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Automatic Monitoring of Boundary Layer Structures with Ceilometers

New robust algorithm for online retrieval of boundary layer structures enables new tools for air quality monitoring and forecasting. Why? It covers not only ideal boundary layer diurnal evolution, but also situations involving clouds, fog, and precipitation.

Ceilometers are eye-safe, compact and robust lidar systems designed for unattended operation at airfields and meteorological stations. Their primary task is the detection of cloud base layers, but automatic monitoring of boundary layer structures has become another important application of these instruments.

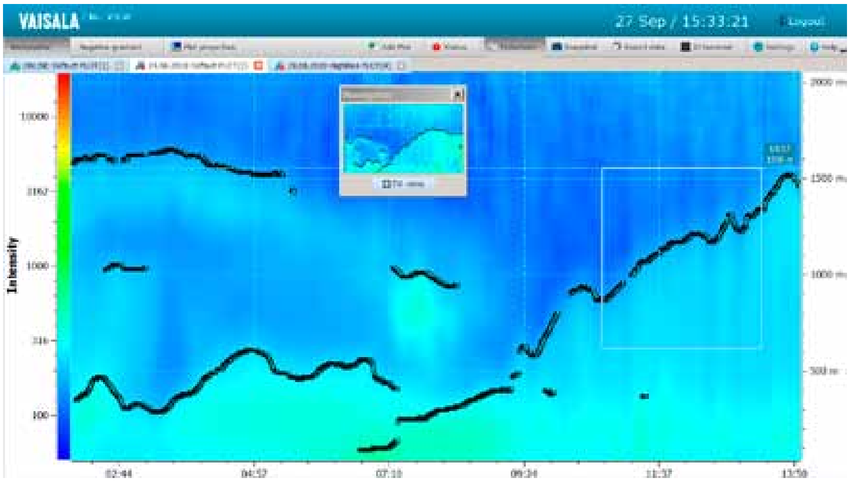
This is due to the fact that the planetary boundary layer height – also known as the mixing layer height – is a key parameter for characterization of air pollution together with urban emission source strengths, traffic emissions and weather influences. As emissions and other near-surface pollutants are diluted in a vertical direction within the planetary boundary layer, monitoring the layer height is critical for estimating the nature, transformation and removal of pollutants.

Vaisala has developed an automatic algorithm for online retrieval of boundary layer depth and additional residual structures that covers not only ideal boundary layer diurnal evolution, but all situations involving clouds, fog, and precipitation.

The new algorithm is part of the Vaisala Boundary Layer View (BL-VIEW), an independent data collection, storage, analysis and reporting tool designed to be used with the Vaisala Ceilometers CL31 and CL51.

Lidar Ceilometers in Boundary Layer Structure Monitoring

Lidar ceilometers are reliable tools for unattended boundary layer structure monitoring around the clock up to heights exceeding 2,500 meters [1, 2]. Comparison to temperature,



Visualization of ceilometer backscatter profiles with Vaisala BL-VIEW. This textbook evolution of a convective boundary layer has been recorded by a Vaisala Ceilometer CL51 in Vantaa, Finland on August 19, 2010. The BL-VIEW user interface enables convenient zooming to details with the computer mouse; the navigator window preserves the view of the whole day.

humidity, and wind profiles reported by RASS, sodar, radio soundings, and weather mast in-situ sensors has confirmed their ability to detect convective or residual layers [3].

In addition, ceilometers with a single lens optical design enable precise assessment of inversion layers and nocturnal stable layers below 200 meters. This design has been chosen for the Vaisala Ceilometers CL31 and CL51 [5].

The single lens optical design of Vaisala's ceilometers uses the inner part of the lens for transmitting and its outer part for receiving light (see Figure 1). This provides overlap of the transmitter light cone and the receiver field-of-view over the whole measuring range and allows reliable detection of also the very low nocturnal stable layers below 200 meters not seen by other instrument types.

In addition, the CL51 has a larger lens and a more powerful laser source than the CL31 to enable cloud base reports up to 13,000 meters. Its increased signal-to-noise ratio reveals also weak elevated aerosol layers.

Gradient Method – Standard for Identifying Vertical Extent of Aerosol Layers

A widely applied approach to identify the vertical extent of aerosol layers within the planetary boundary layer is the gradient method that searches the range and overlap corrected attenuated backscatter profile for local gradient minima [4]. Its application to ceilometer data involves averaging in time and range.

The Vaisala CL31 recommended report interval for aerosol investigation is 16 s; profile range resolution is 10 m. Applying 1,800 s and 360 m time and height sliding averaging reveals local gradient minima within the profiles and thus information about aerosol layers. This approach works generally well for cloudless days.

In Figure 2, backscatter profiles from a common day with rain and clouds are treated with the gradient method. A low nocturnal layer and a convective boundary layer evolving after about 10:00 local time are visible in this density plot. On the other hand precipitation and cloud bases call for a more sophisticated treatment.

The following section describes the steps suggested to turn this standard gradient method into a robust algorithm that is able to identify situations where precipitation or fog prevents the detection of boundary layer height, and does not use high backscatter from preceding clouds for profile averaging.

Enhanced Gradient Method = Robust All Weather Algorithm

The first step towards a robust all weather algorithm is the application of a cloud and precipitation filter. In Figure 2, the large backscatter values from the single 1,300 m cloud at 09:40 are still visible half an hour later when no cloud was detected in that range. High backscatter from clouds and precipitation should therefore not be used in the averaging process.

The result of applying this filter is shown in Figure 3. It reveals that there was no more precipitation after 06:30 and allows a better view on aerosol backscatter from the vicinity of clouds. Reporting of gradient minima is not done during the precipitation event.

Long averaging intervals help prevent false gradient minima hits generated by signal noise. On the other hand, this approach reduces the ability of the algorithm to respond to short scale signal fluctuations in space and time. Signal noise amount depends on range and time of the day. The enhanced automatic algorithm introduces variable averaging parameters that enable a much better view on a stable nocturnal layer at a height of around 100 meters that is detected before and after the morning rain shower (see Figure 4).

The final step towards the enhanced gradient method involves the suppression of false layer hits

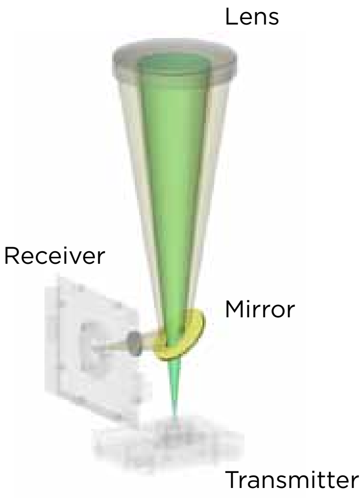


Figure 1. The single lens optical concept of Vaisala's ceilometers.

generated by small fluctuations of the backscatter signal intensity. This is the case around 07:00 at heights between 400 meters and 1,000 meters. Figure 4 shows a nocturnal layer followed by a convective layer with cloud formation reaching 1,600 meters in the afternoon.

Further information:

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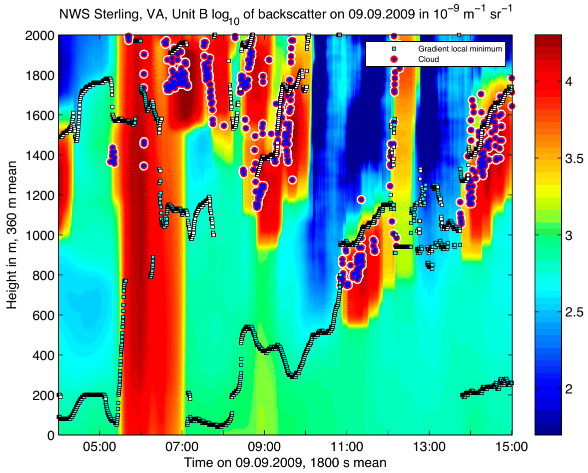

Figure 2. Density plot (local time vs. height) of range corrected attenuated backscatter profiles recorded by a Vaisala Ceilometer CL31 at the U.S. National Weather Service's test site in Sterling, VA on September 9, 2009. Fixed sliding averaging parameters of 1,800 s and 360 m are used that show a nocturnal and a convective layer. On this common day with rain and clouds, fixed averaging parameters do not reveal all aerosol layers in a satisfactory way.

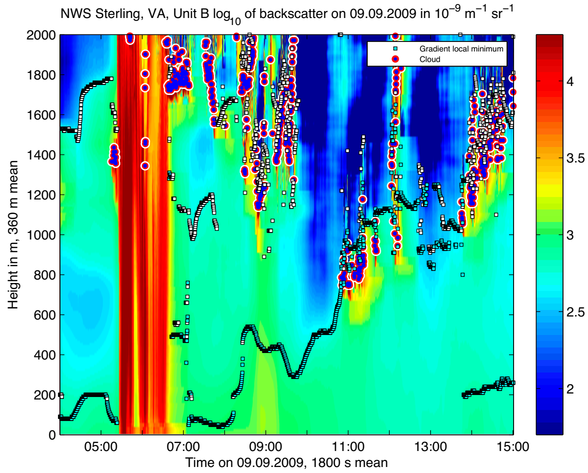

Figure 3. Density plot of range corrected attenuated backscatter profiles recorded by a Vaisala CL31 at the NWS Sterling site on September 9, 2009. A cloud and precipitation filter is applied to the data shown in Figure 2.

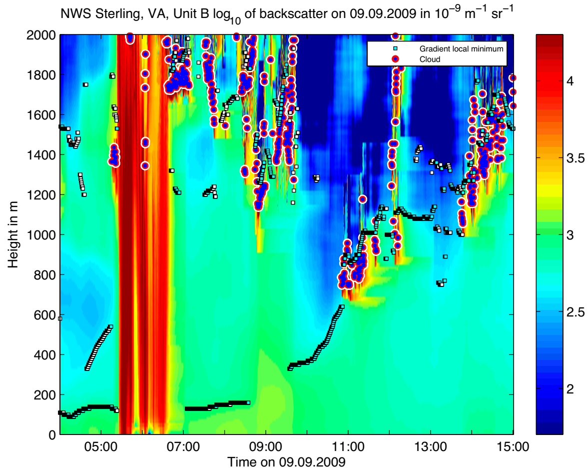

Figure 4. Density plot of range corrected attenuated backscatter profiles recorded by a Vaisala CL31 at the NWS Sterling site on September 9, 2009. All steps of the novel robust algorithm for boundary layer investigation have been applied to the data shown in Figure 2.