

Atmos. Chem. Phys. Discuss., referee comment RC1
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Comment on acp-2021-1066

Anonymous Referee #1

Referee comment on "Ozone-gravity wave interaction in the upper stratosphere/lower mesosphere" by Axel Gabriel, Atmos. Chem. Phys. Discuss.,
<https://doi.org/10.5194/acp-2021-1066-RC1>, 2022

General Comment:

Gravity waves (GW) are a major source of the internal variability of the middle atmosphere. Motivated by lidar observations there is a claim that the gravity wave potential energy density (GWPED) during daylight can be enhanced compared to nighttime measurements at the upper stratosphere and mesosphere. This study seeks to present a theoretical approach to explain this enhancement by gravity wave-ozone interaction, due to changed heating/cooling rates caused by the vertical transport of air parcels by GW assuming idealized inertia gravity waves and an upward level-to-level propagation. The derived theoretical model of GW- ozone interaction was implemented in the well-established HAMMONIA model and all results are based on such model runs.

However, there are major (almost fatally flawed) concerns to some parts of the submitted paper, which certainly require a more controversial and critical scientific analysis to support the results.

Specific comments:

While reading the manuscript, the reviewer usually browses the web to collect background information. During this search, I noticed that the Institute of the Author listed a similar paper with the same title as accepted publication in ACP. If the paper is already accepted this review might already be obsolete (see attached screenshot from 31.01.2022).

Lidar observations have become a standard technique to measure temperature fluctuations in the middle atmosphere. Already a few decades ago such observations were used to derive GWPED. This study was motivated by lidar observations conducted during a campaign at the Davis station (69°S) in Antarctica (Kaifler et al., 2015) and mid-latitude observations at Kühlungsborn (54°N) (Baumgarten et al., 2017,2018). The reviewer did look at all three publications and tried to understand what is mentioned on page 3 lines 53-62. The Antarctic observations (Kaifler et al., 2015) are seasonal summer and winter differences and do not allow to distinguish a day-night comparison and, thus, it is hard to attribute the seasonal GWPED difference between the stratosphere and mesosphere to be caused by GW-ozone interaction. The seasonal differences of the tropospheric GW sources and mean circulation at the middle atmosphere should be considered and are likely contributing a lot to these differences. Secondly, the wind profile is dramatically different between a polar summer and winter condition, which directly affects the critical level filtering due to the strong zonal wind reversal at the summer MLT.

At the mid-latitudes, Baumgarten et al., 2017 showed different climatologies of GWPED for different filtering methods. This points to another major concern when using the numbers. The GWPED seems to depend on the analysis method, which does not provide confidence that the ratios between the stratosphere and mesosphere can be derived reliable enough to support the hypothesis of the proposed GW-ozone effect. In particular, this is also mentioned in Kaifler et al., 2015 as well. Due to the decreased iron layer thickness during the summer at the MLT, the estimated GWPED values are more uncertain and sometimes not derivable applying the same filtering methodology. Erhard et al., 2015 also performed a detailed study to investigate the sensitivity of the different methods to estimate GWPED. These aspects deserve some more clarification in the introduction.

Another crucial concern when dealing with lidar and model data to investigate day-and-night differences are atmospheric tides. The ozone volume mixing ratio shows a very fast response to the terminator (sunlight) (e.g., <https://doi.org/10.5194/acp-18-4113-2018>). This time scale is much shorter than the investigated intrinsic gravity wave periods. Thus, it appears to be unlikely that an air parcel that is in the updraft part of an inertia gravity wave could sustain the volume mixing ratio over hours without getting back to the chemical equilibrium to the ambient atmosphere. Radiative processes seem to happen on much shorter time scales. Thus, the theoretical description of the paper might be correct, but the total effect could be much smaller as one needs a convolution with the time scales.

Atmospheric tides are also important to estimate reliable GWPED. Baumgarten et al., 2019 (<https://doi.org/10.5194/angeo-37-581-2019>) demonstrated that there is also some interday tidal variability. Most of the above mentioned filtering techniques do not account for tides, which have almost similar or larger amplitudes compared to gravity waves at the stratosphere and mesosphere. Thus, the GWPED needs to be corrected for such tidal contaminations. This is also an issue for the HAMMONIA data, which is also affected by tidal modes. It remains unclear how day-night differences could be distinguished from the diurnal excitation due to the ozone absorption and associated heating rates. The advantage of tides is that the migrating tidal modes DW1, SW2, TW3 are sun-synchronous and fulfill the requirements assumed for the theoretical framework presented in the submitted manuscript. GW have random phases concerning their temporal behavior due to the various excitation mechanisms therefore it is unlikely that the updraft phase remains sun-synchronous, which is the key assumption in the manuscript. More likely is a random superposition of GW and a potential cancellation of the updraft and downdraft phases, which may result in a total zero effect.

The results indicate that the effect of gravity-wave-ozone coupling is most pronounced above the stratopause. Recently, a concept called multi-step vertical coupling (MSVC) was introduced Becker and Vadas, 2018 and later publications. Primary GW launched in the troposphere such as mountain waves, frontal waves, jet instabilities, etc. propagate vertically and dissipate generating a body force, which again causes secondary waves,

which propagate further upward and so forth up to the thermosphere.

Considering the above-mentioned physical processes it appears to be unlikely that the ratios between the stratospheric and mesospheric GWPED can be solely explained by the proposed GW-ozone interaction. MSVC, the horizontal propagation of GW, or atmospheric tides play also important roles and deserve a detailed and critical assessment in this regard to understand the vertical profile of GWPED.

However, the theoretical model of dynamical coupling of the ozone heating rate with wave dynamics is certainly of interest but should be contextualized with atmospheric tides and tidal excitations. The claim in the abstract that "ozone-gravity wave interaction is largely responsible for this effect" is certainly not so straightforward justified given the other dynamical aspects and the idealized model simulations.