Spectra classification methodology for hyperspectral InfraRed imaging of Mt Etna volcanic plume with a radiative transfer retrieval model

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Abstract

Quantification of sulfur dioxide (SO2) emission flux is a fundamental task in volcanology to have insights of the composition and the spatial evolution of volcanic plumes. The ground based InfraRed hyperspectral imager HyperCam, from Telops Company, was deployed during IMAGETNA campaign in 2015 and provided high spatial and spectral resolution images of Mt Etna plume. The spectral range of the hyperspectral imager is [7.7 - 11.8 µm] and the measured images contained 320 x 64 pixels with a spectral resolution of 2 cm-1. To process hyperspectral images in quasi real-time, a fast and reliable radiative transfer retrieval model is required. The LATMOS Atmospheric Retrieval Algorithm (LARA), used to retrieve the slant column densities of SO2, includes an accurate line-by-line radiative transfer model and an efficient minimization algorithm of the Levenberg-Marquardt type. But the calculation time remains too high to infer near real time (NRT) estimation of SO2 fluxes. As first, to reach NRT target, a classification methodology of the brightness temperature spectra was developed and then applied on each measured sequence to significantly decrease the processing time. One image previously took a week of calculation to be retrieved. The classification of the spectra, which takes a couple of hours, allows the retrieval of a complete measurement sequence of the field campaign (~400 images) in only two days. The accuracy of the methodology was confirmed, by comparing the SO2 slant column density images obtained after classification with the one obtained by the accurate and time expensive pixel by pixel retrieval processing. The LARA model, the spectra classification methodology and a comparison of the results will be presented.

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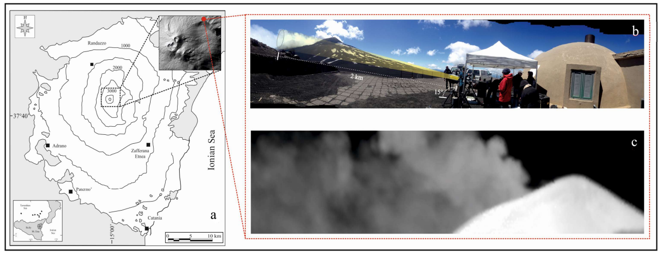


Introduction

Quantification of sulfur dioxide (SO_2) emission flux is a fundamental task in volcanology to have insights of the composition and the spatial evolution of volcanic plumes. **Hyperspectral infrared imager** is a recent technology which allows the acquisition of data-cubes with **high spectral, spatial and temporal resolutions** and so produce heavy data files to process. As volcanic plume monitoring implies the need of a quasi-real-time processing of the data-cubes collected, **retrieval algorithms** must be tailored to those large datasets.

This poster presents the study conducted on a sequence of measurement of the ground-based InfraRed hyperspectral imager HyperCam LWIR (spectral range 7.7-11.8 µm) (Telops Company). The instrument was deployed during the IMAGETNA campaign in June 2015 at Mount Etna observatory during a quiescent stage of volcanic activity (see Huret et al., 2019). A classification methodology of the brightness temperature spectra was developed in order to decrease the processing time of the images with the LATMOS Atmospheric Retrieval Algorithm (LARA).

Tools and Methodology

- The LARA model is a **line-by-line radiative transfer model** associated with a **minimization algorithm** of the Levenberg-Marquard type (*Payan et al. 1998, 2010*). The retrieval of SO_2 Slant Column Densities (SCD) in each spectrum considers the following species: H_2O, CO_2, O_3, N_2O, CO, CH_4 and SO_2; the characteristics of the volcanic plume (thickness, altitude, temperature); the optical thickness due to particules.

- Retrieval of 1 image with the pixel-by-pixel method **= 1 week of calculation.**

- The HyperCam images characteristics:

Sequence	Image resolution	Number of datacubes	Spectral resolution
26 June 2015	320 x 64 pixels	412	2 cm^{-1}

- Classification of the brightness temperature spectra using two parameters in different spectral windows:
  - **T_i** the intersect of the first order regression,
  - **T_{moy}** the mean brightness temperature.

Main class (1000-1040 cm^{-1})
$$T_i = A\,\sigma_i + B$$
Intersect of the first order regression

Sub-class (1140-1180 cm^{-1})
$$T_{moy} = \frac{\sum T_i}{N}$$
Mean brightness temperature

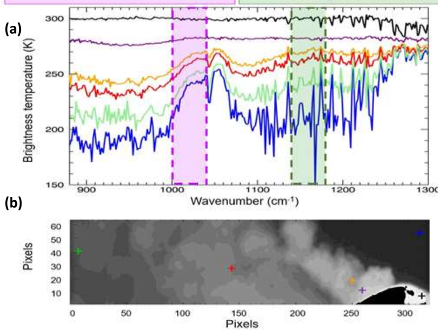
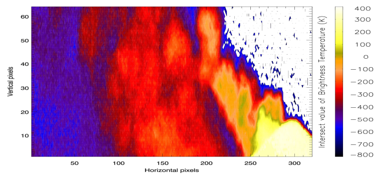


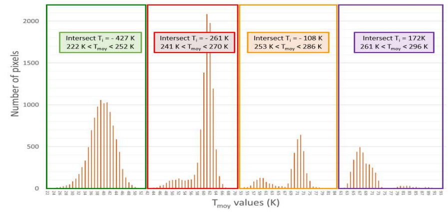
Figure 1: Spectral interval of the main class parameter framed in purple and of the sub-class parameter framed in green.

Results and Discussion

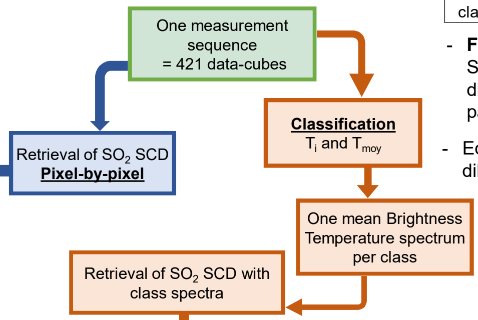
- **Figure 2:** Main class parameter T_i image = opacity of the atmosphere:

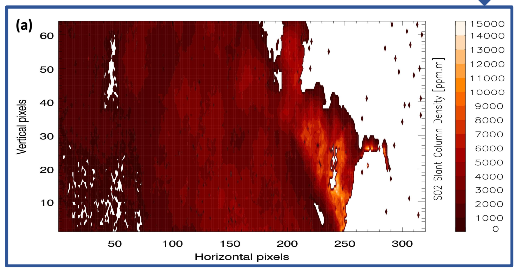


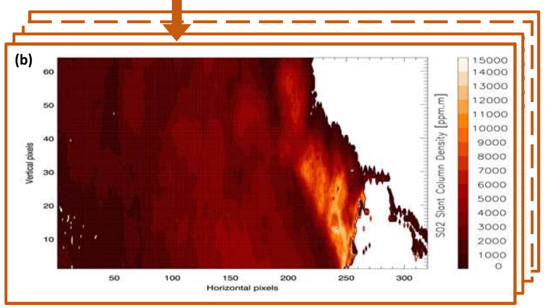
- **Figure 3**: Variability of the T_{moy} parameter values for the intersect T_i of the plume spectra of Fig 1(a):



- **Figure 4**: Scheme of the two retrieval methods with the SO_2 SCD images obtained with **(a)** the pixel-by-pixel retrieval method and **(b)** with the retrieval after classification of the spectra, for the datacube of 26 June 2015 08:25:44 UTC







- The table below summarizes the processing information of both methods for the example of 26 June 2015 measurement sequence of IMAGETNA campaign:

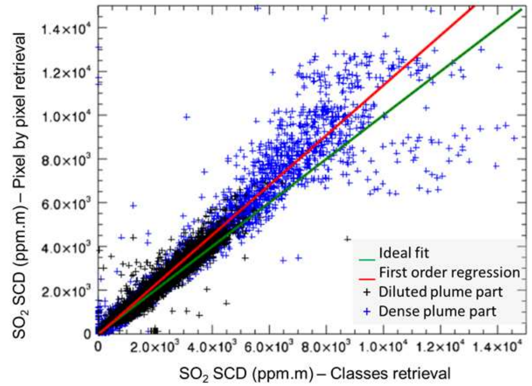
Method	Number of images	Total amount of pixels	Retrieved spectra	Processing time
Pixel by Pixel	1	20,480	20,480	7 days
Spectra classification	412	~ 8 x 10^6	~ 3,400 to 13,300	2 days

- **Figure 5:** Correlation of SO_2 SCD retrieved by pixel-by-pixel process vs SO_2 SCD retrieved after classification (08:25:44 UTC data-cube). 12554 points in diluted plume part and 3144 points in dense plume part, The classification parameters of this example are **ΔT_i=1K** and **ΔT_{moy}=1K**.

- Equation of the 1st order regression for the points corresponding to the diluted plume part:

$$Y = 1.06 * X - 43.4$$

(with a determination coefficient of **R^2 = 0.94**)



Conclusion and Perspectives

- The classification gives **very satisfying results** and **significantly decrease the processing time** of a large sequence of data-cubes.
- This methods has to be tested on other geophysical conditions in order to create lookup tables to apply this classification method to all kind of conditions and to other chemical species (i.e.) other spectral range).
- Then the next important step **is to add flux inversion of SO_2** to monitor the evolution of volcanic plume emissions.

Reference:
Huret et al. (2019) «Infrared hyperspectral and ultraviolet remote measurements of volanic gas plume at Mt Etna during IMAGETNA campaign ». Remote Sensing, 11(10), 1175; https://doi.org/10.3390/rs11101175.

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