Utilisation d'imageurs infrarouges hyperspectraux pour l'étude de panaches volcanique : la campagne IMAGETNA

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4ème colloque du Groupe Hyperspectral de la Société Française de Photogrammétrie et de Télédétection
Grenoble, 11-13 Mai 2016

IMAGETNA project (LEFE-CHAT program)

VOLTAIRE project (ANR agency)

HALESIS Balloon Project (CNES)

IMAGETNA

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

Scientific objectives / Motivations

Background :

Quantification of volcano gaseous emissions

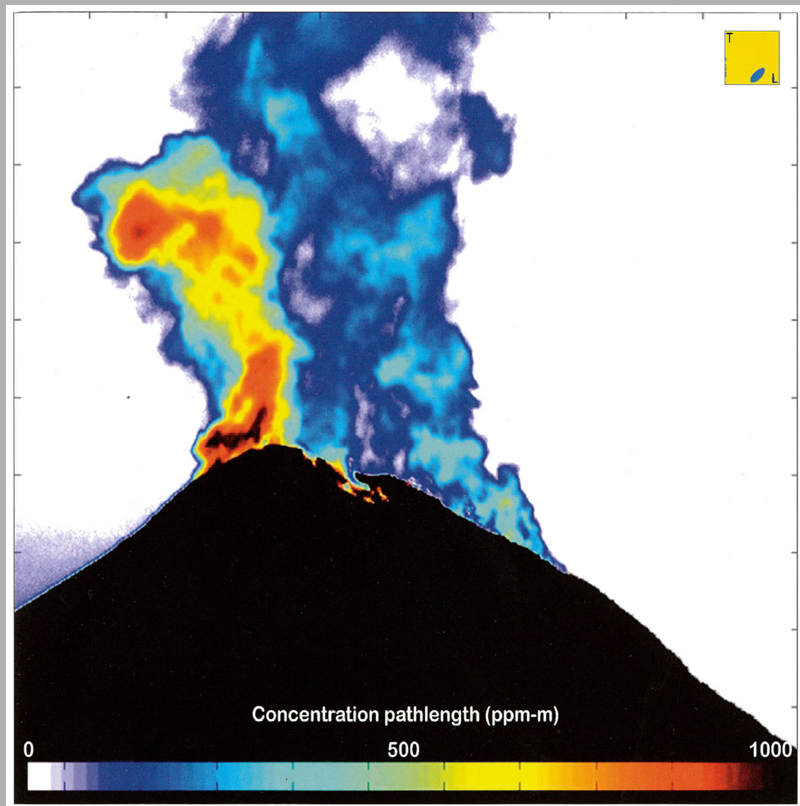
- Information on processes inside the volcano
- Quantify the natural emission source in the context of Climate Change

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

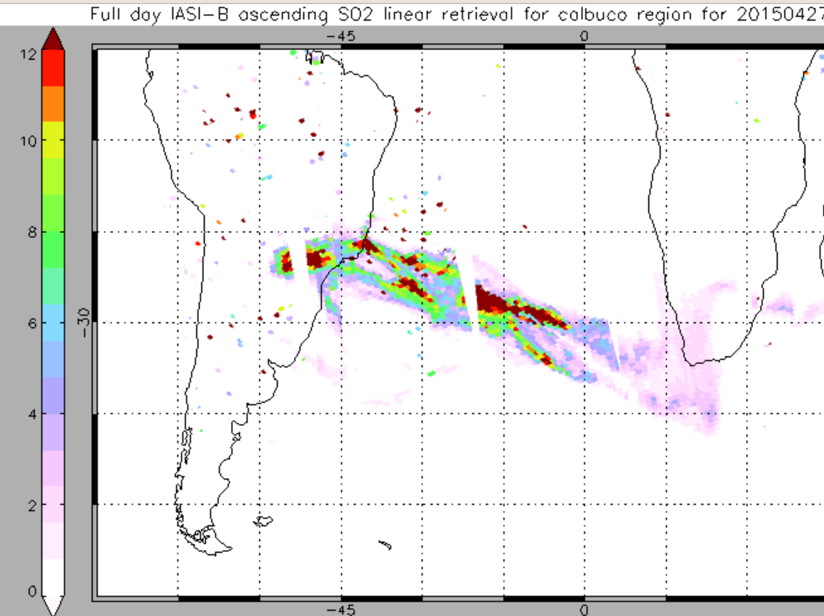
IR hyperspectral imaging is a new technology to be tested, and potentially could give access to several additional species.

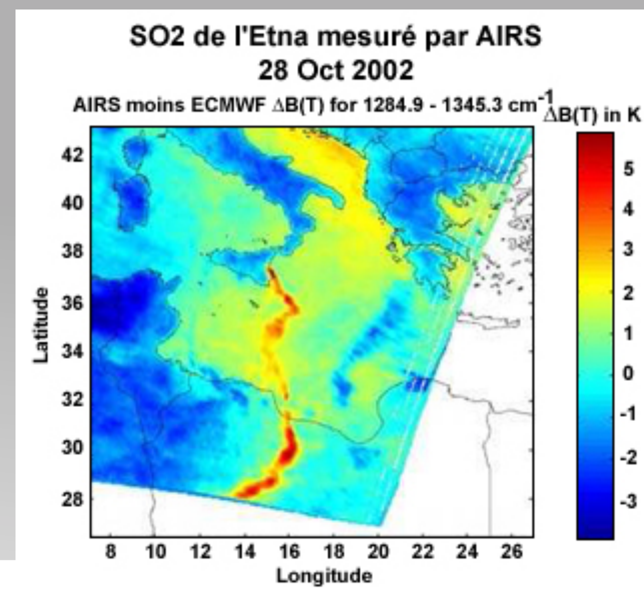
Our motivations :

- 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

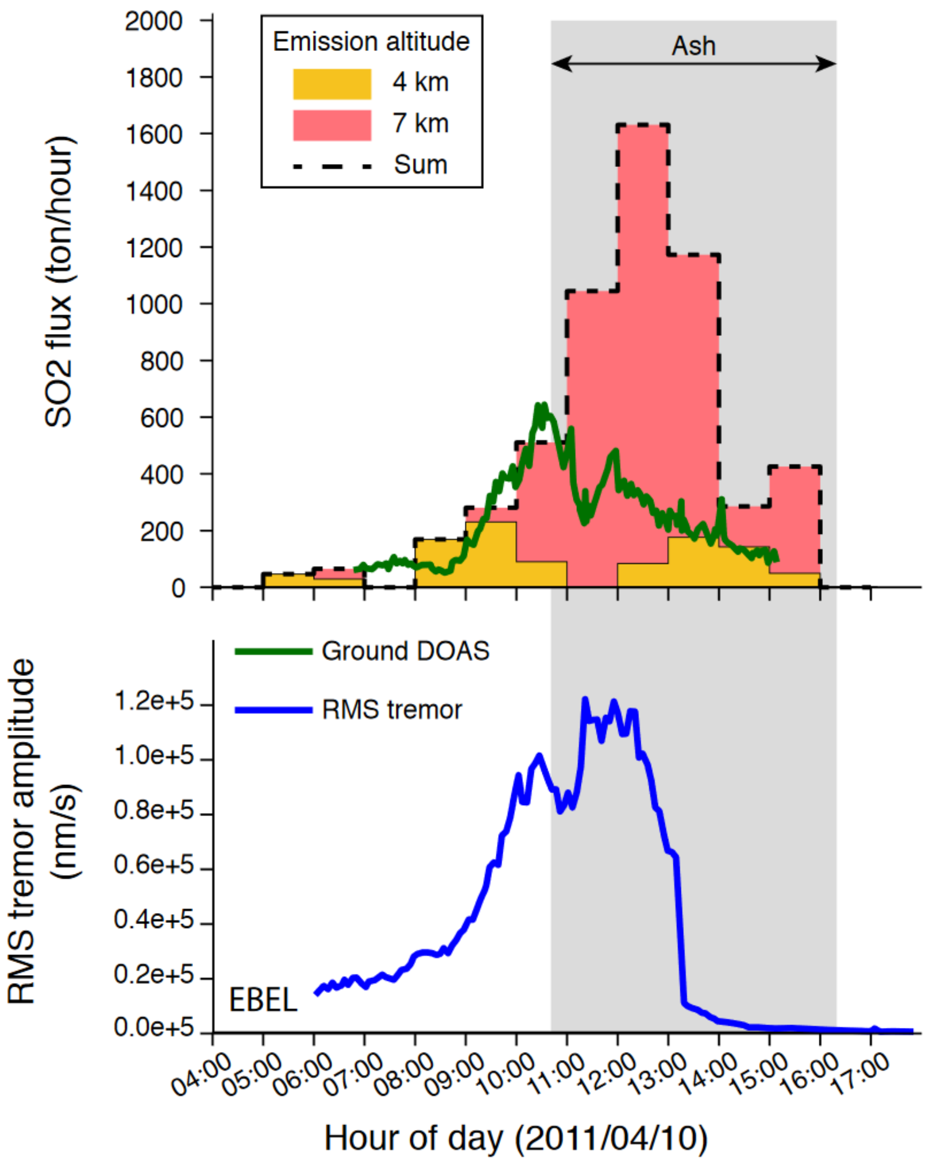


False colour image of SO_2 emissions from the Fuego volcano in Guatemala. The picture was created with a UV camera comparing measurements of scattered sunlight at two wavelengths having different SO_2 absorption strength. The SO_2 amount is shown, integrated along the light path with red colours indicating 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.





Carn, S. A. et al., Quantifying tropospheric volcanic emissions with AIRS: The 2002 eruption of Mt. Etna (Italy). Geophysical Research Letters, Vol. 32, L02301, 2005.



- Boichu et al., ACP 2015

Figure 3. Etna emissions during the 10 April 2011 eruption. (Top) Temporal evolution of the SO_2 flux ($t\,h^{-1}$) measured from ground-based UV-DOAS observations during daylight hours (from Bonaccorso et al., 2011; green line) and retrieved using the inversion procedure which assimilated IASI SO_2 column amount observations (histograms). Yellow and pink areas indicate the proportion of the flux emitted at 4 and 7 km a.s.l respectively. The dashed envelope corresponds to the total flux. The grey zone indicates presence of ash (Bonaccorso et al., 2011). (Bottom) Root mean square amplitude of the seismic tremor (0.5–5 Hz) recorded at the station closest to the south-east Crater where the eruption took place (from Bonaccorso et al., 2011).

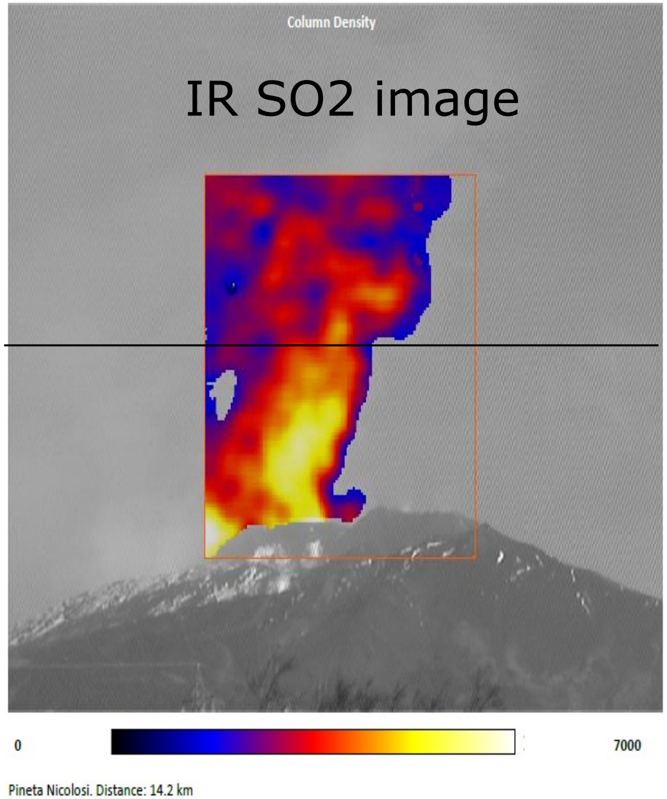
- DOAS-UV-Vis Bias under discussion (Kern *et al.* JGR 2012, JVGR 2013)

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

M. Burton, Univ Manchester



Typical SO2 concentrations on the black line measured

with IR: 1000-4000 ppm.m

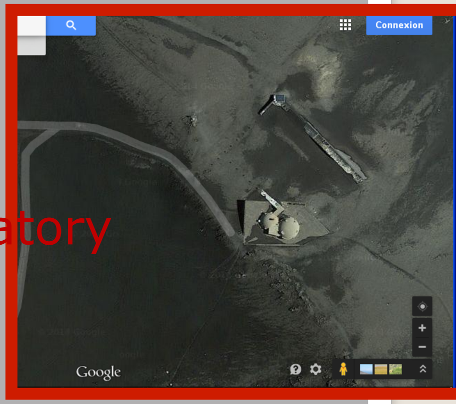
with UV: 100-300 ppm.m

~1 order of magnitude underestimate in UV SO_2 quantification

M. Burton, Univ Manchester

Imagetna campaign

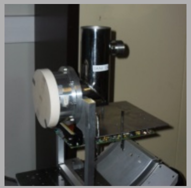
- 21-25 June 2015
- Measurement from Pizzi de Neri Observatory on the north side of the Etna at 2847 m of altitude

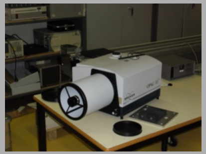


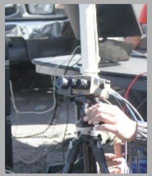

DANGER

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

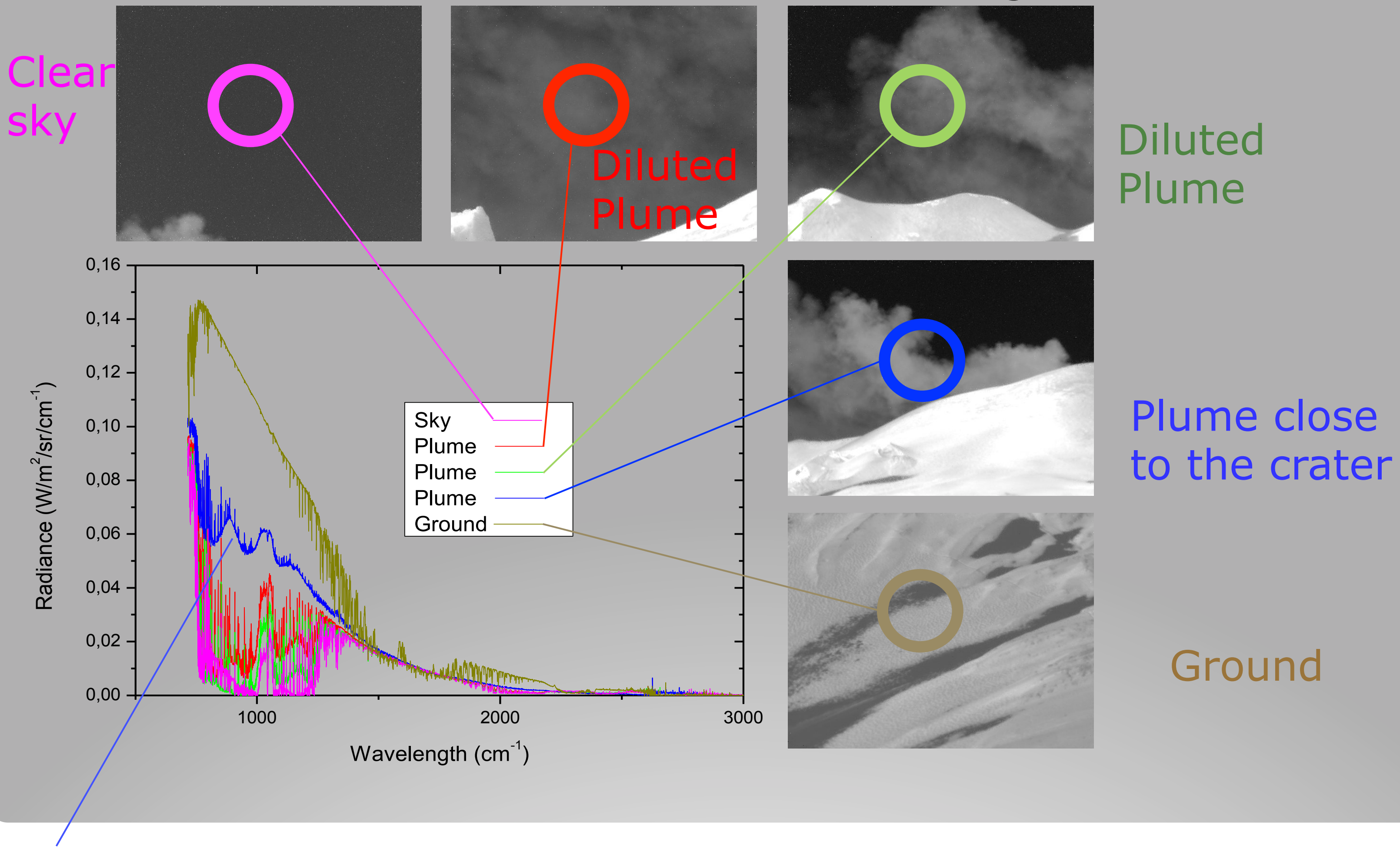
- Common field of view for all instruments

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



Strong signature of aerosols in the plume

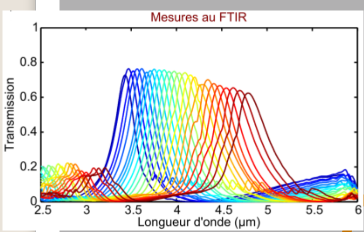
Preliminary measurements : Vitrail, FLIR, FTIR

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

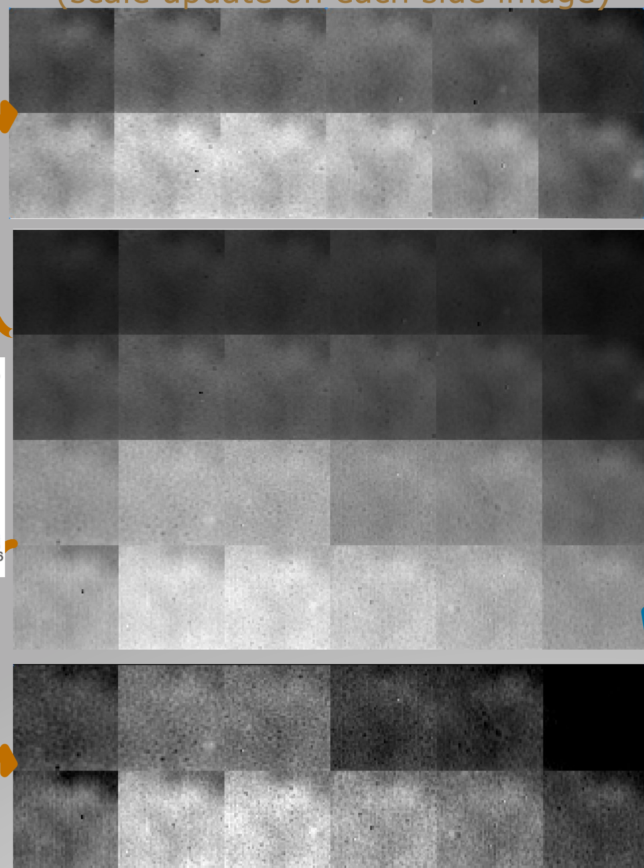
FLIR Camera
with FOV of other instruments

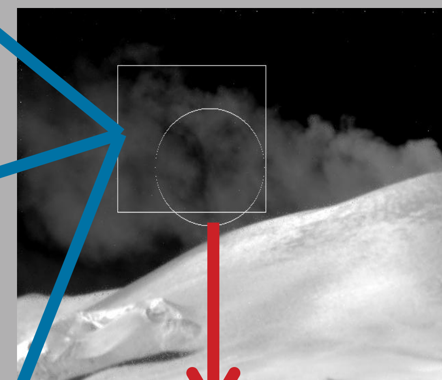
scale update on each side image

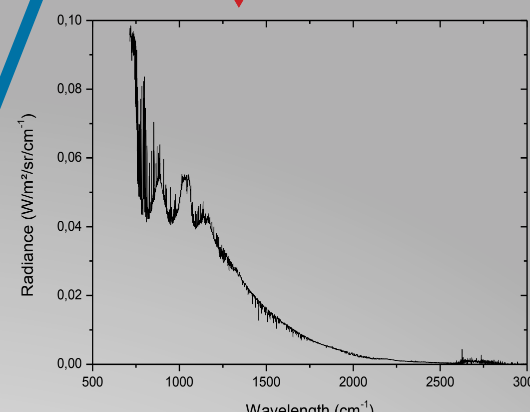
The 24 bands



scale update on each side image







Radiance from FTIR Spectrometer

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

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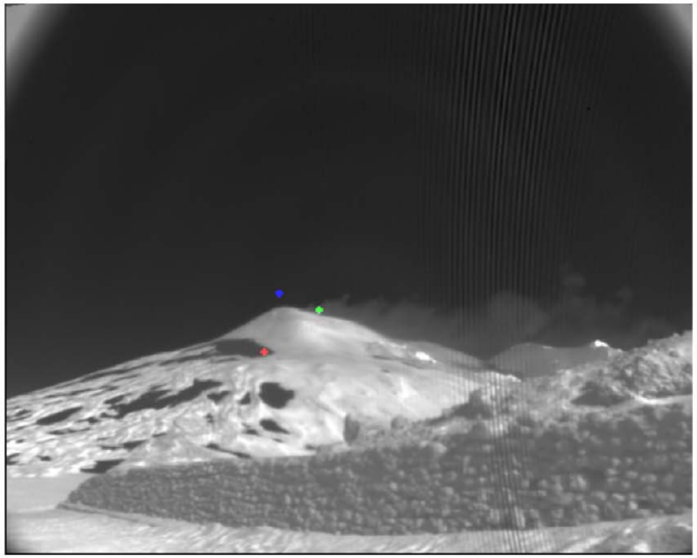
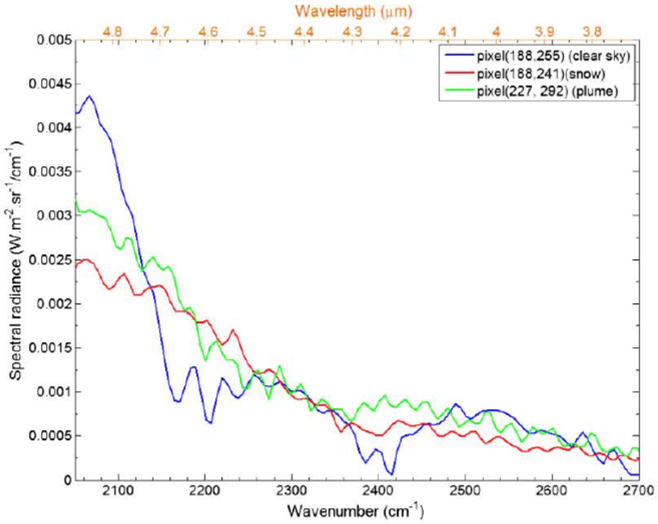
Optics Letters



(a)

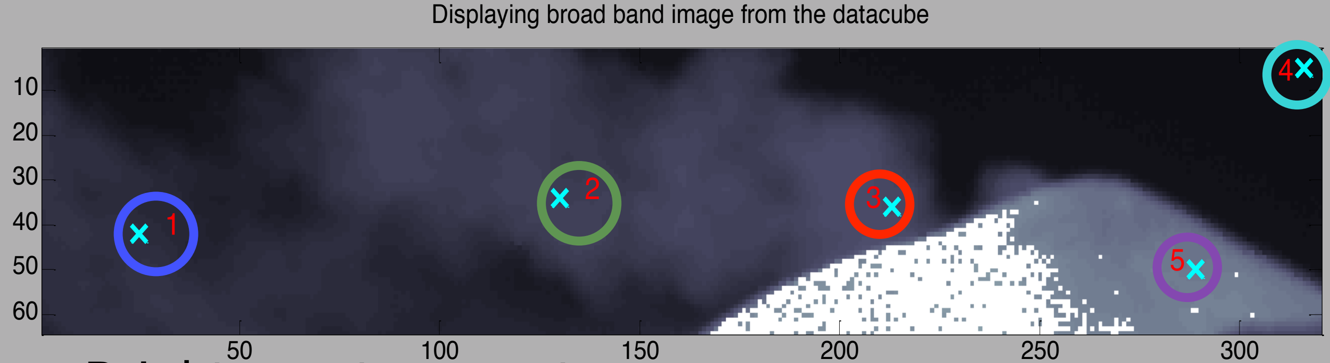


(b)

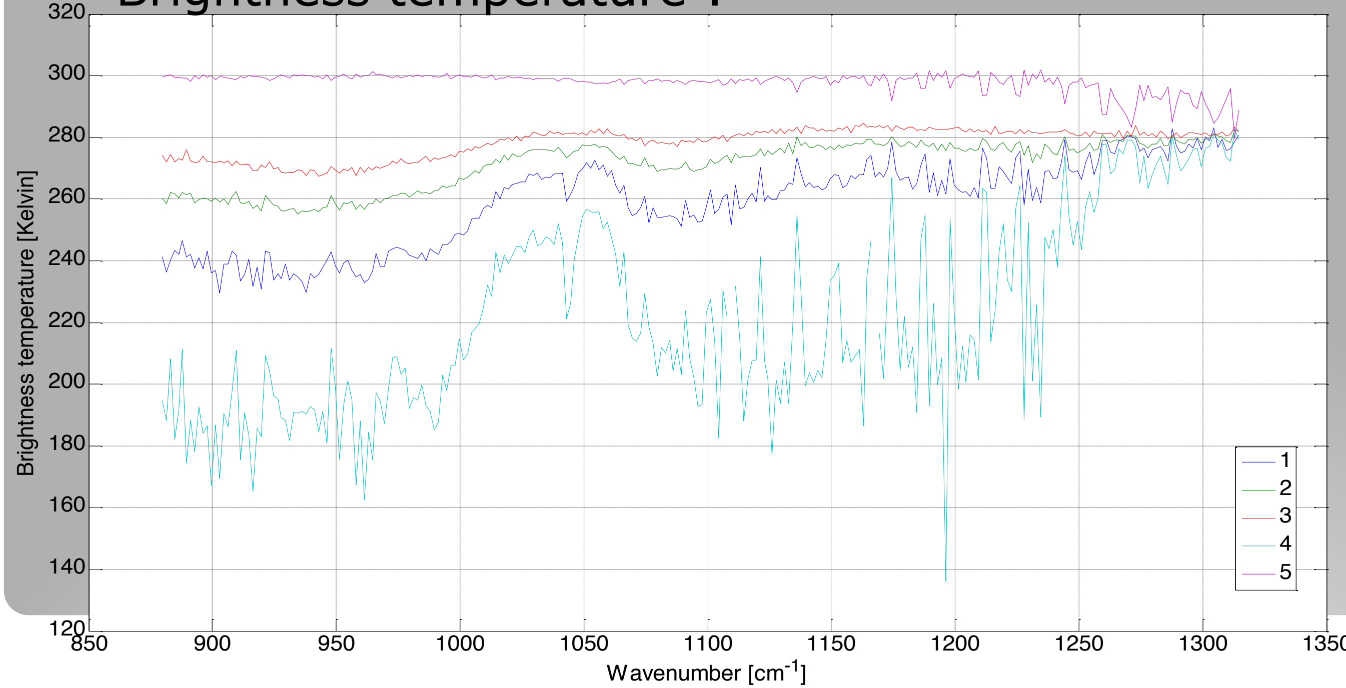
Fig. 6. (a) Location of an example of the points for which the spectra have been calculated: point in the sky (blue), in the plume (green) and in the snow (red). Note that snow appears black in this thermal-IR picture as it is colder than the rocks beside. (b) Obtained spectra, preliminary results.

Pola Fossi et al., Opt. Lett. 2016

Preliminary results : HyperCam



- Brightness temperature :

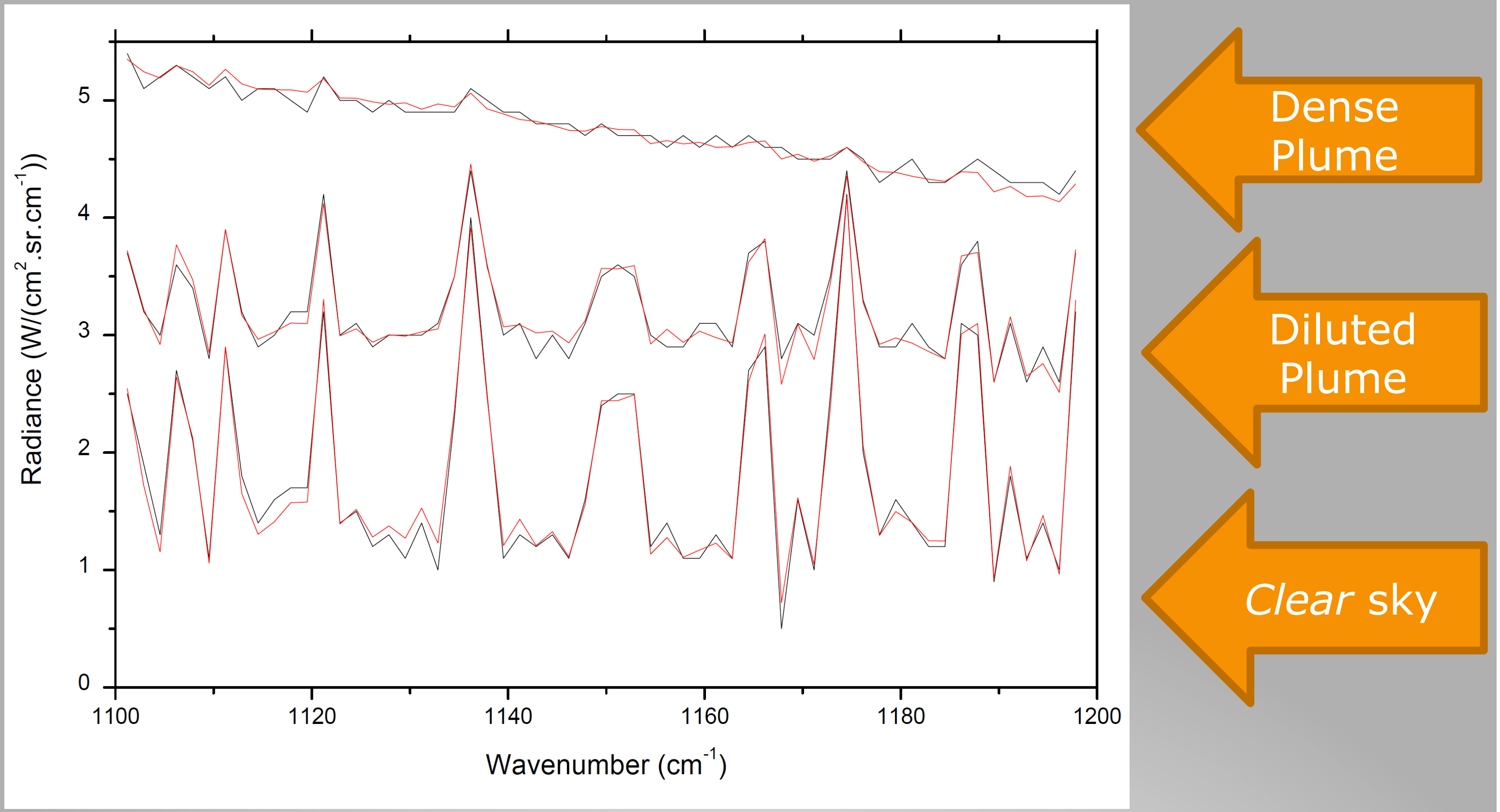


5. Ground
3. Plume
close to the crater
2. Diluted plume
1. Diluted plume
4. Clear sky

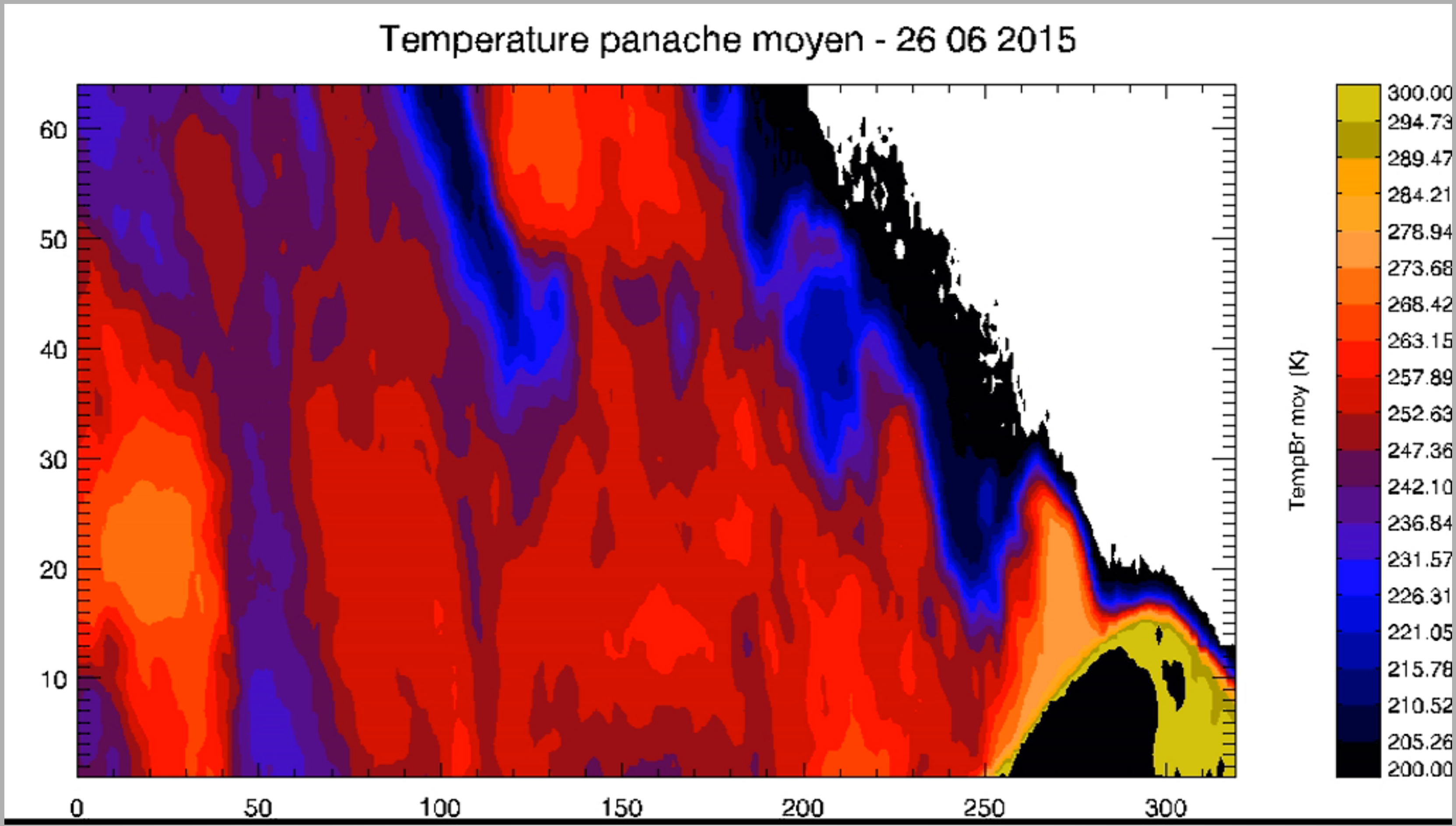
Retrieval strategy : LARA

- 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 "Plume", 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

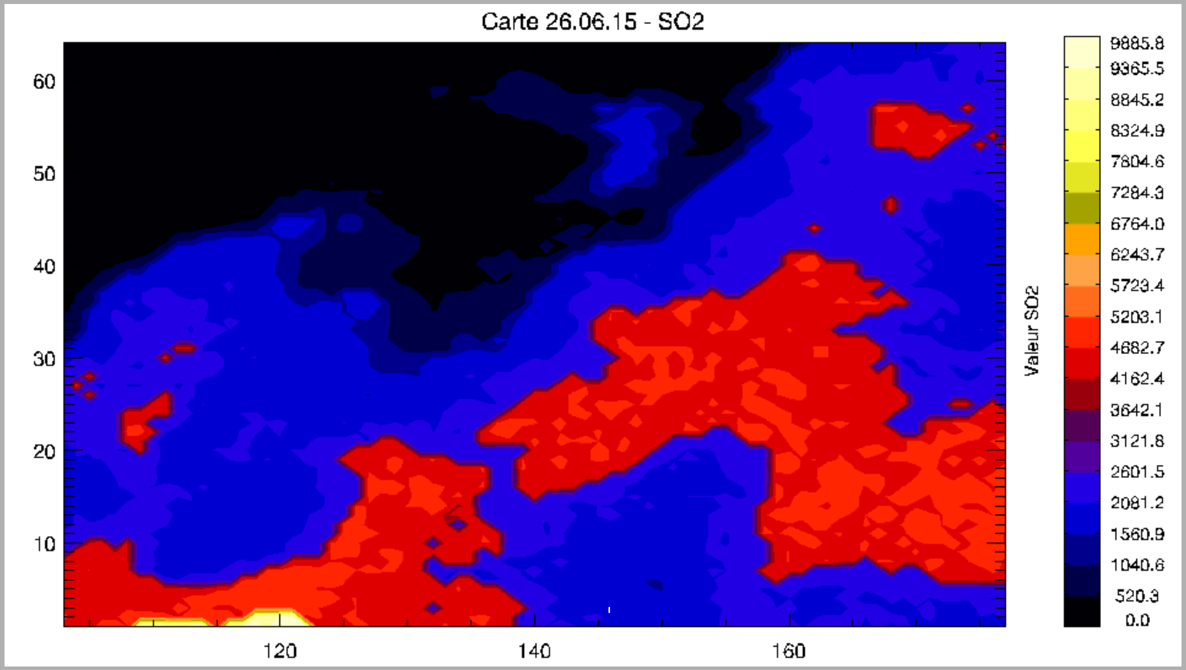
Preliminary retrieval : HyperCAM



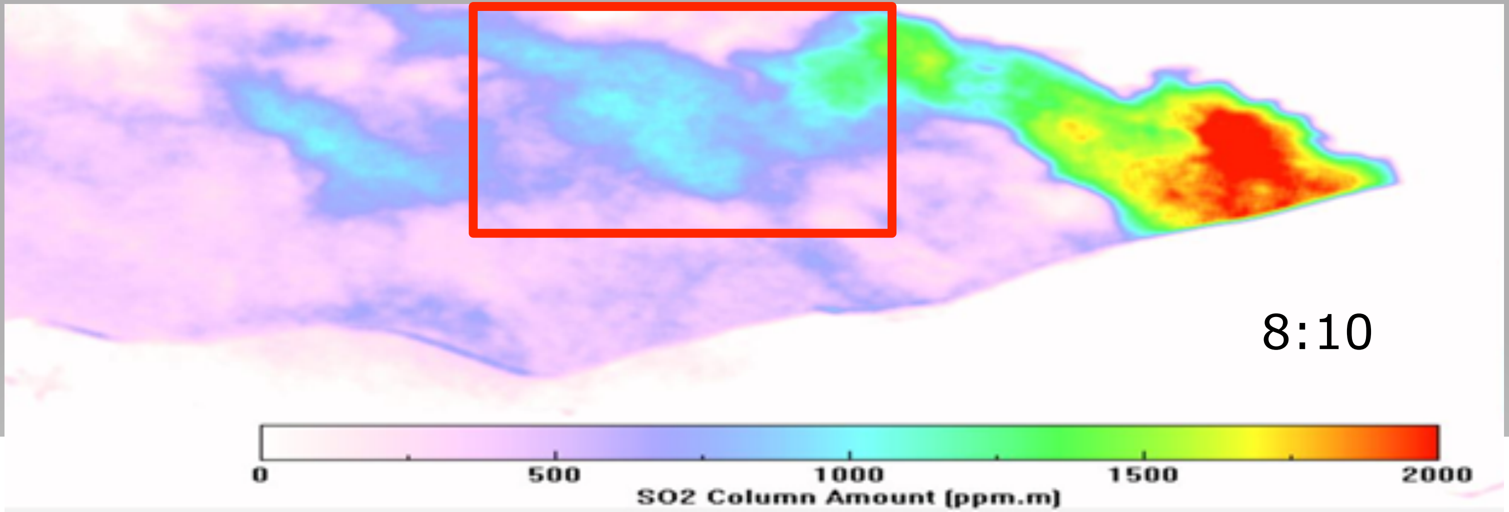
Need to decoralate aerosols and SO_2.
Need to account specific temperature for the plume



Temperature panache moyen - 26 06 2015
60
50
40
30
20
10
0
50
100
150
200
250
300
TempBr moy (K)
300.00
294.73
289.47
284.21
278.94
273.68
268.42
263.15
257.89
252.63
247.36
242.10
236.84
231.57
226.31
221.05
215.78
210.52
205.26
200.00


Carte 26.06.15 - SO2
60
50
40
30
20
10
120
140
160
Valeur SO2
9885.8
9365.5
8845.2
8324.9
7804.6
7284.3
6764.0
6243.7
5723.4
5203.1
4682.7
4162.4
3642.1
3121.8
2601.5
2081.2
1560.9
1040.6
520.3
0.0

8:25


8:10
0
500
1000
1500
2000
SO2 Column Amount [ppm.m]

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 / error budget

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

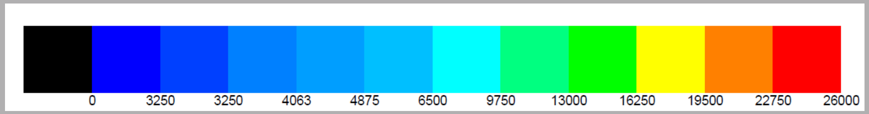
⇒ Validation of the measurements

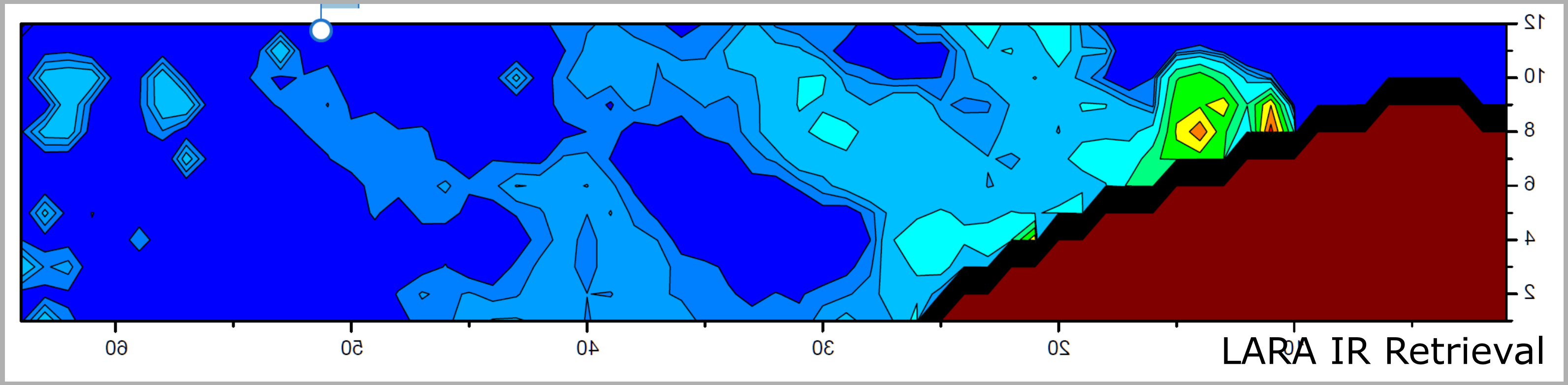
- **test other species détection/retrieval from ImagEtna IR spectra :**

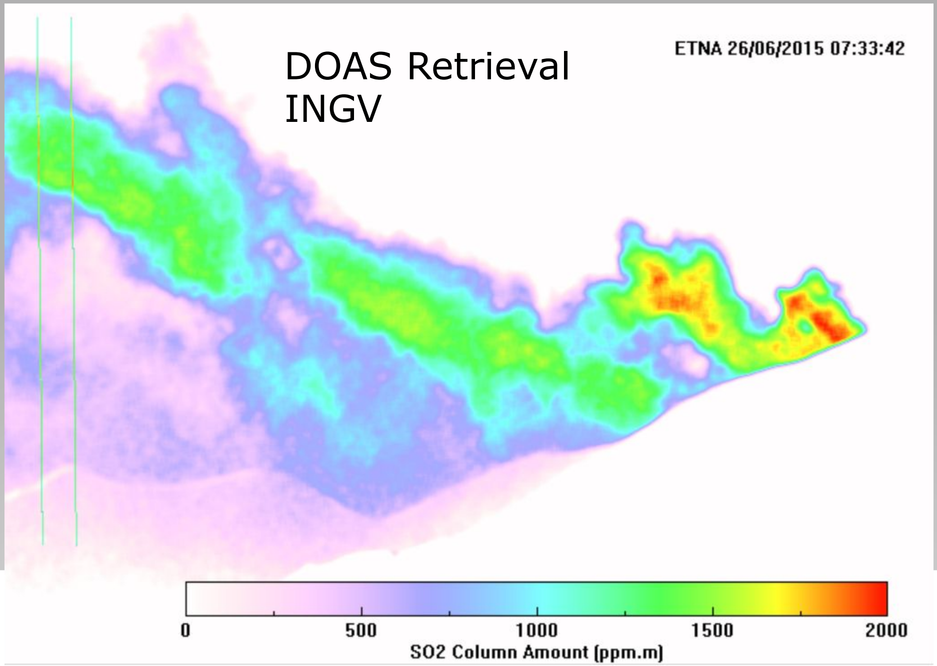
BAND 3.7-4.8 µm : CO_2, N_2O, CO, CS, CH_4, HCl, CH_3Cl

BAND 7.5-12 µm : CO_2, SO_2, NH_3, HNO_3, HCl, H_2S, OCS, CH_4, CO, SiF_4, HF

7:19 UTC – 26/06/2015







We sincerely thank the INGV colleagues who provide us very good conditions for the campaign.

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Thanks to CNES that help to prepare HALESIS Balloon project.

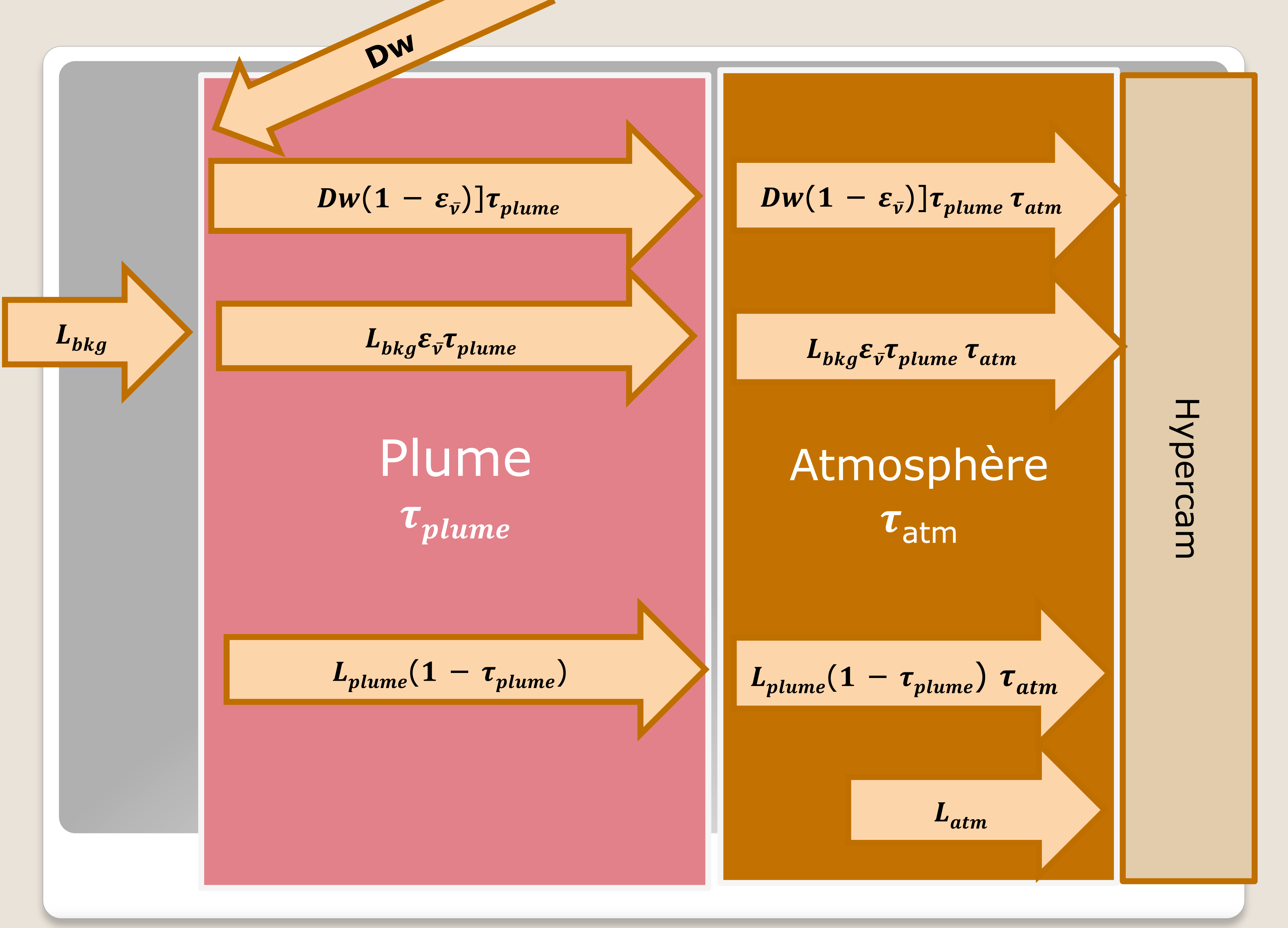
Acknowledgments

Contact : **sebastien.payan@upmc.fr**

Equation du transfert radiatif

$$L_{tot} = \left(\left[L_{bkg}\varepsilon_{\nu} + Dw(1 - \varepsilon_{\nu})\right]\tau_{plume} + L_{plume}(1 - \tau_{plume})\right)\tau_{atm} + L_{atm}$$

- L_{tot} : luminance spectrale totale mesurée par l'Hyper-Cam : Ltot
- L_{bkg} : fonction de l'auto-émission spectrale infrarouge de la surface ou de l'arrière-plan
- ε_{ν}: émissivité spectrale de la surface
- D_w : luminance incidente (downwelling)
- τ_{plume} : transmittance du panache de gaz
- $L_{plume}(1 - \tau_{plume})$: Auto-émission infrarouge spectrale du panache de gaz
- τ_{atm} : transmittance atmosphérique
- $L_{atm}(1 - \tau_{atm})$: contribution de l'atmosphère en auto-émission spectrale

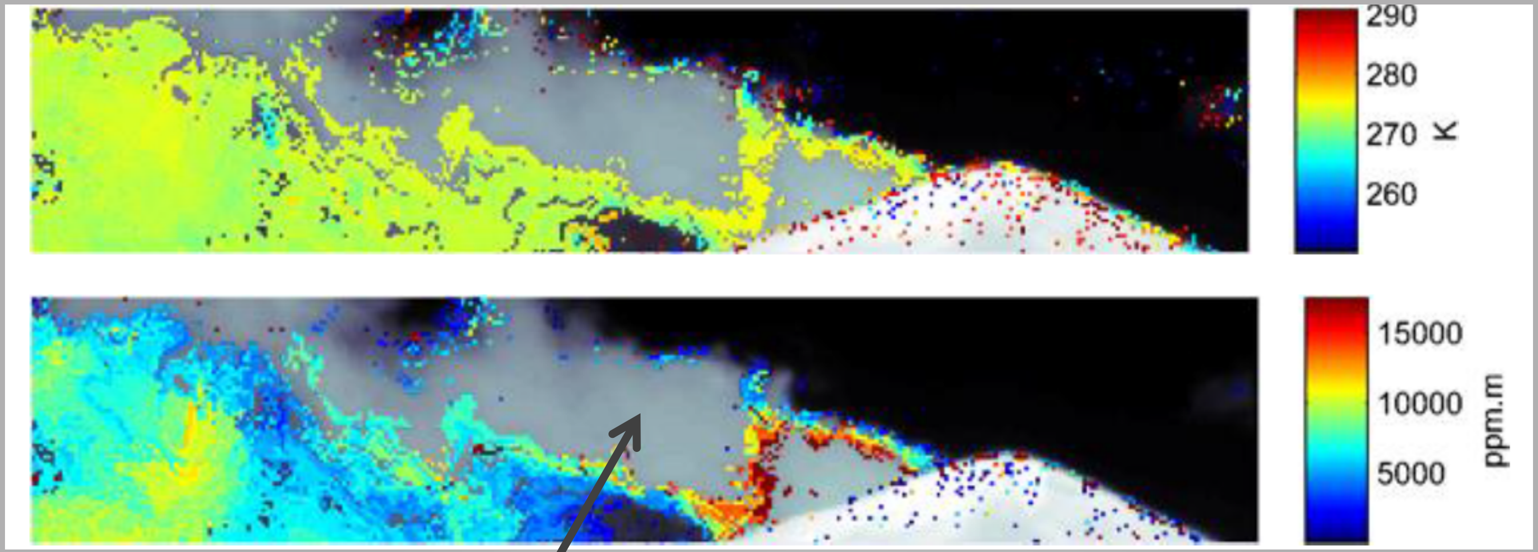


Dw
$Dw(1 - \varepsilon_{\bar{\nu}})]\tau_{plume}$
L_{bkg}
$L_{bkg}\varepsilon_{\bar{\nu}}\tau_{plume}$
Plume
τ_{plume}
$L_{plume}(1 - \tau_{plume})$
$Dw(1 - \varepsilon_{\bar{\nu}})]\tau_{plume}\ \tau_{atm}$
$L_{bkg}\varepsilon_{\bar{\nu}}\tau_{plume}\ \tau_{atm}$
Atmosphère
τ_{atm}
$L_{plume}(1 - \tau_{plume})\ \tau_{atm}$
L_{atm}
Hypercam

Preliminary retrieval : HyperCAM

- Example of 1 image

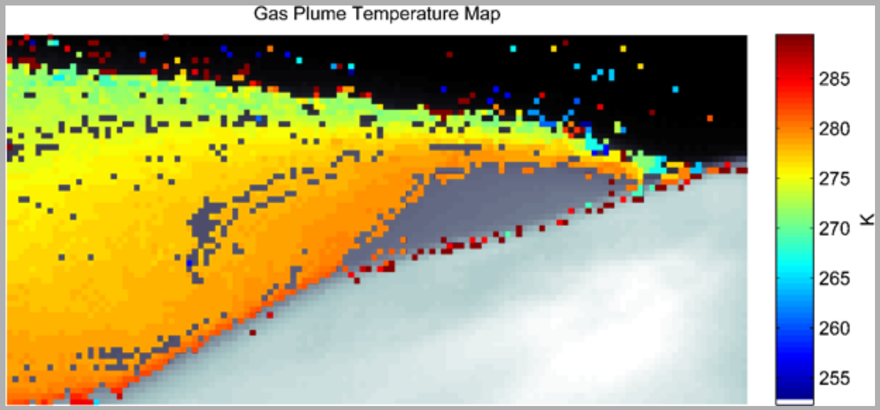
Acquisition 20150622_143749134



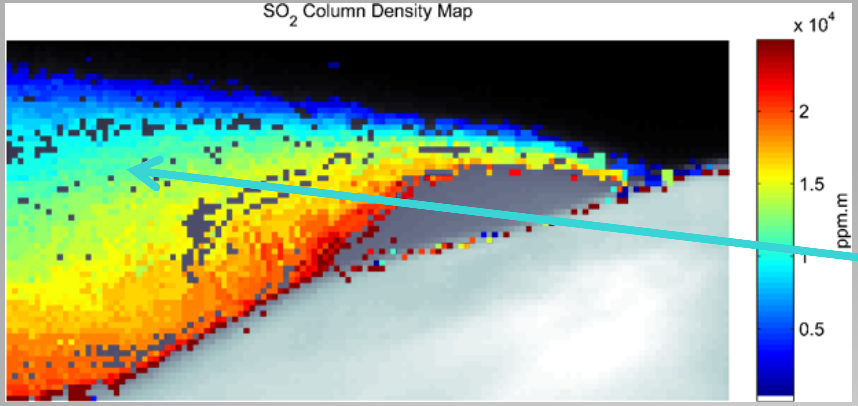
aerosols/ash => Opacity of the plume

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