

A trace gas detection scheme

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Abstract

A general method for trace gas detection from IASI is demonstrated for volcanic SO₂ emissions. This work is performed within Theme 3: ‘Measurements of Atmospheric Composition’ of the National Centre for Earth Observation, UK [6].

Introduction

Detection-only methods allow the high volume of global IASI data to be processed quickly, and are suitable for identifying the presence of species associated with special events like volcanic eruptions. The main difficulty is avoiding false detections caused by variations in the background due to parameters that are not measured. A general detection scheme is introduced which automatically selects the best channels for the separation of the target gas from the background with an optimal set of weights. This method is an extension of brightness temperature filter methods such as that used by Clarisse et al. [1] who have devised a manually selected detection filter for SO₂ based on an equally weighted difference of the brightness temperature in two carefully selected channels in the SO₂ ν_3 band (1371.50, 1371.75 cm⁻¹) and two background channels (1407.25, 1408.75 cm⁻¹).



Figure 1: The finely ground particles of rock in volcanic plumes present a serious risk to aviation. Measurements of SO₂ are correlated with volcanic ash in the first few days after an eruption and a global SO₂ alert system is in operation using IASI data [8]. Reconstruction of the ‘Jakarta Incident’ on 24th June 1982 when a BA Boeing 747-236B flew into a volcanic ash cloud from Mount Galunggung in West Java, Indonesia [2] (the plane eventually landed safely).

Automatic channel selection

Channels are selected in the vicinity of the SO₂ ν_3 band centred on 1362 cm⁻¹. Calculations are performed using the Reference Forward Model (RFM) which is a versatile line-by-line radiative transfer code developed at the University of Oxford [3] based on GENLN2 [5] with optimisations for use with IASI described in [10].

Channels are selected on the basis of maximum information content for SO₂ considering an optimal estimation type linear joint retrieval of SO₂ and brightness temperature. The first step is the selection of the ‘top-pair’, considering 100% column perturbations to a standard SO₂ profile derived from the IG2 climatology [7] and a 20 K brightness temperature (BT) offset ($\kappa^T = \begin{bmatrix} \frac{\partial y}{\partial \text{SO}_{2,\text{col}}}, \frac{\partial y}{\partial \text{BT}} \end{bmatrix}$) where the gain and random error are computed as

$$\mathbf{G} = \mathbf{S}_a \mathbf{K} (\mathbf{S}_y + \mathbf{K}^T \mathbf{S}_a \mathbf{K})^{-1}$$

$$\mathbf{S}_{\text{rnd}} = (\mathbf{I} - \mathbf{G} \mathbf{K}) \mathbf{S}_a$$

where the covariance $\mathbf{S}_a$ contains appropriate *a priori* constraints on SO₂ and BT and the instrument noise covariance is given by $\mathbf{S}_y$. Systematic errors due to water vapour, temperature, and minor contaminants (CH₄, HNO₃) are modelled using IG2 1 σ column perturbations. Sensitivity to surface temperature uncertainty is modelled using a 20 K perturbation. For N sources of error the systematic error is given by

$$\delta \mathbf{x}^i = \mathbf{G} \delta \mathbf{y}^i$$

$$\mathbf{S}_{\text{sys}} = \sum_{i=1}^N E\{(\delta \mathbf{x}^i)^T (\delta \mathbf{x}^i)\}$$

where δy_i are the error spectra due to the perturbation of each error source. Top-pair selected assessing information content of SO₂ component of all 97020 combinations of channels in 1300–1410 cm⁻¹ range

$$H = \log_2 \left(\frac{\sigma_{\text{rnd}}^2 + \sigma_{\text{sys}}^2}{\sigma_a^2} \right) \quad (1)$$

Additional channels are then selected exploring remaining combinations using sequential estimation as described in [4] starting from top pair.

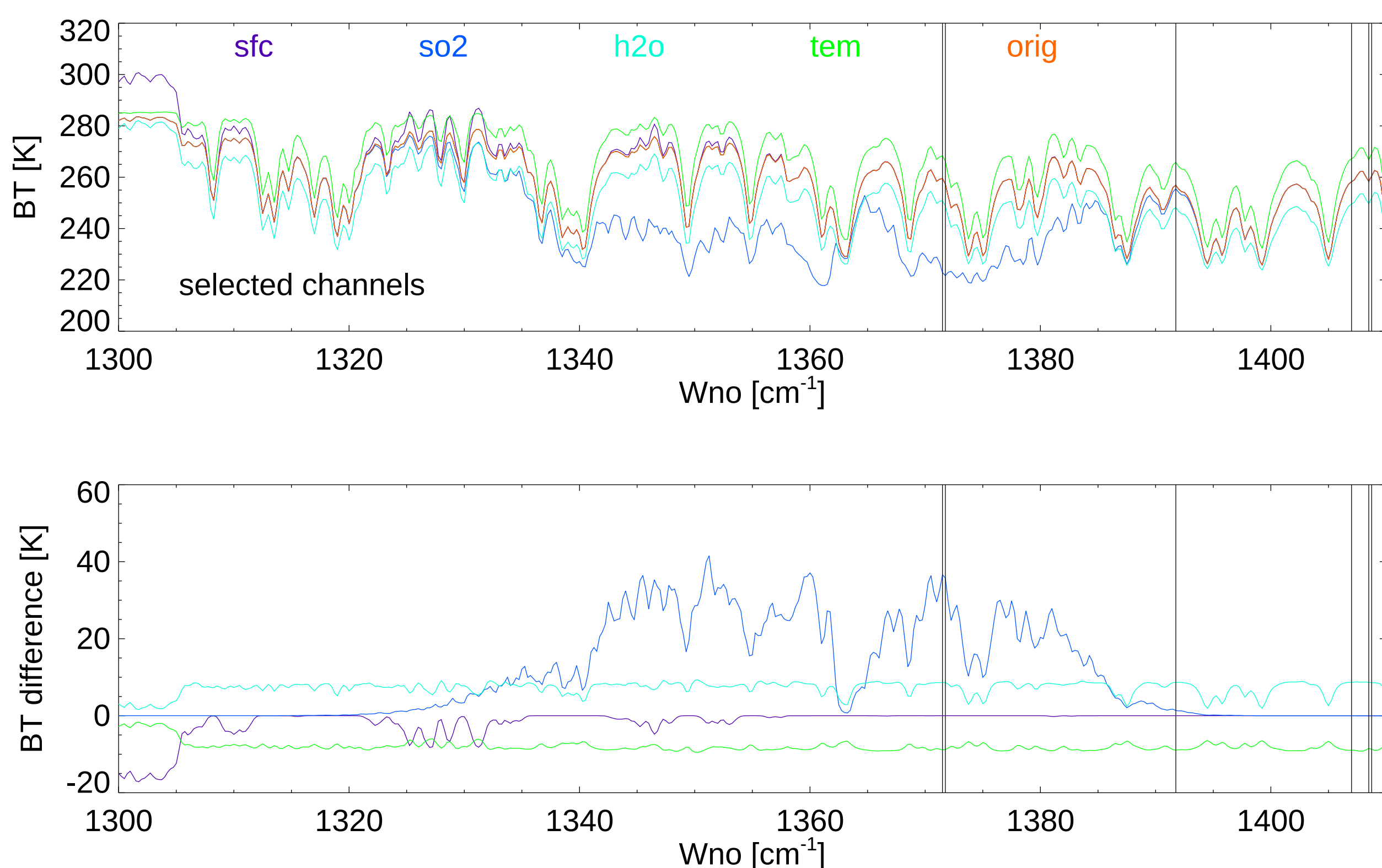


Figure 2: BT spectra for a simulated 100 DU SO₂ event with stratospheric plume (12–22 km) showing contribution of SO₂ and climatological 1 σ column perturbation in water vapour and atmospheric temperature, and a 20 K perturbation in surface temperature. Top four channels selected in order 1371.50, 1408.75, 1407.00, 1371.75 cm⁻¹.

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In the detection step, a set of weights are generated $\mathbf{G} = (\mathbf{K}^T \mathbf{K})^{-1} \mathbf{K}^T$ which separate the SO₂ signal from the background contribution when applied to the IASI spectra. The flag is then expressed in terms of estimated dobson units (DU_{est})

$$\text{DU}_{\text{est}} = \text{DU}_0 (1 + \mathbf{G}(\mathbf{y} - \mathbf{y}_{\text{clim}})) \quad (2)$$

Simulations

The SO₂ flag was tested for a simulated plume between 12 and 22 km for events up to around 100 DU. Up to 10 DU, the estimated and actual DU are very similar. The neglect of non-linearity leads to an underestimated column for larger events.

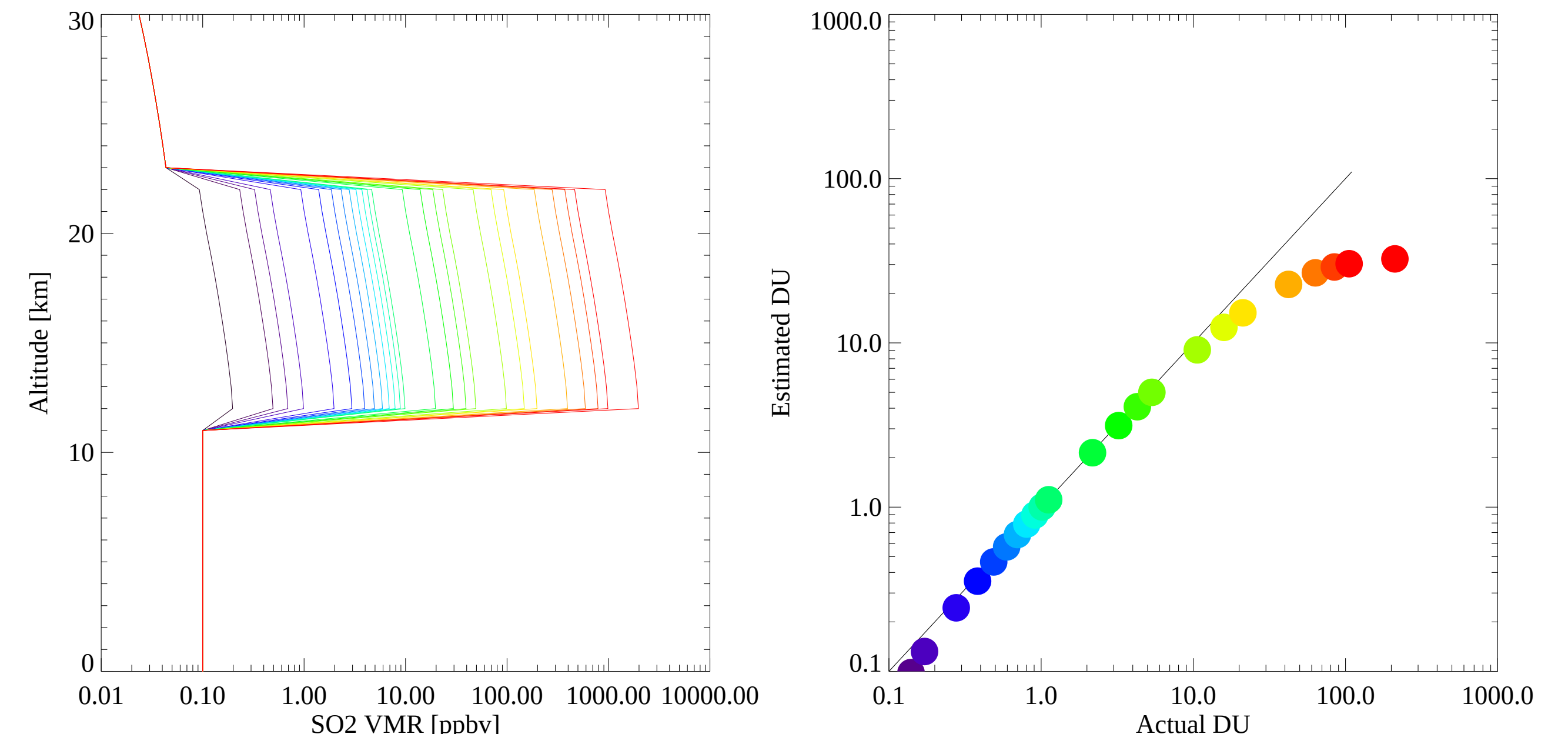


Figure 3: Effects of non-linearity on estimated column amount. For small plumes, linear retrieval gives reasonable estimate of true quantity of SO₂. Ball-park estimates of SO₂ amounts are possible for large events.

Figure 4 shows the random and systematic errors associated with this detection scheme for background levels of SO₂ for the top four channels selected by this analysis and the channels selected by Clarisse et al. [1]. Systematic errors are well below the random noise error in both cases indicating that false detections should be completely avoided.

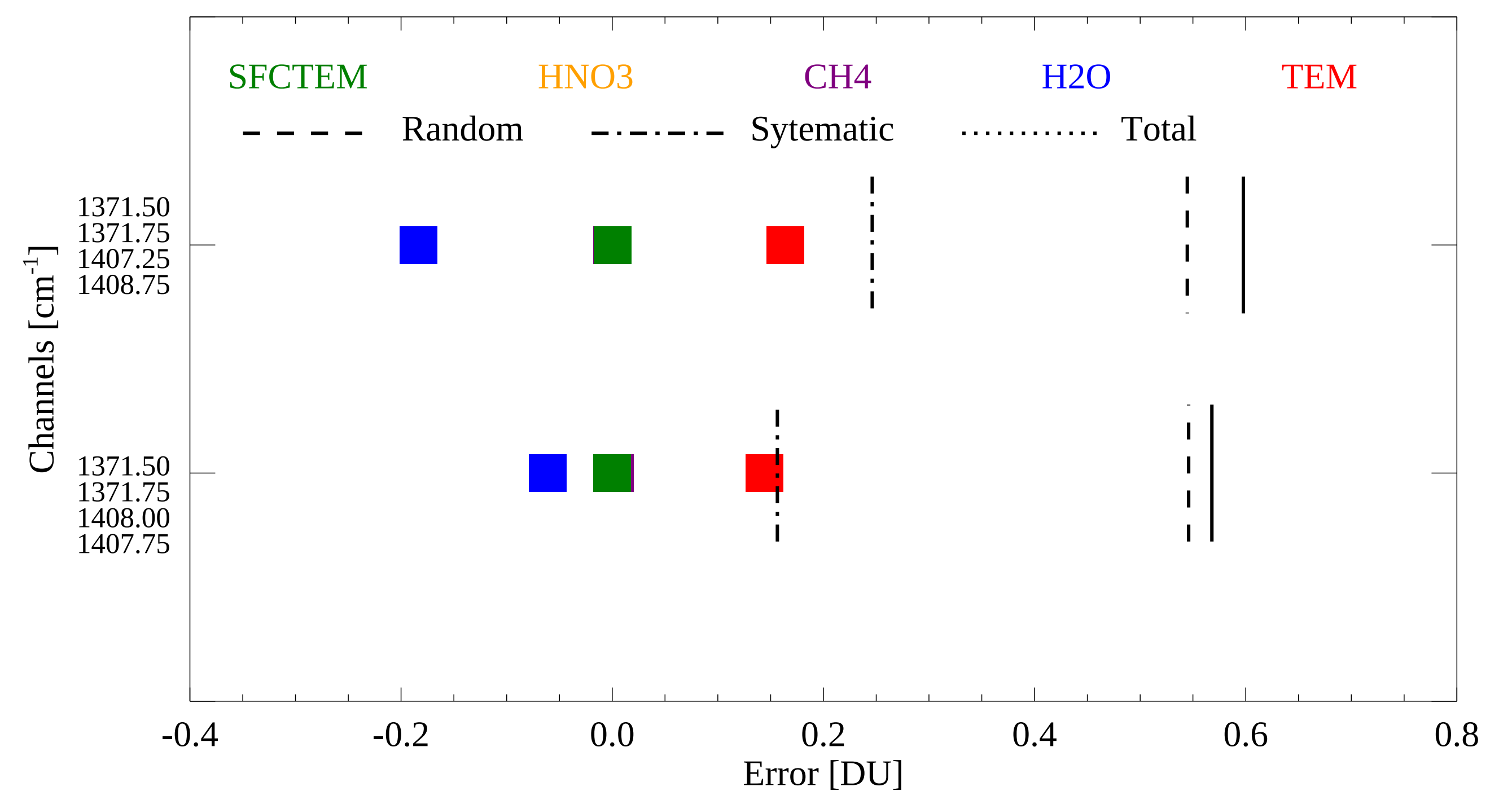


Figure 4: Error analysis for detection step calculated assuming climatological background levels of SO₂. Results for channels selected by this analysis (1371.50, 1371.75, 1407.00, 1408.75 cm⁻¹) shown in bottom row, and results for channels selected by [1] (1371.50, 1371.75, 1407.25, 1408.75 cm⁻¹) shown in top row. The total systematic error ($\sum_{i=1}^N (\sigma_{\text{sys}}^i)^2$) is very low in both cases. Error expressed in terms of Dobson units.

Detection of Kasatochi event

First detected by GOME-2 on its overpass on 8th August 2008 with column amounts of around 150 DU [8]. The SO₂ plume from this eruption is picked out successfully using the new method.

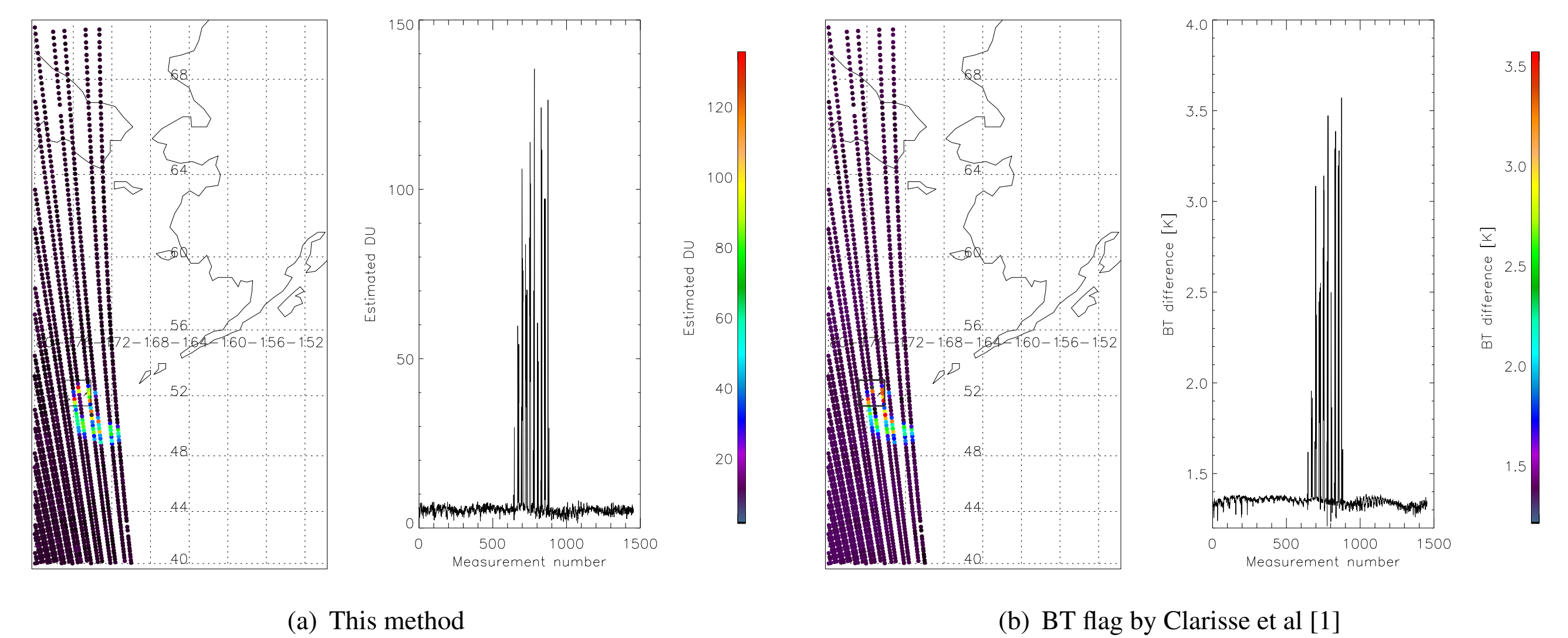


Figure 5: Detection of the eruption of the Kasatochi volcano in the Aleutian Islands, Alaska, showing SO₂ on 8th August 2008, the day after the eruption began.

Conclusions and future work

An automatic channel selection algorithm and detection scheme is implemented using IASI spectra which works well for SO₂. The channels selected by this algorithm are almost identical to those selected by [1] differing by just one background channel. It should be possible to extend the method to other molecules.

References

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