Observing volcanic signatures using satellite infrared spectrometers

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Abstract

Volcanic plumes formed from explosive eruptions are generally a combination of gases (such as SO_2) and aerosol particles (mainly silicate material and sulphate). Interest in the detection of atmospheric volcanic ash is high for several reasons, including beging a hazard to aircraft, altering the short-term global radiation balance, and human health issues.

Using the Infrared Atmospheric Sounding Interferometer (IASI) on MetOp, a method of flagging volcanic signatures is presented. The methodology is based on that of Walker et al. [2011] and Carboni et al. [2012], designed to detect trace gases in IASI data. The principle idea is to use a generalised error covariance that contains not only the instrument noise, but covariance due to interfering trace gases and broadband scatterers (such as aerosols and clouds) that should be unrelated to the required retrieved property. Since these signals are included in the covariance, they need not be retrieved or their variance taken account of in the forward model of the atmosphere.

IASI

IASI is a Michelson Fourier transform spectrometer (FTS) with coverage in the thermal infrared (TIR) from 645–2760 cm^{-1} at a spectral resolution of 0.25 cm^{-1}. The instrument has a polar orbit with a swath width of ∼2200 km and almost global coverage twice daily. Individual measurement pixels within the swath have a circular footprint radius of ∼12 km.

The high spectral resolution allows broadband signals (such as aerosols and clouds) to be distinguished from molecular lines. Within the broadband signals, different particles have very different signals, particularly in the TIR atmospheric window region. Fig. 1 shows simulated IASI spectra for several different particles of interest.

Broadband IR signatures

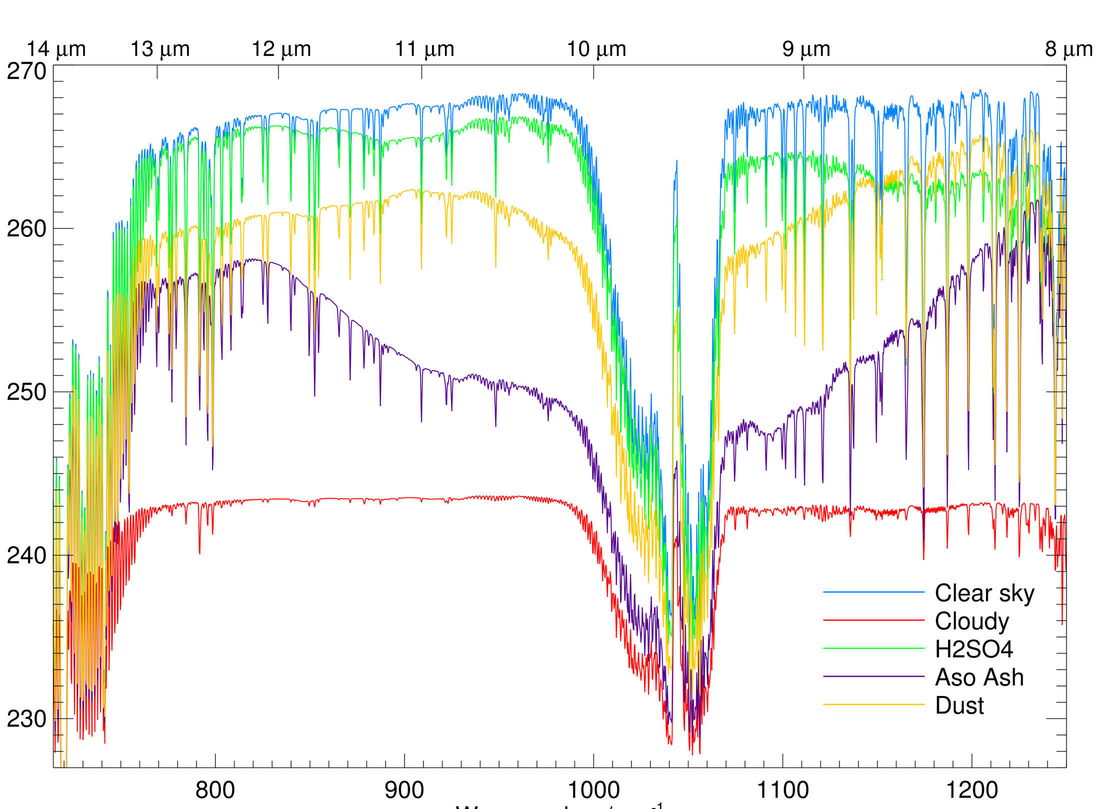

Figure 1: Showing simulated IASI spectra in the 8–14 μm region for five cases: Clear sky, cloudy sky (liquid water), sulphate aerosol, volcanic ash aerosol (with refractive index data obtained from measurement of Aso volcanic ash), and mineral dust aerosol. Clear broadband differences between the spectra provide confidence that different aerosol types and clouds can be distinguished from each other.

Method

Using the notation of Rodgers [2000], we define the measured spectra, $\mathbf{y}$, as a function of the forward model, $F(\tau_0, \mathbf{b})$:

$$\mathbf{y} = F(\tau_0, \mathbf{b}) + \epsilon_{\text{random}} + \epsilon_{\text{systematic}},$$

where τ_0 is the reference volcanic aerosol optical depth, and $\mathbf{b}$ contains the properties of some standard atmosphere and is kept fixed for all of this work. The optical depth is retrieved by linearisation about our calculated value of optical depth, τ_0, so that

$$\mathbf{y} - F(\tau_0, \mathbf{b}) = \mathbf{K}(\tau - \tau_0) + \epsilon_{\text{random}} + \epsilon_{\text{systematic}},$$

where $\mathbf{K}(\tau - \tau_0)$ is the Jacobian of $\mathbf{y}$ with respect to τ. The least squares estimate of τ can be obtained by

$$\tau = \tau_0 + \left(\mathbf{K}^T \mathbf{S}_\epsilon^{-1} \mathbf{K}\right)^{-1} \mathbf{K}^T \mathbf{S}_\epsilon^{-1} \left(\mathbf{y} - F(\tau_0, \mathbf{a})\right).$$

The error covariance matrix, $\mathbf{S}_\epsilon$, is built up from IASI measurements in the days preceeding the eruption and in the same geographical area (so that it contains the variation for this location, and time of year, but no volcanic covariance).

Forward models and Jacobians are calculated for a range of optical depths and plume heights and each value is used in the final equation above to build up a set of linearised optical depth retrievals. The values of τ obtained for each different set of τ_0 retrievals are different, generally settling about τ_0. However volcanic signals stand out above the noise and can be flagged as being of suspected volcanic origin. The final flag for an individual pixel is based on a threshold number of the retrievals flagging high optical depth. Example flags from the Puyehue and Nabro eruptions in June 2011 are shown in Figures 2 & 3.

Plume evolution - Puyehue

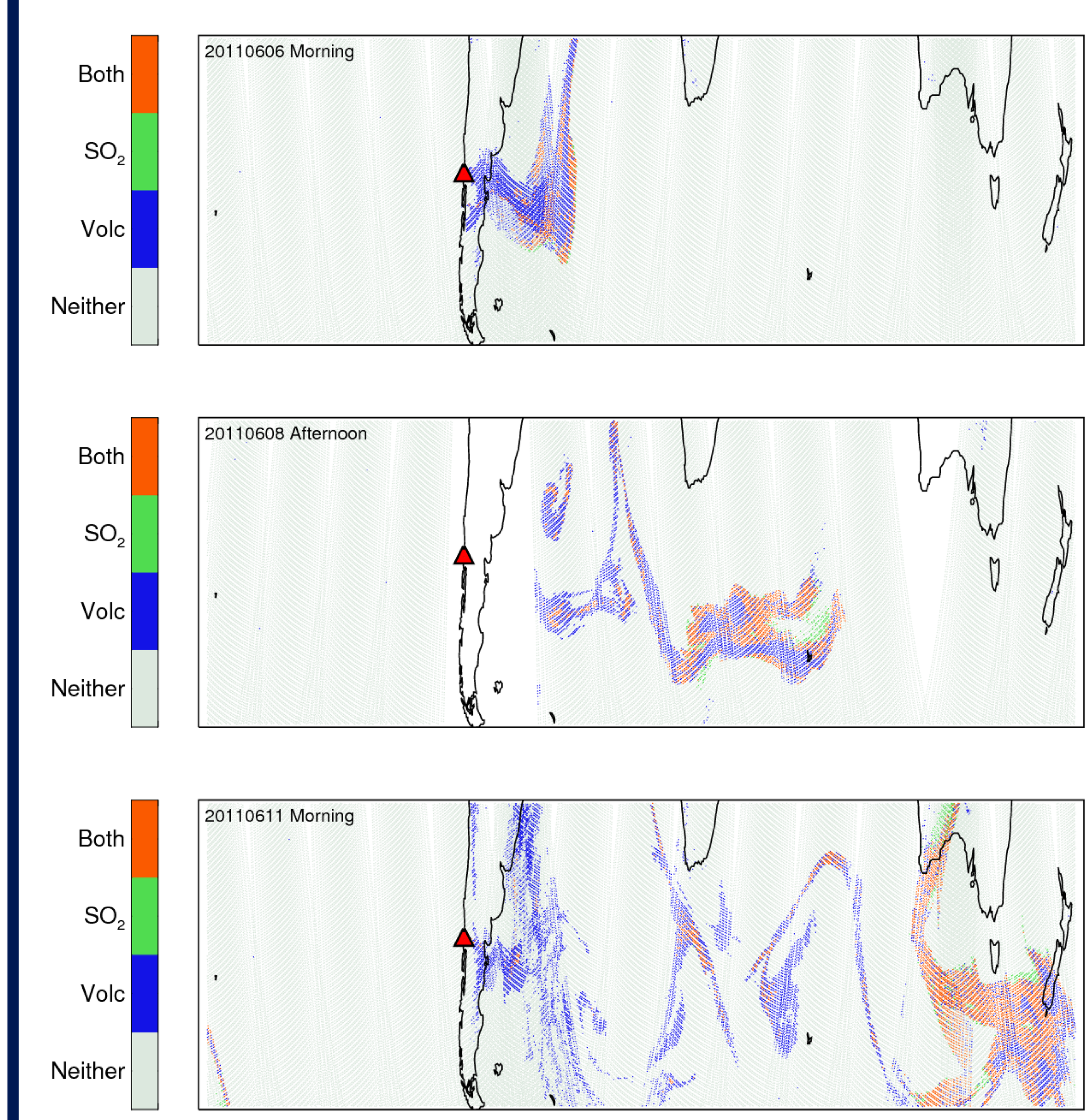

Figure 2: Evolution of the plume emitted from the Puyehue-Cordón Caulle eruption which began on 4th June 2011. The eruption did not produce a large amount of SO_2, unlike the Nabro eruption in Eritrea (see Fig. 3 below). SO_2 flagging is from the method described in Carboni et al. [2012].

Plume evolution - Nabro

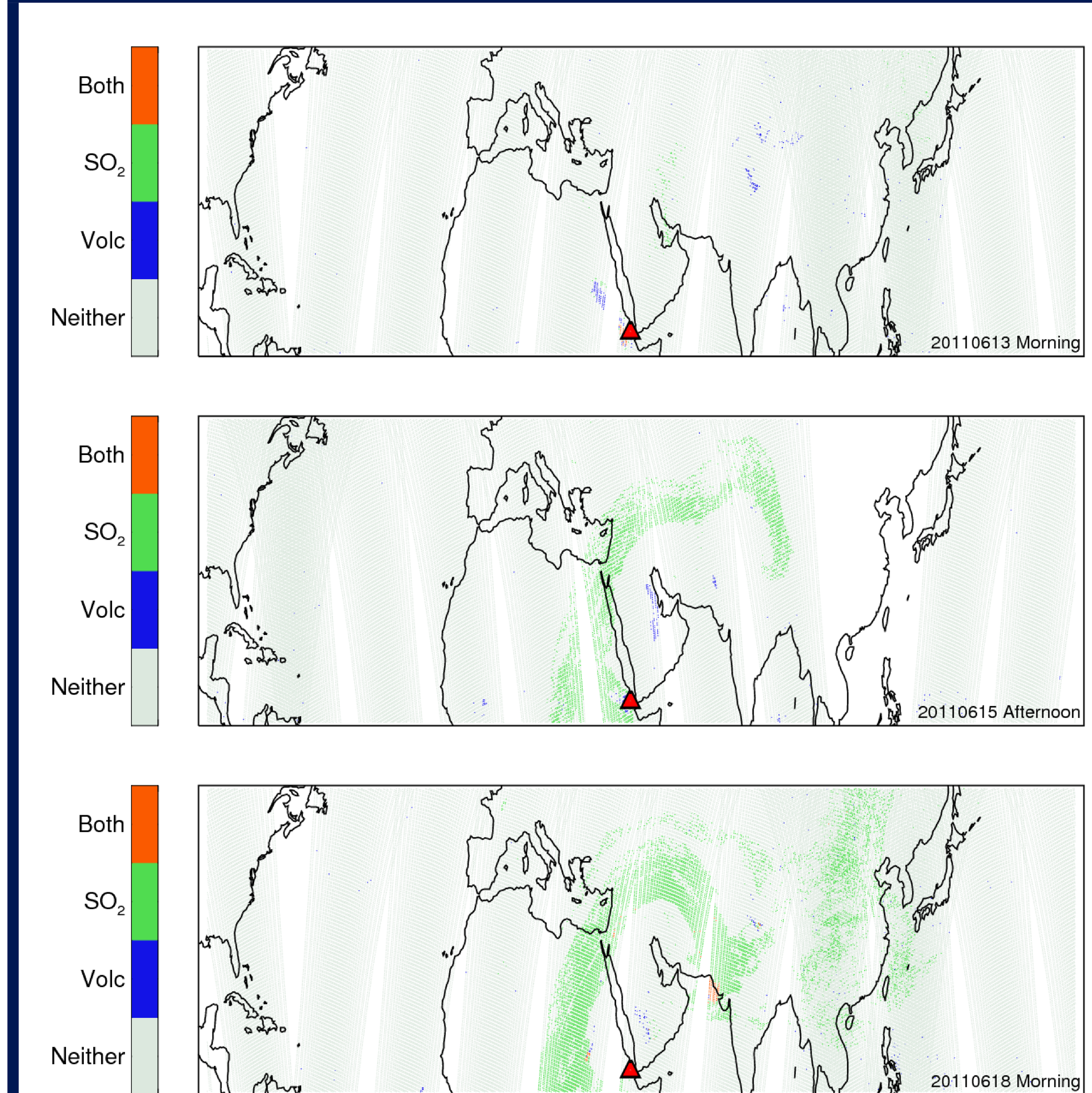

Figure 3: Evolution of the plume emitted from the Nabro eruption, Eritrea which began on 12th June 2011. This eruption was the largest injection of SO_2 into the atmosphere in the last 10 years and dwarfed ash emission.

References

Carboni, E., R. G. Grainger, J. Walker, A. Dudhia, and R. Siddans, 2012. *Atmospheric Measurement Techniques Discussions*, **12**(5):11861–11897, doi: 10.5194/amtd-12-11861-2012.

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Walker, J., A. Dudhia, and E. Carboni, 2011. *Atmospheric Measurement Techniques*, **4**(8):1567–1580, doi: 10.5194/amt-4-1567-2011.