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Atmospheric Chemistry and Physics Discussions

Interactive comment on "Long-term Lidar Observations of the Gravity Wave Activity near the Mesopause at Arecibo" *by* Xianchang Yue et al.

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Response to Editor Hibbins Interactive comment on "Long-term Lidar Observations of the Gravity Wave Activity near the Mesopause at Arecibo" by Xianchang Yue et al. R. E. Hibbins (Editor) robert.hibbins@ntnu.no Received and published: 28 September 2018 Before preparing and submitting a revised manuscript would the authors please provide a response to referee#1's specific comments relating to figures 2a and4a, and referee #2's first general comment. For clarity, these comments are reproduced below: Referee #1 Figure 2a – can you plot the MIL you refer to on the text on the figure Response: The MILs have been plotted on Figure 2a. Fig.2 has been updated in the revised version and is attached to this reply. Figure 4a – it might be easier to compare with other sites/lidar gw studies if you plot the lognormal of the GW PE. Response:

The GW PE in the Figure 4a and 4c of the original version are now plotted by the lognormal in Figure 5a and 5c in the revised version. And the corresponding Fig. 5 is updated in the revised version and is attached to this reply. Referee #2 The authors describe in the Discussion a relation between the wind field as published by Garcia et al. (1997) and Smith (2012) and the observed variation of GWPED. While there is indeed a pronounced altitudinal and temporal correlation, the paper lacks a description of the mechanism that relates the GW activity and zonal wind velocity. All statements are true, but remain vague and unspecific. The interpretation seems to imply pure zonal propagation of the waves, but the lidar data contain waves of all directions. Is the westerly wind between 60 and 70 km taken into account that may filter a lot of the eastward propagating GW? Response: Thank you for reproduced this constructive and kind comments. We have checked the relationship between the climatology of gravity wave potential energy and that of the background wind in the low-latitude mesopause region, and give some clear and specific statement. The updated description in the revised version is as following: "Here we also want to check the relation between our observed GW activity and the wind direction and/or wind speed. Some scientific literatures reported studies about seasonal variation of mean zonal wind in the mesopause region in low-latitude region (see e.g., Fig. 3 in Garcia et al. 1997; Fig. 3 in Smith 2012). This provides us the opportunity to compare our GW E_p climatology shown in Fig. 5a with the mean zonal winds climatology shown in the upper panel of the Fig.3 in Smith (2012) season to season and altitude to altitude. Here we focus on the altitude range 85-100 km. Firstly, the mean zonal winds have a dominated semiannual oscillation with westerly winds prevailing in solstice seasons and eastly winds prevailing in equinoxes seasons, meanwhile, our GW E_p has a semiannual oscillation with minima in winter and summer and with maxima during equinoxes. Secondly, the easterly winds are much larger in the altitude range 85-95 km around vernal equinox than around autumn equinox, which corresponds to the fact that the magnitude of GW E_p in spring is significantly greater than that in autumn. This is also verified by the fitted curve in Fig. 5b. The maximum of E_p at vernal equinox with a value of 404 J.ãĂŰkgãĂŮˆ(-1)

is a factor of 1.3 larger than the second maximum of 319 J.ãĂŰkgãĂŮˆ(-1) at autumn equinox. Thirdly, the largest westerly winds near 90 km in June matches perfectly with the minimum E_p at almost the same altitude range and in almost the same period. Fourthly, the zero wind line near and above 95 km altitude throughout a whole year is accordance to the almost equal E_p near 97 km in all seasons. Fifthly, the transition of mean zonal winds to easterly above 96 km throughout the whole year corresponds well with the overall increase of E_p in the same altitude range. These five features provide strong evidence to a definite relationship between the mean zonal wind direction and wind speed and the GW E_p. This relationship agrees perfectly with the connection of wind and GW in the middle atmosphere demonstrated by Lindzen (1981)."

Response to some other comments of reviewer #1 and #2 In this reply, we also want to reply some comments of reviewer #1 and #2 that was not responded well in the last reply. Reviewer #1 General comments: This paper shows the extended climatology of temperature and potential energy density above Arecibo using lidar data. My main comment about the paper is that the work on gravity wave activity is not a major part of the paper despite it's title. I would like to see included at least one comparison with other gw lidar studies in the mesopause region (regardless of latitude) to see how their results compare in terms of seasonal variation or magnitude of gw activity observed. Perhaps also an expansion of the GW section by also looking at the year to year variation of GW PE if the authors feel it is appropriate and are not planning on doing this for a future paper. Response: We have done comparisons to the gravity wave potential energy observations in the mesopause region at other stations. These comparisons are added in the discussion section of the revised version. The contexts are as following: "We point out a semi-annual cycle of GW E_p with maximum in spring and minimum in summer and a second maximum in autumn and a second minimum in winter in the altitude range 87-97 km. The maximum of the GW E_p alters to autumn below 87 km and above 97 km altitude. These results agree with the observations at other low-latitude station. Gavrilov et al. (2003) studied the GW seasonal variations by using Medium-Frequency (MF) radar observation over Hawaii (22°N, 160°W). They found a

semiannual variation of GW with the maximum intensity at the equinoxes above 83 km, the mean zonal wind had also a mainly semiannual variation in this altitude range. The seasonal variations of GW activities at low-latitude stations are different to those obtained from lidar observations at other latitude stations in the upper mesosphere (Mzé et al., 2014; Rauthe et al., 2006, 2008). Rauthes et al. (2008) provided the seasonal variations of GW E_p at a 54°N latitude station by using a 6-years of lidar temperature observations from 1 to 105 km. They showed an annual-dominated variation of GW E_p with the maximum in winter and the minimum in summer in the mesopause region. Mzé et al. (2014) reported a semi-annual variation of GW E_p with maxima in winter and in summer and minima during the equinoxes in the upper mesosphere (∼75.5 km) by using Rayleigh lidar observations from 1996 to 2012 at a mid-latitude station (∼44°N). They showed that the maximum of E_p was about 144 JãĂŰ.kgãĂŮˆ(-1) on average at 75.5 km in August while the minimum of E_p is about a factor of 2.5 smaller than the maximum. The factor of ratio between the maximum and the minimum is obviously larger than that of 1.5 in the altitude range 87-97 km at Arecibo."

Reviewer #2 Figure 4: I recommend plotting the GWPED per volume. For linear propagation this should be conserved. The strong increase of GWPED close to 100 km would be less pronounced. Response: We have added a figure (Fig. 6 in the revised version) to show the GW potential energy per unit volume (in J.mˆ(-3)). This figure is attached to this reply and the damp of potential energy is clear seen in this figure. The emoticon to the figure in the revised is "Figure 6: Vertical profiles of the potential energy per unit volume (in J.mˆ(-3)) averaged over spring (13 weeks centred at vernal equinox, black line), summer (13 weeks centred at summer solstice, blue line), autumn (13 weeks centred at autumn equinox, red line), winter (13 weeks centred at winter solstice, green line).". The description about this figure in the revised version is as following: "To learn in depth the dissipation of GW in the mesopause region at Arecibo, we multiplied the harmonic fitted E_p with the air density taken from the CIRA-86 reference atmosphere [Fleming et al., 1990], and average every 13 weekly profiles centering at each equinox or solstice. The resulted 4 profiles of the potential energy per unit volume (in J.mˆ(-3)) are plotted in Fig. 6. If GWs propagate upward without energy dissipation, the lines of energy per unit volume would be vertical. Therefore, the four left-sloping lines in Fig. 6 indicate that the damps of GW potential energy occur below ∼95 km in all seasons. The damp of GW potential energy in the mesosphere had been reported by lidar observations at other latitude stations (e. g. Mzé et al., 2014; Rauthe et al., 2008). Both observations of Mzé et al. (2014) and Rauthe et al. (2008) indicate dissipation of GW E_p throughout the mesosphere in all seasons. It is noticed that the green line almost keeps vertical above 94 km which indicate that the GW potential energies are almost conserved in this altitude range in winter. The slops of the other three lines turn to be positive above ∼97 km. The transition of potential energy per volume from decrease to increase with altitude also occurred in the study of lidar observed GW activity at the 54°N latitude station (Rauthe et al. 2008) but with the transition altitude being above ∼93 km.

Please also note the supplement to this comment:
https://www.atmos-chem-phys-discuss.net/acp-2018-731/acp-2018-731-AC3-supplement.pdf

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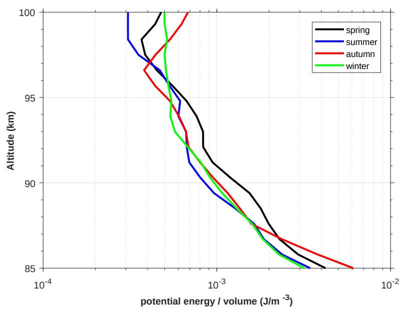

Fig. 1.