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Atmospheric Measurement Techniques Discussions

Interactive comment on "Lidar observations of atmospheric internal waves in the boundary layer of atmosphere on the coast of Lake Baikal" *by* Viktor A. Banakh and Igor N. Smalikho

Anonymous Referee #2

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This paper presents a few case studies of atmospheric internal waves near the shore of Lake Baikal as well as methodology to infer some wave properties (amplitude, frequency) from the wind profiles obtained with a scanning Doppler lidar.

I find the presented case studies and methodology interesting enough to merit publication in AMT when following comments have been addressed.

Major comments

First of all, the structure of this manuscript is unclear. Methods are discussed partly in chapter 1 (introduction) and partly in chapter 2 (observations and analysis), which makes it unnecessarily complicated to follow what has been done. Furthermore, ad-

ditional details need to be given on the methods and measurements. Please add one more chapter on methods (separate from results) containing detailed description of the instrument, scanning protocols, data processing, the site and the calculations used in inferring the wave characteristics. Please see detailed comments below for more specific questions.

My second major comment is that the analysis on the variation of aerosol concentration is neglecting several sources of uncertainty. As it seems to me that this section does not contribute significantly to the conclusions of this paper, I recommend the authors to leave it out. If, however, this section is included, all sources of uncertainty in the analysis have to be accounted for. Please see detailed comments below for more specific comments.

Finally, the results are not discussed with respect to previous studies. Examples of a few previous studies on atmospheric gravity waves (AGW) with a couple of different techniques are listed, but no comparison is made to the characteristics of previous AGW observations or theoretical work. As a consequence the implications of this study (with respect to e.g. NWP, wind power or transport of momentum, energy and trace compounds) are not discussed at all. Please summarize current knowledge on atmospheric internal waves in enough detail to place this work in its context and discuss the differences and similarities of the wave properties from this study with previous observations. For instance, the review by Sun et al. (2015) and the recent studies by Roman-Cascon et al. (2015) and Chouza et al. (2016) might provide a starting point.

Detailed comments

Page 2, line 10: As there are a couple of different versions of the Halo Streamline lidar, the manuscript has to contain at least the following details of the system in use: wavelength, pulse repetition rate, Nyquist velocity, sampling frequency, velocity resolution, minimum range, range resolution, points per range gate, pulse duration, lens diameter, lens divergence, telescope, integration time per ray. Integration time per ray seems to be changing during the campaign (page 2, line 22) and should be given at least for each case study presented here. Also a reference to a detailed description of the Halo lidar (Pearson et al., 2009) would be good to include.

Page 2, line 21-22: It seems that the wind profiles in this study were obtained with a vertical azimuth display (VAD) scan at 60 degree elevation angle. If the VAD scan was carried out by stepping the azimuth angle (as page 2, line 4-6 suggests), please give the number of azimuthal angles included in each scan. Please indicate if the lidar was scheduled to do only VAD scans, or if other scan types were included in the measurement protocol.

Please give details on the Doppler lidar data processing. Was some constant threshold applied to SNR to discard range gates with too low signal or were low-signal measurements filtered in some other way? Was the SNR checked for the artefact described by Manninen et al. (2016)? How were missing radial wind observations (e.g. discarded due to too low SNR) handled in reconstructing the wind profile (c.f. Päschke et al., 2016)? Please discuss also the uncertainty in the obtained horizontal and vertical winds (see e.g. Päschke et al., 2016).

Page 2, line 12-14 : "The measurements were conducted in August 14-28 of 2015 on the western coast of Lake Baikal (52°N, 105°E) at the territory of Baikal Astrophysical Observatory of the Institute of Solar-Terrestrial Physics SB RAS, Russia." Please give the measurement site location with better accuracy, 0.01 degree latitude/longitude (or better) would be suitable. As the manuscript deals with "coastal-mountain lee waves" (page 2, line 7), please present a topographic map of the area of interest (with measurement location indicated) so that the reader can assess the role of terrain height on the observations. How far off from a mountain top are these waves observed? Is it the same mountain for each wave case? How did you conclude that the waves reported here are mountain lee waves and not, for instance, generated by jets or fronts (e.g. Plougonven and Zhang, 2014)?

Page 3, lines 9-15: "Model (1), (2) was applied in the analysis of data in Fig.3 for a height of 766.4 m and 47-min time interval starting from 14:20. From these data, with allowance made for the linear trend, we found the wave addends Va(r,t) for the three components of the wind velocity vector. In Fig. 6, the solid curve shows the dependence of Vx on t. To determine the wave frequency fv =1/Tv, we have used experimental function Vx(t) and calculated the spectral density, which is depicted in Fig.7." Please state exactly how the model was applied to the data. For instance:

- Is <Va> average (mean or median?) of the u,v,w retrieved from the VAD over the wave period? If yes, was this period determined visually or with some other method?

- What do you mean by "with allowance made for the linear trend" – which parameter has a linear trend and how is it taken into account? How do eq. (1) and (2) look like with this linear trend included?

- How were the time-independent parameters in eq. (2) determined – based on a least squares fit?

- How was the spectral density of Vx(t) in Fig. 7 calculated?

Please provide also some measure of uncertainty for the parameters in eq. (2). For instance bootstrap might be applicable.

Page 4, lines 4-6: "It is known [Smalikho and Banakh, 2015b] that SNR is proportional to the aerosol backscattering coefficient beta = rho sigma, where rho is the concentration of atmospheric aerosol, and sigma is the mean aerosol backscattering cross section." SNR does depend on the aerosol backscattering cross section and concentration, but it depends also on the extinction along the path of the transmitted light (Halo output is attenuated backscatter) and the lidar telescope focus. Furthermore, backscattering cross section depends strongly on relative humidity because of hygroscopic growth of the particles. If this section is included in the final paper the uncertainties from these sources need to be quantified. Please see also Engelmann et al. (2008) for further discussion on aerosol flux measurements using lidar technology.

Page 4, lines 6-8: “If we assume that during the measurement time (45 min) SNR does not vary due to turbulent pulsations of the refractive index of air and sigma remains unchanged, then variations of the aerosol concentration can be estimated from the lidar data as SNR variations.” This is probably a good assumption in a well-mixed boundary layer (c.f. Engelmann et al., 2008). However, in this case the aerosol layers are not mixed and the measurement at a constant height can represent quite different aerosol characteristics especially if there was (fresh?) biomass burning smoke present (page 2, line 24). In fact, for the 220 m elevation presented in Fig. 10, the highest SNR seem to coincide with 270 degree wind direction, while lower SNR values are observed for 0-90 degree wind direction (see Fig. 9b). Can you assume that aerosol from opposite wind directions has unchanged optical properties? If not, how does this affect the uncertainty in eq. (3)?

Page 4, line 12-14: “Since the SNR oscillates within the height range 100-500 m in Fig. 9(d), it is evident, that aerosol concentration should vary with time too. These aerosol concentration (SNR) variations can be caused by oscillations of the vertical component of the wind velocity vector, whose amplitude is relatively high.” Please see previous comments: SNR is not equal to aerosol concentration.

Minor comments

Please check the language carefully once more.

Page 1, line 8-9: Please specify if height is above ground level or something else

Page 1, line 21: “Xiaofeng et al., 2001” is not included in References

Page 2, line 4-5: ”During the measurements, the elevation angle phi is fixed, while the azimuth angle theta = omega t of the beam axis position varies with time t and with the rate omega.” To me this statement suggests that the VAD was operated with “continuous wave” method, though the Halo lidar is more commonly operated by stepping

from one azimuth angle to the next, in which case scan duration is determined by the integration time and number of azimuthal directions included in the scan. Please clarify how the VAD scan was operated.

Page 2, line 6: “k,n=1,2,3,. . .” Please give the number of range gates and azimuth angles used in this study.

Page 2, line 7-9: “Lee AIWs (or orographic waves) are one of the types of AGWs, which arise on leeward of obstacles at the stable stratification of an incoming flow [Vel’tishchev and Stepanenko, 2006; Kozhevnikov, 1999].” There are many earlier studies on lee waves. Some early references can be found e.g. in Sun et al. (2015) and in Makarenko and Maltseva (2011).

Page 2, line 15: Is the height above Lake Baikal level?

Page 2, line 23: “The wind in the atmospheric surface layer during the measurements was mostly directed from the north through the mountainous terrain toward Lake Baikal.” What height above ground is “the atmospheric surface layer”? Is this from the Doppler lidar or some surface anemometer?

Page 3, line 1: “Neglecting the wind turbulence, we use the model of a plane wave for the component of the wind velocity vector” Please discuss the uncertainty in neglecting turbulence.

Page 3, line 5: What is the coordinate system for the radius vector?

Page 3, line 8-9: “If the wind direction coincides with the direction of propagation of the internal wave, . . .” How is the wavelength determined if the wind direction does not coincide with the direction of propagation of the internal wave?

Page 3, line 24-25: “Since the amplitude A is not 0 (see Fig. 3(b) and Fig. 5(b)), the direction of propagation of the internal wave did not coincide with the wind direction.” How large was the angle between wind direction and the direction of propagation of the internal wave (for each wave case)? How does this compare with previous observations?

Page 3, line 28-29: “According to the data of Fig. 8(b), the period and amplitude of the wave were, respectively, 9 min and 0.9 m/s.” Is this for horizontal wind speed?

Page 4, line 4-5: “It is known [Smalikho and Banakh, 2015b] that SN is proportional to the aerosol backscattering coefficient” Here a reference to e.g. the instrument description (Pearson et al., 2009) might be more appropriate.

Page 4, line 22: Is time local time?

Page 5, line 5-6: “A total of six cases of AIW formation have been revealed, which always occurred in presence of one or two (in 5 of 6 cases) narrow jet streams at heights of about 200 and 700 m.” I find interesting the observation of two simultaneous jet streams. Are there previous observations of such cases from comparable environments? Can you comment on the possible forcing mechanisms of the jet streams?

Figure 1. It seems a little unusual to me to define VAD with a left-handed axis. Is this the axis used for eq. (1) and (2)?

Figure 8. Please use the same colour map as for other wind speed plots.

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