Atmos. Meas. Tech. Discuss., 6, C4550–C4566, 2014
www.atmos-meas-tech-discuss.net/6/C4550/2014/

Atmospheric Measurement Techniques
Discussions
Open Access

Interactive comment on "An improved algorithm for cloud base detection by ceilometer over the ice sheets" *by* K. Van Tricht et al.

K. Van Tricht et al.

kristof.vantricht@ees.kuleuven.be

Received and published: 3 March 2014

1 Response to Reviewer Comment of Referee 2

We would like to thank the reviewer for the careful evaluation of our work. Many useful concerns were risen. We address each of the specific suggestions and questions (*in cyan italic*) in this response document with reference to Section in the revised version in red and *cited text in the revised version in magenta italic*.

A summary of the proposed changes in the revised version of this paper can be found in the document 'AC C4546: 'General response to Referee Comments', Kristof Van Tricht, 01 Mar 2014', published in the Interactive Discussion of the manuscript.

1.1 General comments

This is a very interesting work, aiming at a feasibility study of using a simple ceilometer to detect bottom height of lowermost optically-thin humid layers occuring in the polar regions. It is based on a development of an algorithm optimized for this purpose, which is successfully applied to measurements taken by two types of Vaisala ceilometers. A statistical study of the thin polar cloud layers is also performed and it shows significant diferences in therms of their occurence and optical depths at two stations in Arctic and Antarctic. I reckon this paper is worth publishing in the AMT, although it needs a minor revision beforehand. The possible improvements are suggested in the supplement.

We thank the reviewer for the detailed review. Below we address the questions that were raised in the review.

AMTD
6, C4550–C4566, 2014

1.2 Questions

1) Why have thin ice clouds no effects on precipitation which is not reaching the surface?

R2.1: We apologize for the misleading formulation. While we wanted to stress the importance of precipitation for the surface mass balance, precipitation not reaching the surface is of course also important in terms of surface energy balance. We have removed "not reaching the surface" in the revised version to include both the importance on mass and energy budget.

2) Standard algorithms by their definition do not aim at all at a detection of thin clouds, regardless of whether the thin clouds are important or not.

R2.2: We strongly agree with this point as also brought up by Referee 1 and we clarified every occurrence of comparison between the PT algorithm and the conventional algorithms.

3) "This paper presents the Polar Threshold (PT) algorithm that was developed to detect optically thin hydrometeor layers (optical depth $\tau \geq 0.01$)." At what range of cloud thickness? At what range of cloud altitudes?

R2.3: We agree that such a value should be accompanied by a height where such cloud occurs in the data. However, since we have estimated optical depths from the cloud base onwards and do not aim at detecting cloud tops, it is difficult to assess the correct height. We have addressed this issue by providing Figure 12 , that gives an estimate of the extinction profile based on the range-dependent sensitivity of the PT algorithm. A higher cloud must have a higher extinction value to be captured by the PT algorithm. Its optical depth must therefore be greater as well. Clouds with optical depths as low as 0.01 occur rather near the surface if they are detected by the ceilometer, as is now

AMTD

6, C4550–C4566, 2014

stated in the revised version (Page 23, lines 25-26). This answer corresponds to a similar concern by Referee 1 (R1.23 in the General Response document).

4) What are the temporal and horizontal resolutions of cloudy conditions?

R2.4: Since we are detecting clouds in separate profiles, the temporal resolution is dependent on the final running mean averaging that produces the final profiles. Therefore a cloud has to be persistent for at least 2.5 minutes to be picked up by the PT algorithm (if not removed by the SNR noise reduction method). This is also mentioned at Page 10, lines 20-22: *For the final analyses, the noise-reduced data were smoothed by applying a running mean over an interval of 2.5 min, determining the final temporal resolution of the data*.

5) A minimum cloud thickness of 50 m is a very thin cloud. Are you sure that by applied averaging you are able to detect statistically significant amounts of 50 m thin clouds?

R2.5: We agree with this comment and increased the minimum thickness a cloud layer must have to 90 m. This implies 9 range bins for PE and 3 range bins for Summit.

6) "The occurrence of optically thick layers, indicating the presence of supercooled liquid." Particles and/or droplets?

R2.6: We are referring to supercooled liquid droplets in the cloud. This is now being explicitly mentioned several times in the revised manuscript (e.g. Abstract, line 21: *The occurrence of optically thick layers, indicating the presence of supercooled liquid water droplets, shows a seasonal cycle at Summit with a monthly mean summer peak of 40 % ($\pm 4\,\%$).*

7) "The results of this study highlight the potential of the PT algorithm to extract information in polar regions about a wide range of hydrometeor types." Range of types? Or range of sizes? Anyway, you are not able to distingwith type nor size from ceilometer data, are you?

AMTD

6, C4550–C4566, 2014

R2.7: As discussed in R1.13 (in the General Response document), we agree that our formulation was confusing. In the revised version of the manuscript, we have adapted this to a more precise formulation.

8) "Ceilometers typically detect cloud bases at a distinct height and increasing backscatter (see e.g. Fig. 1)." What do you mean? Where is it in Fig.1? At what height range?

R2.8: We agree this formulation is confusing for the reader. We adapted this in the revised version as follows:
Ceilometers typically detect cloud bases in regions with high backscatter (see e.g. Fig. 1), that are likely related to liquid-containing portions in case of a mixed-phase cloud.

9) The fact that you need a person to operate the system on site? Isn't it an important limitation for polar applications?

R2.9: We agree with the reviewer and have added this in the manuscript (Page 5, lines 23-24: *and the need for a manned station to operate such systems on site*.)

10) "including the detection of very optically thin hydrometeor features" I feel it is not clear what you mean by this: hydrometeor = liquid particles and/or ice particles?, feature = layer?

R2.10: We mean to detect hydrometeor layers and have adapted this as such in the manuscript (Page 5, line 25): *including the detection of very optically thin ice layers*.

11) "Since the transmittance of the atmosphere is in general unknown, conversion of attenuated backscatter β_{att} to corrected backscatter β is not straightforward." I am not sure what you trying to say. Are you converting β_{att} to β_{att} corrected, which is not equal to β true?

R2.11: We apologize for the confusion in the definition of β_{att}, $\beta_{corrected}$ and β_{true}. β_{att}

AMTD
6, C4550–C4566, 2014

is the value that is reported by the ceilometer. It is the true backscatter coefficient β_{true} that has been subject to attenuation in the atmosphere. The true backscatter coefficient β_{true} therefore is the attenuated backscatter coefficient β_{att} corrected for attenuation. To avoid any confusion, we have replaced every occurrence of "corrected backscatter" by "true backscatter" in the revised version.

12) "The vertical resolution is 30 m for the CT25K." This was my concern for the abstract, can you claim to be able to detect 50 m thin layer when you average over 30 m? I am sceptic here.

R2.12: As discussed in R2.5, we agree with this comment and increased the minimum geometrical thickness of a hydrometeor layer to 90 m.

13) For answering the question of multiple scattering effects you should take to account not only the laser beam divergence but also the size of the field of view of the two instruments. And you did not specify this number for neither of the two in struments. I reckon, you should give a comment on that.

R2.13: We have included this information in Table 1 in the revised version. The field-of-view of both instruments is relatively small, justifying the approximation of no multiple scattering that we have made (Page 8, lines 2-3: *Due to the low beam divergence and small field-of-view of the CT25K ceilometer (Table 1), the effect of multiple scattering is small*).

14) "This includes ice particles and supercooled liquid droplets as well as any form of precipitation." Why? Precipitation is NOT a cloud? Is your algorithm counting it as a cloud? Please clarify this.

R2.14: As related to R1.2 (in the General Response document), the PT algorithm is indeed triggered by precipitation. While the conventional algorithms try to locate the source cloud of the precipitation, the PT algorithm will place the base height of the

AMTD

6, C4550–C4566, 2014

Interactive Comment

hydrometeor layer at the bottom of the detected precipitation. A motivation for this is now given in the revised manuscript under Section 3 as follows:

We do not attempt to distinguish between clouds and precipitation, since our broad definition of a cloud and its importance for the energy and mass budget includes precipitation as well. This is different from the conventional algorithms that try to identify the base of the cloud above the precipitation layer given that the latter does not entirely attenuate the signal.

15) "As the physical variability of the background signal obtained for clear polar air is low." I assume this physical, atmospheric variability is what you are talking about, because of course the variability in the polar clear air signal is very high due to the high noise and measurement at a detection limit.

R2.15: We agree and indeed talk about physical, atmospheric variability. As now further clarified in Section 3, the background signal in clear polar air is very low. Because of this, the variability in this background signal is very low as well. The approach by Platt et al. (1994) can therefore not be used as such.

16) The range correction does not worsen the signal, as after the range correction some features in the signal can be seen more clearly. However, it increases the noise level in the signal.

R2.16: We agree with the reviewer and reformulated the sentence as:

The fast decrease of signal with range and its range correction (evident from the lidar equation in e.g. Munkel et al., 2006) leads to increasing noise levels higher in the profile.

17) Please rewrite Eq. 1

R2.17: We agree that Eq. 1 should be formulated in a more mathematical way. We propose the following changes in the revised version:

AMTD
6, C4550–C4566, 2014

The SNR was calculated for every separate height range bin at time step i and range bin j as:

$$\mathit{SNR}_{i,j} = \frac{\overline{\beta}_{i,j}}{\sqrt{\frac{1}{2M}\sum_{k=-M}^{+M}\left(\beta_{i+k,j} - \overline{\beta}_{i,j}\right)^2}},$$

which is the ratio of the temporal mean $\overline{\beta}_{i,j}$ and standard deviation of the attenuated backscatter over $\pm M$ time steps around time step i and range bin j. Provided that the temporal resolution of the individual profiles is 15 s, M is equal to 20 profiles for a time interval of 10 min.

18) "The atmospheric fluctuations in this interval are small compared to the instrument noise such that the standard deviation over the interval mainly contains internal noise from the instrument." That should depend on height you are taking to account. I would say, at low altitudes the atmospheric variability is much higher than the noise, isn't it?

R2.18: Indeed, at low altitudes the atmospheric variability is much higher than the noise, whereas at high altitudes it will be the opposite (i.e., noise $>$ atmospheric variability). However, as discussed in R1.5 (in the General Response document), our experience is that this is not a problem in practice. If the atmospheric variability near the surface is high, this is related to hydrometeors. As a consequence, the mean backscatter will be high as well, meaning that these periods are not flagged as noise in this procedure.

19) "The SNR threshold was set to 1 as was also done by Heese et al. (2010), and pixels with a lower SNR were removed." Does that mean that if you obtain low, positive mean backscatter from this averaging you must still remove it?

Full Screen / Esc

Printer-friendly Version

Interactive Discussion

Discussion Paper

R2.19: Related to the previous question, this will depend on the standard deviation in the 10 min. Low, positive mean backscatter will be removed if it is lower than the standard deviation (when SNR threshold is 1), whereas it will be retained when it is higher. Consequently, the removal (or not) depends more on the persistency of the signal compared to noise than on the value of the backscatter. As also discussed in R1.2 (in the General Response document), we have assessed the impact of our approach on the results by allowing the SNR threshold to vary between 0.5 and 1.5, of which the results are indicated by the shaded areas in Figures 4, 6, 10 and 11.

20) "In a second step, the noise-reduced data were smoothed by applying a running mean over an interval of 2.5 min." So for SNR calculation and pixel removal you average over 10 min and then what is left over you average to final profile of 2.5 min? I feel this may be not clear enough.

R2.20: The reviewer has correctly interpreted what we mean in the text. To avoid possible confusion, we have further clarified it as: *For the final analyses, the noise-reduced data were smoothed by applying a running mean over an interval of 2.5 min, determining the final temporal resolution of the data.*

21) "The PT algorithm processes every vertical profile." You mean every 2,5 min avarage profile ?

R2.21: The algorithm processes indeed the final 2.5 min averaged profiles. We clarified this in the revised version (Page 12, line 21: *The PT algorithm processes every vertical 2.5* min *averaged and SNR-processed profile separately*).

22) "The CBH detection is triggered if the attenuated backscatter at a certain height in the vertical profile exceeds the threshold." Maybe you could give the theshold precisely also here?

R2.22: The actual backscatter threshold that is used by the algorithm is determined

AMTD
6, C4550–C4566, 2014

only in Section 3.3. We therefore think that it would be inappropriate to mention this threshold already in the general method.

"After the trigger, the algorithm also considers the mean attenuated backscatter 50 m above the trigger point (60 m for the Summit ceilometer). If the backscatter value at this elevated height also exceeds the threshold, the height of the trigger point is set as the CBH. This ensures a certain amount of robustness of the signal at the detected CBH, meaning that a hydrometeor layer should have a minimum geometrical thickness to be detectable by the algorithm." Why not checking all points at that range? Then you could, at least for the PE station, try to see thinner than 50 m layers?

R2.23: The formulation as it was in the original manuscript caused some confusion. The algorithm does not only look at one range bin a certain altitude above the trigger point, but also at all range bins in between. Moreover, as described in R2.5, we increased the minimum thickness of a cloud to 90 m, instead of the original 50 m. Although in theory a geometrically thinner clouds should be detectable by at least the PE ceilometer, we chose for consistency between the different ceilometers, thereby also decreasing the chance of false triggers. For clarification, we therefore propose following changes in the revised version of the manuscript:
After the trigger, the algorithm also considers the mean attenuated backscatter over the minimum cloud thickness distance (set to be 90 m *for both systems) above the trigger point. If the backscatter value over this elevated height also exceeds the threshold, the height of the trigger point is set as the CBH. This ensures a certain amount of robustness of the signal at the detected CBH, meaning that a hydrometeor layer should have a minimum geometrical thickness of 90* m *to be detectable by the algorithm.*

24) "This approach was found to perform best in identifying the base of optically thin hydrometeor layers compared to other algorithms." The other algorithms were not designed for the same purpose, they are not even comparable. I reckon the beauty of your approach is that you did optimize it for the detection of thin polar clouds, and that is the *only one at the moment for serving this purpose. This comparison is not appropriate.*

R2.24: We agree with the reviewer and refer to R2.2.

25) "The optimal threshold is one that allows the detection of hydrometeor layers with a low optical depth while not triggering the algorithm in clear sky conditions." Well, it may be also difficult to distinguish it from the aerosol layers present within the boundary layer, or you do not detect any aerosol?

R2.25: As we describe in Section 4.3, we acknowledge that such sensitive algorithm will inevitably be triggered sometimes in case of elevated aerosol layers:
The drawback of the high sensitivity of the algorithm (detection of features with $\tau = 0.01$) is that CBH detection can sometimes be triggered by layers of elevated aerosol contents. This only rarely happens over the Antarctic ice sheet due to its remote location and clean air (e.g., Hov et al., 2007). This is not the case for Greenland, which is much closer to industrialized countries. In the events of elevated aerosol contents, some aerosol layers will inherently be identified falsely as cloud (Shupe et al., 2011), an issue that occurs in other parts of the Arctic as well, for instance in Svalbard (Lampert et al., 2012).

26) "For example, increasing the threshold from $3 \times 10^{-4}\,\mathrm{km}^{-1}\,\mathrm{sr}^{-1}$ to $30 \times 10^{-4}\,\mathrm{km}^{-1}\,\mathrm{sr}^{-1}$ at Summit decreases the amount of detections by 10 % and increases the mean CBH by 70 m, while at PE the amount of detections is decreased by only 2 %, though the mean CBH increases by 190 m." Does that mean that at PE there are more optically thin clouds which are span over the larger altitude range in the troposphere? Is that what you expect? Or is that an artifact due to e.g. different height resolution of PS and Summit instruments?

R2.26: Our results indicate that there are more optically thin clouds at Summit that are no longer detected when you slightly increase the threshold, whereas these clouds are relatively thicker at PE. However, the altitude range at which they occur is less variable

AMTD

6, C4550–C4566, 2014

Interactive Comment

Full Screen / Esc

Printer-friendly Version

Interactive Discussion

Discussion Paper

at Summit compared to PE. We believe this is not related to artifacts but represents true results. Nevertheless, we report these numbers primarily to motivate our backscatter threshold choice.

27) "The Summit ceilometer data in Fig. 7b indicate that precipitation reaches the surface after 14 h. Since the first two range bins of the profile were excluded, the CBH is located at 60 m in such conditions." But in the case when there is precipitation, than the CBH is at the level of clouds, isn't it? How does your algorithm deal with that?

R2.27: For addressing this question, we refer to R2.14. The high sensitivity of the PT algorithm triggers cloud base detection at the first detectable concentration of hydrometeors in the profile. Since precipitation is equally important for surface mass and energy budget, while it is not feasible to try to locate the base of the source cloud with the PT algorithm, CBH is reported at the base of the precipitation layer in such events.

28) In both cases, the PT CBH is significantly lower compared to the Vaisala and THT CBH. At both study sites, the Vaisala CBH is situated much higher." Well, not always, e.g. Fig. 7a at about 4-6 UTC it is not? "In the case of optically thin features with only low backscatter values, Vaisala sometimes reports the profile as being clear sky." You mean e.g. Fig.7a from 0-4 UTC?

R2.28: We agree that Vaisala does not always report the CBH much higher, only most of the time. Moreover, the clearest example of clear sky reports from Vaisala, while PT detects a cloud, is Fig. 7b from 0-12 UTC. We propose clarification in the text as follows:
In both cases, the mean PT CBH is significantly lower compared to the Vaisala and THT CBH. At both study sites, the Vaisala CBH is mostly situated much higher in the cloud, where backscatter values are peaking. This is to be expected since the primary goal of the Vaisala algorithm is to detect visibility changes for pilots. In the case of optically thin features with only low backscatter values, Vaisala sometimes reports the

profile as being clear sky (e.g. Fig. 7b from 0-12 UTC).

29) Atmospheric sounding by radiosondes has been used in the past for cloud detection validation in polar regions, where higher values of RH are associated with clouds (Gettelman et al., 2006; Minnis et al., 2005; Tapakis and Charalambides, 2012). The RH at the level of the detected CBH should in general be high, assuming the actual presence of hydrometeors at this height. An example case with ceilometer attenuated backscatter measurements and the radiosonde-derived RHice is shown in Fig. 8, which shows that the RHice increases significantly at the cloud base." Higher meaning what % of RH? Please give an exact definition because not always higher RH is a clear indication of cloud. Significantly meaning of how much? RH beyond 100 % ? And at what range? Heights between 0,5-1,4 km? Where in this range is the CBH in your opinion and what is found by the algorithm? Note, that also at about 2 km there is a significant increase of RH but in Ceilometer data I see no clouds.

R2.29: We agree that our formulation was unclear. We have reformulated this section and we added extra information for clarification:
Atmospheric sounding by radiosondes has been used in the past for cloud detection validation in polar regions, where clouds are in general characterized by high RH_{ice} values (Gettelman et al., 2006; Minnis et al., 2005; Tapakis and Charalambides, 2012). Since our primary goal is the detection of optically thin ice clouds, cloud bases will not always be characterized by significant ice-supersaturations, as is the case in the liquid-containing portion of the clouds. Hence, we do not apply radiosonde cloud detection methods such as proposed by Jin et al (2007). Instead, radiosonde-derived statistical RH_{ice} distributions are used to assess the performance of the PT algorithm. The RH_{ice} at the level of the detected CBH should in general be high, assuming the actual presence of hydrometeors at this height, while this is not necessarily the case for clear-sky RH_{ice}. Statistically, clear-sky RH_{ice} values should therefore be lower than cloudy RH_{ice} values. An example case with ceilometer attenuated backscatter measurements and the radiosonde-derived RH_{ice} is shown in Fig. 8. Visual cloud base determination

AMTD

6, C4550–C4566, 2014

based on our definition of a cloud indicates a CBH around 500 m. The radiosonde data show that the RH_{ice} increases significantly (by 45 % at this cloud base, although its absolute value does not indicate ice-supersaturation).

30) "The test indicates that the cloud base RHice values are indeed significantly higher than the clear sky RHice values (p value < 0.01), suggesting that the PT algorithm performs well. Could you explain, I see no connection.

R2.30: We have further explained what we mean in the revised version:
We used a one-sided nonparametric two-sample Kolmogorov–Smirnov test to determine if the RH_{ice} measurements of cloud bases were significantly higher compared to clear sky RH_{ice} values (Hájek et al., 1967). The test indicates that the cloud base RH_{ice} values are indeed significantly higher than the clear sky RH_{ice} values (p value < 0.01). If the PT algorithm would often be triggered in clear sky, both distributions would not statistically differ significantly which suggests that the PT algorithm performs well.

31) There is a paper by Lampert et al., 2012 about the humid layers detection at Svalbard. I am wondering how much your results at Summit compare with their paper.

R2.31: We thank the reviewer for mentioning this study. We have read this paper with interest and included the reference at the point where we mention episodes of elevated aerosol layers at Summit (Page 19, lines 11-12). The sensitive PT algorithm could be triggered in such events. However, comparison of the results by Lampert et al, 2012 with the results we found at Summit is not straightforward. The climatology of Ny-Alesund is very different from Summit, being much more maritime. Since it is extremely difficult to assess the performance of our work at a maritime site, direct comparison is outside the scope of our study.

32) "As our measurements include a variety of atmospheric conditions from ice to supercooled liquid, we assume an average ratio of S = 20 sr for a rough estimation of *the extinction coefficient." Yes, this is very rough assumption and you do not show that you actually can make that assumption. Thus, I think it would be very helpfull if you made an example calculation/estimation of what range of results you would get if you would use the 16 sr and 25 sr, just to give a reader the feeling of how much you risk by taking this average. It will be also a kind of error estimate due to this assumption.*

R2.32: We agree with the reviewer that an uncertainty estimate was lacking. We have conducted the analyses with the lower and upper estimates of the lidar ratio (16 sr and 25 sr) and we found an uncertainty on the derived optical depths of 25 %, which is added in the revised version (Section 4.3) as:

We assessed the degree of uncertainty due to the lidar ratio approximation, by varrying this ratio S between $16\,\mathrm{sr} < S < 25\,\mathrm{sr}$. The resulting optical depth uncertainty was 25 %. This agrees well to similar studies with ceilometer by e.g. Wiegner and Geiß (2012).

33) "This study indicates that using an adapted algorithm for cloud base height detection, the robust and relatively low-cost ceilometer can be successfully used to extract information on a wide range of hydrometeor types." You did not convince me that you can distinguish type of pareticles, nor their size. Thus, please rewrite the sentence to stress our what you mean.

R2.33: We agree with the reviewer that we are not able to distinguish between hydrometeor types. We have clarified this in the revised version as:

This study indicates that using an adapted algorithm for cloud base height detection, the robust and relatively low-cost ceilometer can be successfully used to extract information from various hydrometeor layers over the ice sheets, including the frequently occurring optically thin ice layers.

34) I would add two references: Lampert et al. (2012) and Wiegner and Geiß (2012)

R2.34: We thank the reviewer for pointing us to this relevant literature and have included these references in the revised version.

AMTD

6, C4550–C4566, 2014

Interactive Comment

Full Screen / Esc

Printer-friendly Version

Interactive Discussion

Discussion Paper

35) Fig.5: Why the average profile on the right hand site is below zero from about 2,5 km, i.e. after the liquid cloud? Are the data not noise corrected here? The PT algorithm aims at detecting lower most layer, would it be very difficult that it would detect also liquid layer at the same time?

R2.35: We thank the reviewer for pointing at this issue and we discovered a processing problem during the plotting of this figure. We have solved this issue for the revised version. However, the case that was used for Figure 5 was not very clear anymore. We have therefore found another case that shows more clearly what an example profile looks like. We show on purpose a profile without noise correction to emphasize what the original profile looks like and where the final CBH is placed by the different algorithms.
Regarding the reviewer's second question, it could be possible in theory to detect the base of liquid layers at the same time. The algorithm would therefore be run in two cycles with a different sensitivity (as was also done in Section 4.4). However, this is not the primary scope of this study, and including the detection of liquid layers in the core algorithm would require numerous additional sensitivity analyses to assess the impact of the liquid backscatter threshold choice on the results. We have therefore excluded this option in the main PT algorithm.

36) Fig.7 Why PT algorithm does not detect any cloud from 0-3 UTC on the upper subfigure? There are no clouds there? What does detect then the THT algorithm?"

R2.36: Referring to R2.35, we have discovered a processing issue for this case. This problem has been solved, making the case that was shown in Fig. 7 less suitable for clarifying our point. We have found another case (14 March, 2011), which is more representative for the PE observations. In the current Figure 7, no false detections by the THT algorithm are reported anymore.

1.3 Specific comments

Specific comments such as technical corrections and suggestions provided by Referee 2 throughout the text have been inserted into the revised manuscript.

AMTD
6, C4550–C4566, 2014