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 it is not generally possible to retrieve cloud and aerosol properties from 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 kilometers, e.g. [2, 3]. To investigate the validity of this assumption, a measurement of aerosol properties that is independent of cloud cover is required. Lidar can provide this.

Optimal estimation retrieval

Increasingly common in the analysis of satellite data, optimal estimation is a scheme to determine the state of the atmosphere that, while obeying prescribed physical constraints, is most likely, given a set of observations. [4] For a set of measurements, $y$, this is the atmospheric state, $x$, that satisfies the inverse problem,

$$x_{n+1} = x_n + [(1 + \gamma)y_n - F(x_n)]S_n^{-1}(x_n - x_n),$$

where $y_n$ are the measurements and a priori covariance matrices; $F(x_n)$ the forward model; and $\gamma$ a constant chosen with each iteration to minimise a cost function.

Application to lidar

The few studies to have applied optimal estimation to lidar data linearised their forward models, e.g. [5, 6]. For a non-linear forward model, the Levenberg-Marquardt method utilises an a priori estimate of the mean state of the atmosphere, $x_n$, and iterates towards a solution,

$$x_{n+1} = x_n + \left(1 + \frac{\partial y}{\partial x}x_n\right) [y - F(x_n)]S_n^{-1}(x_n - x_n),$$

where $S_n$ is the sum of the noise of the system and $\epsilon$ the atmospheric state, that while obeying prescribed physical constraints, is most likely, given a set of observations. [4] For a set of measurements, $y$, this is the atmospheric state, $x$, that satisfies the inverse problem,

$$x_{n+1} = x_n + [(1 + \gamma)y_n - F(x_n)]S_n^{-1}(x_n - x_n),$$

where $y_n$ are the measurements and a priori covariance matrices; $F(x_n)$ the forward model; and $\gamma$ a constant chosen with each iteration to minimise a cost function.

Validation

The STFC Chilbolton Observatory hosts an AERONET site. Aerosol optical thickness (AOT) measurements are compared to the retrieved AOT at 10 km in fig. 1, where a strong one-to-one relationship is found. The bias is related to a systematic error in the specification of the lidar. Favourable comparisons can also be made against retrievals using more standard methods [7], where the algorithm resolves significantly greater detail both in and above the boundary layer (fig. 2).

Interaction with clouds

As an initial investigation, the cloud base and boundary layer heights were determined for partly cloudy days using a simple gradient method. Fig. 3 shows the backscatter retrieved against height beneath these features for cloudy and clear profiles. The two plots show no significant difference beyond the presence of clouds and aerosol swelling immediately beneath them.

Figure 1: AOT at 355 nm retrieved by optimal estimation against simultaneous, co-located AERONET measurements at 340 nm. Outliers (blue) are related to the presence of a cloud in the lidar’s field of view.

Figure 2: Aerosol backscatter on 29 Aug 2007 as derived by a standard elastic algorithm [7], assuming a clear atmosphere at 7 km and a constant lidar ratio of 45 (top), and by optimal estimation retrieval, at a resolution of 20 s and 17 m (bottom).

Figure 3: Aerosol backscatter as a function of height for 29 Aug 2007. Colour indicates time of day from 0830 – 1045 for 133 cloudy and 231 clear profiles. The presence of a cloud was flagged by a strong, positive gradient in the range-corrected lidar profile.

This indicates that the presence of a cloud above the boundary layer has no visible effect on the scattering properties of those aerosols. This lends itself to the hypothesis that aerosol properties change over greater length scales than clouds.

References


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