Second review on:

Ozone-Gravity Wave Interaction in the Upper Stratosphere/Lower Mesosphere

by

Axel Gabriel

General Comment:

The reviewer appreciates the efforts undertaken to prepare a revised manuscript. Unfortunately, the revised manuscript did not pick up some of the suggestions and even contains statements that are questionable. The reviewer provides below a detailed list of reasons why the manuscript in its present form is suggested for rejection. In parts, some of these aspects originate from different viewpoints between theoretical approaches and experimental data analysis and the current understanding of vertical coupling processes and so forth. Some simplifications are justifiable for theoretical solutions as the proposed ozone-gravity interaction, but a simple relation to observations is not adequate to support the conclusions. This is really a problematic aspect of the revised manuscript.

Main concerns:

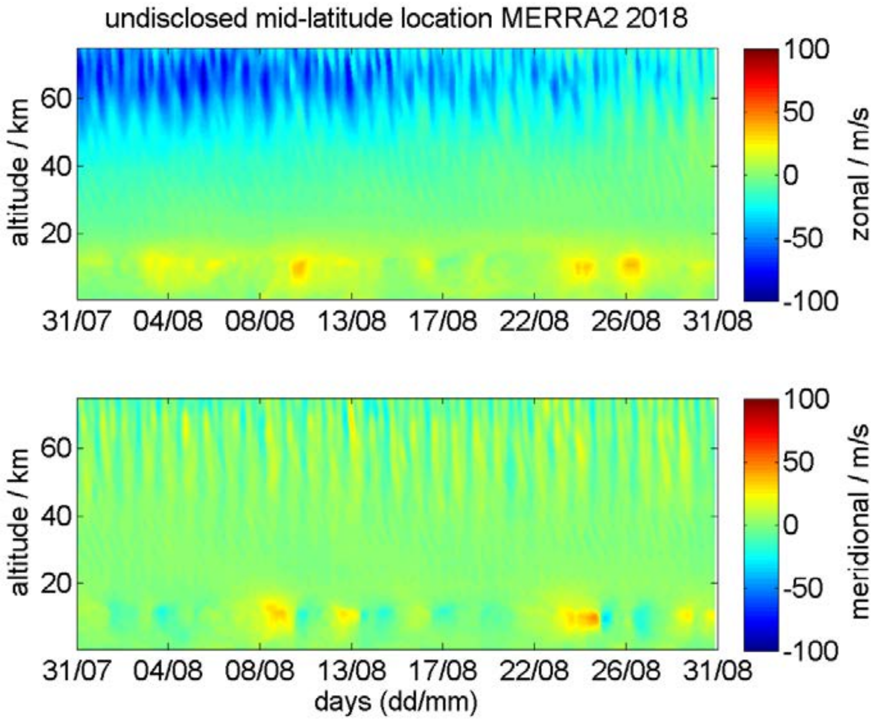
Lidar data interpretation:

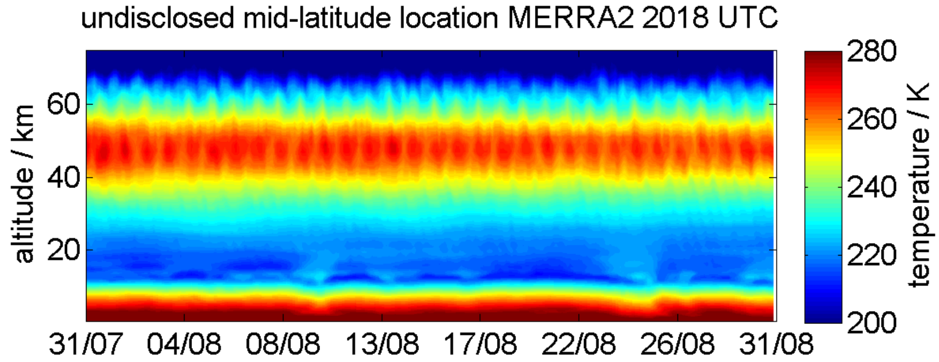
The manuscript is now motivated entirely by one single lidar paper (Baumgarten et al., 2017). The main narrative of the paper is a gravity wave lidar climatology leveraging a daylight capable Rayleigh lidar at the mid-latitudes. Although there is one statement in the conclusion about the day and night differences associated with atmospheric tides and the corresponding filtering, it is only speculated on these differences. During daylight, these lidars show an increased noise floor due to the sunlight, which causes a less good signal-to-noise ratio compared to nighttime measurements, which results in larger or increased fluctuations for the analyzed temperatures. However, this increased variability is mainly the result of hydrostatic integration applied for the temperature inversion and not a sign of geophysical variability. Rüfenacht et al., 2018 show an impressive example of the day and night noise levels in the sister Rayleigh system at Andenes.

Furthermore, even in Baumgarten et al., 2017 there is no convincing signature of such a day and night difference (see Figure 3).

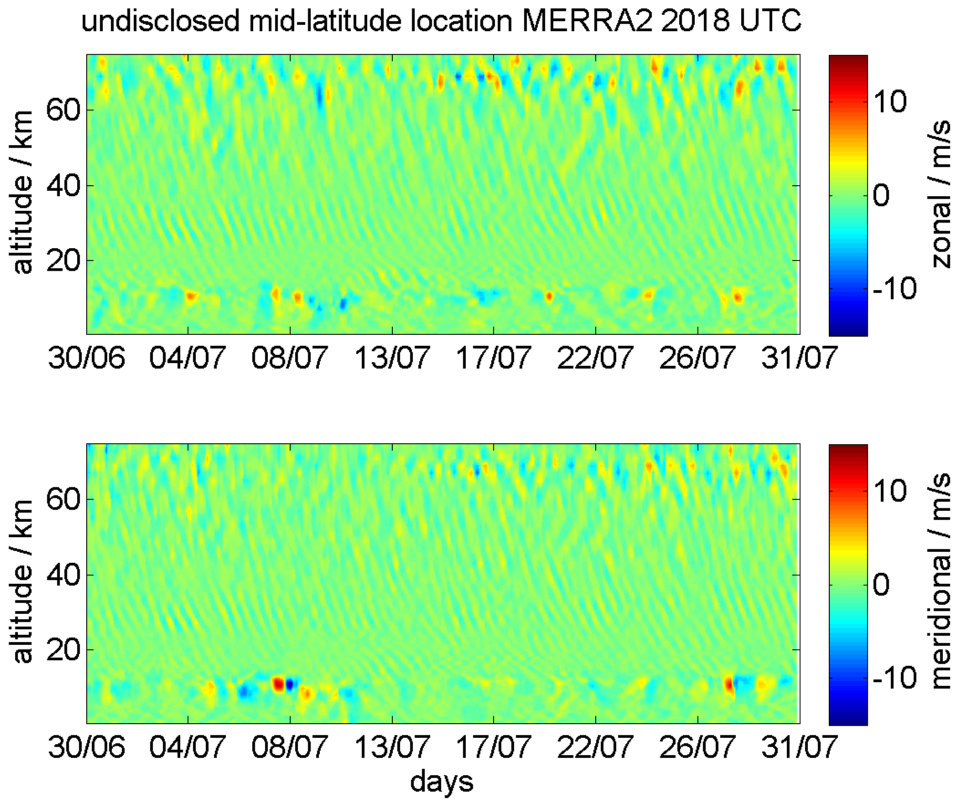
Atmospheric tides:
Although it appears eligible to use HARMONIA without tides as background for the theoretical prediction of the ozone-gravity wave interaction, it is not advisable to ignore tides in the lidar data. Most lidar soundings are significantly biased due to the short record lengths and proper removal of tidal effects is often not possible in the GWPED. Most published amplitudes of individual tidal modes are in the order of a few K, which is often related to a systematic underestimation from the applied superposed epoch analysis. Just looking at Figure 1 in Baumgarten et al., 2019 or attached MERRA2 data reveals a temperature difference between 50-60 km of about 30 K, which corresponds to a lapse rate of -3 K/km. This value is 20-30 times larger than the 0.1 K/km stated in the manuscript, which means that all the discussion and included factors are obsolete. In fact, all factors are increased by a factor 20-30 and, thus, become no longer negligible. The reviewer assumes that the small vertical temperature gradient was estimated from the vertical profile of the mean tidal amplitudes, which is misleading in this case.

Below there are two panels showing data from MERRA2 for an undisclosed mid-latitude location. The dominating feature is the diurnal tide in the wind and temperature.





The corresponding gravity wave activity for the same period is shown below. The mean and atmospheric tides have been removed. The waves discussed by the manuscript are partially resolved from MERRA2 and appear as the coherent structure at altitudes from 16-50 km. Above the coherence disappears, and a superposition of upward and downward phase lines becomes evident. However, it is not clear whether the data assimilation 3DVAR in MERRA2 captures the secondary wave generation around 60 km (fishbone structure Vadas et a., 2018a,b) or whether these waves are reflected from the model top and not sufficiently suppressed by the sponge layer.



The reviewer is not convinced that the arguments listed in lines 425-438 actually are valid looking at the MERRA2 data, which is also confirmed by other meteorological reanalysis and model fields. Furthermore, the gravity residuals reflect almost no coherence above 55-60 km, which also does not support the proposed effect considering that a sun-synchronous phase relation of the gravity waves would be required to sustain a fixed phase relation to the ozone to ensure the day and night differences.

Background winds and atmospheric waves:
Reanalysis data, as well as observations, indicate that the gravity wave amplitudes are strongly affected depending on the phase velocity and direction of the gravity wave relative to the background winds. At the altitudes presented and discussed in the submitted manuscript, these changes are mostly driven by atmospheric tides with rather short vertical wavelengths and, thus, a sudden amplitude growth of the gravity waves is also explainable just by changes in the background winds, which are not captured or considered in the theoretical framework.

Multistep vertical coupling:
As already mentioned, the HIAMCM model, as well as reanalysis data including MERRA2, reveal fishbone structures, which are associated with local body forces of breaking gravity waves or jet-induced instabilities (Vadas et al., 2018a,b, and many others). The GWPED observations are not discussed whether the increase in amplitude could be caused by that effect. The manuscript makes an attempt to justify the amplification only by the ozone effect, which seems unlikely and needs to be quantified. In summary, the cited GWPED data is not supporting the conclusions of the theoretically predicted amplification.

Recommendation:
The reviewer suggests minimizing the lidar part to the introduction and as motivation, but clearly describing that the lidar data does not permit to distinguish between the nature or source of the gravity waves and whether multistep vertical coupling or increased noise during the daylight could explain the tiny anomalies in GWPED as well.
An experimental and convincing case would be to search for a resolved large-scale sun-synchronous wave in MERRA2 or HIAMCM and to run the ray-tracer GROGRAT to track the wave and its amplitude to search for a second case during nighttime to demonstrate the opposite behavior. However, it might

already be helpful to identify gravity waves in ozone data to show that at least the ozone shows some response.

References:
Vadas, S. L., Zhao, J., Chu, X., & Becker, E. (2018). The excitation of secondary gravity waves from local body forces: Theory and observation. *Journal of Geophysical Research: Atmospheres*, *123*, 9296–9325.https://doi.org/10.1029/2017JD027970

Vadas, S. L., & Becker, E. (2018). Numerical modeling of the excitation, propagation, and dissipation of primary and secondary gravity waves during wintertime at McMurdo Station in the Antarctic. *Journal of Geophysical Research: Atmospheres*, *123*, 9326–9369. https://doi.org/10.1029/2017JD027974

Rüfenacht, R., Baumgarten, G., Hildebrand, J., Schranz, F., Matthias, V., Stober, G., Lübken, F.-J., and Kämpfer, N.: Intercomparison of middle-atmospheric wind in observations and models, Atmos. Meas. Tech., 11, 1971–1987, https://doi.org/10.5194/amt-11-1971-2018, 2018.