Atmos. Meas. Tech. Discuss.,
doi:10.5194/amt-2016-162-AC3, 2016

Atmospheric Measurement Techniques Discussions

Interactive comment on "Identification of the cloud base height over the central Himalayan region: Intercomparison of Ceilometer and Doppler Lidar" *by* K. K. Shukla et al.

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Received and published: 17 November 2016

General Comments

In this manuscript Doppler Lidar measurements that were taken at a high altitude site (Manora Peak, India) during an experimental campaign that took place from June 2011 until March 2012 are used in order to calculate the cloud base height (CBH). Six periods (each one of 5 hours) were selected and were further processed based on the cloud coverage. The CBH that was calculated with a Doppler Lidar during these cases was compared against the CBH obtained from a ceilometer, and CBH from MODIS overpasses, and the Lifted Condensation Level was calculated from both radiosonde data and standard surface meteorological measurements. The vertical velocity at the

CBH was also reported. The main focus of the manuscript - a method for the CBH detection from Doppler Lidar measurements -is a novel idea, which in view of the capability of the instrument to accurately measure the wind speed, would be a valuable contribution for future studies, and certainly within the scope of the journal. One major issue is that the methods are not outlined clearly: several important details are either missing or are poorly described; and therefore the results and conclusions are not solid. Furthermore, the results and conclusions would be far more robust if more cases were studied.

Response: We greatly appreciate the detailed review by referee #2. We have tried to address all the issues that they have raised to the maximum extent possible. These changes are implemented/modified here and also in the text. We hope these changes adequately address all the concerns raised.

Specific Comments 1. The CBH detection method from the lidar measurements should be fully described since this is the first time it is reported in the open peer-reviewed literature. Examples showing the application of the method in real SNR profiles would be helpful to that regard. In its present form the method is briefly described and one reference (a report) is given.

Response: We have now included the detailed description about the CBH estimation and also a figure showing the method for the CBH estimation by using SNR profiles for more clarity to the reader in the revised version of the manuscript.

2. The results would be more robust and conclusions far more convincing if more cases were included. At the moment it's not clear why only six cases are selected out of a large dataset (June 2011-March 2012). In fact, it is even obscure how these cases were selected. It is briefly mentioned that the selection was based on the cloud coverage, residence time of clouds and availability of simultaneous datasets (P3, LN5); rather it would be expected that the exact method by which the selection was made should be fully detailed and analytically presented in the Methodology section.

Response: Although, the ARM site deployment was during June 2011 – March 2012, we do not have the Doppler lidar data during the monsoon (June – September 2011) period because of washout of the aerosol particles. Moreover, either no/less percentage of cloud coverage or less cloud residence time ($\sim$1-2 hours) are observed during other seasons. Hence, we have particularly selected those cases, where we have maximum cloud coverage and residence times during the daytime boundary layer (05-10 UT) convection period. Also, another aspect for selecting these cases is the availability of simultaneous datasets with other instruments like Ceilometer, radiosonde and other meteorological instruments. Some of the cases are rejected because of sudden spikes and other consistency checks. These aspects are clearly mentioned in the revised version of the manuscript

Technical Comments

P1 LN25-26: ": diurnal pattern:" It is not correct to refer to "diurnal" patterns since you only show 5 hours of measurements.

Response: Yes, agreed and we have now modified the terminology wherever appropriate in the revised manuscript.

P2 LN35: ":::: from the fair-weather ABL clouds." It is not clear at all why these are fair weather cases.

Response: Yes, these cases cannot be considered as fair weather cases as they persist for much shorter timescales and now we have modified this terminology in the revised manuscript.

P3 LN 10-11: ": and shows an increase in the pollutants level in the current climate:". Not clear what you mean.

Response: Typo mistake has been corrected and replaced 'climate' by 'scenario' in the revised manuscript.

P4 LN 8-9: It would be helpful if you discuss briefly the data process used for TSI

images in order i) to obtain the presence of clouds ii) to estimate the percentage of thin and opaque clouds. Probably the part of the text in Results and Discussion section should be moved here.

Response: We have now moved some text of results and discussion to the section 2.1 in the revised manuscript for the explanation of data analysis procedure of TSI.

P4 LN 14: ": over a high altitude site:". Is this Manora Peak? Please state so.

Response: Clearly stated in the revised manuscript.

P4 LN 14: "DL." Please provide details of the instrument you used (company, model, technical characteristics, etc.).

Response: We have now added a separate table with the technical specifications of the Doppler Lidar in the revised manuscript.

P4 LN 24: "-20 dB". How was this threshold decided? Any reference?

Response: We have made a detailed analysis regarding the appropriate threshold condition for the used dataset in the current report. Based on the careful inspection of datasets from September 2011 –March 2012, and followed Lenschow et al., (2000) & Pearson et al., (2009) methodology for SNR criteria over the DL dataset and arrived at '-20 dB' is an appropriate threshold. The detailed description about the threshold methodology and corresponding references are also added in the revised manuscript.

Lenschow D.H., Wulfmeyer, V., Senff, C.:2000 Measuring Second- through Fourth-Order Moments in Noisy Data. J. Atmos. Oceanic Tech., 17, 1330-1347, 2000.

Pearson, G.N., Davies, F., Collier, C.: An analysis of the performance of the UFAM pulsed Doppler Lidar for observing the boundary layer. J. Atmos. Oceanic Technol., 26, 240-250, 2009.

P5 LN28-29: For the current data set, the averaging interval was 30 min oversampled for every 10 Min". It is not clear what you mean that. Can you please clarify?

Response: The vertical velocity and cloud statistics Value Added Product (VAP) uses a 30-minute averaging time window, but produces output using a 10-minute sampling interval. Thus, every third sample is statistically independent.

P6 LN3-4: “Additional checks are applied to minimize false detections by rejecting temporally isolated peaks”. Which tests? Please be more specific.

Response: The additional checks to remove false detection are now described in more detail for better clarity in the revised manuscript. CBH estimates from profiles immediately before and after the current profile are compared and if both differences exceed 1km then the current CBH estimate is rejected.

P6, Section 3.2. How was CBH from ceilometers calculated? 1) Using equation (1) or 2) from backscatter coefficient profile.

Response: Here, we have used the visibility threshold for the detection of cloud base height by using Ceilometer and it is described in detail in Väisälä Oyj (2002) and Morris (2012)). We have also added above mentioned references in the revised version of manuscript.

P6, Section 3.3. Please be clear from the beginning that you are using the method described in Hutchinson (2002).

Response: We have now modified section 3.3 considering the suggestions in revised version of the manuscript.

P7 LN 26-27: “: raw: and:: :masked: : :cloud images by TSI at hourly interval: : :”. 1) What is the difference between “masked” and “raw” images? 2) How were these images obtained from the original 30 sec images?

Response: 1) The first step toward Total Sky Imager (TSI) image analysis, TSI software masks out obstructions-the imager, its arm, and the sun-blocking band in the raw images. This is the difference between raw and masked images. 2) As instrument gives the original images at the interval of 30 sec, we have taken the original images

at every 1 hour interval.

P8 LN 14-15: “If cloud is present in the atmosphere then red pixel value is greater than where no clouds.” Please rephrase.

Response: Sentence is rephrased in the revised manuscript.

P8 LN 14-15: Stull and Eloranta, 1985 and Zhang and Klein, 2013 references are missing from the reference list.

Response: References are added in the reference list in the revised manuscript.

P8 LN33: “: showing high percentage of opaque cloud during 12.5-14.5 LT”. This text refers to Figure 3? If so clarify.

Response: From Figure 3 (a-b), it is clearly seen that during study period (10.5-15.5 hrs) the percentage of opaque and thin clouds shows the reverse pattern. It means that when opaque clouds are higher then thin clouds are lesser and vice-versa. Similar kinds of patterns are also observed by the Doppler Lidar and Ceilometer.

P8 LN 32-6: It’s not clear how the thin/opaque cloud percentage links to the SNR or backscatter time series in Figure 4. Please be more precise.

Response: Interpretation was done by using the thin/opaque cloud percentage observed by the Total Sky Imager over the Manora Peak, when thick clouds are present overhead of Doppler Lidar and Ceilometer. It will give the high backscatter in comparison to thin clouds in both the parameters (SNR & Backscatter) which is clearly evident from the Figure 4.

P9 LN 1-2: “It is interesting to note that the temporal evolution and duration of thin and opaque clouds in both the instruments are in reasonable agreement during all events.” How thin and Opaque clouds can be inferred from ceilometers and Doppler lidars?

Response: The observed temporal evolution and duration of thin and opaque clouds are observed by the Total Sky Imager (TSI) and not by the Doppler Lidar and Ceilome-

ter. We have clarified this part more clearly in the revised manuscript.

P9 LN 11-13: “Figure 6 depicts the temporal variation of CBH observed by the DL and CM along with lifted condensation level (LCL) height estimated by using surface MET parameter and RS on (a) 12 October 2011 (b) 21 November 2011 (c) 11 December 2011 (d) 20 January 2012 (e) 08 February 2012 and (f) 14 March 2012”. This is a repetition of the legend of Figure 6 and could be omitted or shortened.

Response: We have shortened the paragraph in the revised manuscript.

P9 LN15: “::: during the convective period:::”. How is the convection period defined?

Response: Usually daytime we observed high vertical velocities (means positive velocity and updrafts are more dominant) which are an indicator of convection and our observational period is also during daytime and hence we have considered them as convective period.

P9 LN 16-20: “ABL cloud heights are estimated by using LCL (Stackpole, 1967). The well-mixed ABL air parcels which have a dry-adiabatic temperature profile and a constant mixing ratio are used to determine the LCL profile (Craven et al., 2002). For the detection of CBH, the LCL is a good approximation as the CBH depends on the relative humidity and temperature near the surface. The LCL depends on the temperature and dew point temperature above the surface and thus a good proxy for CBH.”: This text could be moved to Section 3.4.

Response: We have now moved this paragraph to section 3.4 in the revised manuscript.

P9 LN 22: “: LCL heights with the MET and RS shows a similar pattern: : :” In all cases RS LCL and LCL do not agree. Why?

Response: In general, LCL has reasonable agreement with both the instruments, however, in some cases differences are observed due to the drift of balloon over the site and also different instruments with different methodology. We have tried to make this

explanation in a better way for better clarity.

P9 LN 23-24: “From Figure 6 (a-f), it is clearly observed that in all the cases, CBH is coupled with the LCL estimated from the surface meteorological parameters.”. The differences between CBH from Doppler Lidar and ceilometer are not small in some cases (e.g. 12/10/2011 13.5 – 14.5) and even the trends are not always the same (e.g. 14/3/2011 11.5 – 13).

Response: We agree that in some cases an over estimation of $\sim$ 500 m in CBH is observed. The overestimation of the CBH by using DL in comparison to Ceilometer may due to different instruments specification and different retrieval methodologies for the CBH respectively. Moreover, for the first time we are dealing with the Doppler Lidar CBH estimation and to establish the concrete methodology, more statistical analysis would be beneficial to arrive at certain conclusions.

P10 LN3: “::: where the differences are slightly higher and need to be investigated for possible inconsistencies.” Which would the reasons for these inconsistencies?

Response: Doppler Lidar also responds to higher aerosol concentration in the form of aerosol backscatter apart from cloud coverage. In some cases, higher aerosol concentration could lead to higher values in Doppler Lidar as compared to Ceilometer especially in the afternoon hours leading to forenoon-afternoon asymmetry in AOD over the Himalayan region (please refer Dumka et al., 2006; Shukla et al., 2015 for further details). Moreover, discrepancy during March 2012 may be attributed higher aerosol long range transport from middle-east locations to Indian regions which could have manifested in higher values in DL as compared to CM.

P10 LN7: “R2 =0.76” It is 0.81 in Figure 10. A general comment regarding the comparison between CBH from lidar and ceilometer: would you expect any differences on the basis of the different operation wavelengths of the two instruments?

Response: Typo mistake in the correlation values has now been rectified in Figure 11

in the revised manuscript. During observations, both the Lidars will see the clouds at the same height but the minor differences in the cloud base height might be due to their retrieval algorithms and assumptions involved.

P10 LN15: ":::: micropluse.." is micropulse

Response: Implemented

P10LN24: ": :large scale updrafts: : :". More evidence would be required to support the statement that the detected updrafts are due to large scale movements.

Response: We apologize for the typo mistake, what we mean large scale updrafts are about the higher magnitude of updrafts observed in DL during the event. We have modified the sentence in the revised manuscript.

P11 LN4: "R2=0.76" same comment as above.

Response: Corrected

P11 LN 13-27: Part of the text is more relevant with the "Results and Discussion" section rather than the "Summary and Conclusions".

Response: We have now rearranged these two sections in the revised manuscript.

P14 LN16: Rodts et al., 2014 does not appear in the text.

Response: We have removed Rodts et al reference from the reference list in the revised manuscript.

P14 LN21: Sarangi et al., 2014 does not appear in the text.

Response: We missed it somehow and now included Sarangi et al reference in section 2 in the revised manuscript.

P14 LN35: Stull, 1985 does not appear in the text. Figure 9: MODIS measurements for 12/10/2011 and 11/12/2011 can not be seen. Figure 10: Are the data points 10-minute mean means? Please provide all relevant information, why are some values excluded

from the dataset?

Response: We missed it and now we have included Stull reference in the introduction section of the revised manuscript. We do not have the MODIS over pass over our site at the above mentioned dates (October & December 2011) that is why data on those two days are not available. Yes, data points are at every 10 min interval and we did not exclude the data points in correlation plot. It is clearly seen from the figure 5 that some data gaps are observed in the temporal variation of the CBH with the Doppler Lidar and same is replicated in the correlation plots.

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