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Can ceilometers be used as rapid response rain gauges?

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Abstract

Ceilometers measure the height of cloud base from the time taken for a short pulse of laser light to be reflected back from the cloud. They also receive a backscatter signal from the rain, which is proportional to the projected cross-sectional area of the raindrops and so should increase approximately monotonically with rain rate. This project is to examine if ceilometers can act as rain gauges with an accurate estimate of rainfall every thirty seconds, rather than conventional gauges that estimate the rain rate to an accuracy of 1 mm/hr every 12 minutes. Several months of ceilometer data from Chilbolton have been analysed and compared to the data from a special drop counting gauge that can estimate the rain rate to 0.2 mm/hr every minute. It is found that the ceilometer rain rate are not accurate and the limitation is the change in the window transmission as droplets on the ceilometer lens attenuate the light. Corrections can be made for this window transmission, but the proposed solution is to install a more efficient hot air blower that prevents any raindrops resting on the lens.

Introduction

- Rainfall rate is one of the most important meteorological variables.
- Radar provides a snap shot of the rainfall rate with a good temporal and spatial resolution. However, in order for calibration of the radar rainfall estimate, means of measuring rainfall rate changes every minute are required.
- Tipping bucket rain gauges take a few minutes to estimate rainfall rate.
- It was expected that ceilometers have the potential to measure the rainfall rate every few seconds.
- However, no one has reported the investigation of ceilometers used as rain gauges.

Methodology

- Compare the rainfall rates inferred from values of the backscatter profile (β), obtained every 30 seconds from a CL51 ceilometer located at Chilbolton, with those measured by a rapid response rain gauge next to the ceilometer.
- Short ceilometer pulse's vertical resolution is 10 m. In most cases, the range gate at 100 m is used, because
  - It is the best to use the lowest possible range gate in order to avoid wind-drift, i.e. the rain will fall to some distance away.
  - Range should not be too low as there would be no signal due to no overlap of the transmit and receive optics.
  - If range is too high then there will be a large signal from the cloud droplets.
- Window transmission is used as a correction of the comparison, as rain drops on window lens will result in decrease of illuminated power and hence reduction of β.
- An example of contrasts between β, rainfall rate and window transmission are shown in figure 1.

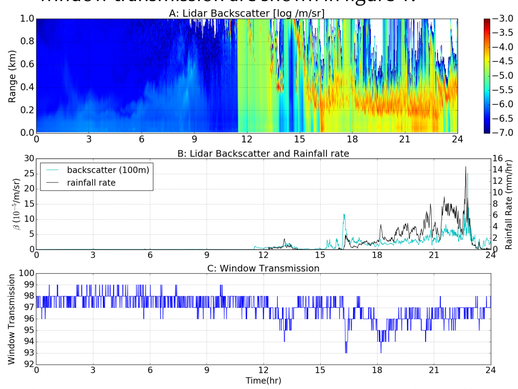

Figure 1. With cloud base at 300 m, ceilometer and rain gauge observations at Chilbolton, 1 August 2016. Panel A shows ceilometer backscatter profile. Panel B shows rainfall rate and backscatter coefficient β below cloud base at 100m. Panel C shows variation of window transmission.

Results

Case 1 Low and Inconsistent Cloud Base

- It was expected that higher rainfall rate would give higher β. Based on data of August 1 2016, this relationship was plotted with and without adjustment of window transmission (see figure 2). Improvement can be seen after the adjustment.

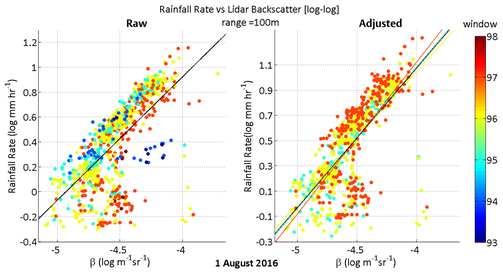

Figure 2. Scatter plot of rainfall rate β (at 100m) with (right panel) and without (left panel) adjustment. Plots are coloured according to window condensation. Solid lines are the first-degree best fitting curves.

Case 2 Higher Cloud Base

- The accuracy of case 1 is only 52%. It was expected that low and inconsistent cloud base would be an issue. Therefore, another case (1 October 2016) with high and consistent cloud base is tested (see figure 3). However, the result is still not sufficiently accurate (accuracy of 64%).

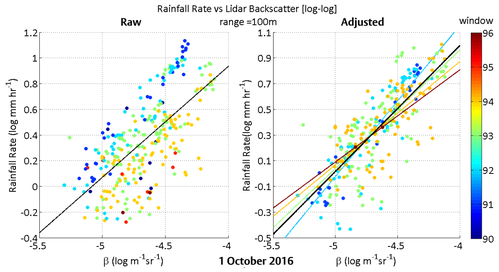

Figure 3. Scatter plot of rainfall rate versus β (at 100m) with (right panel) and without (left panel) adjustment. Plots are coloured as the window transmission. Solid lines are first-degree best fitting curves.

Further cases

- To further examine the comparison, some other dates of data have been processed, but the relationship between rainfall rate and β is very noisy for light rain (see figure 4). It is suspected that light rain gives a small change in β, and this is masked by the individual small drops on the optics that lead to inhomogeneous illumination of the rain by the ceilometer.

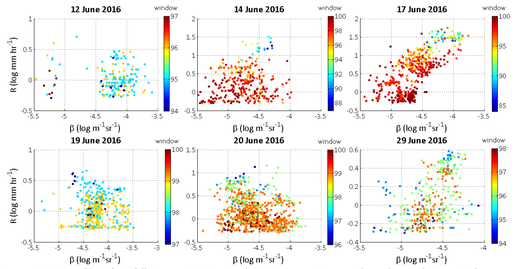

Figure 4. Scatter plots of rainfall rate against β on six days. Scatter points are coloured according to window transmission.

Error discussion

- Attenuation by water vapour absorption is probably negligible. Errors are around 2% at 100 m (Wiegner and Gasteiger 2015).
- Inhomogeneous illumination due to individual droplets on the optics is considerable. Hence, reliability of window transmission as a correction is doubt.

Experiment on droplets on the window

- An Experiment has been manipulated on the CL31 ceilometer at University of Reading's atmospheric observatory on 25 January 2017.
- Water was sprayed on the lens three times. A hot air blower was used to boost evaporation in the latter two sprays. Experiment result is shown in figure 5. A big fall can be observed at the beginning while no significant change has appeared in the next sprays.

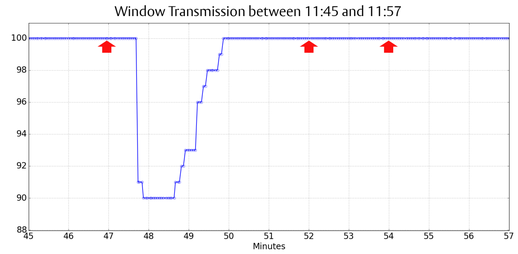

Figure 5. Window transmission (experiment) between 11:45 and 11:57 GMT at Reading on 25 January 2017. Three times of sprays are marked.

- The surface diameter of the window transmission photodiode detector (0.5 mm) is much smaller than the effective lens diameter (96 mm) (Vaisala 2004). Hence, it is suspected that occasionally individual rain drops would not affect window transmission considerabley.

Conclusion

- Ceilometers do have potential to measure rainfall rate.
- This measurement is more accurate when cloud base is high and consistent.
- Accuracy of such measurement is approximately 50%.
- Window transmission is not a reliable adjustment.
- **Need to prevent drops on the lens.**
  - Installing a more effective hot air blower.

References

1. Vaisala, 2004: Vaisala ceilometer CL31 user's guide. Accessed 17 February 2017. [Available online at http://www.vaisala.com]
2. Wiegner, M. and J. Gasteiger, 2015: Correction of water vapor absorption for aerosol remote sensing with ceilometers. *Atmos. Meas. Tech.*, **8**: 3971–3984,doi:10.5194/amt-8-3971-2015.

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