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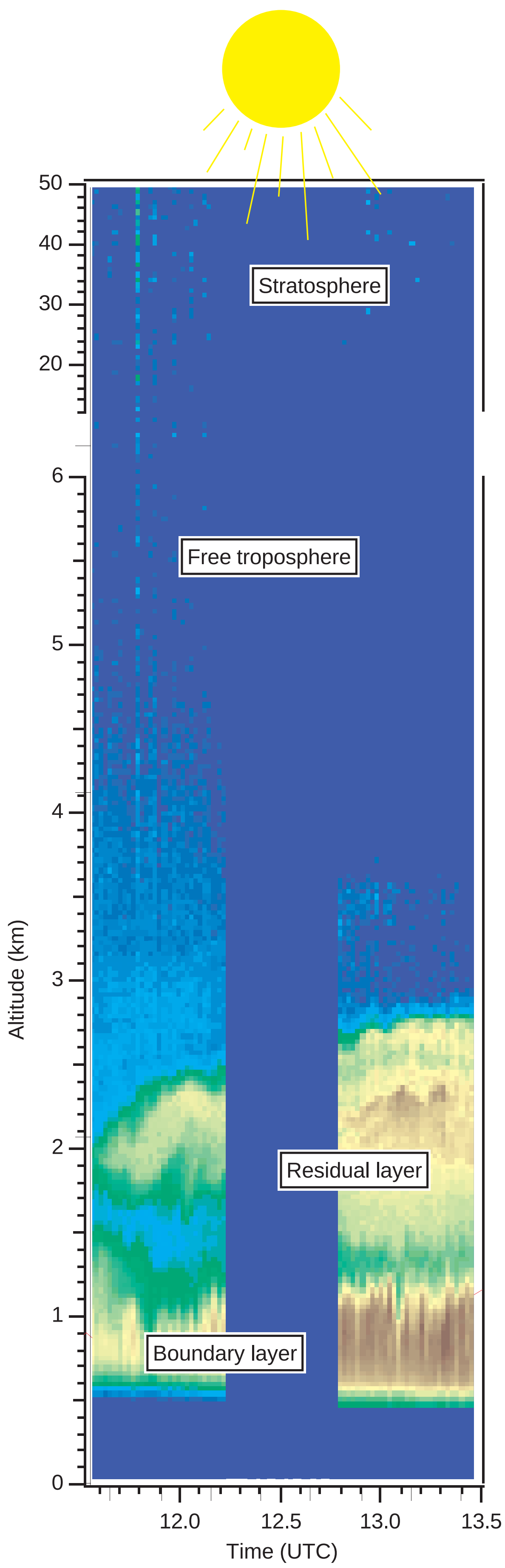
Aerosols: Closure of the radiation balance



The structure of the atmosphere above Bilthoven on July 26, 1995, as seen by the RIVM tropospheric ozone lidar. Color codes indicate the amount of aerosol present. A thick and strongly scattering aerosol layer (Residual layer) is observed above the boundary layer. The extinction properties of this layer are shown under 'residual layer free troposphere'.

Aerosols and radiation: closure experiments

Quantifying the radiation effect of aerosols is difficult. Aerosols are variable in time, horizontal and vertical distribution, and optical properties. In "Closure experiments" the direct effects of aerosols on incoming solar radiation are measured in different ways in an attempt to create a consistent representation that can be used in models.

The effect of aerosols can be expressed as a change in the incoming radiation in W / m^2. However, this value will change with the angle of the incident light beam even is the aerosol layer does not change. The Aerosol Optical Depth (AOD) is a better measure. It expresses the scattering that would take place if a light beam would enter the atmosphere from zenith.

This experiment

Below, we show simultaneous measurements on cloudless days:

- Total AOD as a composition of:
  - Boundary layer AOD measurements with nephelometer and lidar
  - Residual layer and free troposphere AOD measurements with lidar
- Total AOD using direct solar radiation measurements with pyrheliometers

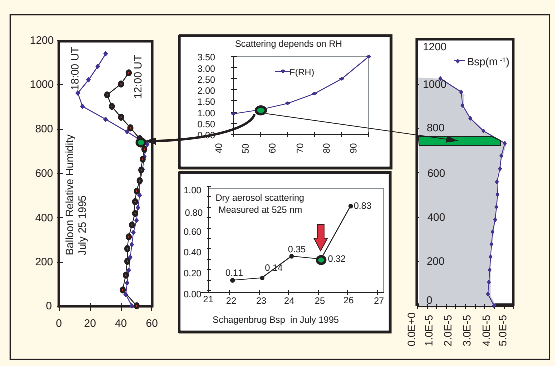
AOD is wavelength dependent. For this closure experiment, all AOD values are recalculated to a common wavelength of 525 nm.

Boundary layer AOD

The determination of the boundary layer AOD is based on ground level nephelometer measurements, radiosonde humidity profiles and lidar mixing layer measurements.

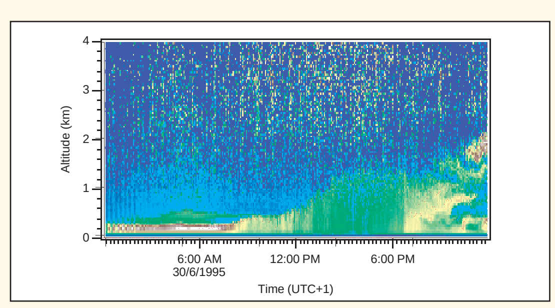
Nephelometer and radiosonde

Nephelometer measurements were performed at ECN in Petten. Aerosol scattering was measured for different levels of relative humidity. Using radiosonde humidity data, the extinction profile and the integrated AOD over the boundary layer is calculated.



Boundary layer height and mixing

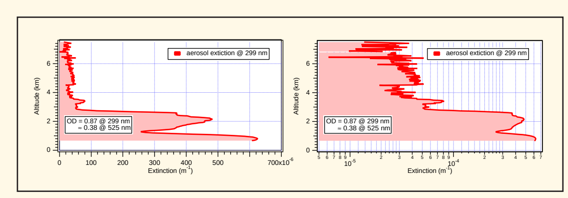
RIVM boundary layer lidar measurements are used to determine the height of the boundary layer. In addition, the degree of mixing is also observed. This helps to determine the optimum time for the closure calculation.



Lidar measurements of the development of the boundary layer as seen by the RIVM boundary layer lidar. Green and brown colors indicate the presence of aerosols, blue colors are associated with relatively clean air. The figure shows a full diurnal cycle with a typical development of the boundary layer on a clear summer day. As a result of surface heating, the convective boundary layer rises from several hundred meters in the morning to 1.5 kilometers in the afternoon.

Residual layer and free troposphere AOD

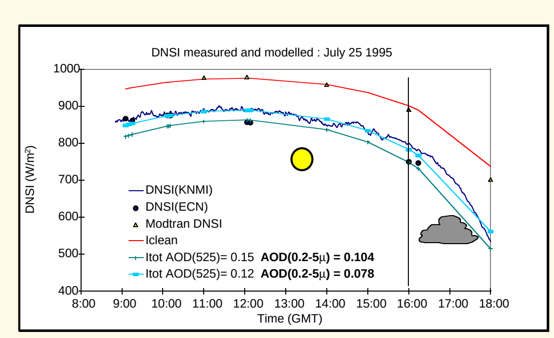
The RIVM tropospheric ozone lidar also provides aerosol extinction profiles at 299 nm. These profiles are calculated using the Klett method (Browell, Appl. Opt. 24, 2827-2836, 1984). It is important to know that this procedure is based on assumptions about the aerosol optical properties. Numerical results should be interpreted with care accordingly.
The total AOD is calculated as the integral under the extinction curve (shaded area) at 299 nm, corrected for ozone extinction and converted to 525 nm with an assumed wavelength dependence of $\lambda^{-1.5}$.



Direct solar radiation measurements

The Direct Normal Solar Irradiance (DNSI, the irradiance measured perpendicular to the incoming beam) was measured using pyrheliometers at de Bilt (KNMI) and at Petten (ECN). The measured irradiance levels are compared with those expected on the measurement location on this day. The expected levels (I_{clean}) were obtained using MODTRAN, using actual atmospheric parameters as input. The AOD is derived from the difference between the expected I_{clean} and the observed DNSI levels.

This difference is more than 100 W / m^2 for this day!

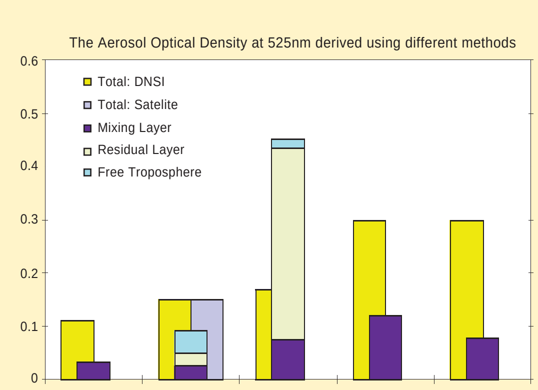


Results

The figure gives the results of the closure experiments for 5 days in 1995 and 1996.

- The yellow bars show the AOD derived from the DNSI data, using MODTRAN calculated values for the clean air DNSI level.
- The stacked bar shows the total AOD obtained for the mixed layer, residual layer and free troposphere.
- For July 25 an estimate of the AOD level was obtained from satellite observations (TNO, Veefkind, pers. com.)

Lidar measurements of the residual layer and free troposphere are available for two of the five days only.



Conclusions

Five days were evaluated, analysing the Aerosol Optical Density in different layers:

- All days show that a significant part of the extinction of radiation by aerosols takes place above the boundary layer
- Lidar measurements indicate that residual layers may be responsible for considerable additional extinction. However, reliable quantitative results cannot be obtained with the current lidar setup and analysis.
- In order to evaluate the effect of emission reductions on radiative forcing by aerosols, knowledge is needed on the aerosol vertical distribution and composition.