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Atmospheric Chemistry and Physics
Discussions

Interactive comment on "Identification of gravity wave sources using reverse ray tracing over Indian region" *by* M. Pramitha et al.

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The paper presents backward ray-traces of GWs observed in two stations in India. Evidence is presented that these waves are generated by wind shear. The arguments presented are convincing, the paper is, in general, well structured and the findings very interesting. However, there are a number of points in the description of the data and the investigation which need to be improved. The English needs editing.

Reply: First of all we wish to thank the reviewer for going through the manuscript carefully, appreciating the actual content of the work and providing potential solutions for further improvement. We have taken care most of the issues suggested and tried to minimize the errors in English usage in the revised manuscript.

Major comment: You discuss in your paper that the high phase-speed, high frequency GWs you observe in the MLT region are likely generated in the troposphere. You can rule out convection and orography as sources but find indication for strong wind shear. The generation of high phase-speed waves by wind shear I consider extremely interesting: to my knowledge most studies which relate high-phase speed GW observations in the MA to sources are about convection (e.g. Taylor et al., Planet. Space Sci., 1988, Wrasse et al., Vadas et al.) While literature which relates GWs to shear often focus on low phase-speed GWs (e.g. Pfister et al., JAS, 1993, Leena et al., JASTP, 2012, Preusse et al., ACPD, 2014; papers on the obstacle effect you have quoted). Therefore I would like to suggest the following changes:

1. Change the title! For instance: Evidence for the excitation of high phase-speed gravity waves by wind shear in the troposphere from air glow observations over India. You can still explain the ray-tracing in the abstract. The abstract, however, should focus somewhat more on the source processes.

Reply: Thanks for suggestion. We have changed the title as suggested.

2. Do more (redo) literature research on evidence for shear generated GWs (e.g. starting from papers quoting Fritts, 1984). And on sources for waves observed in the airglow. Include a paragraph either in the introduction or in the discussion section or both highlighting a) which sources are identified for high phase-speed GWs in the MLT b) evidence for GWs from shear from measurements and which phase speeds they discuss. In this way you can better place your paper in a context.

Reply: We have provided few sentences related to sources of waves identified for high phase-speed GWs and also provided references related to the evidence of GWs from shear measurements as suggested in the revised manuscript. .

General comments: 1. Section 3 is a one-to-one copy of the ray-tracing equations as given in the appendix of Marks and Eckermann, 1995. Since you are not referring to these equations later, this can be completely omitted from the paper. A brief qualitative description what ray-tracing does would be more helpful to the reader. However, one essential information is currently missing: Did you use a program packet provided by others (e.g. GROGRAT) or did you do your own coding? If you did your own coding you should have some validation. In this case, please mention which tests you performed (e.g. in an appendix). Reply: In order to apply ray tracing we used the same ray tracing equations that is provided in the Eckermann, 1995. And we developed matlab code by using Runge-kutta fourth order method. For that we checked WKB parameter value less than one. This information is clearly mentioned in the revised manuscript (page 9).

2. P19600 L3, P19602 L10 and Figure 6 You use a threshold for the WKB parameter of 1 to terminate the ray, which is a default value in the GROGRAT settings(, too?). In this way you guarantee the accuracy of the backward ray-tracing. However, GWs propagate through regions where WKB is violated and terminating the rays at this altitude means loosing information on the true source location. The best example is the tropopause and the tropopause inversion layer. The very rapid change of the buoyancy frequency in a very narrow altitude layer violates WKB for almost all waves. This, I think, is what you observe in Figure 6: the rays stop at about 18km in plots 6a,b, Which corresponds to the rapid change of buoyancy frequency in panel c and hence indicates a ray termination by WKB violation. (On the other hand, if table 1 is correct: why do the rays in F6 not reach 13 km?) By the way, figure 6 therefore contradicts the interpretation presented in P19602 L10 though of course the extrapolated intrinsic frequency would be lower than the buoyancy frequency.

Reply: We have re-plotted this figure in the revised manuscript. Note that all the wave events which propagated down to the upper troposphere terminated between 10 and 14.5 km, except the case G2 which got terminated at 17 km due violation of the WKB approximation. As mentioned, the violation of the WKB approximation at 17 km could be due to sharp temperature gradients near tropopause. In the present study we have not calculated the propagation of past the level of violation of WKB approximation. This

information is clearly mentioned in the revised manuscript (page 16)

3. My suggestion is to calculate past WKB violation but indicate at which altitude WKB violation occurs. You could include a further panel in Figure 6. On the other hand it may be helpful to have the buoyancy frequency and the intrinsic frequency in the same panel. Definitely it would be helpful to have a second x-axis (top-axis) for panels 6a and 6b which show the vertical wavelength and period of the wave. Also the horizontal wavelength would be interesting information. If you calculate past WKB violation then you can indicate also the altitude above which the source must be located, here 8 km. Of course this is now with some uncertainty as WKB was violated above this point, on the other hand WKB violation should much more affect the amplitudes because of partial reflection than the wave parameters.

Reply: We have included the altitude where WKB violation occurs and also provided buoyancy frequency and the intrinsic frequency in the same panel in Figure 6 as suggested. Note that in the present study we have not calculated the propagation of past the level of violation of WKB approximation.

4. Section 6 In order to identify the source altitude it would be helpful to provide one additional figure showing profiles of the Richardson number in the center of the terminal positions of the rays for both stations. The high phase speed and short period of these waves for which you identify shear as the most likely source is very interesting. This should be discussed! Which other evidence is there for waves from shear and which are the typical scales and phase speeds of the waves identified in these studies? You could scan papers referring to Fritts 1984 and set your findings in relation. Also, even though you cannot determine the source amplitude, you may give a feeling which amplitude is necessary in order to be compatible to the observations.

Reply: In order to check the KH instability, we have used the radiosonde data available near to the termination point. For Gadanki we have used data VOMM (130N, 800E) observed on 17 March 2012 and for Hyderabad location we have used data from Goa

(15.500N, 73.30E) observed on 8 March 2010. We have calculated the Richardson number profiles for both the stations and provided as additional figure (now figure 8) as suggested. We also included the discussion related to shear generated waves while relating to the Frits (1984) reports.

Specific comments 1. P19589 LL9 Of course you need to be selective in the references you are quoting (use e.g. or note that there are more studies than those quoted) but I would like to add a few further suggestions. Please add: depth of the heating: Salby and Garcia, JAS, 1987 obstacle effect: Pfister et al., JAS, 1993 topography: Queney, BAMS, 1948, Eckermann and Preusse, Science, 1999 geostrophic adjustment: O'Sullivan and Dunkerton, JAS,1995, Plugonven and Zhang, Rev. Geophys., 2014

Reply: We have included these references in the revised manuscript as suggested.

2. P19589 L18 remain a challenge (Geller et al., J.Clim., 2013) Reply: Added.

3. P19589 LL19 This should be explained better: hodograph analysis may be used for two aims: a) to determine the wave parameters in which case it could be combined with other means like a ray-tracer; b) to discern between upward and downward propagation in which case it is indication though not final proof of a source at a specific altitude (e.g. the tropopause)

Reply: Modified these sentences as suggested.

4. P19590 L1 I think the real point is to identify the source of a GW which has already propagated for some distance, both in the vertical and the horizontal.

Reply: Modified.

5. P19590 L3 Please add also a few examples for the stratosphere: e.g. Hertzog et al., Ann. Geophys., 2001

Reply: Added.

6. P19590 L20 Applying a method to a new place is not really a "first time" and whether it is "successfully" we will see at the end of the paper: both phrases read strange in the introduction -> please delete them Reply: Deleted.

7.P19590 Please add a few lines at the end of the introduction to outline the structure of the paper.

Reply: Added.

8.P19592 L2 You need the intrinsic phase speed to calculate the vertical wavelength. Please mention this (e.g. provide the equation)! This means you need the background wind. Please give the source for the wind data. omit "also" (in general: reduce the use of "also")

Reply: We have mentioned and provided the equation for the same in the revised manuscript. The background atmosphere used is the same developed background atmosphere. The dispersion relation is , where is the vertical wave number of the wave.

9. P19592 L15 suggest to replace "elsewhere ncitep" by "by ncitet{}". Reply: We are sorry to say that we do not understand what reviewer wants to convey here.

10. 2.2. I guess from your text that you use a 2D detector and use one direction for the spectral resolution and one direction for 1D spatial imaging, correct? If yes, please say so explicitly. In addition, please specify the spatial extent and resolution of the imaging. This defines the observational filter and is therefore essential to the interpretation of the results.

Reply: Yes, we use a 2-D detector. Further, the spatial extent of the measurement in the E-W direction is $\sim$170 km, with a spatial resolution of $\sim$11 km. In the N-S direction the spatial extent and resolution are 330 km and 50 km, respectively. We have included this information as suggested.

11. P19593 LL5 These are geostationary satellites, so it should be particularly one of

them which is mainly providing the data for India. Mentioning geostationary is important because in this way you get complete coverage at short temporal sampling (the 1 hour data you are referring to later).

Reply: We have mentioned clearly about the geostationary satellite as suggested.

12. P19597 L5 What do you mean here? Since the waves are high frequency they don't propagate far and a region of 5X 5 is sufficient? Or: since the waves are high frequency, you need a resolution of at least 5 to capture the relevant variations of the background.

Reply: Since these are high frequency waves they will propagate very fast with less horizontal wavelengths and thus maximum of 5oX5o grids is enough.

13. Figure 3: Why do you compare a single snapshot from ERA-interim with climatologies? It would be helpful to have a) also a comparison based on an ERA monthly mean and b) a motivation in the text why a single-day comparison is also helpful.

Reply: In order to check whether ERA interim data is suitable to Gadanki location we checked this data with climatology developed data. As suggested we also provided the discussion related to monthly mean from ERA-Interim.

14. P19599 L15 How did you obtain molecular diffusivity?

Reply: Molecular diffusivity is given by (Chester S. Gardner 1995) where Coefficient of molecular viscosity is given by (S.L.Vadas 2009 et al). Gardner, C.S., (1995), Scale-Independent Diffusive Filtering Theory of Gravity Wave Spectra in the Atmosphere, Geophysical Monograph 87.

15.Section 6: I would like to suggest to modify the title of this section: Discussion of potential source processes

Reply: Modified as suggested.

16. P19603 L11 A presumable source altitude larger 10km is the second argument

that rules out topography. I think at this point you should omit a reference, since a) the arguments are very clear and b) you could quote quite a large number of references, so highlighting one is not really appropriate.

Reply: Reference is omitted as suggested.

17. P19603 L17 I don't think that this is a good argument even to be discarded. Deep convection is very frequently accompanied to clear sky in the vicinity. The DAWEX campaign would be a further example.

Reply: Deleted this sentence in the revised manuscript.

18. P19603 LL20 Please first discuss the potential source time. For this you should include in Figure 6 an altitude profile of the time, most helpful for the further discussion would be of course absolute times, i.e. the observation time at the ray-start and according times along the ray (GROGRAT would provide relative times with respect to the ray start).

Reply: Altitude profile of the time is also provided in the revised manuscript as suggested.

We once again thank the reviewer for going through the manuscript carefully as providing constructive comments which made us to improve the manuscript content further.

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Interactive comment on Atmos. Chem. Phys. Discuss., 14, 19587, 2014.