LBA-ECO CD-03 Cloud Base-Backscatter Data, km 67 Tower Site, Tapajos National Forest

Typical Application of Data:

Ceilometers have been used to observe boundary-layer aerosols (e.g. Zephoris et al. 2005) and boundary-layer mixing height (e.g. Eresmaa et al. 2006). The ceilometer is also able to detect rain droplets quite well through the use of the ceilometer backscatter profile. The rain droplets are a large target for the laser compared to other aerosols; therefore a strong, distinct return signal is seen from the cloud base to the surface on the backscatter profile. By determining a return-echo threshold value for rain droplets, rain events can be detected from the ceilometer backscatter profile. The threshold value can be verified using tipping-bucket rain gauge data from the same site.

Using the ceilometer data complements the traditional rain-gauge approach as the ceilometer detects all rain events, including light ones when the rain gauge may not catch any rainfall due to wind, etc. or not enough to force a tip. Second, the ceilometer gives the instantaneous start time for precipitation, whereas with the tipping bucket rain gauge, light precipitation may have been falling for several minutes before the first tip is recorded.

Theory of Measurements:

The basic measurement theory and formulae used for the ceilometer internal processing algorithms for cloud base and backscatter detection is detailed in the following section. The following is information obtained from the Vaisala CT25K Ceilometer Users Guide (Vaisala Oyj, 2002) regarding these measurements. Since all backscatter and cloud detection algorithms are done in the ceilometer internal software, please refer to the aforementioned users guide for additional information.

Basic Principle of Operation:

The operating principle of the CT25K ceilometer is based on measurement of the time needed for a short pulse of light to traverse the atmosphere from the transmitter of the ceilometer to a backscattering cloud base and back to the receiver of the ceilometer.

With the speed of light being: c = 2.99 x 108 m/s (= 186,000 miles per second)

A reflection from 25,000 ft will be seen by the receiver after t = 50.9 micro seconds.

The instantaneous magnitude of the return signal will provide information on the backscatter properties of the atmosphere at a certain height. From the return signal, information about fog and precipitation, as well as cloud, can be derived. Since fog and precipitation attenuate the light pulse, the cloud base signal will appear lower in magnitude in the return echo. However, the fog and precipitation information also provides data for estimating this attenuation and computing the necessary compensation, up to a limit.

In its normal full-range operation the CT25K ceilometer digitally samples the return signal every 100 nanoseconds from 0 to 50 microseconds, providing a spatial resolution of 50 feet from ground to 25,000 feet distance. This resolution is adequate for measuring the atmosphere, since visibility in the densest clouds is in the order of 50 feet.

Noise Cancellation:

For safety and economic reasons, the laser power used is so low that the noise of the ambient light exceeds the backscattered signal. To overcome this, a large number of laser pulses are used, and the return signals are summed. The desired signal will be multiplied by the number of pulses, whereas the noise, being random, will partially cancel itself. The degree of cancellation for white (Gaussian) noise equals the square root of the number of samples; thus, the resulting signal-to-noise ratio improvement will be equal to the square root of the number of samples. However, this processing gain cannot be extended ad infinitum since the environment changes. For example, clouds move.

The instantaneous return signal strength is in general form (the Lidar equation):

Pr(z) = Eo*(c/2)*(A/(z^2))*Beta(z)*e^(-2* integral from 0 to z of omega*(z')dz

where Pr(z) = Is the instantaneous power received from distance z [W = Watt].

Eo = Is the effective pulse energy (taking all optics attenuation into account) [J = Joule = Ws = Watt - second].

c = Is the speed of light [m/s = meters per second].
A = Is the receiver aperture [m2].
z = Is the distance in question [m].
Beta(z) = Is the volume backscatter coefficient at distance z [m^-1 srad^-1, srad = steradian].

and the expression: e^(-2* integral from 0 to z of omega*(z')dz, is the two-way atmospheric transmittance and accounts for the attenuation of transmitted and backscattered power by extinction at various distances (z') between transceiver and distance in question (z). The expression equals 1 in a clear atmosphere (i.e., no attenuation).

Height Normalization:

Assuming a clear atmosphere, it can be seen that the power is inversely proportional to the square of the distance or height i.e., the strength of a signal from 10,000 ft is generally one-hundredth of that from l,000 ft. The height-square dependence is eliminated by multiplying the value measured with the square of the height (height normalization). However, noise, being height-independent from a measurement point of view, will then be correspondingly accentuated with increasing height.

The Backscatter Coefficient:

The volume backscatter coefficient, Beta(z), of the Lidar Equation represents the portion of light which is reflected back towards the ceilometer from a distance z (e.g., by water droplets). It is obvious that the denser a cloud is, the stronger the reflection will be.

The relationship can be expressed as:
Beta(z) = k*omega(z)

where
k = Is a constant of proportionality.
omega(z) = Is the extinction coefficient (i.e., the attenuation factor in a forward direction).

The extinction coefficient relates to visibility in a straightforward manner. If visibility is defined according to a 5 % contrast threshold (World Meteorological Organization definition for Meteorological Optical Range MOR, equals daylight horizontal visibility), then

omega = 3 / V
where

omega = Is the extinction coefficient
V = Is MOR visibility (5 % contrast).

The constant of proportionality, k, also called the Lidar Ratio, has been subjected to a lot of research. Although the Lidar Equation can be solved without knowing its value, it must remain constant with height if accurate estimates of the extinction (or visibility) profile are to be made. It has been found that in many cases, k can be assumed to equal 0.03, tending to be lower in high humidities, to 0.02; and higher in low humidities, to 0.05. However, in e.g. precipitation of various kinds, k will have a wider range of values.

Assuming a value 0.03 (srad-1) for k and visibility in clouds being in the range 15 ... 150 m (50 ... 500 ft) gives the range of value for Beta:
Beta = 0.0006 ... 0.006 m-1 srad-1 = 0.6 ... 6 km-1 srad-1.

Sky Condition Algorithm to calculate cloud-base heights:
The CT25K sky condition algorithm uses a time series of ceilometer data to calculate the cloud cover and the heights of different cloud layers. The algorithm is based on so-called Larsson algorithm, developed by Swedish Air Force and Swedish Hydrological Institute (SMHI), but further modified at Vaisala. The algorithm updates sky condition information every five minutes, based on data gathered during the last 30 minutes.

The algorithm reports up to four different cloud layers below 25000 feet. The sky condition algorithm collects data for 30 minutes. All cloud heights are rounded to the nearest 50 ft (~15 m) and a weight factor is assigned. Each measurement has a total weight of five which is divided between different cloud layers according to Table 1 below.

Table 1: Weight Factors

	1st layer	2nd layer	3rd layer
1 layer detected	5	-	-
2 layers detected	3	2	-
3 layers detected	3	1	1

In addition, a weight factor of 2 is applied to the data collected during the last 10 minutes to make the algorithm more responsive to variations in cloudiness.
The weighted cloud hits, counts, are assigned to the cloud height categories or bins (i.e. 0 ... 100 ft, 100 ft ... 200 ft etc.). The bin width increases with the distance according to Table 2 below.

Table 2: Bin Widths

Height	bin width
0- 5000 ft	100 ft
5000- 15000 ft	500 ft
15000-25000 f	1000 ft

The counts are summed starting from the lowest bin. The bins where the sum exceeds 1/33, 3/8, 5/8 and 7/8 of the maximum value are recorded as layer heights. The corresponding cloud amounts for these layers are 1,3,5 and 7 oktas. In addition, the minimum number of counts (hits) for each layer has to be exceeded:

Table 3: Minimum Number of Counts (Hits) for Each Layer

1st Layer	17 (3.4 hits)
2nd Layer	10 (2 hits)
3rd Layer	25 (5 hits)
4th Layer	25 (5 hits)

In case the minimum count is not exceeded in the assigned bin, the algorithm seeks three bins upwards and then three bins downwards if one of these bins has the required number of counts. However, if none of the bins contains enough counts, the original bin is used as the layer height. If the resulted layers are close to each other, it is reasonable to combine them rather than define them as separate layers. If the distance between two cloud layers is less than the minimum distance shown in Table 4 below, the layers are combined. The height of the combined layer is that of the lower layer and the cloud amount of the combined layer is that of the upper layer.

Table 4: Minimum Distance Between Different Cloud Layers

Layer Height	minimum distance
< 1000 ft	100 ft
1000-2000 ft	200 ft
2000-3000 ft	300 ft
3000-4000 ft	400 ft
4000-5000 ft	500 ft
5000-15000 ft	1000 ft
15000-25000 ft	5000 ft

Overcast (8 oktas) is reported if all the measurements during the last 30 minutes have a hit. Overcast height is assigned according to the bin where 14/15 of the total count value is exceeded.

However, overcast is not reported if there are weak hits during the latest 15 minutes period. A weak hit is defined as a backscatter signal which is less than 80% of the reference. The reference value depends on the previous measurements, i.e. it's a kind of sliding average value of signal strength.

Calculated Variables:
The variables calculated include the backscatter coefficient Beta(z) at profile heights from the surface to 25,000 feet at 100-foot (~30 m resolution), and is internally calculated by the software. The cloud-base heights (up to three) are also internally calculated by the software.

Processing Steps:
The raw data provided by the ceilometer were cloud-base and backscatter profile information reported every 15 seconds. From these data, an averaging program was used to calculate the statistical moments (mean, variance, skewness, and kurtosis) of the cloud-base and backscatter profile at 30-minute intervals. Each cloud base level was averaged, as well as backscatter profile level. A value of -9999 was assigned if no cloud base was reported during the interval. No further processing of the raw data from the ceilometer was done before the averaging program was run on the data.

Processing Changes and Special corrections/Adjustments:
No changes or special corrections were made to the data during processing.

References

Eresmaa, N., A. Karppinen, . M. Joffre, J. Rasanen, and H. Talvitie, 2006: Mixing height determination by ceilometer. Atmos. Chem. Phys., 6, 1485-1493.

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