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Atmospheric Chemistry and Physics Discussions

Interactive comment on "Seasonal changes in gravity wave activity measured by lidars at mid-latitudes" *by* M. Rauthe et al.

M. Rauthe et al.

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We appreciate the comments from the reviewers. We have considered their remarks regarding contents in detail and would like to respond to the reviewers' remarks point by point in the following.

Referee #1:

General Remarks:

Comment to Equation 2 (page S5635 – S5637): We agree with both reviewers that the approximation is an oversimplification and have reworded the paragraph. We now

present the whole equation. Unfortunately, it is not possible to use the complete equation because there is no wind and phase velocity data available for the period and altitude range of our temperature soundings. We believe that making assumptions about these parameters is not adequate because especially the range of phase velocities is too large to find one appropriate value. To discuss our results in a better way, we added the equation (3) described by the reviewer. The additional parts can be found in section 3.1.

Comment to page 13573 (page S5637, paragraph 4): We have changed the order in the section. The paragraph which presents the summarised results of Gerding et al., 2008 (now published in ACPD) can be found at the end of section 4. After this change the order of section 4 is more concise now. Furthermore, we have extended the description of the results of Gerding et al., 2008.

We agree with the reviewer that our wording concerning the interaction of gravity waves and planetary waves was misleading and we have re-phrased the paragraph. We intend to show that similar processes influence both phenomena and have replaced page 13753 (lines 19 – 26) with the following:

'In summary, the observations show that the change of planetary wave activity accompanies a change in the gravity wave activity and vice versa. Impressive examples of this coupling are stratospheric warming events which lead to an increase in the planetary wave activity and a decrease of the gravity wave activity due to the stronger filtering. We suggest that these similarities between the different scales are due to the background fields, i.e. the temperature changes due to waves which imply also changes in the wind field and vice versa. The filtering and damping of waves of all scales are also modified.'

Comment to the wavelet analysis (page S5638, paragraph 1): We realize that our

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explanation of the data processing was too brief and have therefore expanded the paragraphs which describe the wavelet analysis in section 2.2 and 2.3.

In a separate case study (not shown) we have tested the dependence of the results on the chosen parameters (maximum wavelength as well as number of resolved wavelengths) in the wavelet analysis. As expected the number of resolved wavelengths determines only the resolution of the wavelet spectra and not significantly the amplitudes. The reduction of the maximum resolved wavelength does not change the wavelet spectra significantly. In both cases the cone of influence does not change because it is only defined by the finite length of profiles or the time series.

Page 13746: We agree with the referee that substituting the amplitude by the average absolute fluctuations results in slightly lower value. We re-phrased the paragraph (page 13746, line 9) to point this out.

Page 13751: We agree with the reviewer that the conserved quantity is the wave action. We have reworded the description in section 2.2 (page 13746, lines 12 – 14) and in section 3.3 (page 13751, lines 12 – 13) to point this out more clearly.

Furthermore, we have added a discussion about the problem using single profiles. However, a strong decrease of the potential energy indicates dissipation throughout a large part of the middle atmosphere. The importance of this result is emphasised in the discussion section and we have added the following paragraph.

'One important result of our measurements concerning the gravity wave activity is that damping of waves is observed at nearly all altitudes and in all seasons. Even though this continuous dissipation seems to be natural most global circulation models favour gravity wave parameterisations which deposit their momentum close to regions of strong wind shear based on Lindzen, 1981. Due to our observations a parameterisation of Warner and McIntyre, 2001 seems to be more realistic because of the

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continuous momentum deposition.'

Page 13746: We know that we can derive the density profile from our measurements, but single case studies have shown that there are no significant differences if we use the climatological values. Therefore, we abstain from this procedure for the whole data set. We have added this information in the text.

Specific Comments:

We have accepted most suggestions given in the specific comments and have incorporated them into the revised manuscript. We thank Referee 1 for the improvements of our text. In the following we address only those points in details which are more than simply changes in the wording or typing mistakes.

Page 13745, line 12: The photon counting is the main cause of the statistical uncertainty of the lidar measurements. We have added this information.

Page 13746, line 1: We have clarified the notation and adapted the wording in the whole revised manuscript.

Page 13747, line 3: We have changed the text to clarify in which parts which measurement results are discussed.

Page 13747, line 19: We have realised the misleading wording. 'Possible range' should mean that the dominating modes exist in all altitudes where we are able to observe them with our measurement and analysing method. We have changed the

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wording.

Page 13748, line 17; Page 13750, line 22:

We have realised that the explanation is too short and have extended the corresponding paragraph:

'As indicated above the data evaluation is limited to durations of 3 – 5 h to get a comparable data set in all seasons. We use the first 3 up to 5 h of our measurements including the whole altitude range. Because of the different start times of the measurements due to weather and seasonal restrictions the selected parts of the measurements have different local times every night. For this reason we avoid systematic errors due to the selection. A more detailed analysis of the influence of the measurement duration on the amplitude can be found in Rauthe et al., 2006. However, we would like to point out that a large part of the tidal contribution is eliminated in the resulting temperature fluctuations.'

Page 13750, line 20: The reviewer is right. We have revised the sentence: 'For the first time this gravity wave activity is analysed from lidar measurements in such a large altitude range.'

Page 13751, line 23; Page 13752, line 21; Page 13753, line 8: We have realised that our wording is misleading. We have carefully revised our manuscript to use clear terms.

Page 13754, line 7: We have added a brief explanation of the theoretical conception: 'It is confirmed by theoretical conceptions as described e.g. by Fritts, 2003, in which the wave forcing changes the wind and temperature profiles and this process starts in

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the mesopause region.'

Page 13756, line 17: The referee is right, that the back-tracing can not be performed only based on our measurements. But we plan to combine the lidar data with the radar data from our site which will allow to determine the propagation direction of waves. We have clarified this point in the revised manuscript.

Page 13756, line 18: The same topic has been mentioned by Referee 2. Please compare the answer to the last comment of Reviewer 2.

Page 13757, line 18: Please compare to the answer on general comment (page S5637, paragraph 4). We have changed the wording in the abstract, section 4 and in the conclusion.

Figure 3: We have tested finer colour scale increments, but there is no real improvement because the differences between the blue colours are too small. Therefore, we abstain from changing the figure because it is more important to have the same colour bar for the three pictures than to show the details of the amplitudes. For clarifying the maxima are indicated by crosses.

Referee #2:

Page 13745, line 12: The reviewer is correct and we have made a mistake. What we would have like to say that only in the troposphere the typical observed temperature fluctuations are smaller than the uncertainties (cp. Fig. 1), i.e. in the stratosphere and

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mesosphere our observations are trusted also when taking the measurement error into account. We have corrected the mistake: 'Only in the troposphere the typical temperature fluctuations are smaller than the uncertainties of the measurement.'

Page 13746, line 11: The same topic has been mentioned by Referee 1. Please compare the answer to the last comment of Reviewer 1.

Page 13749, Fig. 5 and description: The reviewer is right that the influence of tides might induce more significant seasonal dependencies of the dominating vertical wavelengths. It would indeed be very helpful to separate the gravity waves from the tides. But since we have only nighttime lidar data, it is unfortunately not possible to clearly separate the gravity waves and the tides. So the measurement time is too short to identify the tides well enough. Therefore we do not try a separation, but we have re-phrased section 3.1 to carefully point out the influence of tides in our measurements.

Page 13749, discussion around Eq. (2): The same topic has been mentioned by Referee 1. As mentioned in the answers to Referee 1 we agree that the approximation is not valid. Please compare the answer to the first comment of Reviewer 1.

Page 13750, discussion of the dominating vertical wavelength: As suggested by the reviewer we studied the results of Fritts and VanZandt, 1993. Unfortunately, in the referred paper only the vertical dependence is discussed. According to the equation the dominating wavelength increases with height by one order of magnitude from the troposphere to the mesopause. As stated in the paper the variation of $H_\star$ can be neglected. The theoretically expected increase is indeed found in our measurements but it is not nearly as strong as predicted by the equation. If we understand the paper correctly the seasonal dependence exists based on the variation of $H_\star$ (which is

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not discussed in the paper) and N. The dependence on N is always included and discussed in our paper. Altogether, the equation of Fritts and VanZandt, 1993 is one possibility to examine the results of vertical wavelength more adequately, but we have decided to discuss additionally the equation described by reviewer 1. The influences of the tides are also referred to in section 3.1.

'Other theoretical studies predict also a seasonal dependence of vertical wavelengths e.g. Fritts and van Zandt, 1993. A reason for the absence of seasonal dependence in our observations may be the influence of tides which have vertical wavelengths longer than 25 km.'

'It is likely that the small vertical wavelengths are typical for internal gravity waves, whereas large vertical wavelengths can also be caused by tides. Since due to the limitation of nighttime data it is unfortunately not possible to clearly separate between the gravity waves and the tides.'

Page 13752, Fig. 9: We agree with the reviewer, that some parts of the information of Figure 9 are hard to grasp. But in contrast to the suggested Figure of the reviewer, in Figure 9 the additional information about the variability of the gravity wave activity is shown by the standard deviations. This is an important result which we would not like to skip. Furthermore, we compare this variability of the gravity wave activity with the planetary wave activity. Details of the seasonal and altitudinal behaviour can also be seen in Figure 6. However, we have reworded the paragraph to emphasise, which information can be seen in Figure 6 and which in Figure 9:

'The monthly mean temperature fluctuations and their standard deviations are shown in Fig. 9. As described in Sect. 3.2 the largest seasonal differences between the monthly mean temperature fluctuations can be found between 40 and 70 km (cp. also Fig. 6). Furthermore, the variability of the monthly means (indicated by the bars) below 80 km is much smaller in summer than in winter. In further studies, which will be published

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in a separate paper, we will show that during so called stratospheric warmings and associated mesospheric coolings the gravity wave activity is smaller than for mean winter conditions. The total variability of the gravity wave activity increases in the winter stratopause region and also in the lower mesosphere (cp. bars in Fig. 9). Above 80 km the variability is too high to identify seasonal differences (cp. also Fig. 6). In contrast to the temperatures and the planetary wave activity the temperature fluctuations (i.e. the gravity wave activity) show typical summer characteristics between March and September and not only between May and August, i.e. the fluctuations increase only slowly up to 70 km.'

Page 13756, line 16: We realise that our explanation of the correlation between the strength of the gravity wave activity and the wind was too brief. Therefore we have expanded the discussion:

'In our present data set we did not find a direct correlation between the strength of the gravity wave activity and the wind direction and/or wind speed taken from ECMWF analyses (not shown). On the one hand we find that if there is a change of the wind direction, i.e. a different filtering, there is no indication for a correlated change in the observed gravity wave activity. On the other hand a large difference between wind maximum and wind minimum in an ECMWF wind profile would imply that more waves should be filtered and the observed gravity wave activity (temperature fluctuations) should be smaller. However, in our lidar observation no correlation between maximum wind differences and observed temperature fluctuations is found.'

Interactive comment on Atmos. Chem. Phys. Discuss., 8, 13741, 2008.