On the use of hyperpectral infrared imagers for studying volcano plumes: IMAGETNA

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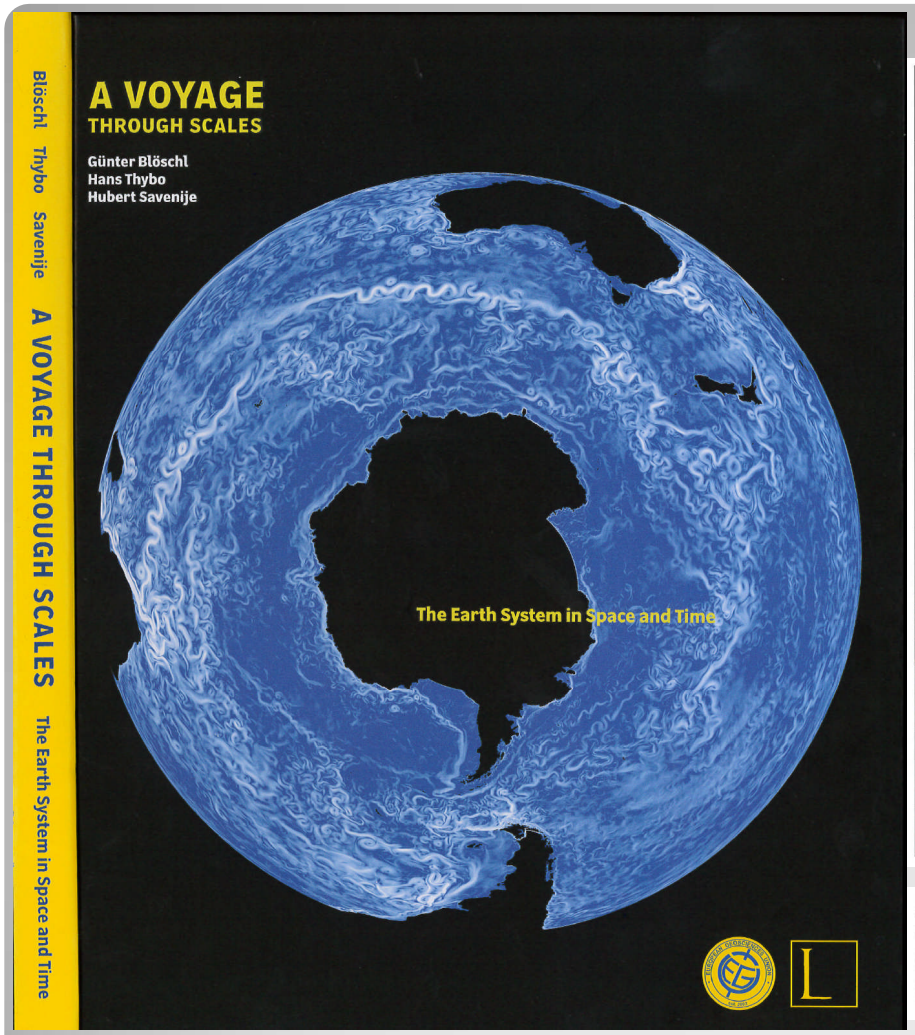
IMAGETNA project (LEFE-CHAT program)

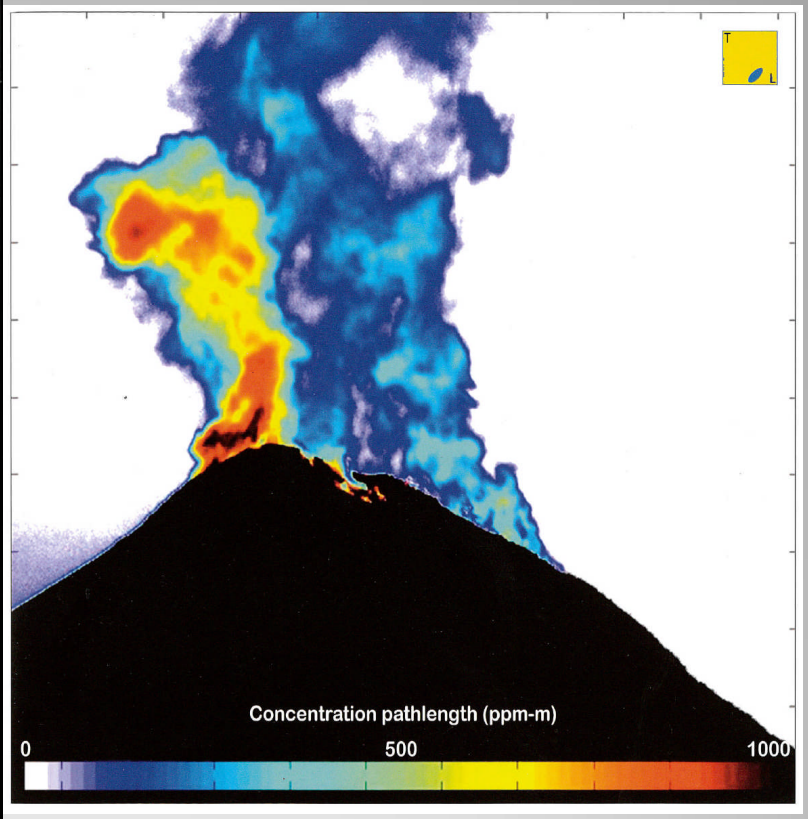
VOLTAIRE project (ANR agency)

HALESIS Balloon Project (CNES)

IMAGETNA

- **Scientific objectives**
- **Instrumentations involved**
- **Campaign at ETNA**
- **Préliminary results**





False colour image of SO_2 emissions from the Fuego volcano in Guatemala. The picture was created with a UV camera comparing measurements of scattered sunlight at two wavelengths having different SO_2 absorption strength. The SO_2 amount is shown, integrated along the light path with red colours indicating high values. Such imaging data can be used to estimate volcanic emissions of SO_2 on short time scales and provide a link between local in-situ measurements and large scale satellite observations.

Last year at EGU

Scientific objectives / Motivations

Background :

Quantification of volcano gaseous emissions

- Information on processes inside the volcano
- Quantify the natural emission source in the context of Climate Change

Pratt et al. (2014, JVGR) : Review of imaging technics available to investigate volcano plume: SO_2 DOAS Imaging, Lidar scanning, IR imaging …

IR hyperspectral imaging is a new technology to be tested, and potentially could give access to several additional species.

Our motivations :

- How relevant is limb IR hyperspectral imaging for studying volcano emissions ?
- Compare several hyperspectral imagers
- Test/Improve imager retrieval code
- Get technical expertise of such instrumentation for atmospheric chemistry study

ETNA Data Collection 7th May 2014

Pineta di Nicolosi, 14.2 km range
- UV-based SO2 imaging camera and
- Bruker Imaging FTIR

Objective: to test the impact of scattering on UV measurements of volcanic SO2

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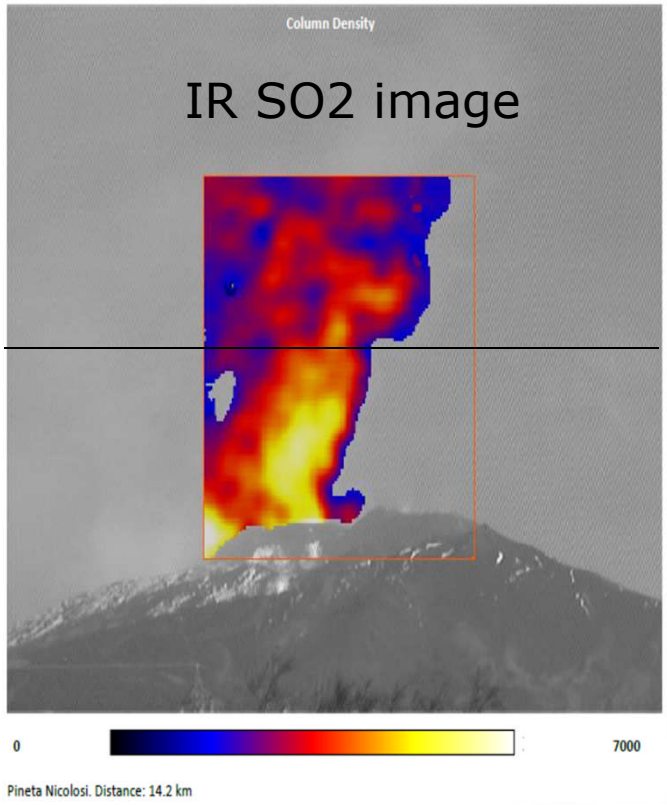


Typical SO2 concentrations on the black line measured

with IR: 1000-4000 ppm.m

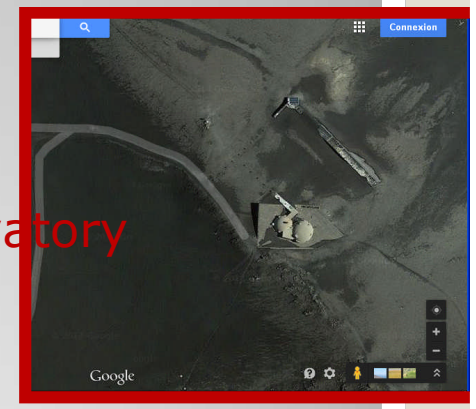
with UV: 100-300 ppm.m

~1 order of magnitude underestimate in UV SO_2 quantification

M. Burton, Univ Manchester

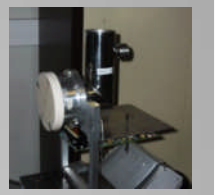
Imagetna campaign

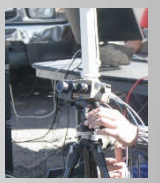
- 21-25 June 2015
- Measurement from Pizzi de Neri Observatory on the north side of the Etna at 2847 m of altitude



Instrumentation deployed

7 Instruments (3 imagers)	Characteristics	
Vitrail IR imager *Under development at ONERA*	[3; 5] µm ,24 bands 80x80 pixels, 100 Hz	Intercomparison
OPAG 33 *Operated by ONERA*	FT-IR spectrometer [3.5;14] µm (1 cm^{-1})	Validation
Camera LWIR Operated by ONERA	[8.6; 9.5] µm, 1 band	Coregistration
SIBI IR imager *Under development at ONERA*	Infrared scan MWIR	Intercomparison
SO_2 network *from INGV*	SO_2 measurements	
UV Imager *from INGV*	SO_2 measurements	Validation
HyperCAM from TELOPS *operated by LPC2E & LATMOS*	[7.7-11.8] µm 320x256 pixels, 0.25 cm^{-1}	Intercomparison




5 days of measurement / Several Terabytes of data

Measurements

- From 6:00 to ~14:00 pm
  - To get the best thermal contrast between sky and plume
  - To prevent for convective clouds which develop in the afternoon

- Common field of view for all instruments

distance to the plume : 1.5 km
Sequences with simultaneous measurements.

Example of field of view (image in the IR from HyperCam)

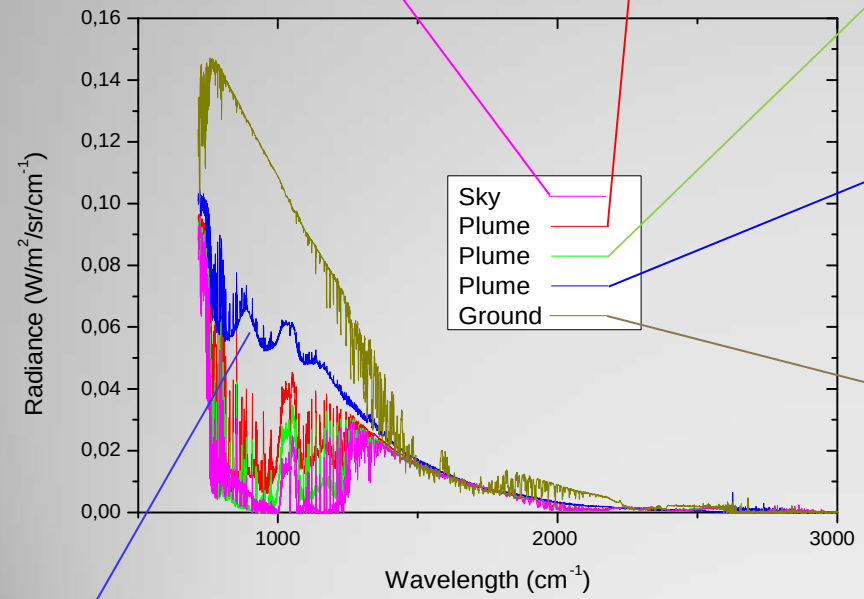
Preliminary measurements : FTIR

- Radiance obtained for several lines of sight

Clear sky

Diluted Plume

Diluted Plume



Plume close to the crater

Ground

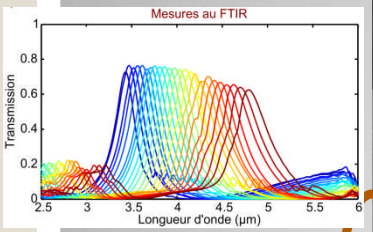
Strong signature of aerosols in the plume

Preliminary measurements : Vitrail, FLIR, FTIR

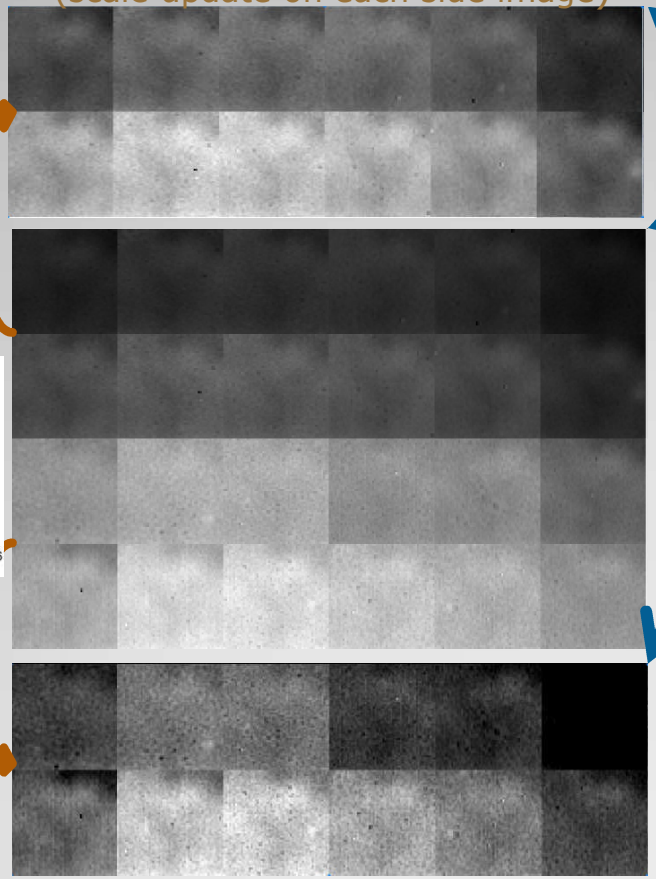
VITRAIL imager : 24 bands
(scale update on each side image)

scale update on each side image

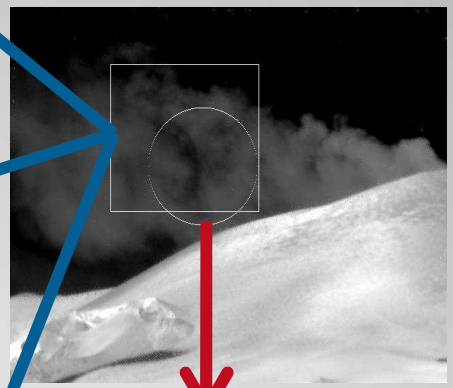
The 24 bands

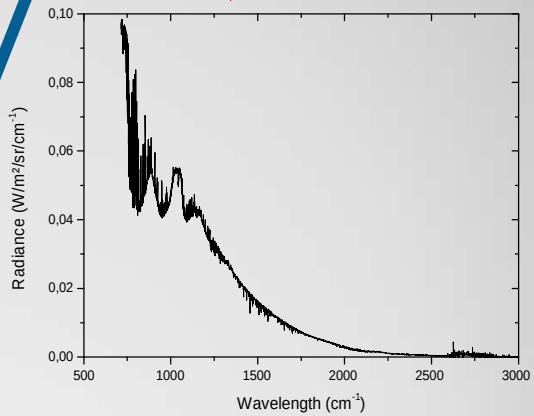


scale update on each side image



FLIR Camera
with FOV of other instruments





Radiance from FTIR Spectrometer

- Retrievals will be done with LBRLTMH Radiative transfer model, but challenging !

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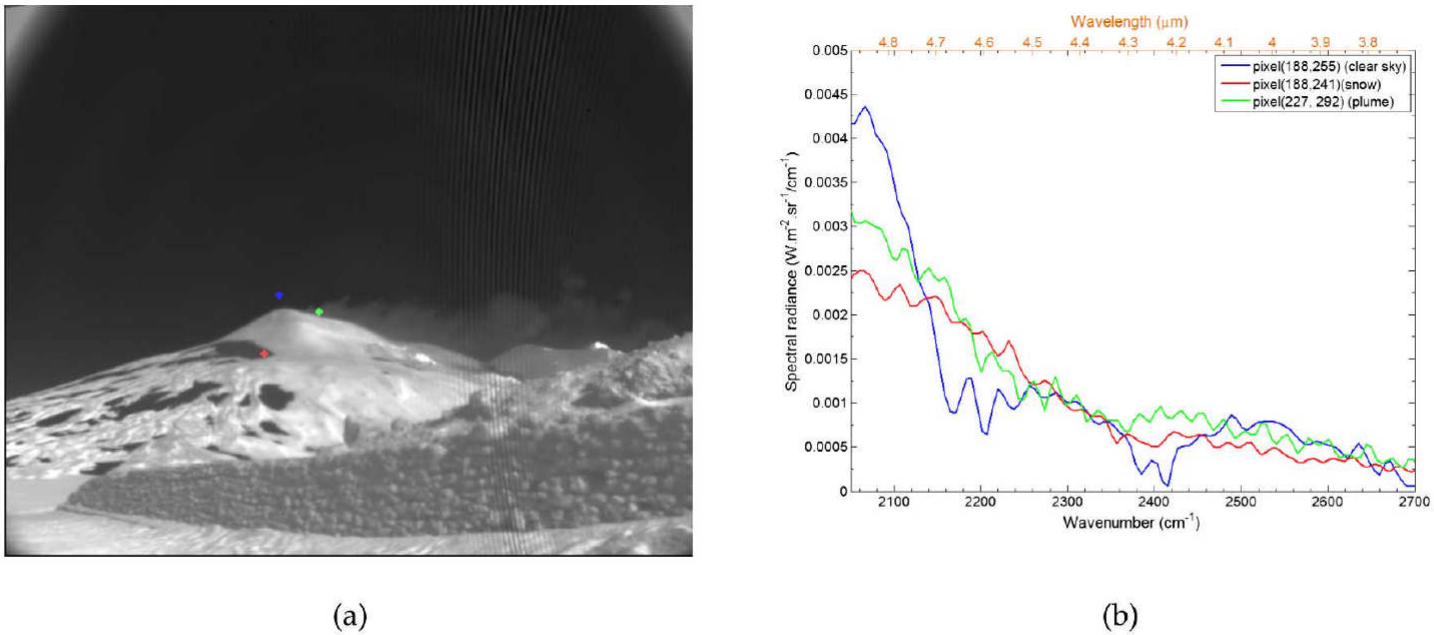
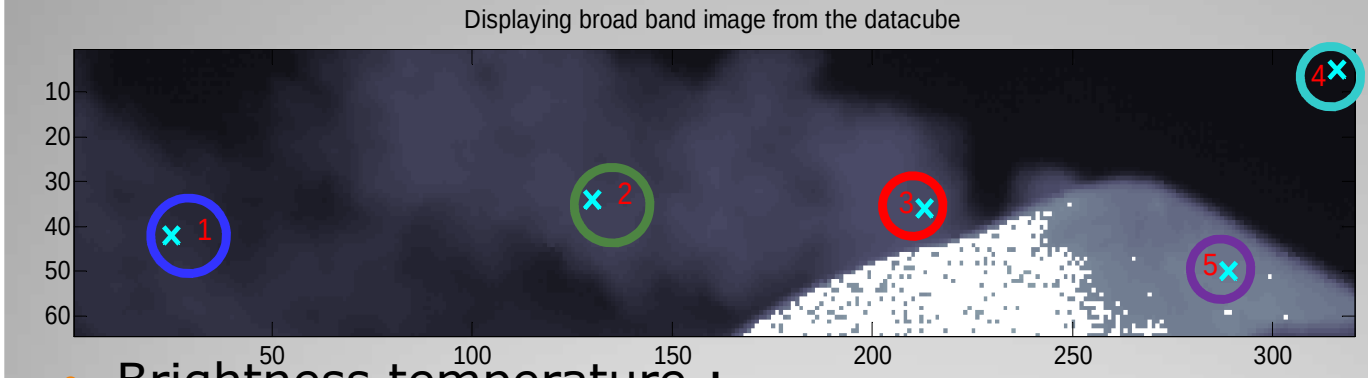


(a) (b)

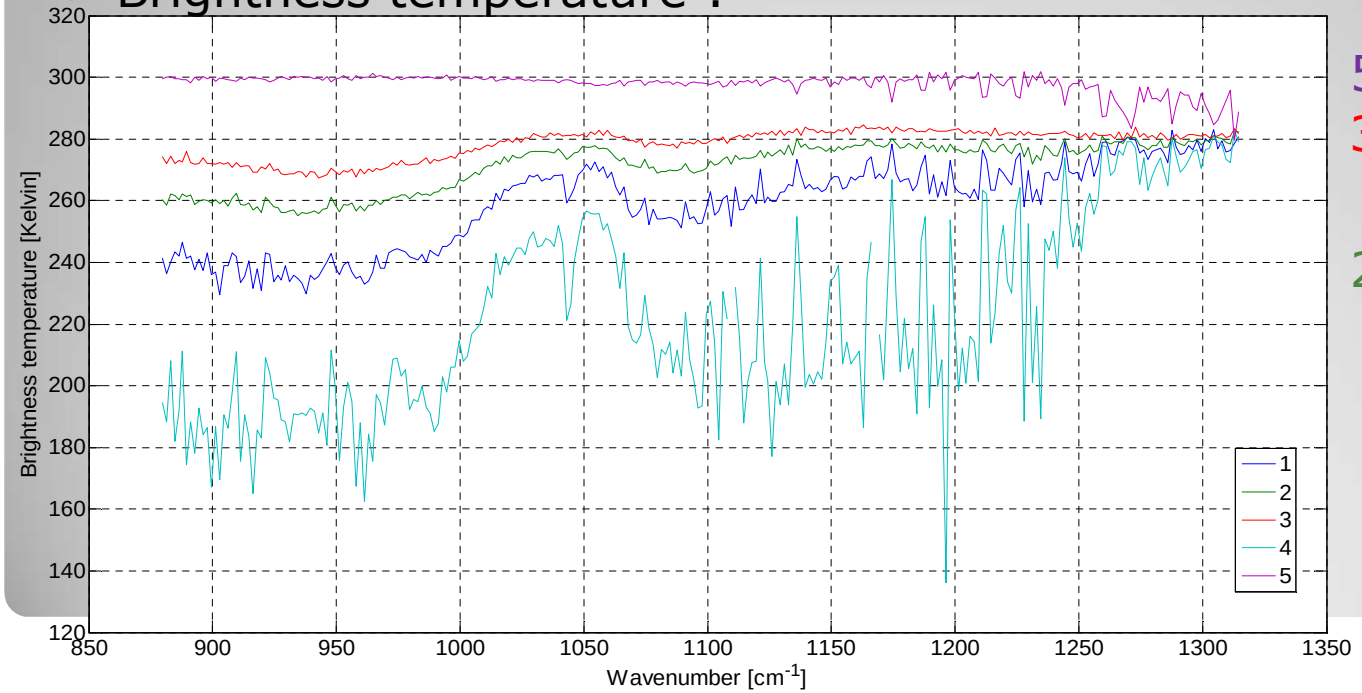
Fig. 6. (a) Location of an example of the points for which the spectra have been calculated: point in the sky (blue), in the plume (green) and in the snow (red). Note that snow appears black in this thermal-IR picture as it is colder than the rocks beside. (b) Obtained spectra, preliminary results.

Pola Fossi et al., Opt. Lett. 2016

Preliminary results : HyperCam



- Brightness temperature :

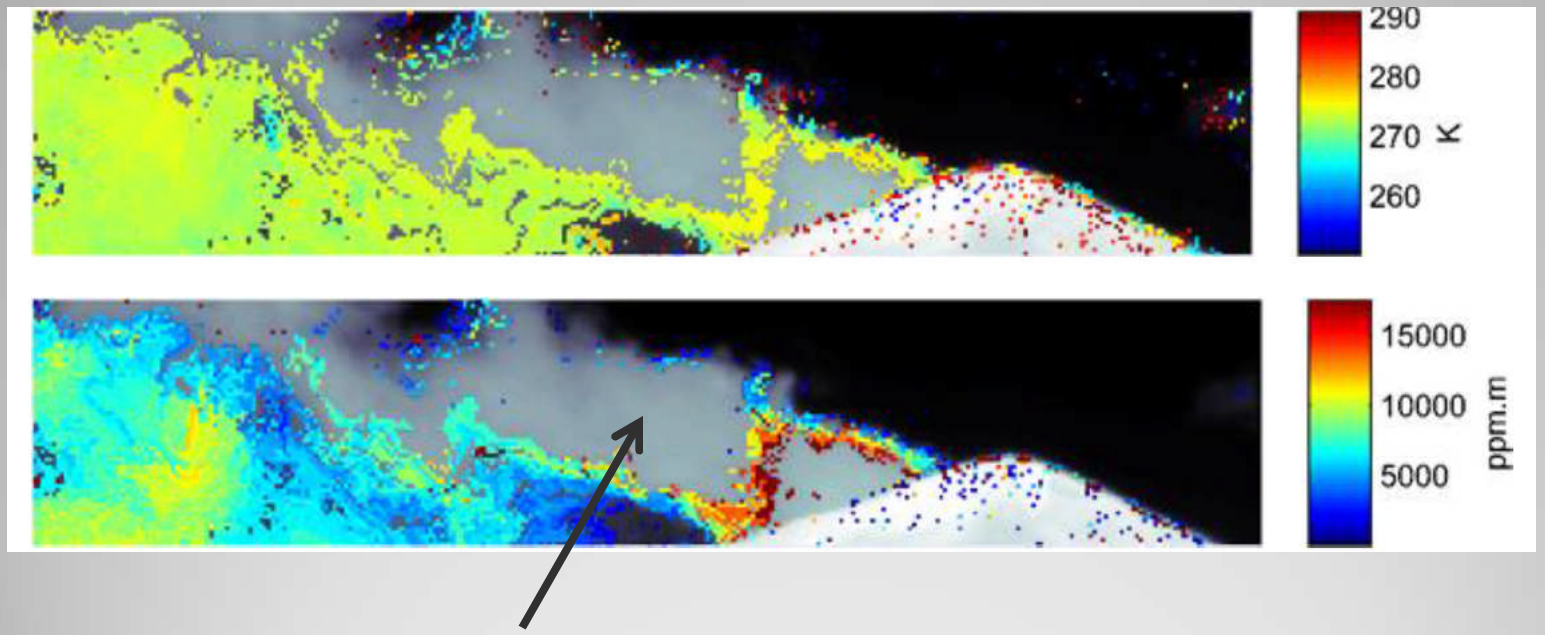


5. Ground
3. Plume close to the crater
2. Diluted plume
1. Diluted plume
4. Clear sky

Preliminary retrieval : HyperCAM

- Example of 1 image

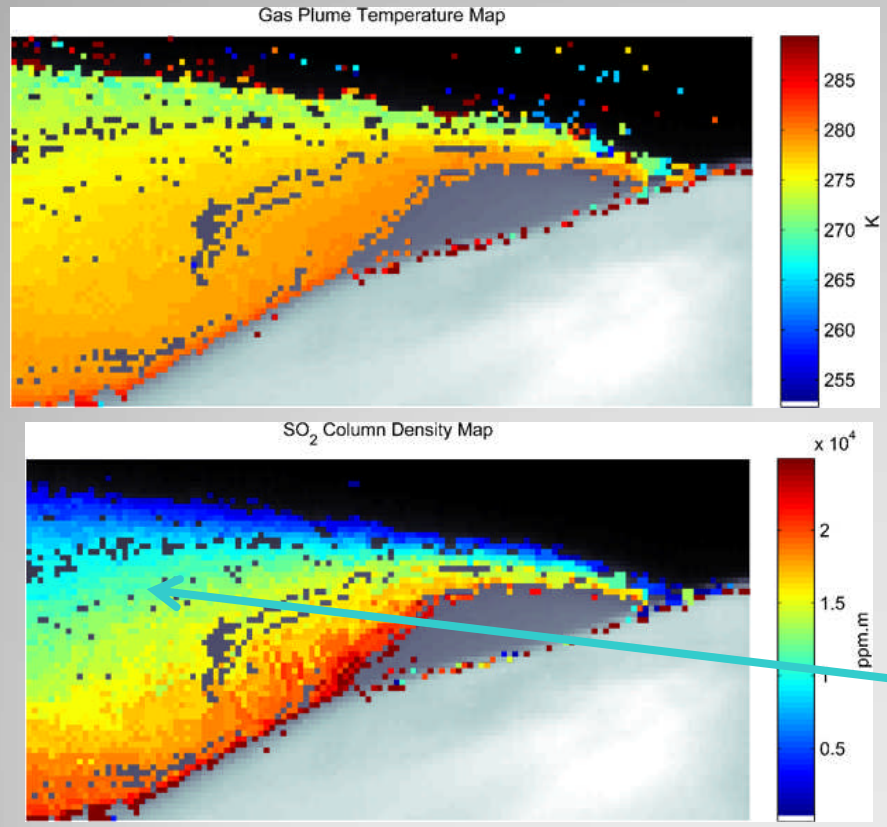
Acquisition 20150622_143749134



aerosols/ash => Opacity of the plume

Preliminary retrieval : HyperCAM

Acquisitions 20150625_092442572 à 20150625_092857795



Median spectrum for 4 mn of measurements

- SO_2 column densities : 10 10^3 ppm m .

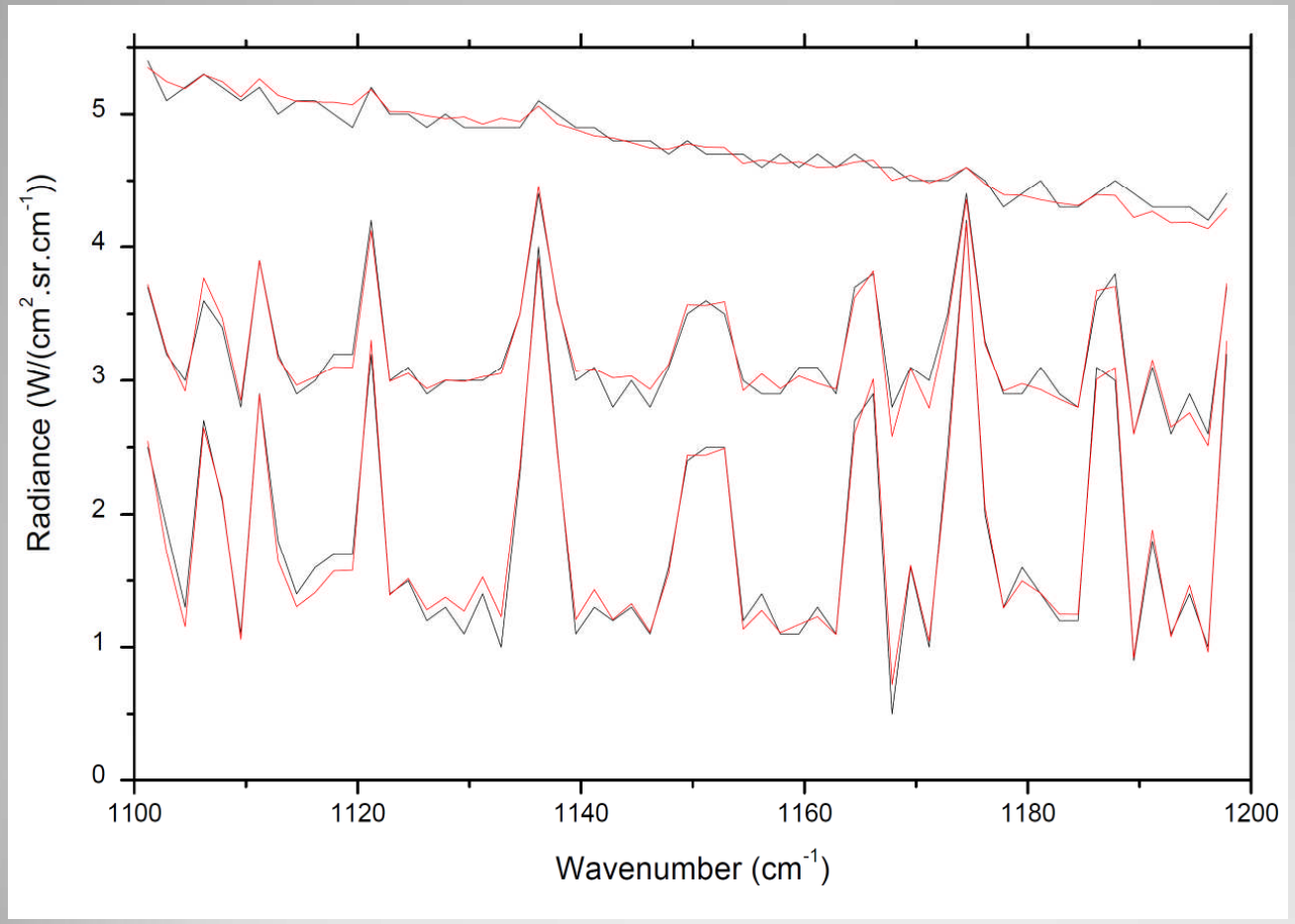
- SO_2 Order of magnitude [10^3; 25 10^3] ppm.m, depends on the dynamic of the emissions. Kantzas et al. (2010) : 3 10^3 at ETNA using UV camera.

=> to be compared with our simultaneous UV measurements

Retrieval strategy : LARA

- Radiative transfer model and inverse model LARA (J. Bureau, S. Payan) with HITRAN2012
- Window: 1100 - 1200 cm^{-1}, for SO_2
- State vector: x=("cloud", H_2O, SO_2, CH_4, N_2O, O_3)
- T(z) extracted from ECMWF ERA-Interim analyses and Trapani Balloon soundings
- H_2O(z) profiles scaled from ECMWF ERA-I
- Aerosols modelled as a "cloud" (modelling of exponential optical thickness) at the same temperature than atmosphere

Preliminary retrieval : HyperCAM



Dense Plume

Diluted Plume

Clear sky

Need to decoralate aerosols and SO_2.

Need to account specific temperature for the plume

Next Steps

- **Identify interesting sequences with simultaneous measurements.**

⇒ To compare IR spectrum obtained by the different instruments

- **Aerosols/ash perturbation**

⇒ Retrieve aerosol composition and concentration

- **Retrieve SO_2 column densities using LARA model (Line-By-Line Transfer Model) for FTIR, Vitrail and HyperCam.**

⇒ Evaluation of the different instrumental performances / rerror budget

- **Comparison SO2 column densities from IR spectra with UV Camera**

⇒ Validation of the measurements

- **test other species détection/retrieval from ImagEtna IR spectra :**

BAND 3.7-4.8 µm : CO_2, N_2O, CO, CS, CH_4, HCl, CH_3Cl
BAND 7.5-12 µm : CO_2, SO_2, NH_3, HNO_3, HCl, H_2S, OCS, CH_4, CO, SiF_4, HF

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Acknowledgments

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