Author's response on "Temporal variability of tidal and gravity waves during a record long 10 day continuous lidar sounding" by Kathrin Baumgarten et al.

Anonymous Referee #2

This paper presents a study of gravity wave and tidal activities in the stratosphere and lower mesosphere using lidar temperature measurements that span continuously over 14 days. Such continuous measurement is unprecedented and is extremely valuable for the study of wave propagation through this region and interaction of waves at different time scales. This work is fairly thorough, and the key points are well described and supported by analyses from various angles. Because of this, I think this work should be published. I do find some various places where the manuscript can be improved and have given my suggestions below.
Aside from that, it's important to note that tides are global features while GWs are highly localized. The decrease of diurnal oscillation seen in this measurement does not necessarily mean a decrease of the global diurnal tide amplitude. Such decrease could be due to interactions among different tidal modes or with planetary waves. Nevertheless, I think the analysis in this work does make a case that it is possible the local decrease of the diurnal oscillation is related to a GW. The authors do need to carefully distinguish between diurnal tides (global) and diurnal oscillation (local) in the text.

We thank the reviewer for the helpful and constructive comments. The line numbers for the changes refer to the manuscript with marked changes. Regarding the global features of tides, we added a statement in the manuscript, which makes clear that the diurnal variations observed by the lidar are not necessarily features of the global tidal field (P6L3). Detailed answers to the comments are given below.

page 2, line 25: This is perhaps not a fair comparison. A lidar's capability is not measured by the altitude range it can measure (unless they all measure the same thing).
The Rayleigh and metal lidars measure different regions and serve different purposes.
If the lidar data used in this study included the mesopause region, then this statement would be appropriate.

Our statement was too general. A lidar using only one scattering mechanism is not enough to cover the entire middle atmosphere. We have rephrased the sentence to make clear, why especially the RMR lidar at Kühlungsborn is a better tool to analyze the short-term variability of atmospheric waves than other remote sensing techniques (e.g., radars) (P2L32).

page 3, line 26: It is not clear how 'strong solar background' is related to the starting altitude. Does it make it lower or higher? Please explain.

The signal-to-noise ratio depends on the solar background. It becomes worse during the day. The altitude of the start temperature should be a little bit above the altitude where the noise overcomes the signal level. Otherwise artificially added variations could be wrongly interpreted as wave variations.

page 3, line 31-32: please specify the cut-off periods/vertical wavelength of these filters. *Done*

page 4, line 12: suggest changing to '... data set contains not only ..., but also ...' *Done*

page 5, line 1: remove 'using' *Done*

page 5, Figure 2: Since the data is averaged for 2 hrs (stated on page 3, line 28), the

highest frequency that can be resolved is 1/(2hr). Even though the data point is every 15 min, the figure better not extends to higher frequency because there is really no information beyond 1/(2 hr). Caption: not sure what the 'first' and 'second' half mean and how they relate to the error bars. Need clarification. It's not clear what data was used to calculate this spectrum. Is it from 50 km temperature only or average over an altitude range around 50 km? How is the PSD 'smoothed'? The

We changed the plot to take into account that beyond a frequency of 1/(2 h) no real information is available. The data used for the plot are the temperature deviations from a mean temperature over the entire days (the 'unfiltered' data). To estimate an error of the spectrum, we have to acknowledge the variability over the time. As a first guess, we have calculated three different spectra at 50 km altitude. The difference here is related to the time which is covered for the calculation. Spectrum 1 is calculated from data over the whole time, the data for spectrum 2/3 covers the first/last 5 days, respectively. This is not entirely true for the actual error estimation, but it is sufficient to show a potential variation of the spectrum. The spectrum is smoothed with a Hanning filter (P4L28).

page 5, line 9: it'd be good to specify the order of the Butterworth filter used. *Done*

page 5, line 16: 'more perturbed' means larger amplitude?

In this case 'more perturbed' means the wave structures are less regular. This is independent from the amplitudes; it is only related to the occurring frequencies, which are much more different.

page 5, line 18: why this is due to propagating conditions, not the source?

It could also be related to different sources of gravity waves, from where the GW are able to propagate in this altitude region. We have added this in the manuscript (P6L1 and P15L31).

page 7, line 2-5: It's not clear which panels in figures this sentence refers to. The wave activity difference is obvious at 50 km, but not at 60 km. The sentence needs to be more specific for the readers to make the comparison. Also, why using 6-14 hr for the vertically-filtered then using 8-24 hr for the temporally filtered? Use the same time range (e.g. 8-14 hr) for comparison makes more sense.

We improved the text with additional references to the figure panels.

page 7, line 8: 'increased' to 'largest'

We decided to skip this change, because in this case, we only want to say that the wave amplitudes are grown compared to below. That the diurnal wave signature is largest here is another fact which is mentioned later.

page 7, line 13-page 8 line 1: I think the short-term tidal variability is well recognized in the science community. It is not 'unexpected.' Even using satellite data, researchers have been trying to extract short-term variabilities, such as doi:10.1002/2016JA022528. page 8, line 10: The 'monthly mean' probably means 'average over the 14 days'?

The monthly mean is an average over the 14 observations. The name indicates that the values are representative for the month May. We removed the word 'unexpected' to take into account that even satellite retrieval try to extract the short-term variability of tides. We added some information about these approaches in the introduction (P2L22). There are some limitations in the methods for the

extraction of tidal signals from satellites. We have mentioned these also in text as already written in the answers to referee 1.

page 8, line 10: 'relevant' to 'noticeable' *Done*

page 8, line 11: 'at an altitude of 50 km' to 'from 30 to 50 km' *Done*

page 8, line 23: besides -> aside from *Done*

page 8: line 26-27: This statement implies that the composite analysis does not include oscillations from GWs Doppler shifted into the tidal periods. I don't see how this can be the case. The wavelet method and the tidal fitting are no different. Neither can separate out the Doppler shifted GWs from tides.

During the composite analysis the data are sorted with respect to the local solar time based on the assumption that the tidal phase is constant over time compared to the phase of gravity waves. GW are assumed to have randomly distributed phases because of their different excitation mechanisms. All waves which are randomly produced (GW) will be averaged out in the composite. Therefore we assume that only tidal signatures are remaining in the data. Such a statement is now within the text (P10L2).

page 8: line 5: 'that for' to 'from' *Done*

page 8, line 15-16: Where is the 'strong diurnal component' in Figure 6? I don't see any.

In Figure 6 no strong tidal features can be seen. The expression was related to Figure 4 just to remind the reader to the tidal variability compared to the GW variability in Figure 6.

page 8, line 11-20: Similar to the discussion about Figure 4, the text often does not refer to specific panels in the figure, which makes it hard to understand what features the authors are pointing to.

We improved the text to clarify which Figure panel is described.

page 10, line 11-12: Is this also due to sponge layer? If so it's better to state the sponge layer here than later on page 11.

This is right. We mentioned this in the text now (P11L13).

page 12, last paragraph: While I agree with authors that ozone is perhaps not the main cause of the tidal variability during the 14 days, the argument here is not accurate. Because tides are global structure, they are forced and therefore related to the global structure of the ozone layer. Planetary scale perturbations of the ozone could cause tidal variability, but it may not show up as a correlation between local ozone concentration and local tidal amplitudes. Lack of correlation at a single site does not support the argument that they are not related because it could be a weaker ozone at other longitudes that causes the weaker global tides.

We mention the possibility of a change of ozone at other longitudes now in the text (P14L3).

Figure 11: The amplitude of temperature perturbation is not a complete representation of GW energy. The potential energy, which is related to N squared is more appropriate.

Because of the quick change in the temperature gradient from the stratosphere to the mesosphere around 50 km, the GW potential energy variation may be quite different from temperature perturbation amplitude.

We agree with your statement that temperature amplitudes do not completely represent the GW energy. But in this case, this is not necessary, because the purpose of Figure 11 is to demonstrate that the strongest decrease of the diurnal oscillation appear in the same altitude range as the GW from the temporally filtered data. An influence of a changing N is minimized due to the normalization and therefore it is negligible. Additionally to this, GW from the temporally filtered data have large vertical wavelengths, they are of a similar scale like the tidal wave signal. Consequently, they might be able to interact.