW spectra in experiments EXP1, EXP2 and EXP3 are not very big, and they do no produce very big changes in the TDT. What is the thinking behind the changes in these spectral parameters?

First, we aim to demonstrate that the whole atmosphere parameterization works very well for a mechanistic global circulation model like MUAM, improving the underlying physics of GW propagation and dissipation. Furthermore, we can show the robustness of this parameterization with respect to different GW phase speed spectra. The sensitivity tests are all within the range of uncertainties of the observed GW parameters in the lower atmosphere. Nevertheless, some differences in the spetra indicate possible interactions with the TDT which supports the present understanding of additional tidal forcing mechanisms, besides the main solar forcing.

6. What is the physical basis for including only one horizontal wavelength in the spectrum? Aren't the GW with higher momentum fluxes at shorter wavelengths, i.e., < 100 km?

Here we used a GW spectrum that has been tested and validated in previous modeling studies cited in our manuscript, demonstrating a realistic mean circulation in the middle atmosphere. GW parameterizations have to be used in GCM to resolve the subgrid-scale waves. These schemes reduce the computational cost, efficiently accounting for the missing GW physics. To maintain high computational efficiency, often a representative horizontal wavelength is used in GW parameterizations in GCMs. In a statistical manner an important portion of the GW activity can be attributed to 300 km horizontal wavelength. Of course it is possible that there are multiple wavelengths present in the atmosphere for a given moment, however, our results in the mesosphere and lower thermosphere are less sensitive to the horizontal wavelength as variations in the wavelength weakly influence GW dissipation compared to other parameters. From the perspective of GW propagation and dissipation the most important two aspects are (1) an accurate representation of physics of GW dissipation and (2) intrinsic phase speed of GWs.

7. Is there a difference between the part of the spectrum that is effective in determining the zonal mean circulation, and the part of the spectrum that interacts efficiently with tides? If so, please discuss in the context of making the choices that you do in the parameters for EXP1, EXP2, EXP3.

At present, we cannot seperate the spectrum into parts that rather effectively change the zonal mean circulation and those that affect the tides. Fast and slow GWs both strongly influence the zonal mean circulation, but at different geographical locations and different heights (as described in the manuscript). As the zonal mean circulation is a very important factor for tidal propagation, the whole spectrum of GWs can also have an impact on the tides.

8. What do Sections 3 and 4 and Figures 2-7 (the bulk of the paper !!) have to do with GW-TDT interactions, which is supposed to be the main focus of this paper?

Sections 3 and 4 will be better addressed in the new title.

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