Observing stratospheric sulphur dioxide and sulphate aerosol using MIPAS

Andrew Smith, Charlotte Birch, Anu Dudhia, Don Grainger

Atmospheric, Oceanic and Planetary Physics, University of Oxford.

smith@atm.ox.ac.uk

Abstract

The **M**ichelson **I**nterferometer for **P**assive **A**tmospheric **S**ounding (MIPAS) is one of the main experiments on ESA's Envisat platform. MIPAS was operational from 2002 to 2012 measuring atmospheric limb emission spectra from 4.1–14.5 μm. This makes it possible to measure the ν_1 and ν_3 SO_2 bands at 8.6 and 7.3 μm, as well as less well defined sulphate aerosol broadband features.

Using a singular value decomposition technique of MIPAS spectra, conversion of SO_2 to sulphate aerosol can be seen after the June 2011 eruption of Nabro, Eritrea. Quantitative SO_2 concentrations obtained using the MORSE retrieval scheme allow estimation of the converted sulphate aerosol mass.

Aerosol flagging using SVD

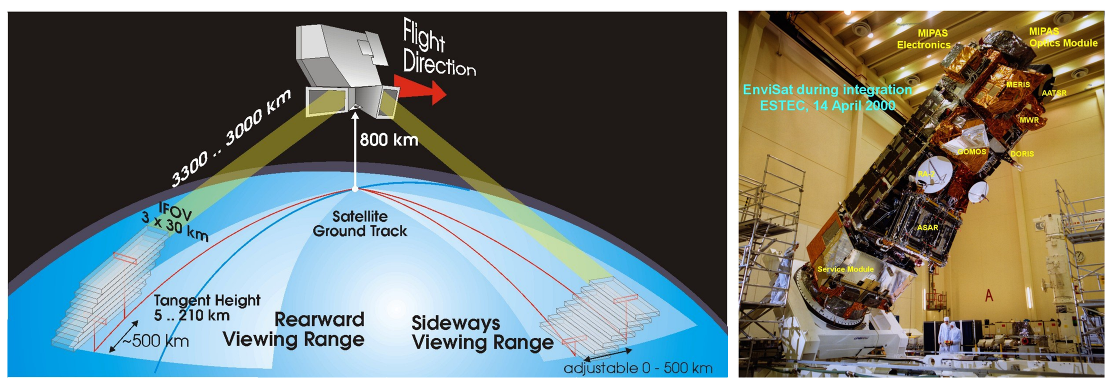

Figure 1: The MIPAS pointing geometry, and before launch on the ESA ENVISAT platform. *(Credit: U. Leicester, UK).*

Using singular value decompositon, standard atmospheric variability taken from measurements before an eruption can be removed, leaving suspected volcanic signatures [Grainger et al., 2013]. The eruption of Nabro, Eritrea was extremely rich in SO_2 emissions, with very little ash. As a consequence, the volcanic singular vector is close to a sulphate aerosol, with the SO_2 ν_3 band at 1362 cm^{-1} clearly evident. Comparisons with an IASI sulphate flag [similar to Clarisse et al., 2013] show good agreement.

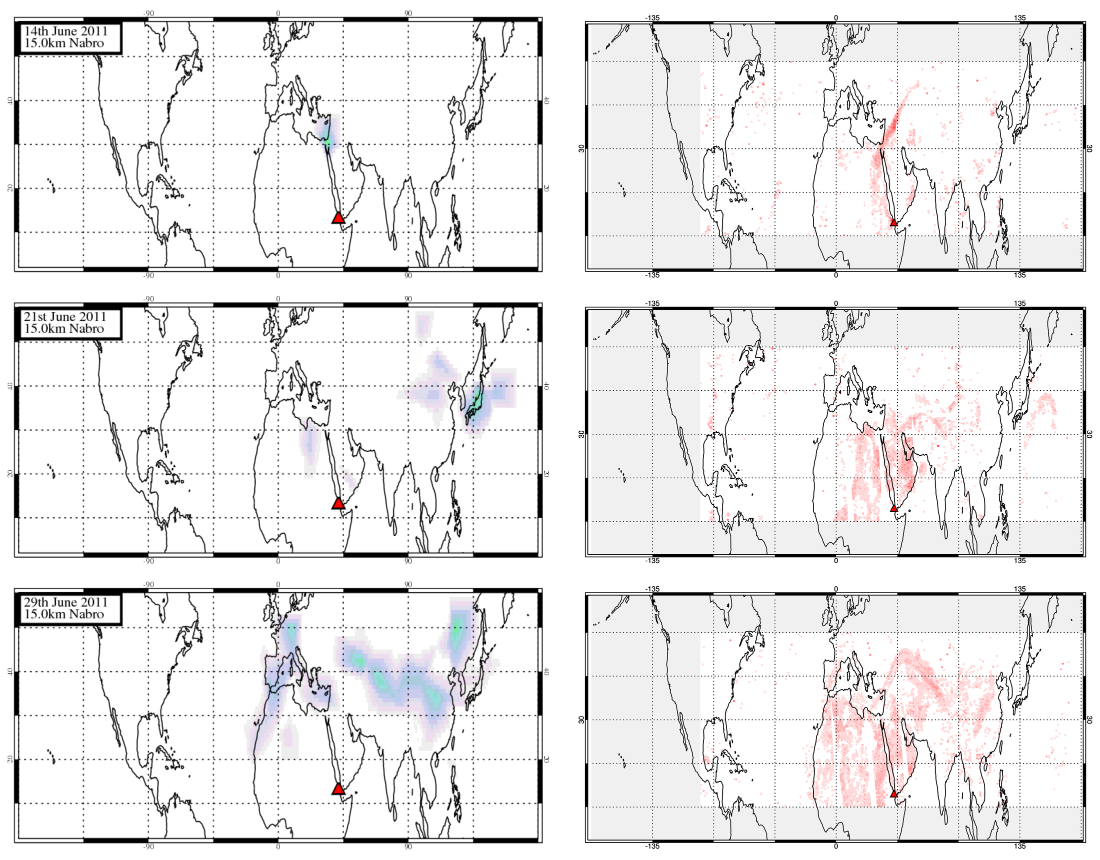

Figure 2: Time evolution of the Nabro plume from MIPAS, using singular vector amplitudes (left) at an altitude of 15 $\pm$ 1.5 km and IASI (right). IASI is a nadir viewer, and so sees further down into the atmosphere.

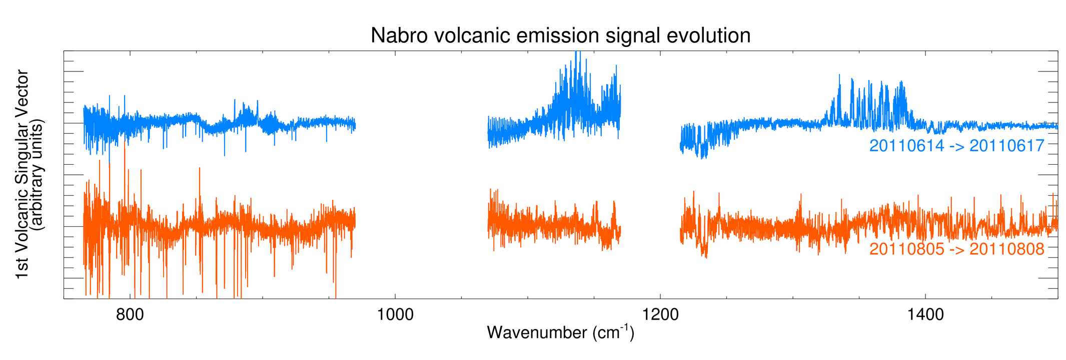

Figure 3: Evolution of plume spectral emission from the Nabro eruption as emissions of SO_2 are replaced by H_2SO_4 aerosol.

Extinction and SO_2 retrievals

The MIPAS Orbital Retrieval using Sequential Estimation (MORSE, `www.atm.ox.ac.uk/MORSE/`) is capable of retrieving a large number of atmospheric molecules, and is currently being adapted to retrieve extinction (β^{ext}) in specific regions of the MIPAS spectra. These microwindows have been selected in regions where one would expect the clearest aerosol signals, and the method has been altered so that the spectrally flat continuum is retrieved while putting as much uncertainty as possible into residual molecular features. SO_2 retrieval uses 5 microwindows in the ν_3 band centred at 1362 μm.

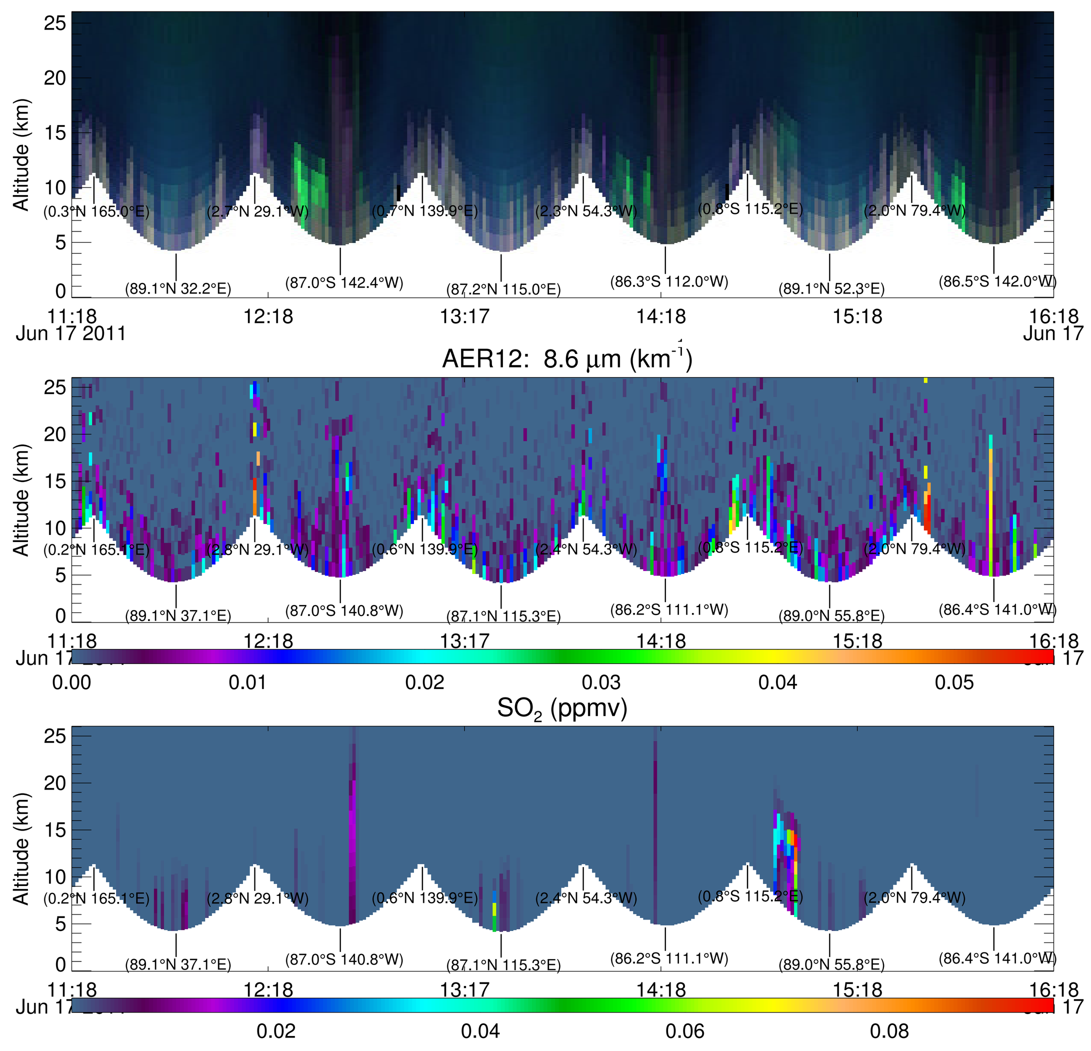

Figure 4: Showing three consecutive MIPAS orbits from 17th June 2011. The top panel shows a false colour image designed to expose volcanic signals (which show as green); the middle, aerosol extinction at 8.6 μm; and the lower, SO_2.

Figure 4 shows MIPAS orbits from 17th June 2011. The extinction retrieval shows PSCs over Antarctica, tropical convective clouds, and ash from the Puyehue-Cordón Caulle (Chile) eruption. The stratospheric Junge layer is not visible as it is much thinner than most tropospheric signals and is missed. The SO_2 retrieval shows weak signals from the Puyehue eruption at 12:40 UTC and a signal of unknown source close to the North pole at 13:25 UTC. The injection from Nabro can clearly be seen at 15:00 UTC. Zonal means of extinction (Fig. 5) can pick out noisier, stratospheric signals.

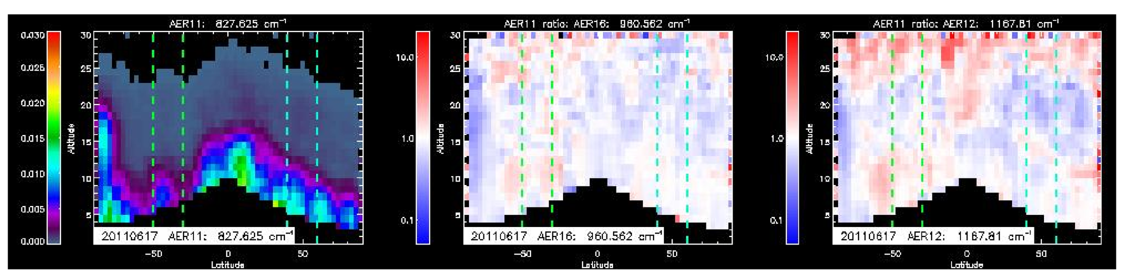

Figure 5: Smoothed zonal means of extinction in extinction microwindows at 12.1, 10.4 and 8.6 μm for all orbits on 17th June 2011. The first panel shows absolute extinction, while following panels are normalised to the first panel.

Estimating sulphate mass

To obtain an estimated stratospheric mass of sulphur, extinction was first converted into stratospheric aerosol optical depth:

$$\mathrm{AOD}_{\mathrm{strat}} = \int_{z_{\mathrm{tropopause}}}^{\infty} \beta^{\mathrm{ext}}(z)\, dz, \qquad (1)$$

and averaged to obtain zonal mean $\mathrm{AOD}_{\mathrm{strat}}$. Assuming an aerosol size distribution [Grainger et al., 1993] and H_2SO_4 refractive index [Tisdale et al., 1998], $\mathrm{AOD}_{\mathrm{strat}}$ can be converted to a mass per square kilometer.

In Fig. 6, $\mathrm{AOD}_{\mathrm{strat}}$ and SO_2 column amounts are shown, and sulphur mass is compared to a simple model of SO_2 conversion to sulphate aerosol, via gaseous H_2SO_4 [Miles et al., 2004].

Figure 6: Evolution of stratospheric aerosol and SO_2 from the beginning of June 2011. The lowest panel gives mass of sulphur inferred from column SO_2 and aerosol extinction measurements.

Decay of stratospheric SO_2 follows the modelled curve well, but aerosol mass is over-estimated. There are several reasons why this could be:

- Ash aerosol adding additional optical depth;
- Incorrect microphysical assumptions of H_2SO_4aerosol;
- Errors in extinction retrieval;
- Radiance offsets in MIPAS data.

These possibilities are currently being investigated.

References

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