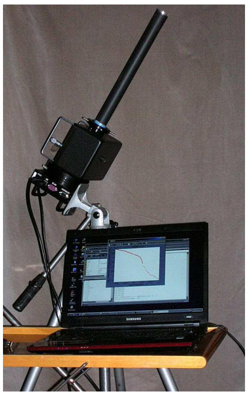
Stratospheric aerosol optical depths and extinction profiles retrieval from ground-based spectral measurements of twilight sky brightness.



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Abstract

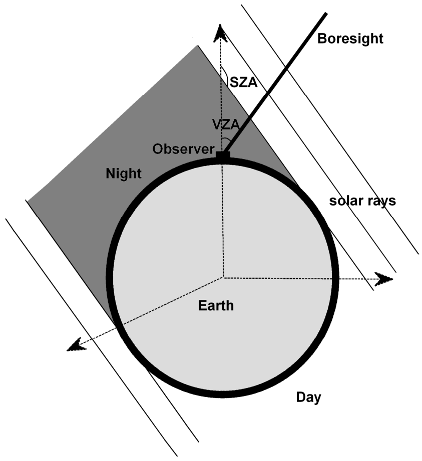
Lower stratospheric and upper tropospheric aerosol extinction profiles were retrieved from ground-based spectral measurements of twilight sky brightness. The measurement dataset covers the period from September 2009 to August 2011 including the minor eruption of Nabro occurred in Eritrea on 13 June 2011. Radiative transfer computations in a Monte Carlo approach are used to feed the retrieval algorithm and to better understand the role of single and multiple scattering in the twilight period.

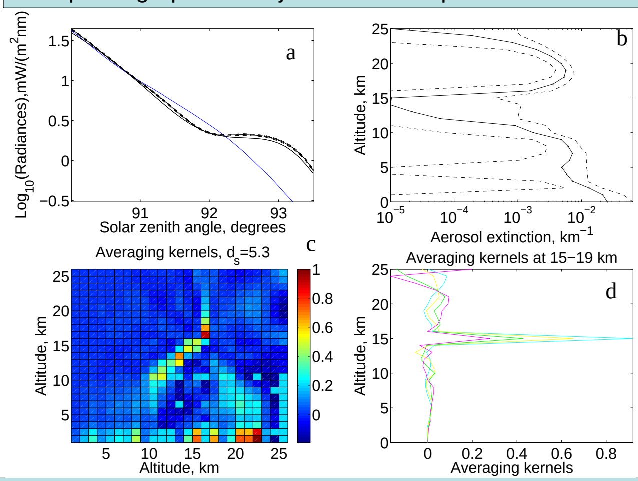
The measurements.

During twilight when the solar zenith angle (SZA) is greater than 90°, the lower part of the atmosphere above the observer is shadowed and the upper part is sunlit. The boundary between the shadowed and sunlit parts of the atmosphere shifts with the progress of twilight leaving the lower layers of the atmosphere in the Earth's shadow. This gives us a natural possibility of atmospheric sounding.

When the Sun is below the horizon, only the scattered light can be measured by a spectrometer. The intensity of the scattered light depends on the vertical extinction profiles of the different atmospheric species, as well as on aerosol and molecular phase functions.

The measurements were carried out in the period from October 2009 to August 2011 in Tbilisi, Georgia (41° 43' N, 44° 47' E). We used a SBIG ST-9XE CCD camera equipped with SBIG SGS spectrograph and a sunshade that allowed to reduce the field of view down to 4°. The spectrograph was adjusted to take spectra between 700 and 800 nm





The retrieval algorithm

A single scattering forward model with multiple scattering corrections obtained from the Monte Carlo code (Oikarinen et al., 1999) was developed. To amplify the dynamics of the twilight curve and to remove all constant calibration factors, the measurement vector y was presented as the first differences of logarithm of intensity vs. SZA:

$$y_i = \log\left(\frac{I_{i+1}}{I_i}\right)$$

An error-weighted least-squares fitting to retrieve the aerosol extinction profiles was performed by means of a Levenberg–Marquardt algorithm.

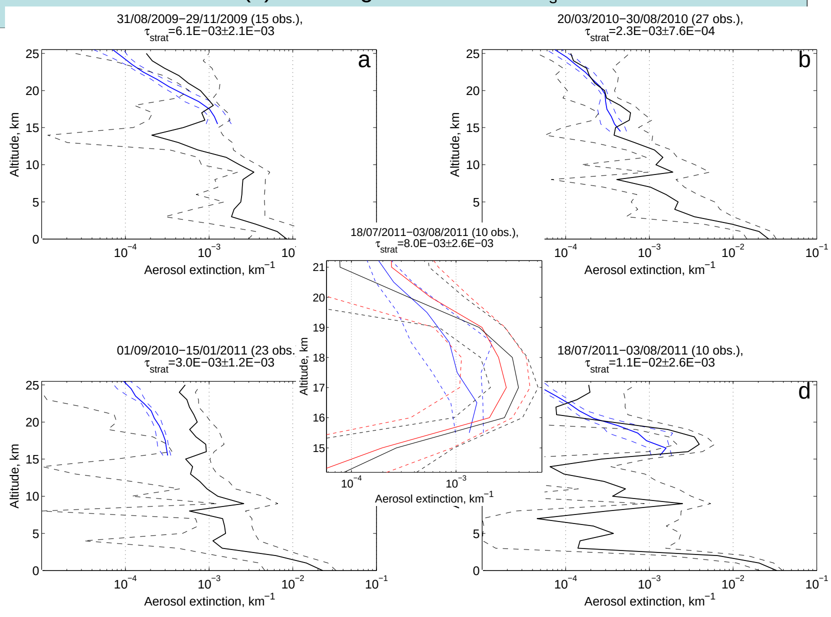
The cost function was presented as:

$$\chi^2 = [\mathbf{y} - f(\mathbf{x})]^T \mathbf{S}_\varepsilon^{-1} [\mathbf{y} - f(\mathbf{x})] + (\mathbf{x} - \mathbf{x}_\mathrm{a})^T \mathbf{S}_\mathrm{a}^{-1} (\mathbf{x} - \mathbf{x}_\mathrm{a}).$$

[above] Panel (a) shows an example of the twilight sky brightness at wavelength 780 nm as a function of solar zenith angle measured in 14/07/2011 after the Nabro volcano eruption in July 2011 (black solid dotted line). The measured curve is fitted by the modeled one (solid line). Measurement uncertainties are shown by dashed lines. The blue line on the panel shows twilight sky brightness in volcanically quiet conditions (24/06/2011).
Panel (b) shows the aerosol profile retrieved from the black curve presented on the panel (a) and corresponding uncertainty (dashed lines). Panel (c) shows averaging kernels which correspond to the profile presented on the Panel (b). The degree of freedom d_s is shown above the plot. Panel (d) shows averaging kernels at altitudes 15-19 km.

Aerosol extinction profiles and stratospheric optical depths.

To investigate the retrieved aerosol profiles variability, for each altitude the 15.87th, 50th and 84.13th percentiles were calculated from an ensemble of retrievals **[right]**. The 50th percentile is the median value; the 15.87th and 84.13th percentiles represent the distribution width. The same percentiles from an ensemble of OSIRIS aerosol extinction profiles (http://osirus.usask.ca) are presented by blue curves.
The post-Nabro enhanced stratospheric aerosol layer persisted at about 17 km altitude during July – beginning of August 2011 (panel d).
The post-Nabro measurements were reprocessed using multiple scattering correction for volcanic conditions (inset, red curves). In this case aerosol extinctions in the stratospheric aerosol layer are smaller and better agree with the OSIRIS results.



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