Final report on the operation of a Campbell Scientific CS135 ceilometer at Chilbolton Observatory

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RAL Space

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Summary

A Campbell Scientific CS135 ceilometer has been operating at Chilbolton Observatory in a configuration suitable for data analysis since 11th Oct 2012. There have been some changes to the data acquisition rate and algorithms since then. Data from twelve days since that date have been selected as case studies for comparison with other Chilbolton Facility for Atmospheric and Radio Research (CFARR) instruments. These have been chosen to highlight the performance of the CS135 for a variety of cloud heights and types and also during rain and snow.

The CS135 performance has been assessed in 4 ways. Firstly time-height plots of the range-corrected signal are compared with two other CFARR lidars/ceilometers and one 35 GHz cloud radar. Secondly the reported cloud base heights (CBHs) are compared between the CS135 and the Vaisala CFARR CT75K ceilometer. Thirdly individual profiles are compared to show the performance of the CBH algorithm from each ceilometer. Finally the assignment of the number of cloud layers (0 to 4) and obscuration when no cloud is detected are compared for the 2 ceilometers.

Case study dates

Table 1 shows details of the days chosen for the case study. Unless stated, there was no precipitation during the selected days.

Date	Conditions, reason for selection, comments
Group 1	
03/01/13	Stratocumulus mostly below 0.5 km. Lowest cloud of selected days.
12/02/13	Stratocumulus mostly below 1.5 km. Higher cloud than 03/01/13.
30/11/12	Mixed cloud including super-cooled water cloud at ~ 5km from 00UT to 09UT.
19/12/12	Approaching warm front with descending cloud, initially ice cloud. Rain from ~0930UT to end of day.
18/12/12	High (~7 – 9 km) ice cloud not detected by CS135 nor CT75K ceilometers. With 19/12/12 data gives qualitative assessment of sensitivity.
05/03/13	Mixed supercooled water and ice clouds between 3 km and 7 km from 18UT.
Group 2	
15/10/13	Stratocumulus below 1.0 km.
30/10/13	Cumulus up to 2.0 km and brief supercooled water at around 4 km from 17UT to 18UT. Rain from 21UT onwards.
05/11/13	Mixed ice and supercooled water cloud in the range 4 – 7 km from 12UT to 23UT. Rain until 1030UT.
07/11/13	Ice cloud for most of day from 3 km to 10 km, brief occurrences of supercooled water.
Group 3	
18/01/13	Snow until 13UT and light snow 15UT to 18UT.
09/02/13	Snow from 04UT to 16UT and 22UT onwards.

Table 1: Details of case study days (in 3 groups as described later).

Case study instruments

4 instruments are used to show time-height plots of clouds and rain during the case studies.

The **CS135 and CT75K ceilometers** both operate at a wavelength of approximately 905 nm. They produce similar elastic backscattering coefficient profiles and also produce values for CBH. They report a maximum of 4, 3 CBHs respectively. An anti-speckle algorithm, effectively a median filter, is applied to the CT75K data. CT75K data are produced with a nominal calibration, but a further calibration factor is calculated using the measured backscattering from optically thick stratocumulus cloud.

The **Halo Doppler lidar** is a heterodyne system operating at 1.55 μm. It has been included in the study because it is more sensitive than the ceilometers and so can see more tenuous/high ice cloud. It does not report CBHs so cannot be included in the CBH comparison study.

The **Copernicus 35 GHz cloud radar** is an in-house developed system which also operates continuously. A cloud radar is useful to the comparison because it more easily detects multiple cloud layers. It is relatively more sensitive to larger particles than a lidar, so can easily detect tenuous ice clouds. It is less sensitive to the relatively small water droplets in cumulus and supercooled water clouds, particularly at altitudes below 2 km. Like the Doppler lidar it does not report a CBH.

Case study results

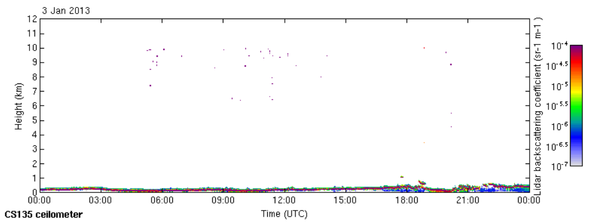
The results of the case studies are shown below in figures 1-3. 1 page is devoted to each day. The cases studies are split into 3 groups:

1. An early set, up to March 2013, discussed previously in the interim report but reproduced here.
2. A later set, from October and November 2013. They are discussed separately because there have been changes to the operating conditions and data acquisition algorithms in the intervening period. Treating them separately makes it easier to detect any differences in performance.
3. 2 snow cases from January and February 2013. These are discussed separately as falling snow is likely to provide challenging conditions for detecting cloud bases.

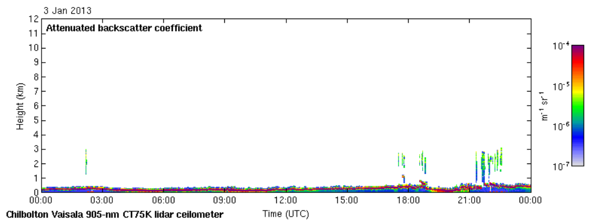
The first four plots for each day show time-height plots from each of the 4 instruments. The height scale was recreated for each ceilometer using the range resolution and azimuth angle reported in the data files. On 18/10/13 the scaling of the CS135 backscattering profile data was changed by a factor of 0.0548. Prior to that date the data in the CS135 files are given in units of $(1.83 \times 10^6$ srad km$)^{-1}$, since then the units are $(10^5$ srad km$)^{-1}$. It should be noted however that this calibration is approximate; a calibration using stratocumulus cloud was applied on 03/12/13, after the data used in this report were recorded. A stratocumulus calibration has been applied to all CT75K and Halo lidar data used in this report. Hence some difference in signal magnitude is to be expected between the 3 lidars.

The second four plots show the results of the CBH comparisons between the CS135 and CT75K. The first shows the comparison of all as-recorded CBH values over a 0 – 12 km height range. The second shows the same data over magnified time and height scales. For the third and fourth plots some additional processing was carried out. The CS135 and CT75K are not time-synchronised and report profiles at different time intervals. The CT75K reports measurements at 30 s intervals. The CS135 time intervals have changed during the measurement period from 60 s at the start to 10s at the end. To allow regression analysis of the CBH the data from both instruments were time-averaged to 5 minute intervals. Only cases where 1 CBH was reported were included in the average, to attempt to avoid cases where multiple cloud layers would cause an unintentional spread in the measurements. The third plot shows the time-averaged first CBH values from each instrument and the fourth plot shows the same data as a scatter plot rather than a time series. On some of the scatter plots, on days when predominantly water clouds (including supercooled water) and no precipitation were present, a dashed manual fit line is shown. This is discussed further in the next section.

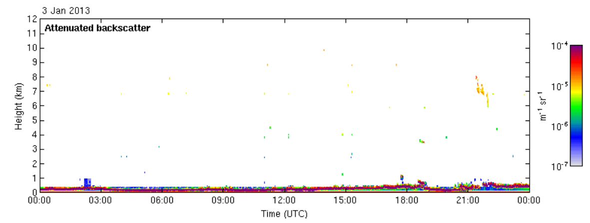
3rd January 2013



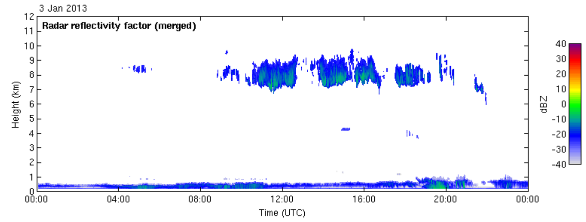
CS135



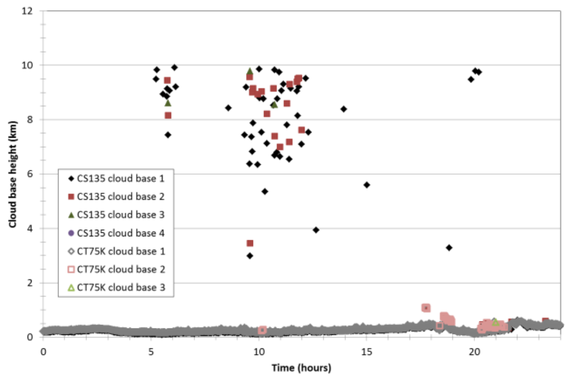
CT75K



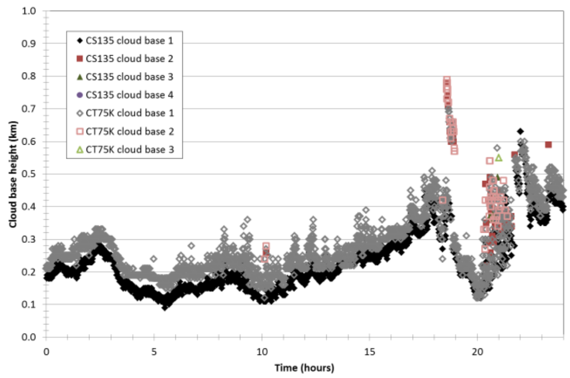
Doppler lidar



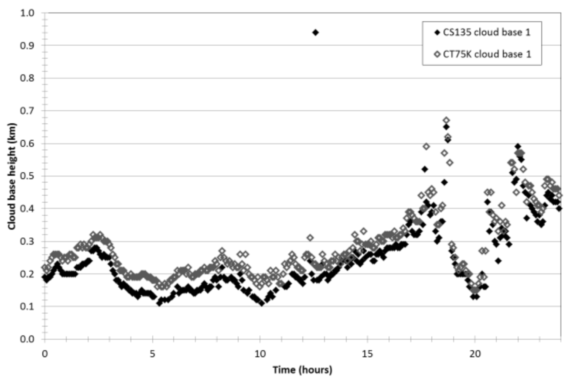
Copernicus 35 GHz radar



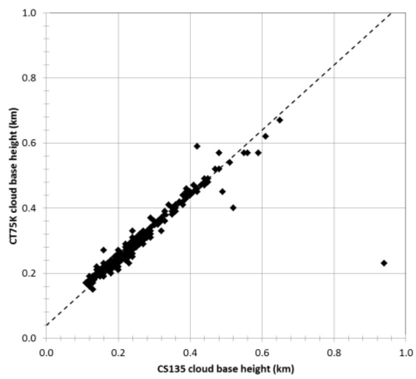
All cloud base heights



All cloud base heights, magnified scale

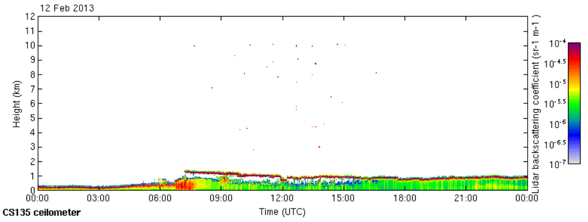


5 minute average 1st cloud base height

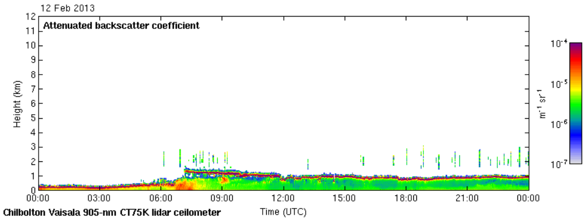


5 minute average 1st cloud base height, scatter plot

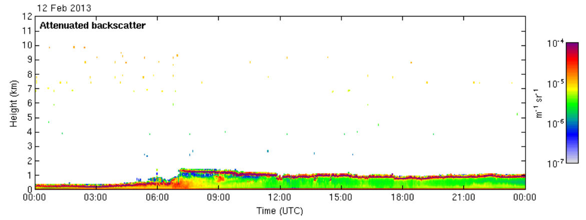
12th February 2013



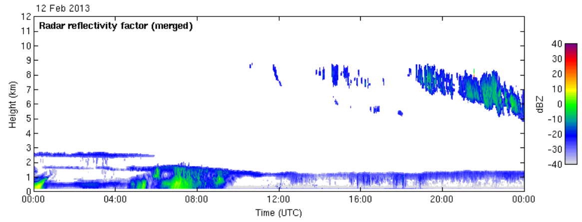
CS135



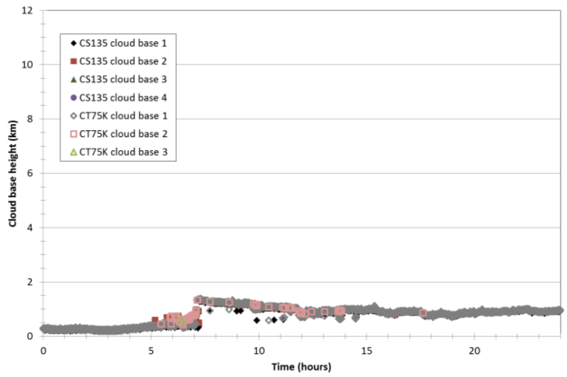
CT75K



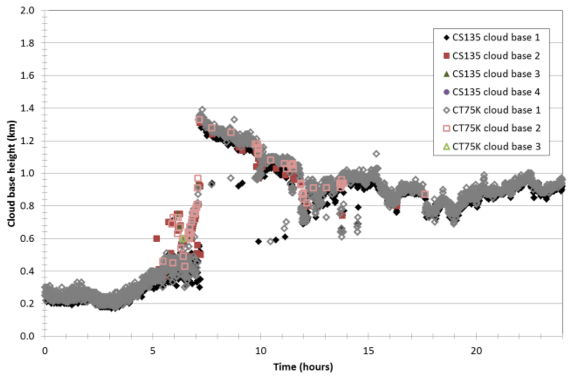
Doppler lidar



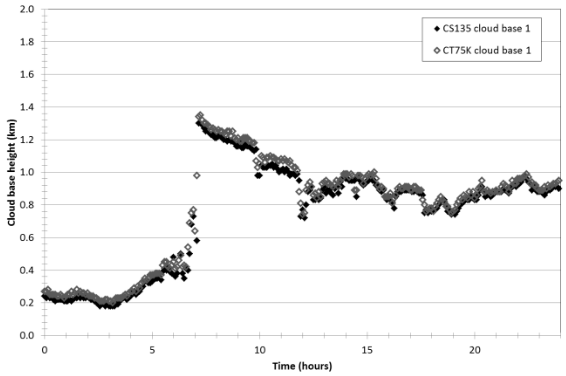
Copernicus 35 GHz radar



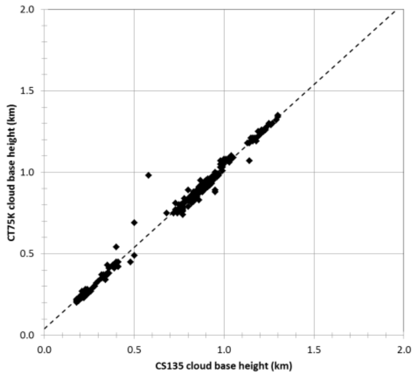
All cloud base heights



All cloud base heights, magnified scale

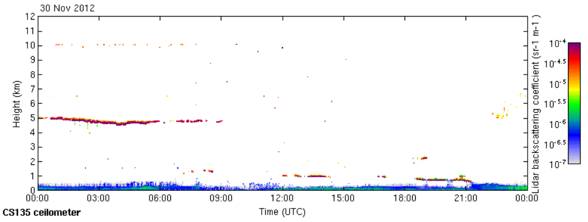


5 minute average 1st cloud base height

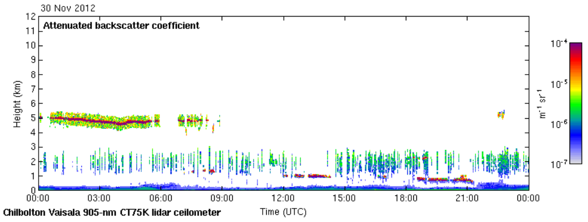


5 minute average 1st cloud base height, scatter plot

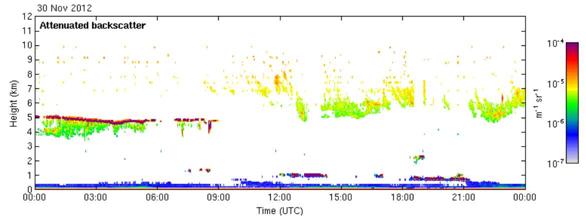
30th November 2012



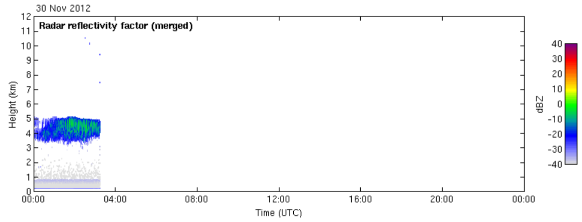
CS135



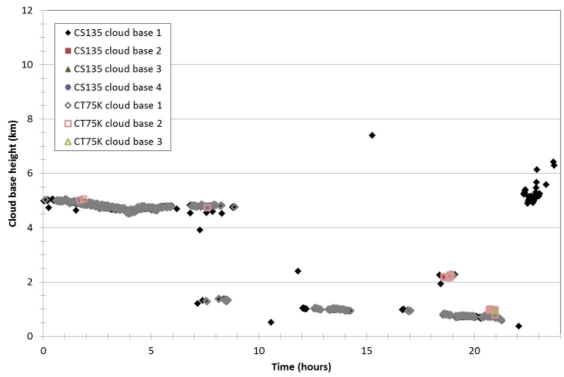
CT75K



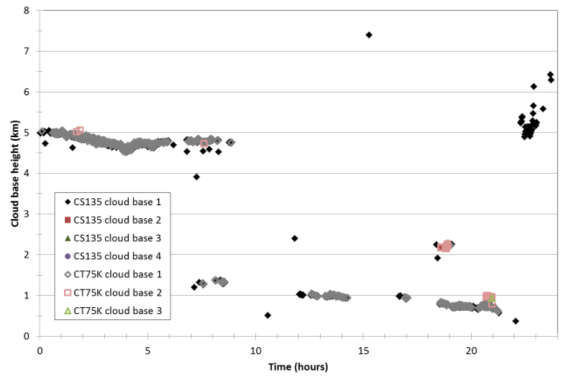
Doppler lidar



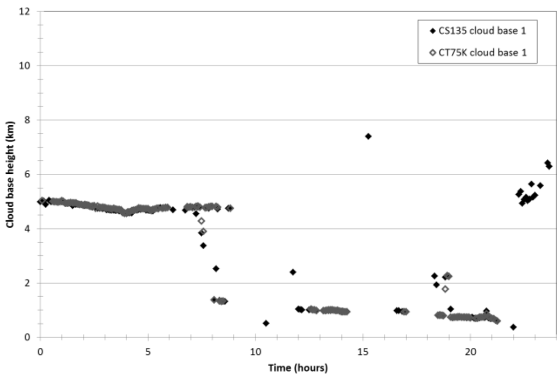
Copernicus 35 GHz radar (incomplete)



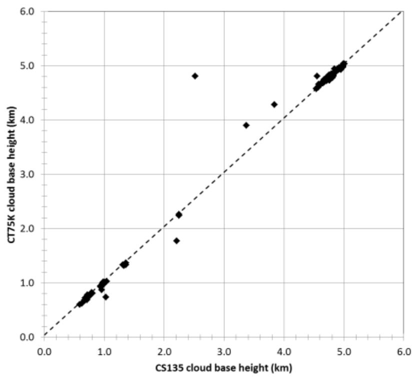
All cloud base heights



All cloud base heights, magnified scale

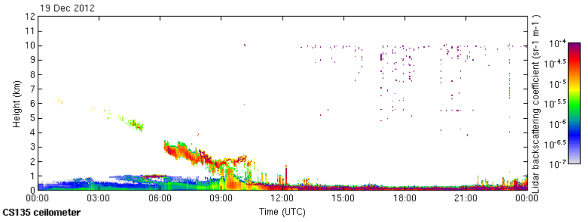


5 minute average 1st cloud base height

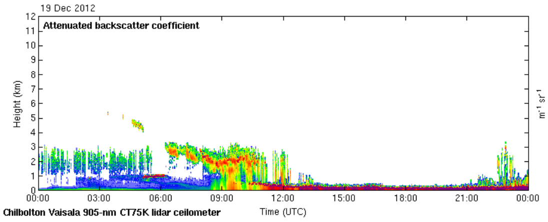


5 minute average 1st cloud base height, scatter plot

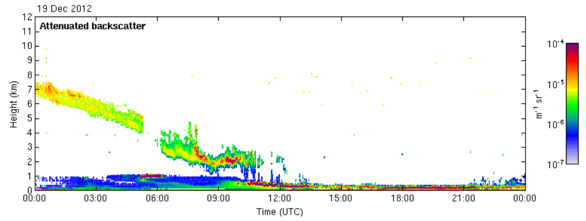
19^{th} December 2012



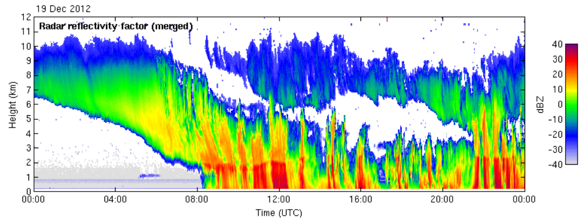
CS135



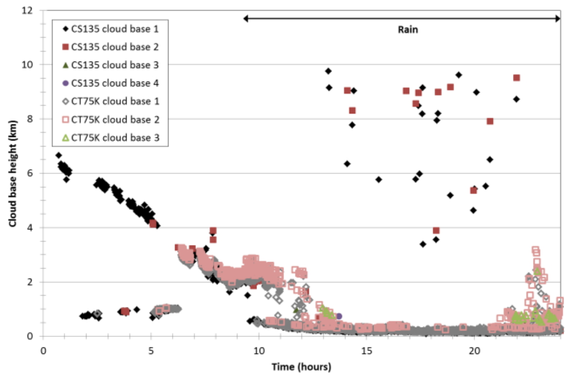
CT75K



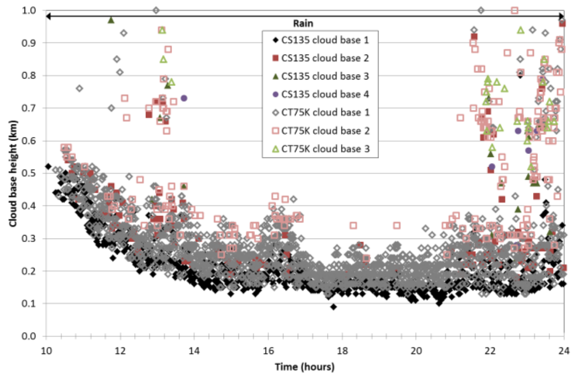
Doppler lidar



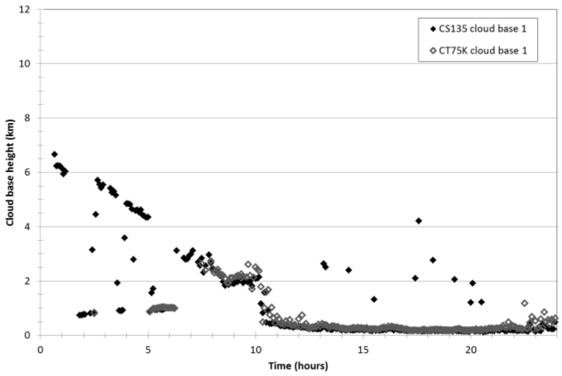
Copernicus 35 GHz radar



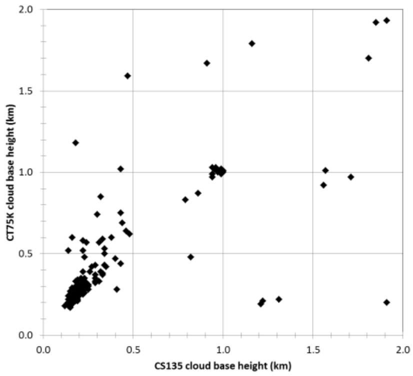
All cloud base heights



All cloud base heights, magnified scale

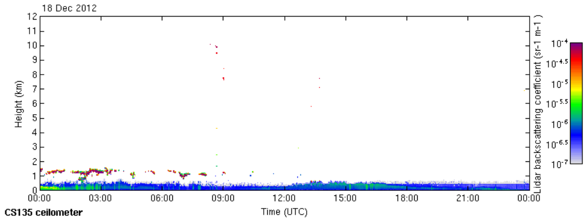


5 minute average 1^{st} cloud base height

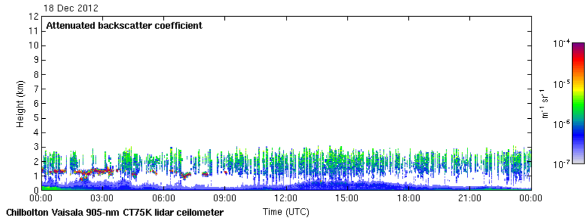


5 minute average 1^{st} cloud base height, scatter plot

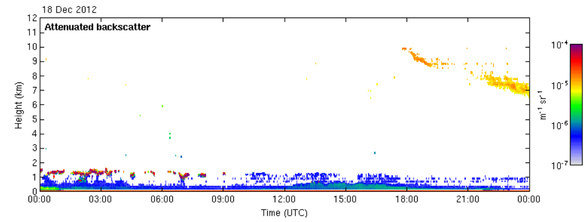
18th December 2012



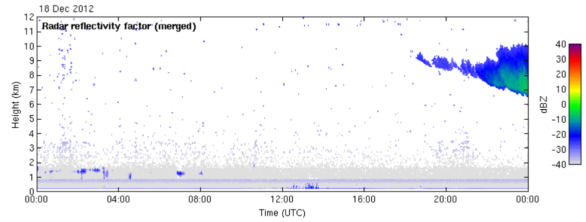
CS135



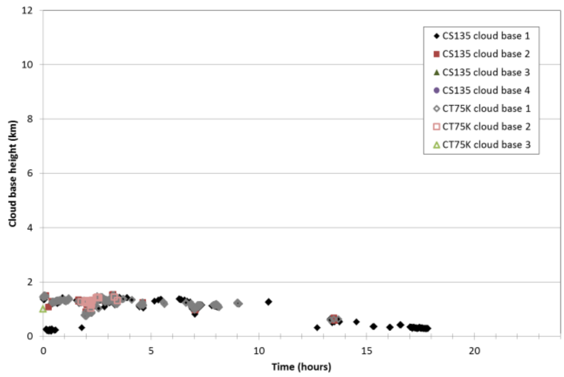
CT75K



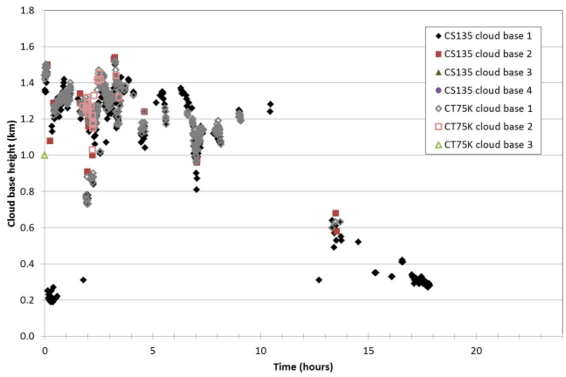
Doppler lidar



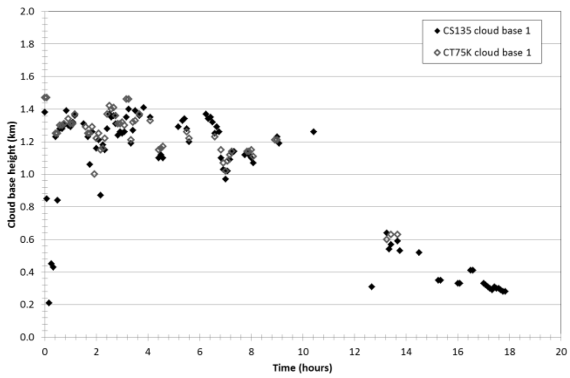
Copernicus 35 GHz radar



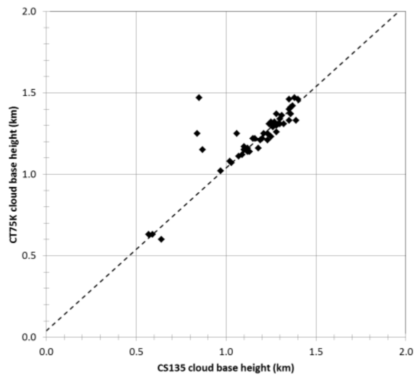
All cloud base heights



All cloud base heights, magnified scale

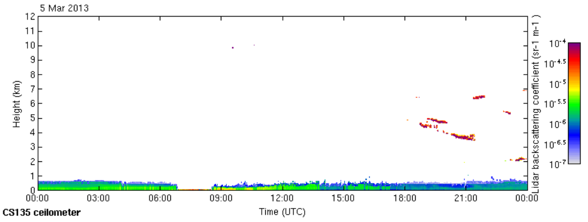


5 minute average 1st cloud base height

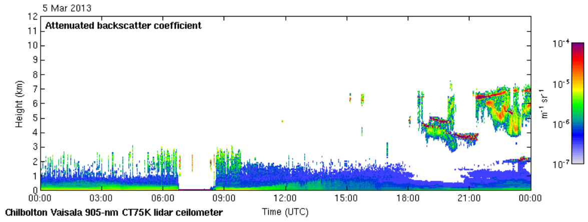


5 minute average 1st cloud base height, scatter plot

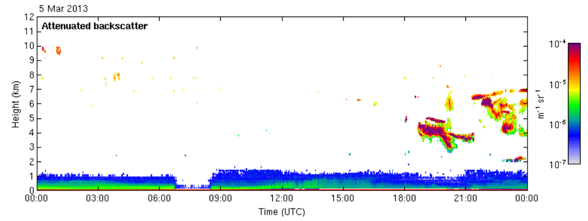
5th March 2013



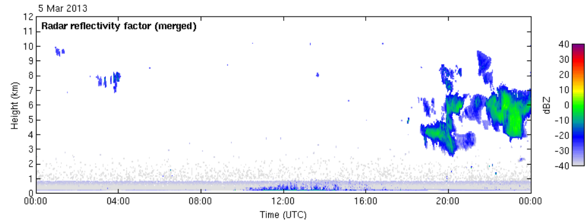
CS135



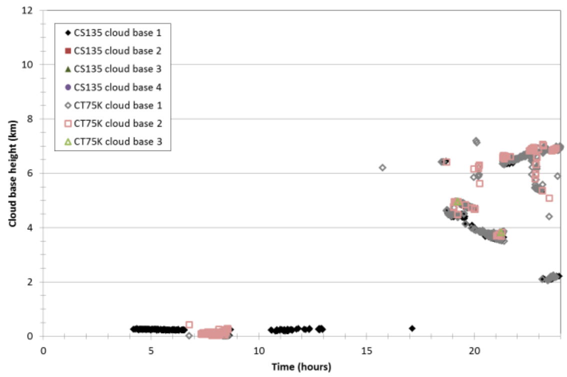
CT75K



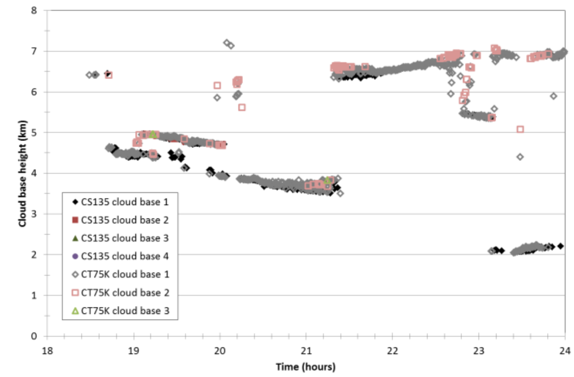
Doppler lidar



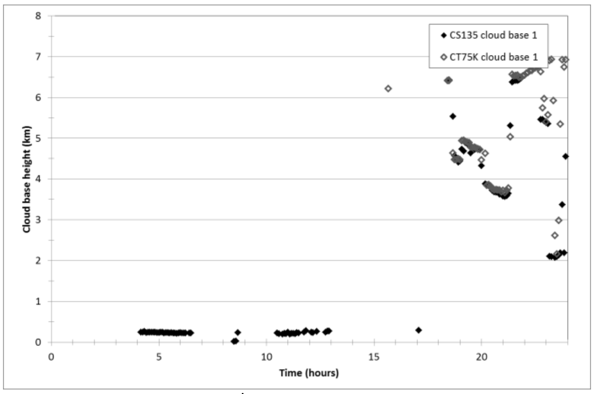
Copernicus 35 GHz radar



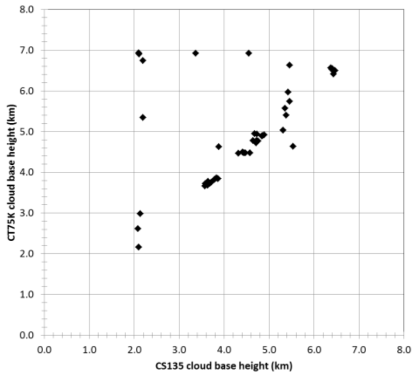
All cloud base heights



All cloud base heights, magnified scale



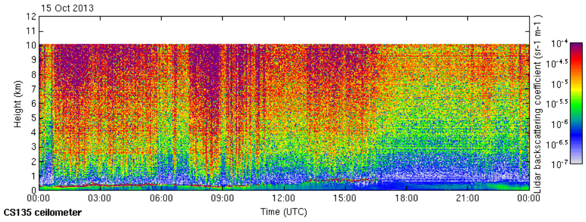
5 minute average 1st cloud base height



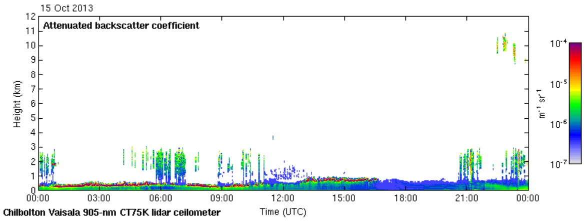
5 minute average 1st cloud base height, scatter plot

Figure 1: Intercomparison of backscattering coefficient and cloud base height for 6 days early in the operation of the CS135 at Chilbolton Observatory.

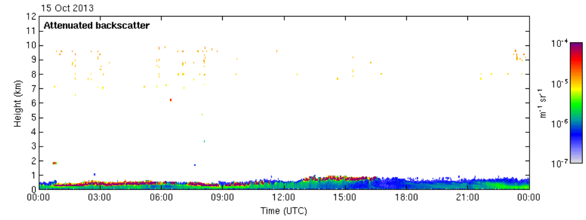
15th October 2013



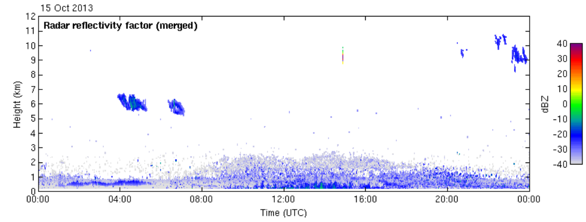
CS135



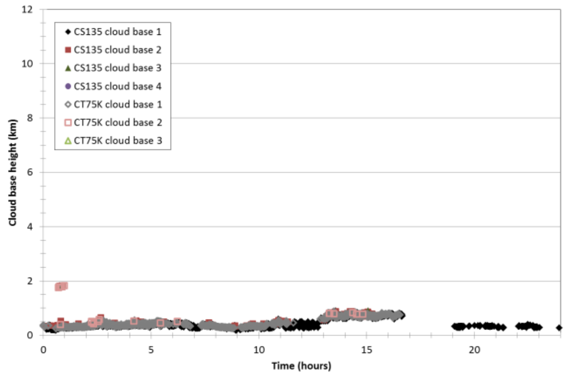
CT75K



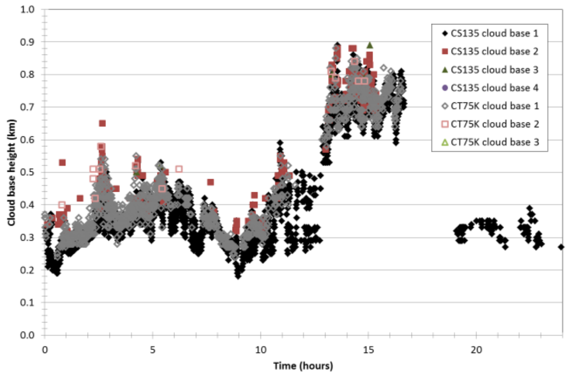
Doppler lidar



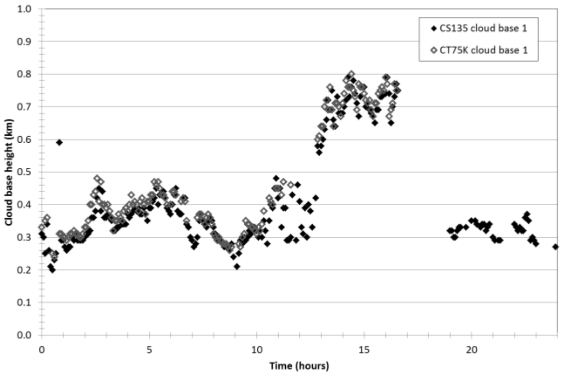
Copernicus 35 GHz radar



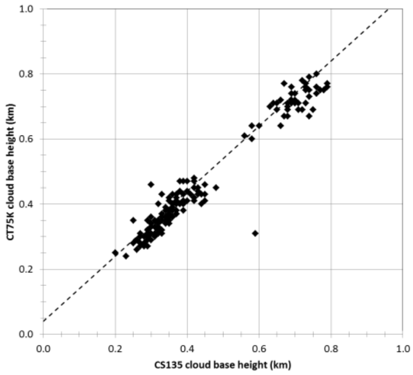
All cloud base heights



All cloud base heights, magnified scale

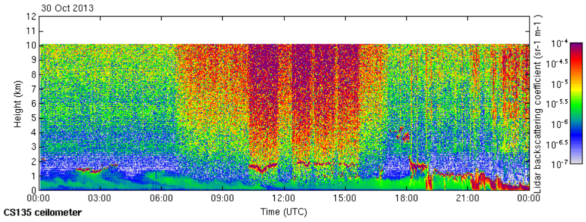


5 minute average 1st cloud base height

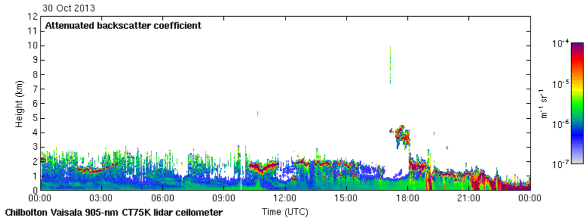


5 minute average 1st cloud base height, scatter plot

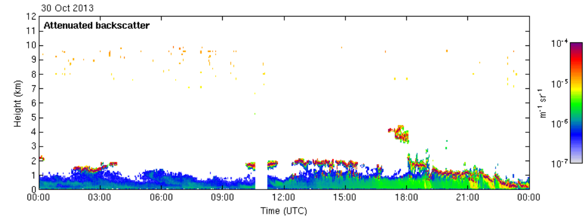
30th October 2013



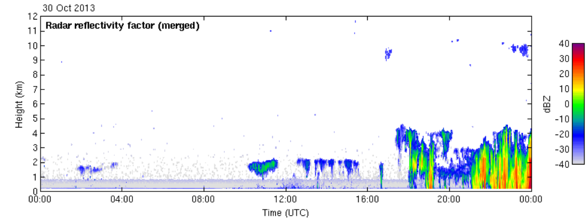
CS135



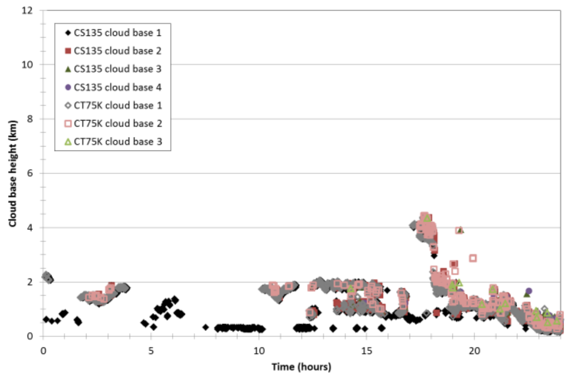
CT75K



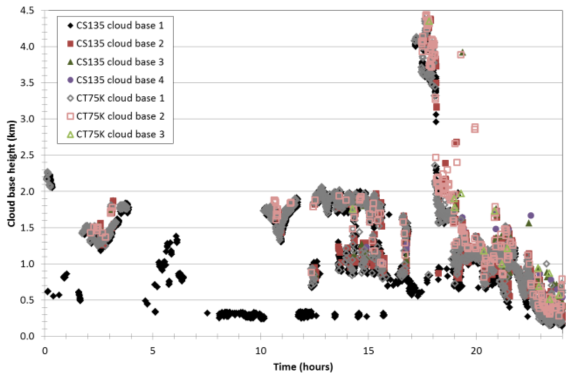
Doppler lidar



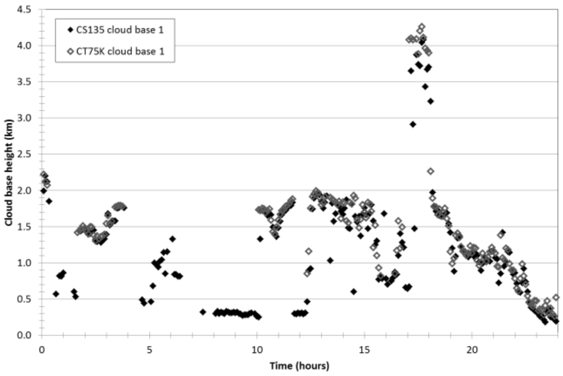
Copernicus 35 GHz radar



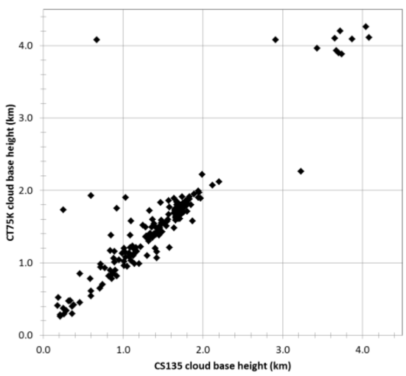
All cloud base heights



All cloud base heights, magnified scale

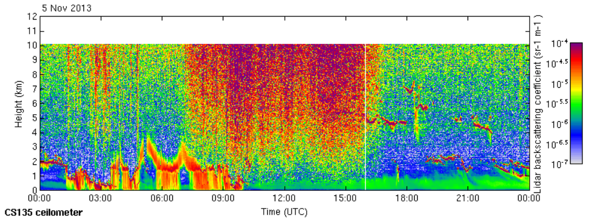


5 minute average 1st cloud base height

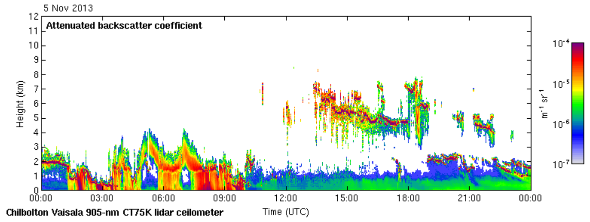


5 minute average 1st cloud base height, scatter plot

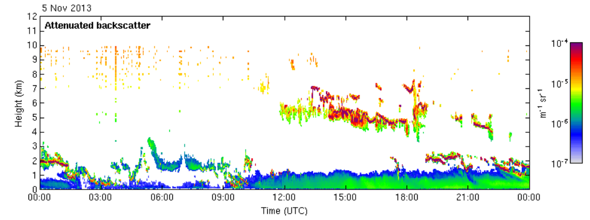
5th November 2013



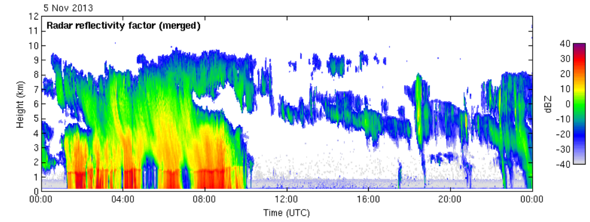
CS135



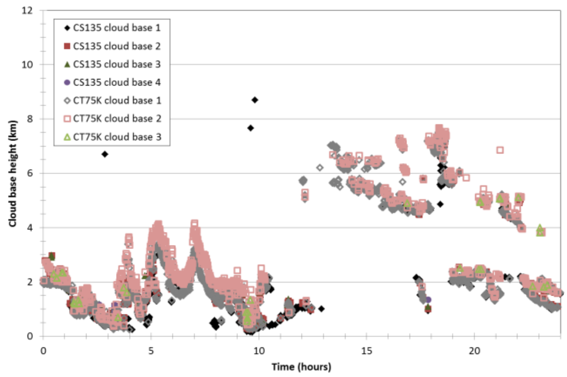
CT75K



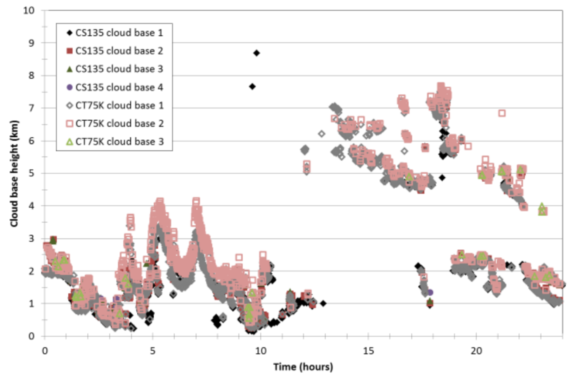
Doppler lidar



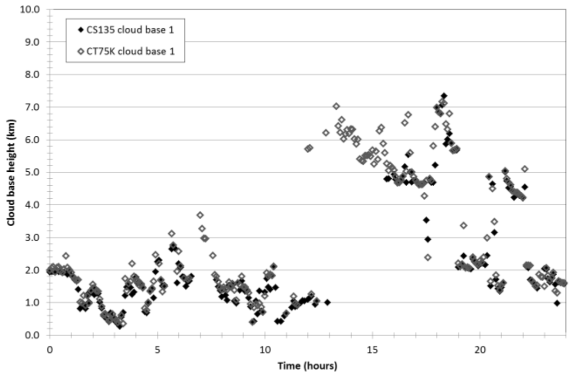
Copernicus 35 GHz radar



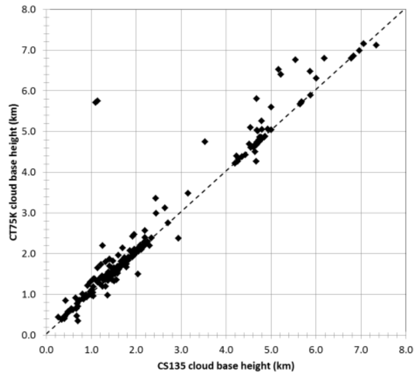
All cloud base heights



All cloud base heights, magnified scale

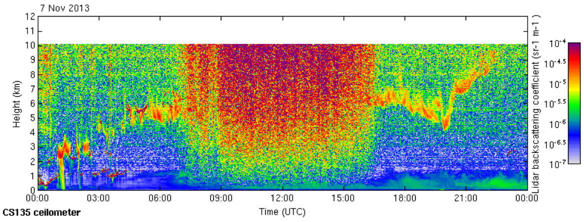


5 minute average 1st cloud base height

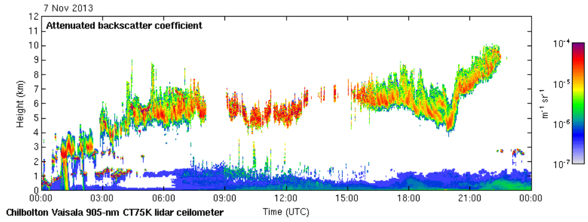


5 minute average 1st cloud base height, scatter plot

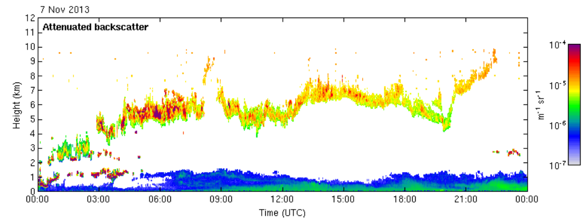
7th November 2013



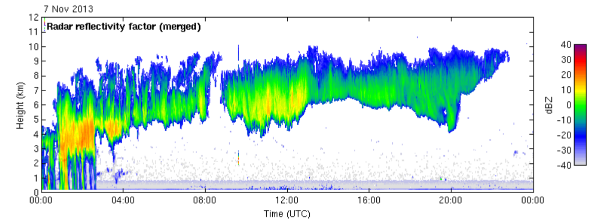
CS135



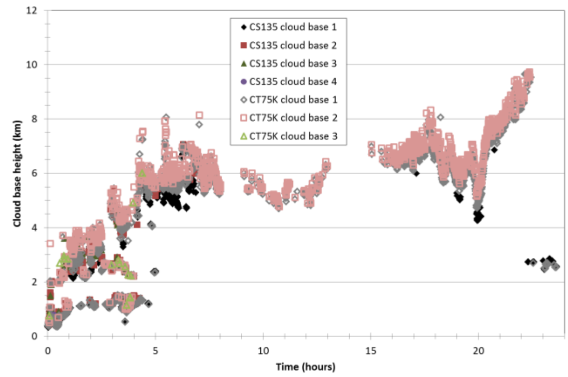
CT75K



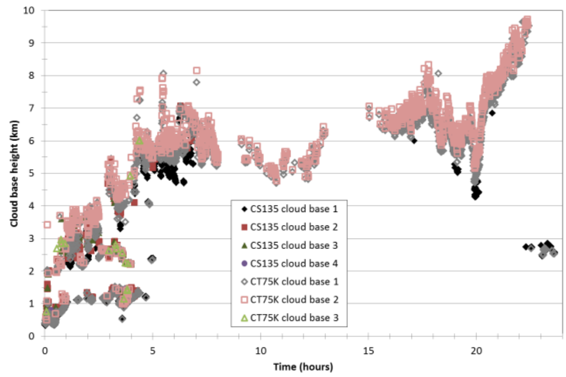
Doppler lidar



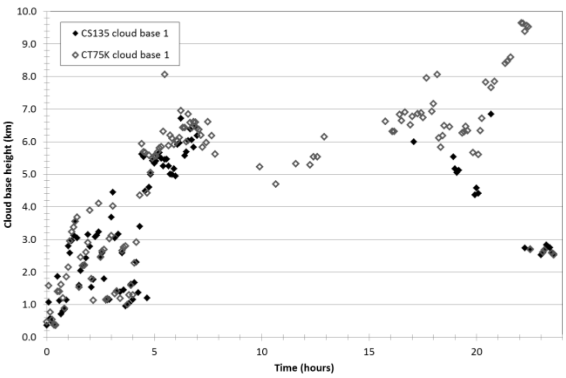
Copernicus 35 GHz radar



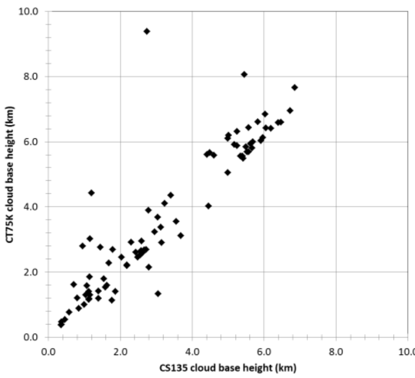
All cloud base heights



All cloud base heights, magnified scale



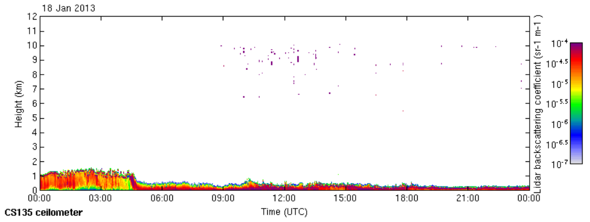
5 minute average 1st cloud base height



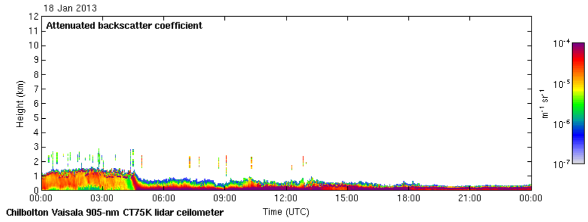
5 minute average 1st cloud base height, scatter plot

Figure 2: Intercomparison of backscattering coefficient and cloud base height for 4 days later in the operation of the CS135 at Chilbolton Observatory.

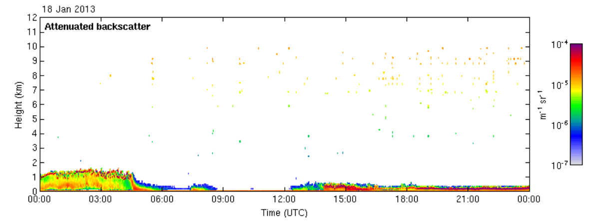
18th January 2013



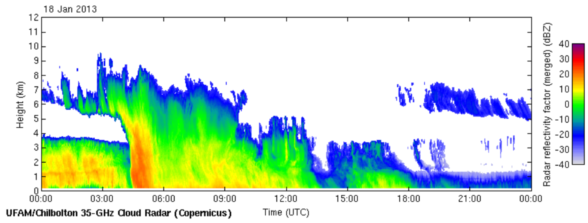
CS135



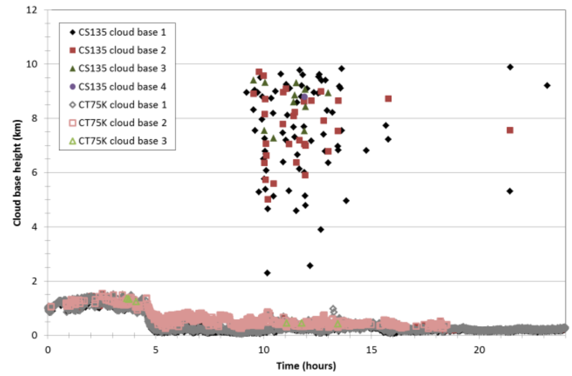
CT75K



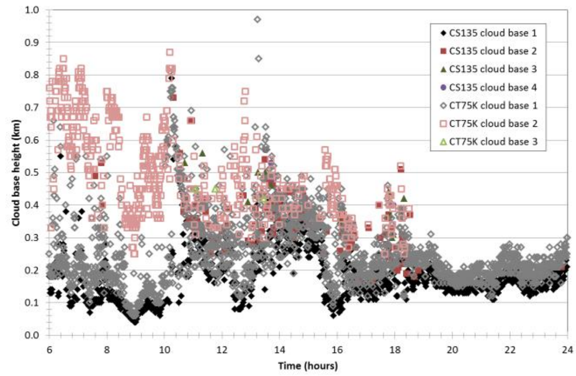
Doppler lidar



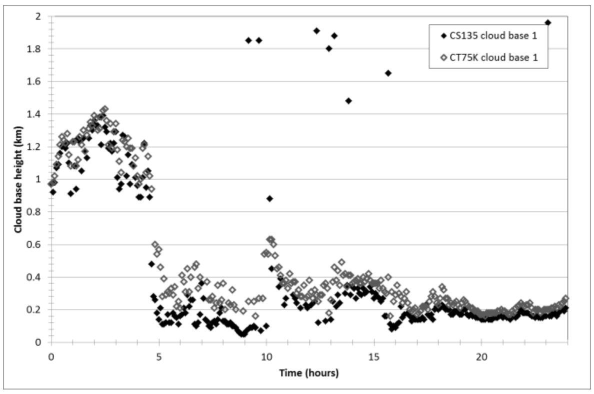
Copernicus 35 GHz radar



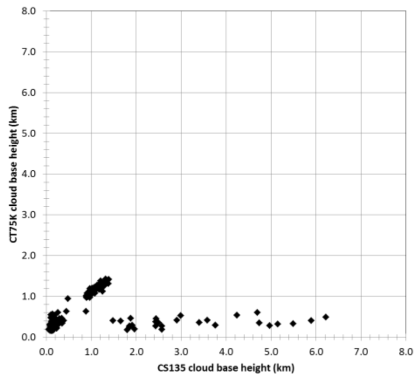
All cloud base heights



All cloud base heights, magnified scale

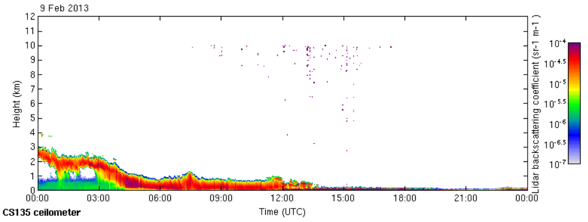


5 minute average 1st cloud base height

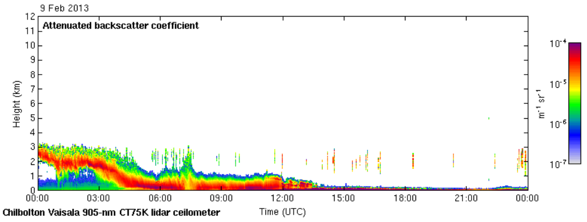


5 minute average 1st cloud base height, scatter plot

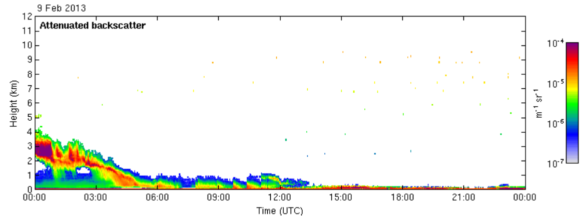
9th February 2013



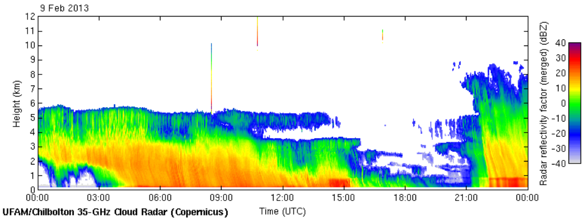
CS135



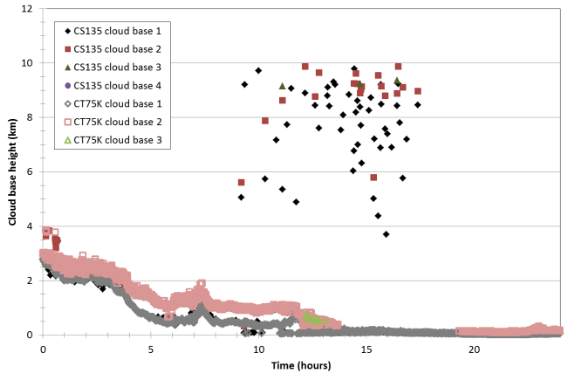
CT75K



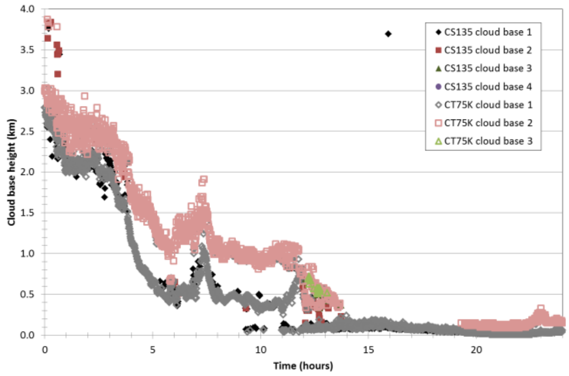
Doppler lidar



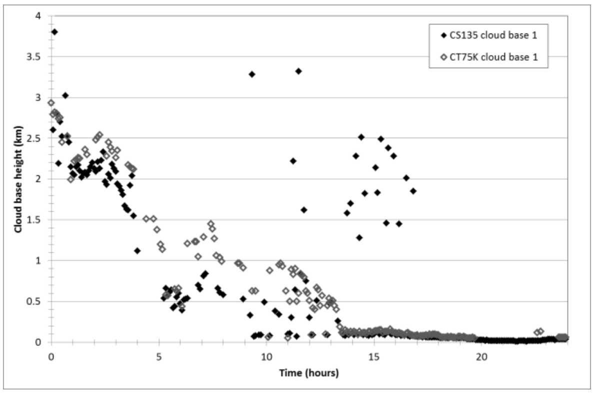
Copernicus 35 GHz radar



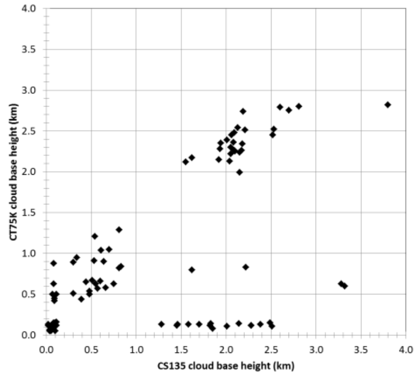
All cloud base heights



All cloud base heights, magnified scale



5 minute average 1st cloud base height



5 minute average 1st cloud base height, scatter plot

Figure 3: Intercomparison of backscattering coefficient and cloud base height for 2 snow days earlier in the operation of the CS135 at Chilbolton Observatory.

Observations from intercomparisons

1. The CS135 is performing well and detecting clouds broadly in line with expectations.

2. The noise levels in the CS135 plots are larger than in the CT75K plots. This results partly from the use of a speckle reduction algorithm with the CT75K and Doppler lidar data. In addition, the CS135 reporting interval has been reduced during the measurement period, resulting in more statistical noise in the profiles.

3. Daylight causes increased noise in all ceilometer measurements. This is particularly apparent in the CS135 plots from 30/10/13, 05/11/13 and 07/11/13 but it is likely that it is more clearly seen then due to a difference in the data processing in operation at that time. In addition, scattered noise at higher altitudes can be seen in other plots from days where very low cloud, rain or snow was present. On 03/01/13, 18/01/13, 09/02/13 and 19/12/13 this results in the intermittent erroneous assignment of a cloud base height to these signals, typically at altitudes at or above 6 km, although sometimes down to around 4 km. This is most noticeable with the CS135 running without 'speckle reduction' and higher resolution than the CT75K on those days.

4. Both the CS135 and CT75K detect the supercooled water layer at ~ 5 km on 30/11/12. The Doppler lidar, cloud radar and to some extent the CT75K show ice cloud to be present below this more easily detected water cloud layer, but it is not detected as a cloud base by either ceilometer. The data from ~ 18UT – 24 UT on 05/03/13 show a similar effect. The CT75K sees thin supercooled water layers (which produce a relatively strong signal) embedded within deeper, tenuous ice layers, whereas the CS135 sees only the supercooled water layers.

5. The CS135 shows less sensitivity than the Doppler lidar and the cloud radar to high ice clouds. This is shown by the data from on 18/12/12 where it does not detect the ice clouds in the height range ~7 – 11 km. It does however detect them as a cloud base from soon after 00 UT on 19/12/12 at a height of ~ 6.5 km. Initially the continuous descending ice layer is only detected intermittently by the CS135.

6. On 19/12/12 the CS135 detected the descending ice clouds earlier and so at a higher altitude than the CT75K. It is suspected that the CT75K currently has an intermittent minor fault which reduces its sensitivity and hence its ability to detect high ice clouds in particular. This fault is also responsible for the broad intermittent noise signals which can be seen at heights ~ 2 km on several of the case study days. From ~10UT on 05/03/13 this fault was no longer present, and as a result the CT75K showed good sensitivity to the high clouds from ~18UT onwards.

7. On 05/11/13 and 07/11/13 further ice and supercooled water clouds were detected. Since changes to the data processing algorithms have been made since the cases described above, it is interesting to compare the sensitivity of the CS135 to these clouds. Without a detailed analysis of all ice cloud cases by day and night only a simple qualitative analysis is possible. By day the sensitivity of the CS135 to ice clouds is much reduced compared to night time observations, as expected. The CT75K shows a similar but smaller effect. During the early hours of 19/12/12 the Halo Doppler lidar shows the ice clouds as having a similar backscattering coefficient to around 18UT onwards on 07/11/13. In the latter case the CS135 appears more sensitive to the ice clouds than in the former. This implies an improvement in the sensitivity of the CS135 to ice clouds during the measurement period, but more complex data analysis would be required to verify this.

8. Although there is generally good agreement between the CS135 and CT75K CBHs, there is a persistent small offset between them, with the CS135 tending to read CBHs ~ 40m lower than

the CT75K. This effect appears to be relatively constant with height (although it is less easily seen on plots with larger ranges of CBH values). This effect continues throughout the observation period, apparently unaffected by the changes in algorithms which have occurred. In order to illustrate this effect a manually fitted dashed line has been added to the CBH scatter plots for some days. The manual line has a gradient of 1 and an offset of the CT75K CBH with respect to the CS135 CBH of 40 m. It has only been done for days with no precipitation and for which the clouds are predominantly composed of water (including supercooled water). The cause of this offset is investigated in more detail later. The presence of ice clouds or precipitation tends to cause more scatter in CBH values. An automated linear least-squares fit was attempted first but it was found that the presence of outliers caused the fit to not illustrate the trends in the scatter plot that are apparent to the eye. Outliers are caused either by the presence of different cloud layers in the respective fields of view of the instruments or by a difference in which layers are assigned a CBH by the instruments.

9. The first CBHs recorded by the CS135 and CT75K continue to agree well during the rainfall from ~0930UT on 19/12/12. They also agree reasonably well, although with some discrepancies, during the snow cases of 18/01/13 and 09/02/13.

10. On 05/03/13 over the period 04-13UT the CS135 detects a low cloud base that was not detected by the CT75K. There was fog and mist during this period (particularly from 07UT to 0830UT), resulting in strong, low aerosol layers within the boundary layer. It appears that the CS135 detects this as a cloud base whereas the CT75K does not. There is also a discrepancy in CBH measurements at the end of the day, which shows on the both CBH time and scatter plots. It is likely to arise mainly from the instruments looking at different regions of the sky during changing conditions.

11. There are periods on 15/10/13 (11UT-13UT and 19UT-23UT) and 30/10/13 (08UT-10UT and 11UT-12UT) where the CS135 reports a first cloud base height which is not apparent in the time-height plots and which is not reported by the CT75K. These cases are investigated in more detail later.

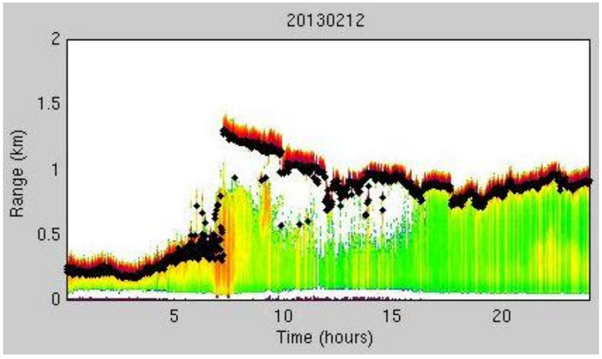
12. There are cases on 05/11/13 (13UT-16UT) and 07/11/13 (08UT-16UT) where there is ice cloud present which is assigned a cloud base by the CT75K but not the CS135. In these cases the CS135 tends to either assign 0 cloud layers or transparent obscuration.

13. There is 1 case of fog during the case studies: 07UT-09UT on 05/03/13. During this either full or transparent obscuration is reported. When the obscuration was full the vertical visibility was in the approximate range 0 – 44 m or 0 – 49 m (2 values given in the message) or a single value of up to approximately 400 m (2 equal values given in the message). The co-located PWS100 reported the visibility 10 m above ground as 100 – 110 m during the same period.

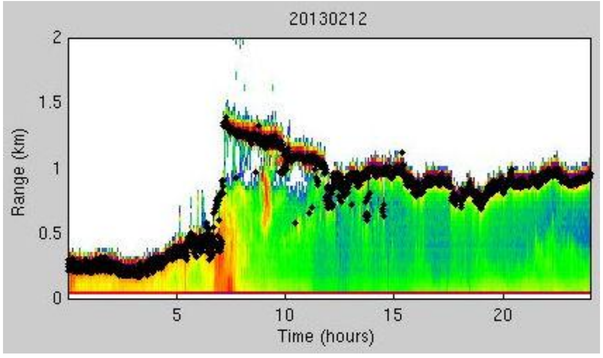
Cloud base height intercomparison

In order to further investigate the performance of the 2 instruments some cases were selected for further study. Cloud layers which were as stable as possible in height were chosen so as to minimise the effects of the different zenith angles (6° for the CS135 and 4° for the CT75K) and azimuthal orientations (approximately S, W respectively) for the two instruments. The CS135 and CT75K time-height backscattering coefficient plots are re-drawn and overlaid with the first cloud base height values shown as black points. The backscattering coefficient as a function of height is plotted for each instrument at a single time and the reported CBH superimposed as a dotted line. Details are shown in figure 4, with comments on the measurements shown with the data for each day. Note that axis scales vary between plots in order to highlight different features. Where it was more helpful to use different scales for data from the 2 instruments, the scale for the CS135 is shown on the left-hand axis and that for the CT75K on the right.

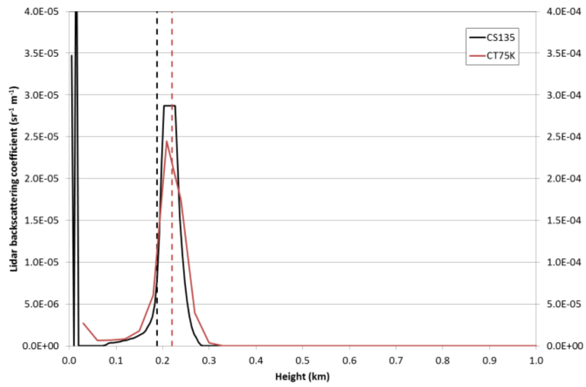
12th February 2013



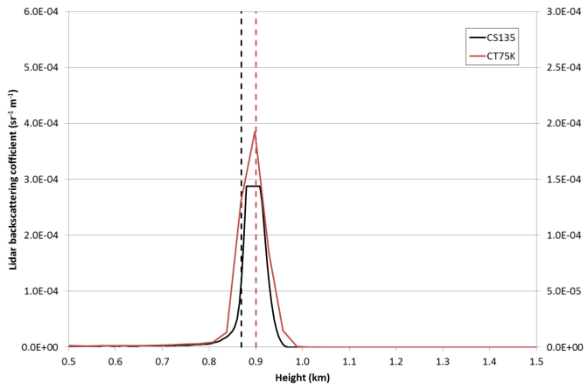
CS135



CT75K



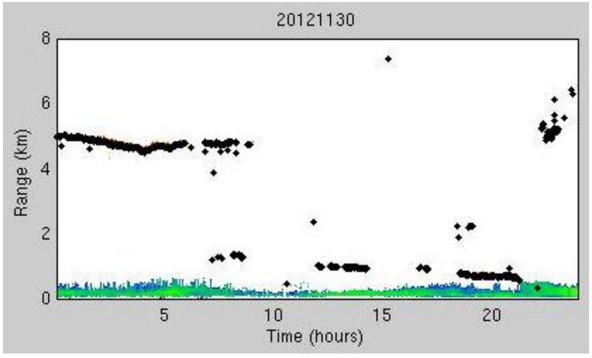
0248UT single profile



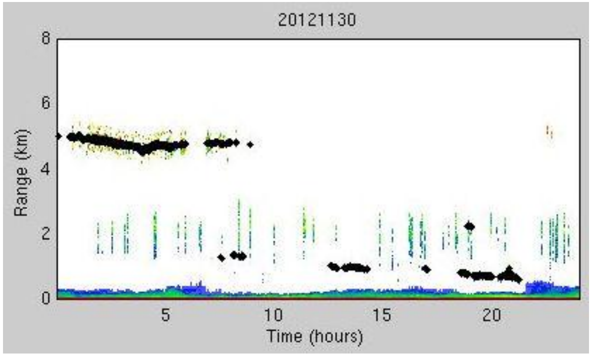
1727UT

The single profiles show that the measured peak heights agree very well, but that the algorithms used to calculate cloud base height differ between the two ceilometers. This result will be reproduced on other days (see below) and is the dominant source of the difference in reported CBHs between the instruments. The CS135 in both single profiles are clipped.

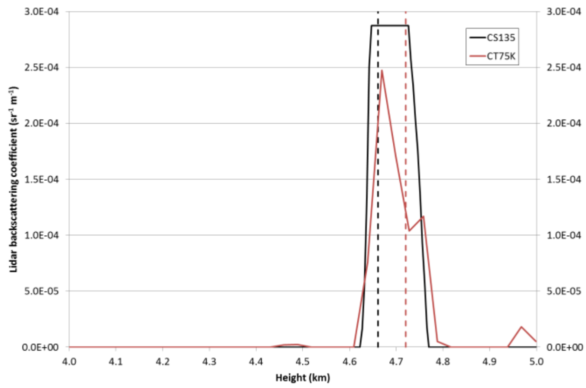
30th November 2012



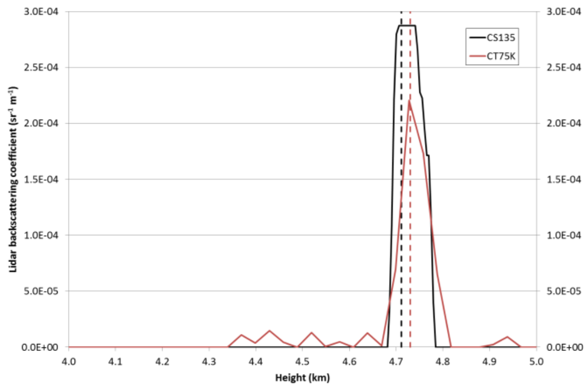
CS135



CT75K



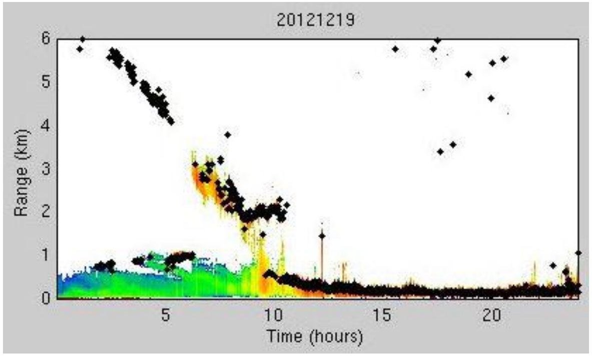
0336UT



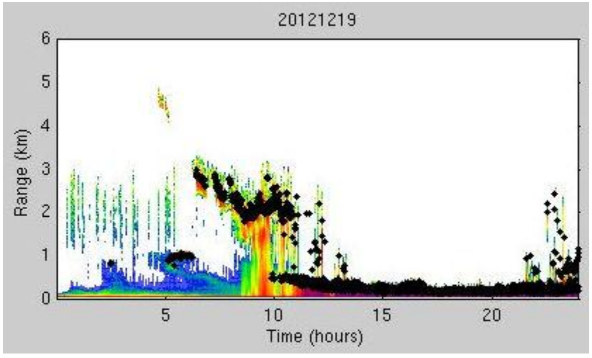
0448UT

The profiles are now from supercooled water clouds at a considerably greater height than on 12th February 2013, but a similar trend of the CS135 reporting a lower CBH than the CT75K is seen. There are some further high clouds after 2200UT which are detected and reported by the CS135 but not by the CT75K.

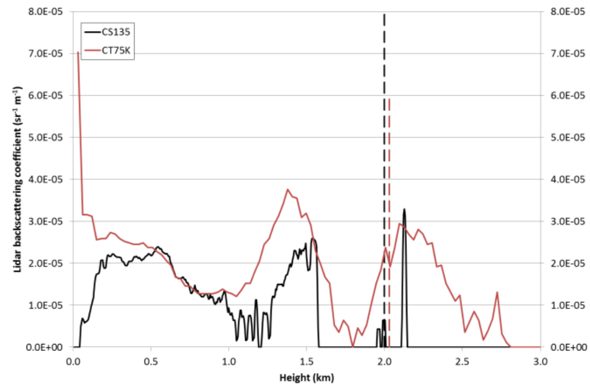
19th December 2012



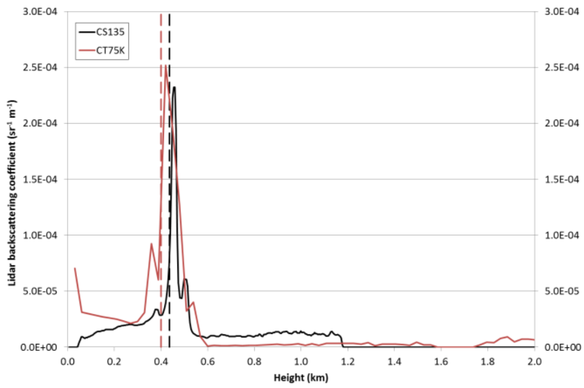
CS135



CT75K



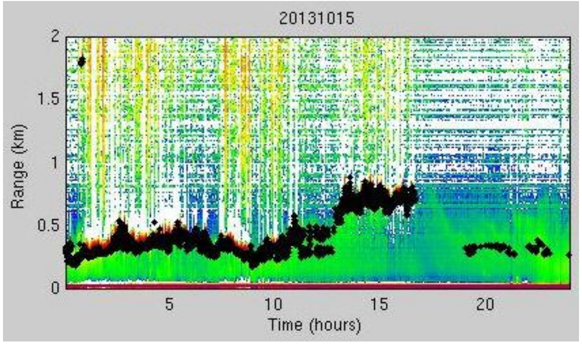
0930UT



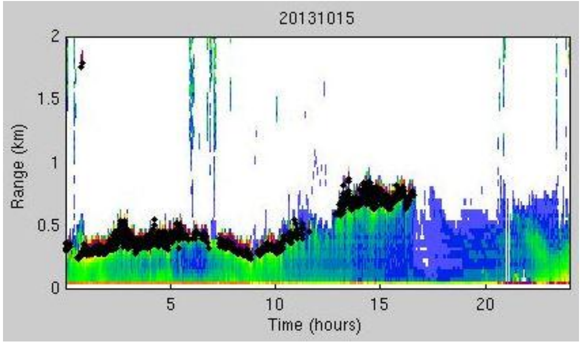
1100UT

The two profiles shown are recorded during rain, at a time when the cloud base was high, or thin enough to allow some transmission to higher altitudes. There is good agreement in the cloud profiles. As with 30th November 2012, the CS135 detected high clouds early in the day that were not detected by the CT75K. These clouds would normally be visible to the CT75K but the presence of an intermittent broad background signal at around 2 km until around 0600UT indicates that it was showing the effects of the minor fault. This appears worse in cold conditions, possibly due to condensation on the optics.

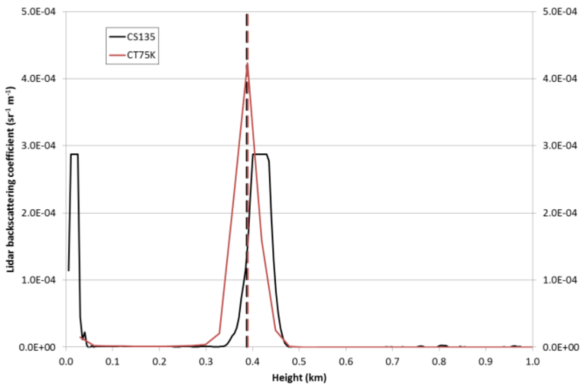
15th October 2013



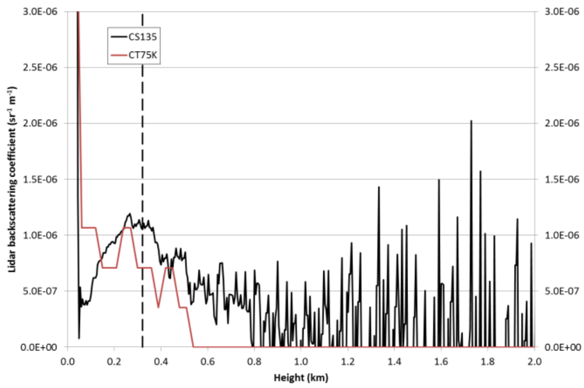
CS135



CT75K



0400UT

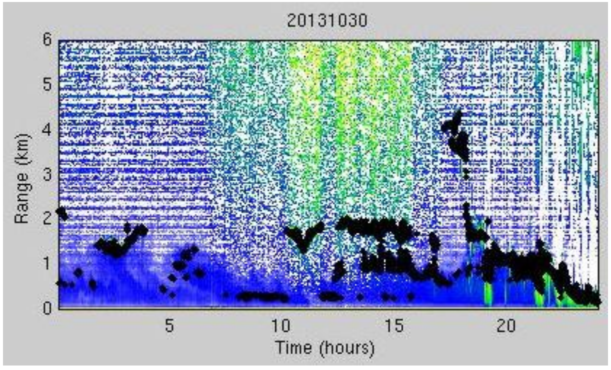


1921UT

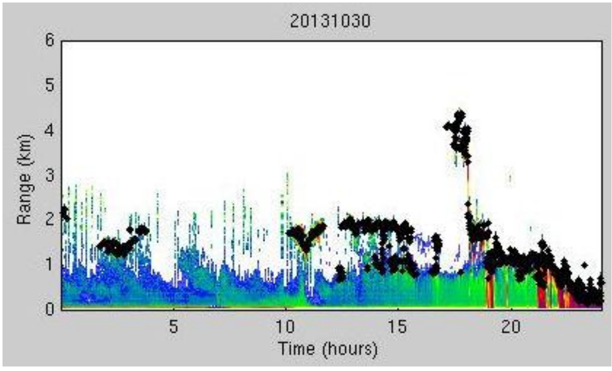
It is likely that the small difference in reported CBH at 0400UT reflects a real difference in the clouds observed by the two instruments, as the underlying trend seen in figure 2 is still for the CS135 to report lower CBH values.

From around 1100UT to 1300UT and 1900UT to 2300UT the CS135 assigns a CBH to what appears to be boundary layer aerosol. The profiles from 1921UT show an example of this. The CT75K reports 0 cloud layers at the same time.

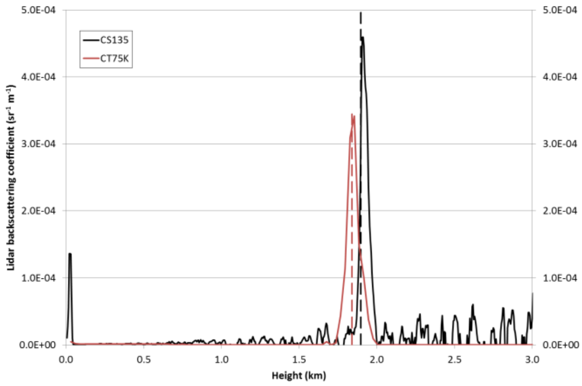
30th October 2013



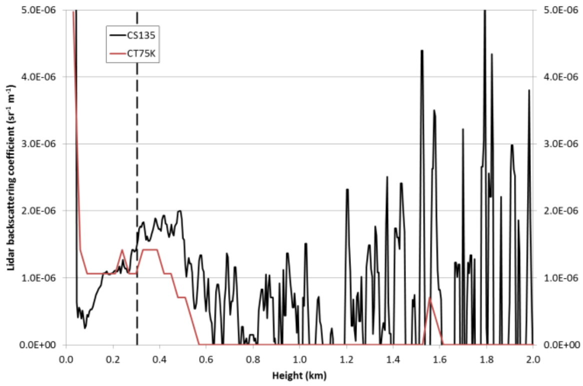
CS135



CT75K



1300UT

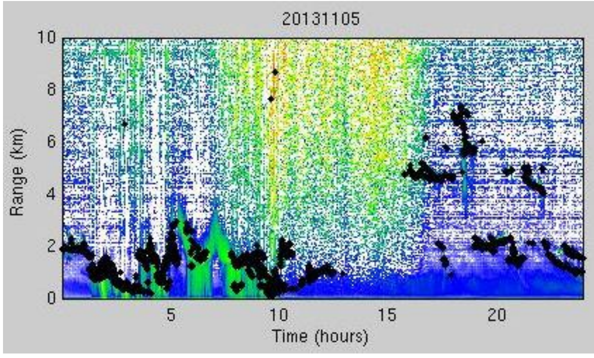


1201UT

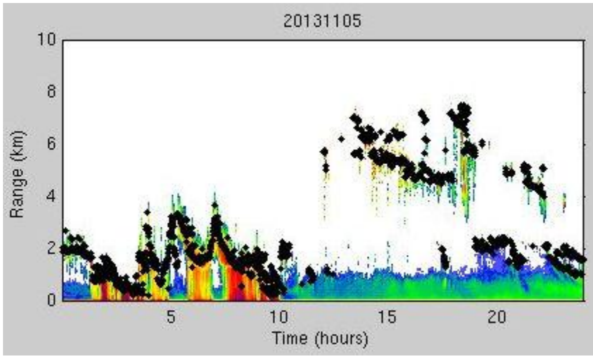
As for 15th October 2013 it is likely that the different cloud profiles at 1300UT reflect a real difference in the observed clouds.

From 0800UT to 1000UT, 1100UT to 1200UT and occasionally at other times the CS135 again assigns a CBH value to what appear to be boundary layer aerosols. The 1201UT plot shows an example of this.

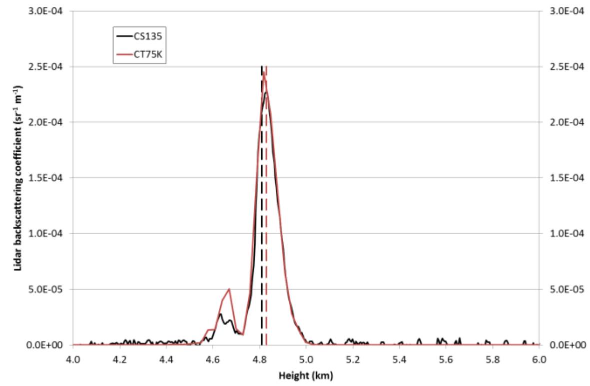
5th November 2013



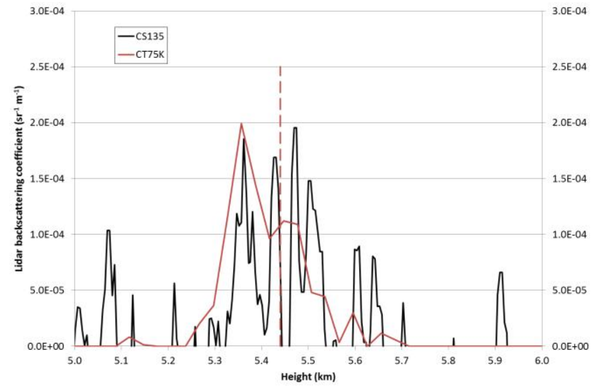
CS135



CT75K



1700UT

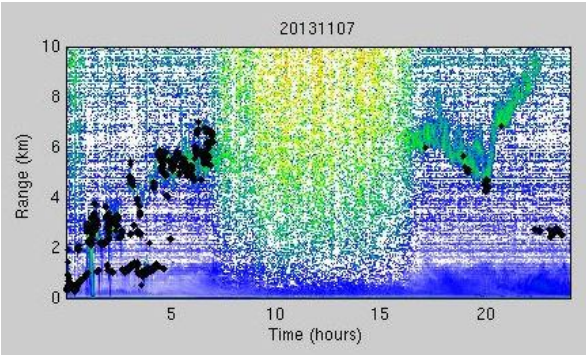


1500UT

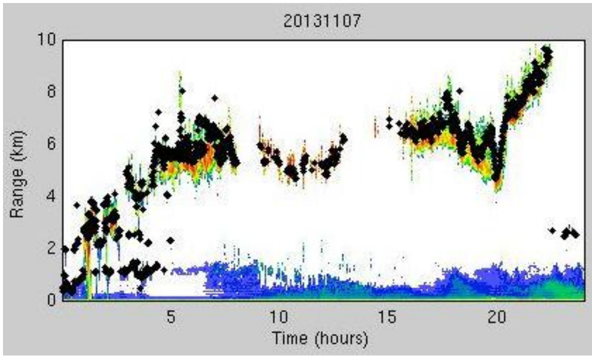
The profiles through supercooled water cloud at 1700UT show very good agreement.

The profiles at 1500UT show that the CT75K more easily detects the mixed ice and supercooled water cloud and can assign a CBH. The CS135 is showing signals from that cloud but increased sky background noise relative to the signal means that it is not assigned a CBH. In addition the CT75K has more time and height integration, helping to reduce statistical noise.

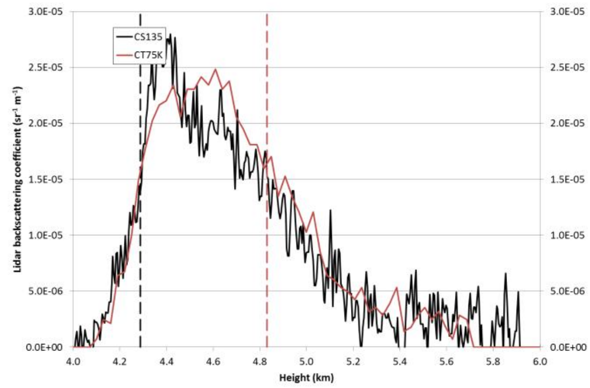
7th November 2013



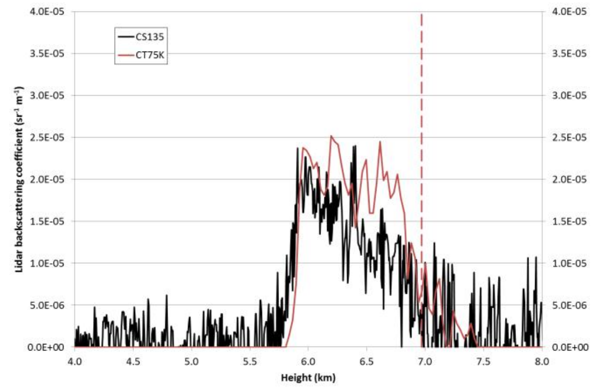
CS135



CT75K



1959UT



1800UT

At 1959UT both instruments report a CBH for the ice cloud. That from the CT75K is considerably higher, above the height of the peak signal. In contrast, the CS135 CBH corresponds to the rising edge of the peak, as it usually does for a water cloud.

The CT75K assigns a CBH for more of the day than the CS135 (including some during daylight hours), probably due to its higher power.

At 1800UT only the CT75K assigns a CBH to the ice cloud, which is higher than that at 1959UT. It again assigns it above the height of the peak signal. The CS135 measures a cloud signal that can be easily discerned by eye but does not assign a CBH. This may be because the signal to noise ratio is lower than at 1959UT.

Figure 4: Intercomparison of backscattering profiles and calculated cloud base heights

Figure 4 shows that the differences in CBH from the two instruments appear to result from differences in the CBH algorithm, since the backscattering peaks from clouds tend to overlap much more closely than the CBH values.

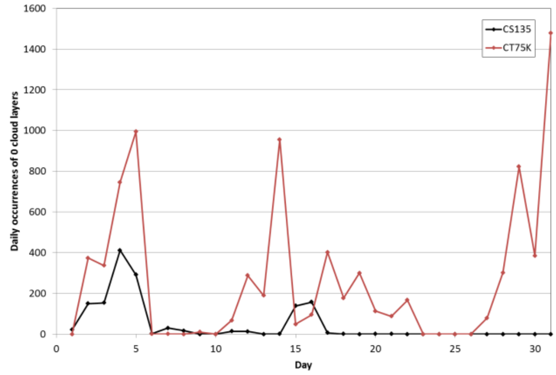
In ice clouds the difference in the CBH tends to be more pronounced compared to that reported from water clouds. It appears that the difference in CBH algorithms becomes more pronounced for the relatively tenuous ice clouds. Water clouds are much denser and attenuate the laser beam much more rapidly. Hence they produce much sharper, better defined backscattering peaks.

It should be noted that as the heights scales used in figure 4 are derived from the range step and reported zenith angle for each instrument, any errors in these will result in an incorrect height scale. In addition, the CT75K has a range resolution of 30m, rather lower resolution than the ~4.97m of the CS135. This will affect the resolution of the CT75K CBH values.

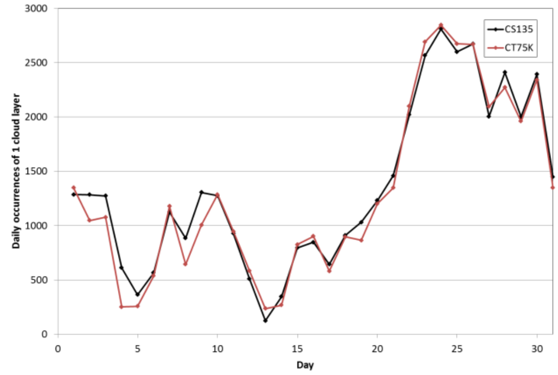
The CS135 water cloud peaks on the 30th November 2012, 12th February 2013 and 15th October 2013 appear flat topped. This is an artefact of the operating parameters on those days that limited the output data to around 3 x 10^{-4} (srad m)$^{-1}$.

Identification of number of cloud layers, partial and total obscuration

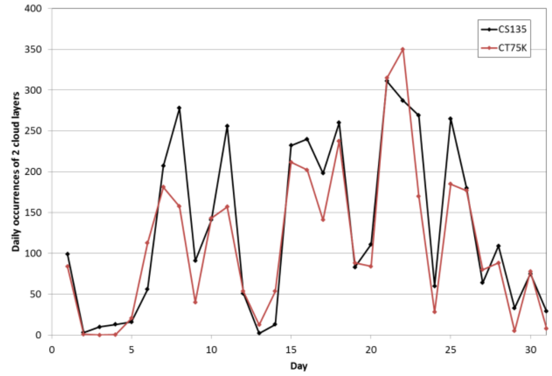
A comparison has been made of how the CS135 and CT75K assign number of cloud layers and partial and total obscuration codes to a range of cloud conditions. The number of occurrence of 0-4 (or 0-3 for the CT75K) cloud layers and code 5 or 6 (full/transparent obscuration) are compared. This was done on a daily basis for March 2013, reporting a total number of occurrences for each sky condition. Figure 5 shows plots of the number of occurrences as a function of day for conditions 0-6. As the two instruments acquire a different number of profiles each day the number of occurrences from the CT75K are normalised according to the number of measurements made by the CS135. The plots for the 2 instruments would therefore be the same if they agreed in their interpretation of the sky conditions. It should be noted that the data acquisition rate for the CS135 approximately doubled (60s to 30s spacing) partway through 21/03/13. This will increase the levels on the plots but they are still normalised.



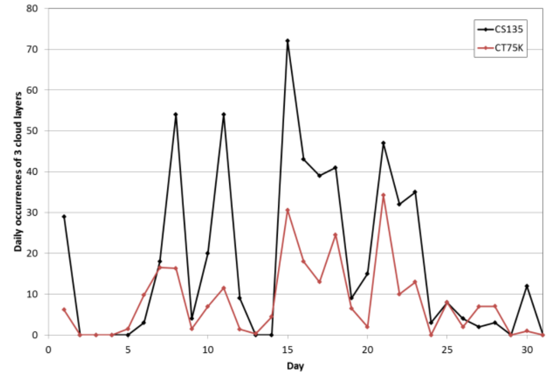
0 cloud layers



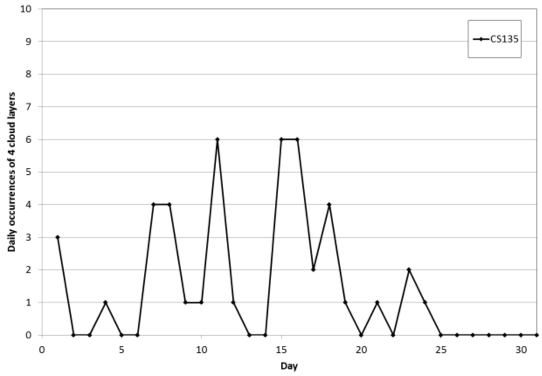
1 cloud layer



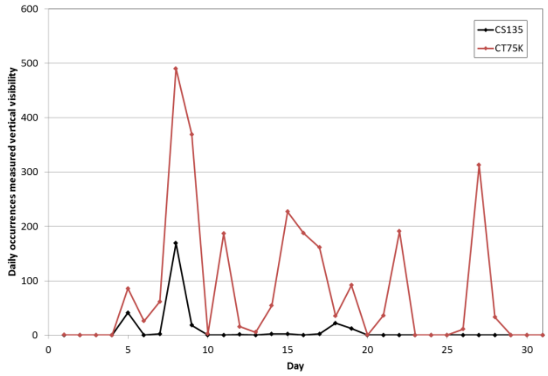
2 cloud layers



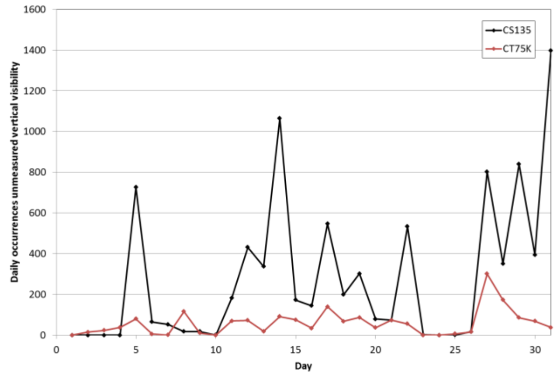
3 cloud layers



4 cloud layers



Code 5: full obscuration



Code 6: transparent obscuration

Figure 5: Occurrences of sky condition codes 0 to 6 for March 2013

Often the agreement between instruments is good, particularly for cases of 1 or 2 layers. There are also cases where there are significant differences.

There are circumstances in which the CS135 and CT75K can report obscuration due to scattering in the atmosphere but clouds are not reported because the criteria for a cloud base is not realised. They may reported 'full obscuration' meaning that although there is no cloud base as such there is sufficient scattering in the atmosphere to limit the vertical visibility. Alternatively they may report 'obscuration detected but determined to be transparent' meaning that scattering is detected but not only does it not constitute a cloud it is not sufficient to obscure visibility.

The CT75K is more likely to report 0 layers while the CS135 reports transparent obscuration (code 6). 14/03/13 is one such case. It was largely clear until midday. There were then mixed height clouds, including ice clouds at 2-3 km later in the day. On this day the CS135 reports no '0' layers but > 1000 cases of transparent obscuration. The CT75K reports ~1000 '0' layers but only ~ 100 transparent obscuration cases. This seems to be a difference in how the two instruments treat no distinct cloud layers. 31/03/13 (also clear until late morning) also shows similar significant differences between 0 and 6 codes.

The CS135 tends to report less cases of full obscuration than the CT75K. Days where there were large differences include 8, 11, 15, 16, 17 and 27 March. These all had rain, drizzle or fog for a significant part of the day. Again this difference appears to arise from how the instruments treat full obscuration cases. A detailed analysis of how those cases have been assigned by the CS135 has not been performed, but from the graph, the CS135 sees more cases of 2 or 3 cloud layers than the CT75K on many of those days.

Conclusions

In the study to date, the CS135 and CT75K have performed consistently in most respects. The range calibration of the CS135 is good and the ~40 m discrepancy in CBHs between the two instruments appears to result from a difference in how CBH is determined rather than a difference in range scales. The CS135 normally detects water clouds with adequate sensitivity, including those at higher altitudes (up to ~6.5 km in case studies so far). It is less likely to detect more tenuous ice clouds than the CT75K, at times when the latter is providing optimum performance. This is probably not unexpected given that the CT75K is a relatively high sensitivity ceilometer, being essentially 4 ceilometers operated in combination.

There are differences between the CS135 and CT75K in how they report 0 cloud layers/transparent obscuration/full obscuration. The CT75K is more likely to report 0 layers while the CS135 reports transparent obscuration (code 6). There are also differences in the number of cases where they report full obscuration, with the CS135 reporting fewer cases. This effect particularly appears to occur on days with rain, drizzle or fog.

Possible future work

A mixing layer height (MLH) algorithm has been developed by Campbell Scientific. The Halo Doppler lidar provides added information on MLH from its vertical velocity measurements and so would provide valuable data with which to assess the performance of the MLH algorithm.

It would be interesting to assess the sensitivity of the CS135 to high and/or tenuous clouds. Ideally the CS135 would need to be calibrated to enable this. Although there have been some cases of saturation of the peak backscattering signals from low clouds, it should be possible to calibrate the CS135 data using the measurements from optically thick stratocumulus clouds. The probability of detection of multiply scattered radiation as a function of height would also need to be calculated from the optical properties of the instrument.

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27/03/14