Impact of clouds on aerosol scattering as observed by lidar

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Cloud – aerosol interactions

As the global mean density of aerosols increases, their impact on the global energy budget becomes increasingly important. A significant and poorly understood component of this relates to the aerosol's interactions with clouds. [1] These interactions have been investigated using satellite observations, but due to the large swath of each pixel, it is not possible to separate the cloud and aerosol properties with a single set of radiance measurements. Hence, it has become common practice to assume that aerosol properties vary over length scales much greater than that of a cloud, such that retrievals can be averaged over several days and tens of kilometres, e.g. [2, 3].

Observation with lidar

Lidar is an active remote sensing technique, conceptually similar to radar, that monitors the light backscattered from a laser beam. The height of the scattering feature is calculated from the time-of-flight of the photons. With an average vertical resolution of 10 m and measurements once a minute, this method can directly resolve clouds and monitor the changes to the background aerosol distribution.

Lidars most commonly estimate the aerosol backscatter coefficient, β, being the cross-section for backscattering summed across all particles in the observed volume. The method used depends on the number of wavelengths at which the backscattered light is observed.

A simple investigation

A simple first experiment is to seek any difference between the properties of aerosol in the regions between clouds and those in cloud-free skies. Variations in the total aerosol loading will be corrected by normalising backscatter profile by the average value through the planetary boundary layer (PBL). The top of the PBL can be identified by the sharp decrease in backscatter that occurs at the transition to the free troposphere.

Clouds can be identified by their uniquely large backscatter. The cloudy atmosphere can then be investigated by plotting normalised backscatter for observations between passing clouds. The clear atmosphere is be represented by an average over several hours of profiles without observed cloud.

Instrumentation

This work uses measurements from a commercially produced Leosphere EZ lidar stationed at the NERC Chilbolton Facility for Atmospheric and Radio Research in Hampshire. These are available from `http://badc.nerc.ac.uk/browse/badc/chilbolton/`. This monitors only the primary wavelength of a frequency-tripled Nd:YAG laser at 355 nm, but also measures the depolarisation of the scattered light, giving a measure of the sphericity of the particles to distinguish between cloud and aerosol. The backscatter is derived using Leosphere's proprietary algorithm, a variation on the Klett-Fernald scheme [4, 5]. This assumes that the backscatter and extinction of aerosols are proportional with a ratio that can be deduced from knowledge of the source of the air mass.

Single-channel measurements

Left: Vertical profiles of aerosol backscatter from observations between clouds with colour indicating time of day. Plotted in black is the same profile, but averaged over a cloud-free period of the same day. Backscatter is normalised by its average value within the PBL and height is normalised by PBL height.
Right: Variation of backscatter with height and time over the day. PBL height used in the left plot is plotted as diamonds.

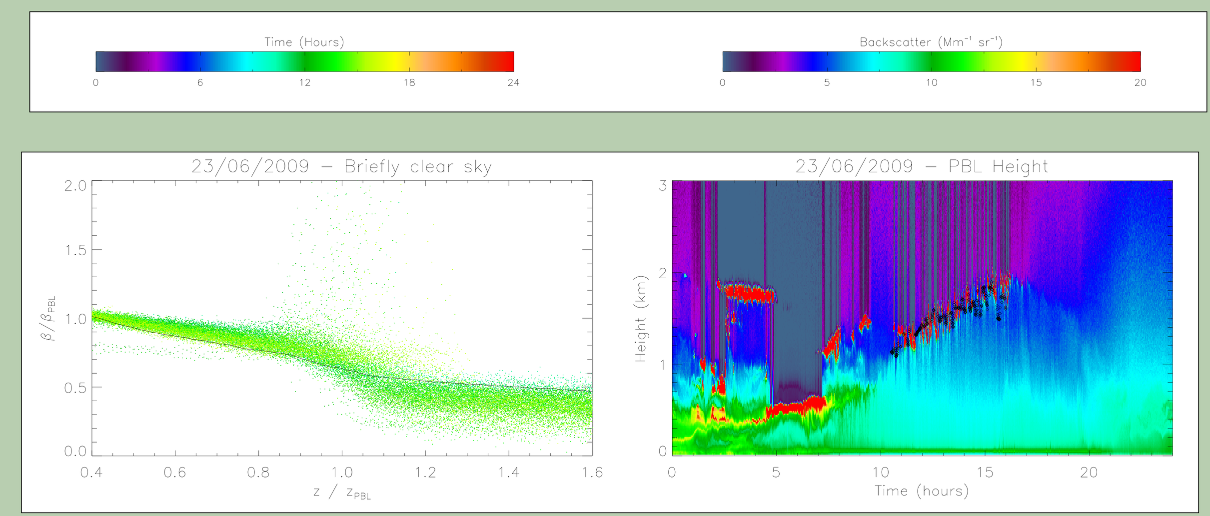

Figure 1: June 23rd, 2009 with 1700 – 2000 taken as clear.

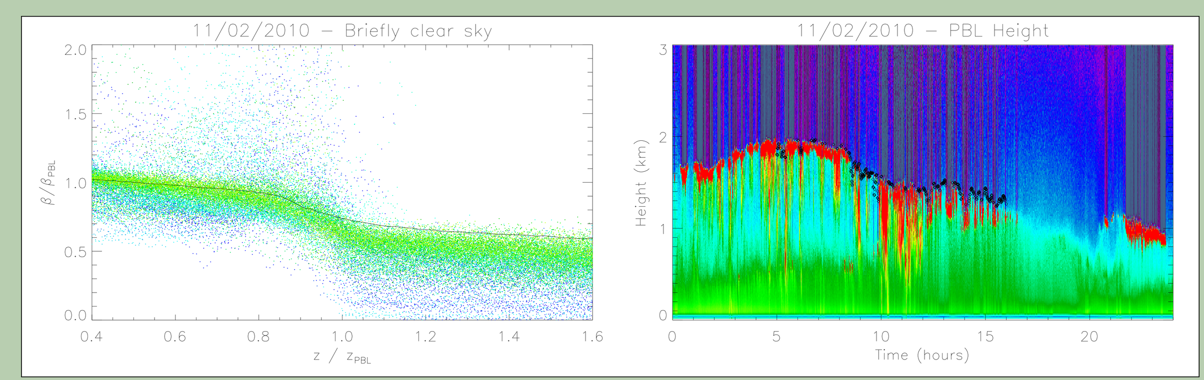

Figure 2: February 11th, 2010 with 1700 – 1900 taken as clear.

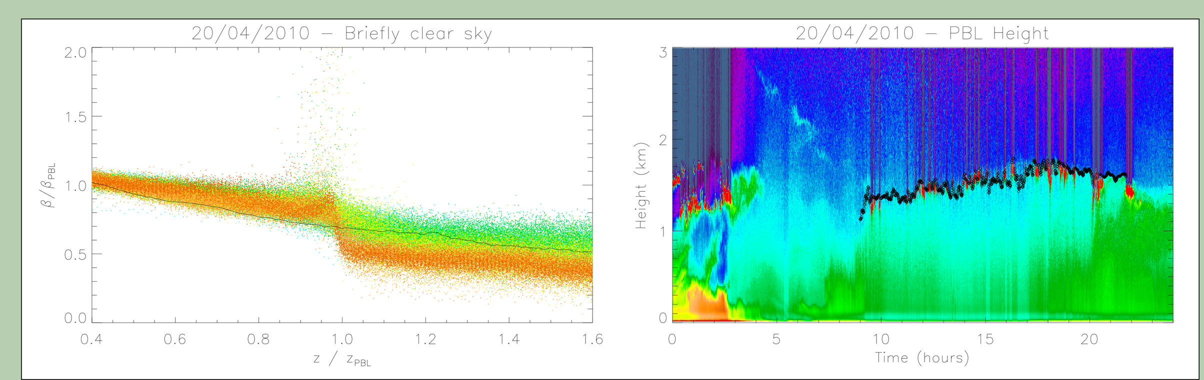

Figure 3: April 20th, 2010 with 0500 – 0900 taken as clear.

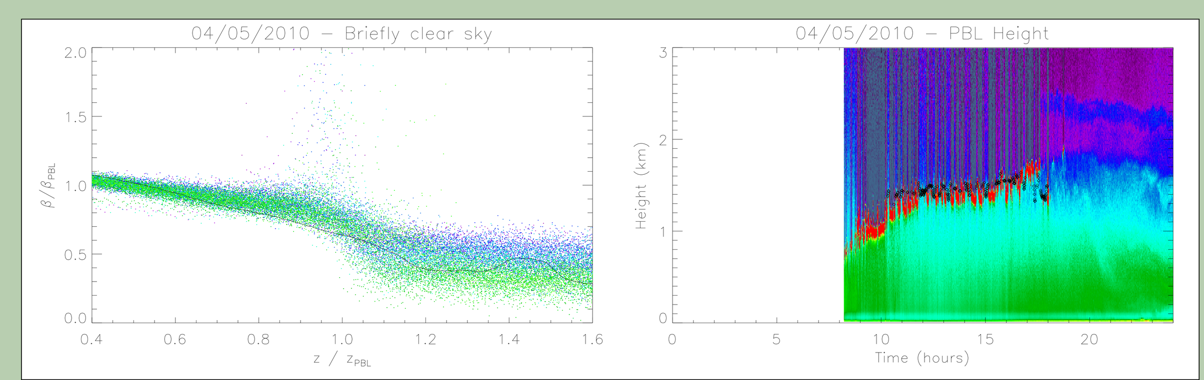

Figure 4: May 4th, 2010 with 1900 – 2200 taken as clear.

Discussion

The profiles provide no immediate conclusion. The expected tendency for backscatter to reduce immediately above the PBL is observed and this decrease could be said to be greater in cloudy conditions than for clear skies in figs. 1 and 2. This might indicate that the clouds are entraining aerosols from the background distribution, reducing their abundance. Alternatively, aggregation within the cloud may have increased the size of the aerosol particles, which would decrease the backscatter both through a decreased number of particles and by the reduced backscattering cross-section of larger particles.

An increase in backscatter just beneath the top of the PBL is observed late in the day of in fig. 3. This is likely due to the presence of more tenuous clouds, the so-called twilight region. [6]

The simple threshold technique for determining PBL height, as plotted on the right of figs. 1–4, qualitatively performs well, selecting heights clearly within the cloud layer, which would be expected to cap the PBL. However, the wide spread of backscatter values in fig. 4 demonstrates that the transition between the PBL and free troposphere is not always a sharp transition. In these cases, a more representative height will needed to be defined. The exponential distribution of the clear sky profile would indicate that a scale height may be appropriate.

References

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