Istituto Nazionale di Geofisica e Vulcanologia

PRISMA

Utilizzo di sensori iperspettrali per la stima della CO_2 emessa sorgenti vulcaniche in troposfera.

C. Spinetti, M.F. Buongiorno

Picture courtesy of B. Behncke

SU,MMARY

- Vulcanic Emissions

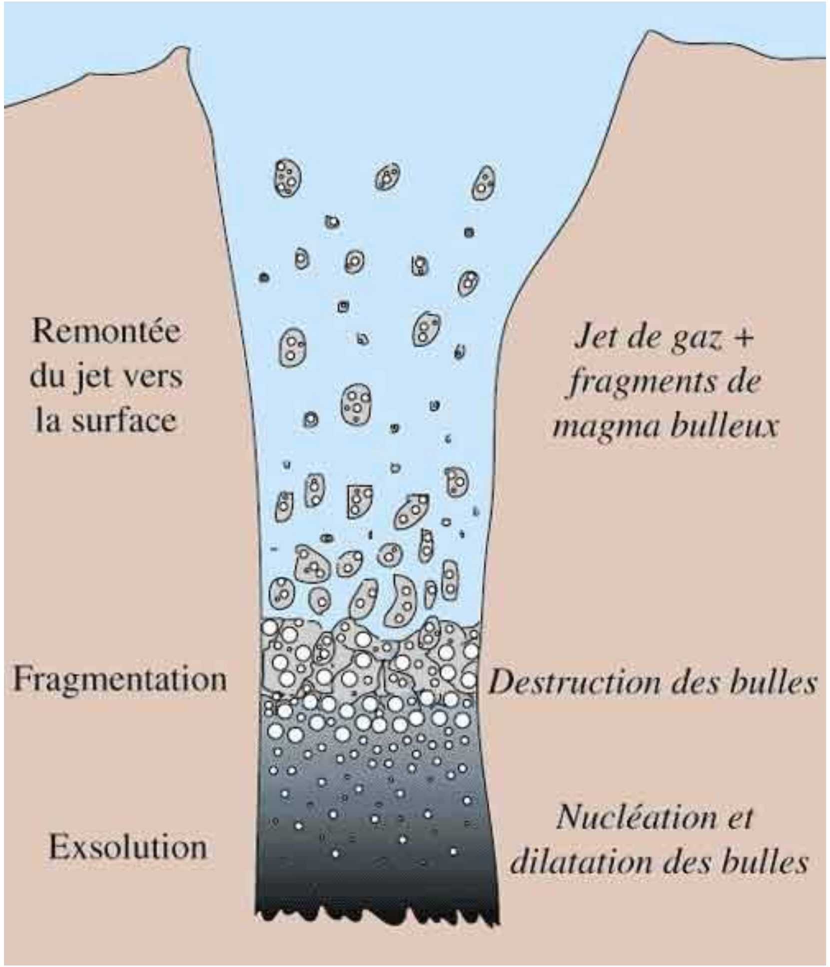
•The algorithm for the estimation of carbon dioxide
•contained in a volcanic plumes

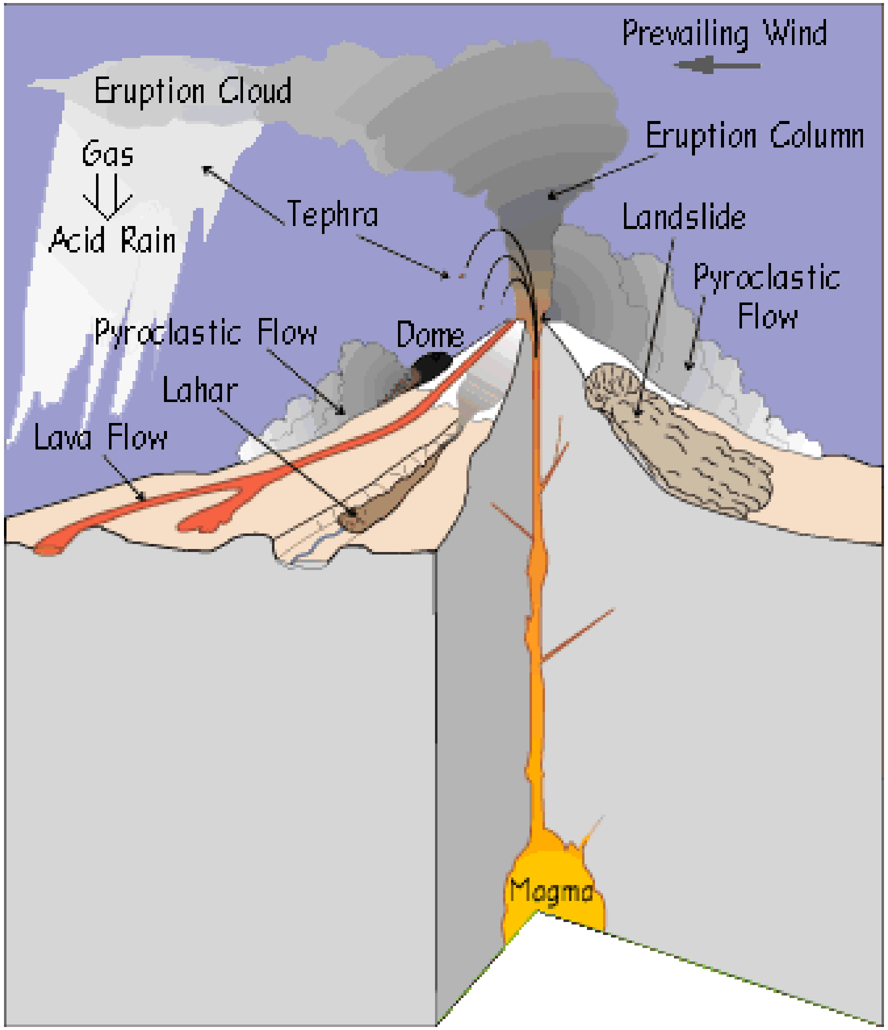
•The task of ASI_AGI project
•The algorithm
•Applications with Hyperion satellite data
•Applications with MIVIS airborne data
•Applications with hyperspectral airborne data

- conclusions

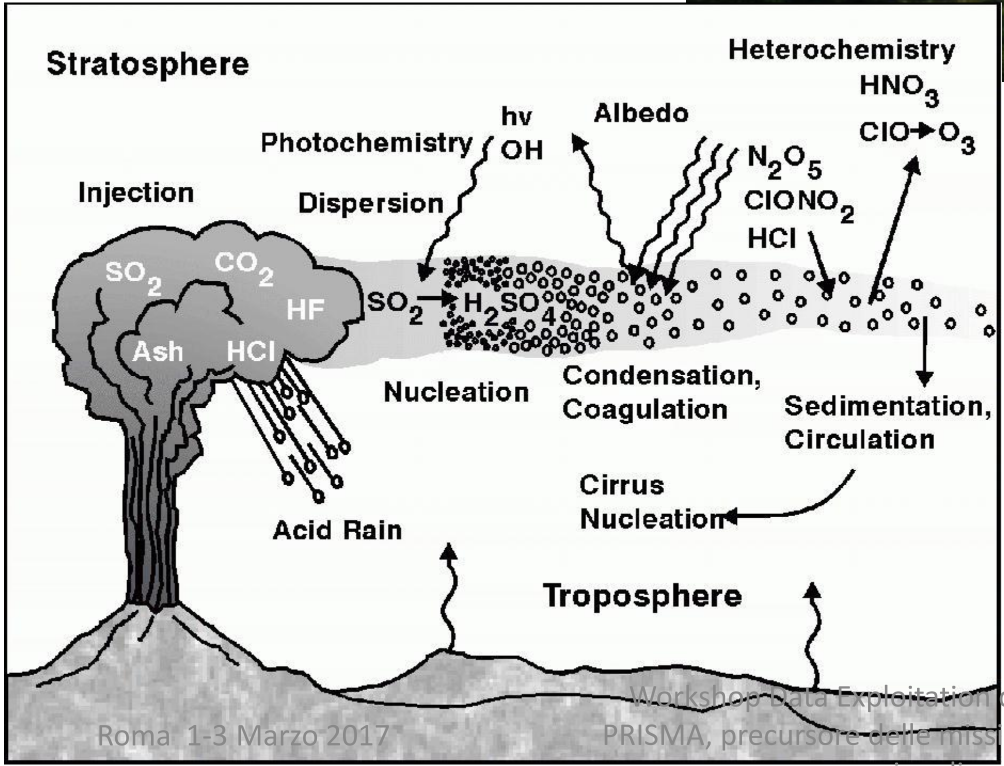
TITLE	Name of the institute	
Development of algorithms and products for applications in agriculture and land monitoring to support the PRISMA mission (SAP 4 PRISMA)	Istituto di Metodologie per l'Analisi Ambientale IMAA CNR	Vincenzo Cuomo
Singergistic use of PRISMA products with high resolution meteo-chemistry simulations and their validation from ground and satellites (PRIMES)	CETEMPS - Univ. de L'Aquila	Guido Visconti
Hyperspectral systems analisys for integrated geophysical applications (ASI-AGI)	Istituto Nazionale di Geofisica e Vulcanologia (INGV)	Fabrizia Buongiorno
Advanced methodologies for analysis, integration and optimization of PRISMA level 1 and 2 products - OPTIMA -	Istituto di Fisica Applicata Nello Carrara (IFAC -CNR)	Ivan Pippi
Coasts and Lake Assessment and Monitoring by PRISMA HYperspectral Mission (CLAM PHYM)	Institute of Marine Sciences (ISMAR - CNR)	Luigi Alberotanza

Volcanic emissions in atmosphere





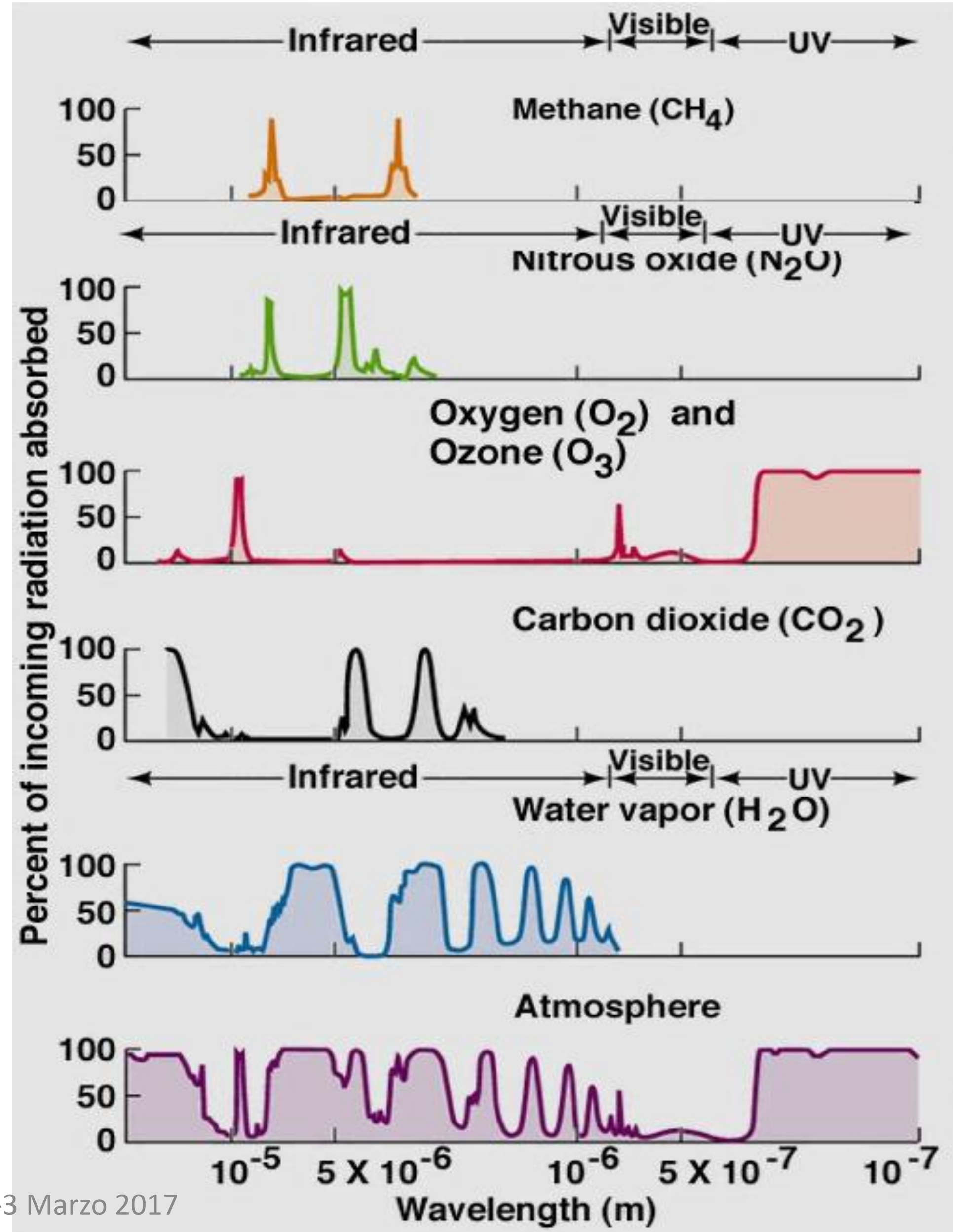
Volcanic plume



- ✓ Volcanoes inject in the troposphere H2O, CO2, SO2, H2, CO and in lower quantities H2S, HCl, HF, He, …
- ✓Those gases can be responsible of acid rains, pollution of aquifers, ….
- ✓ More globally, the volcanic plumes have an impact on the climate.
- ✓ Some historical eruptions are known to have induced colder climate during some years

Components of a volcanic plume

- **Water Vapor** represents 70-90% of the gases contained in the volcanic plume
- **Carbon Dioxide** The active volcanoes injects 130 million tons of CO2 per year into the atmosphere
- **Sulphur Dioxide** The active volcanoes injects 1 million tons per year of SO2 into the atmosphere
- **Particulate solid and liquid**? Variable dimensions from meters (lava bombs) to microns/nm particles (aerosols). **Volcanic ash and aerosols** can cover millions of km2 according to the height reached in the atmosphere
- The liquid particulate is due to heterogeneous nucleation of sulfuric acid.



atmospheric
absorption features

volcanic

volcanic

Volcanic CO_2 emissions

Volcanic gases flux (1975-1995)

Species	Global Volcanism (Gg/yr)	Etna/Global Volcanism
H_2O	$5.0 \cdot 10^6$	10%
CO_2	$(8\text{-}20) \cdot 10^4$	(7-16)%
SO_2	$1.3 \cdot 10^4$	11%
HCL	$(4\text{-}110) \cdot 10^2$	9%
HF	60-6000	8%
Br	77	2.6%
Zn	9.6	51%
Cu	9.4	5.9%
Mn	42	0.6%
Pb	3.3	4.5%

Volcano	CO_2 (T/d)
Mt. Etna	11000-70000
Popocatepetl	6400-40000
Oldoinyo Lengai	7200
Augustine	6000
Mt. St. Helens	4800
Stromboli	3000
Kilauea	2800
White Island	2600
Erebus	1850
Redoubt	1800
Grimsvotn	360
Vulcano	270

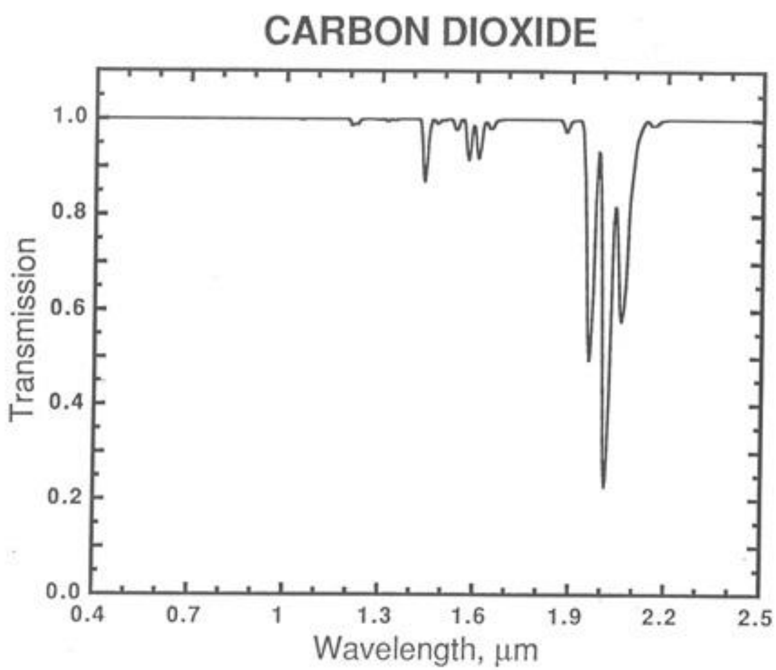
DATA SOURCE:
Symonds et al., 1994; Gerlach et al., 1997; Allard et al., 1998; Varley et al., 1998; Delagdo et al., 1998; Kopenick et al., 1996; Allard et al., 1991; Wardell and Kyle, 1998; Brantley et al., 1993; O'Keefe, 1994

Volcanic Carbon Dioxide Retrieval

CO_2 absorption lines are present in the spectral range of hyperspectral imaging spectroradiometer VNIR-SWIR

weak absorption 1270 nm and 1610 nm

strong absorption 1950 nm and 2100 nm



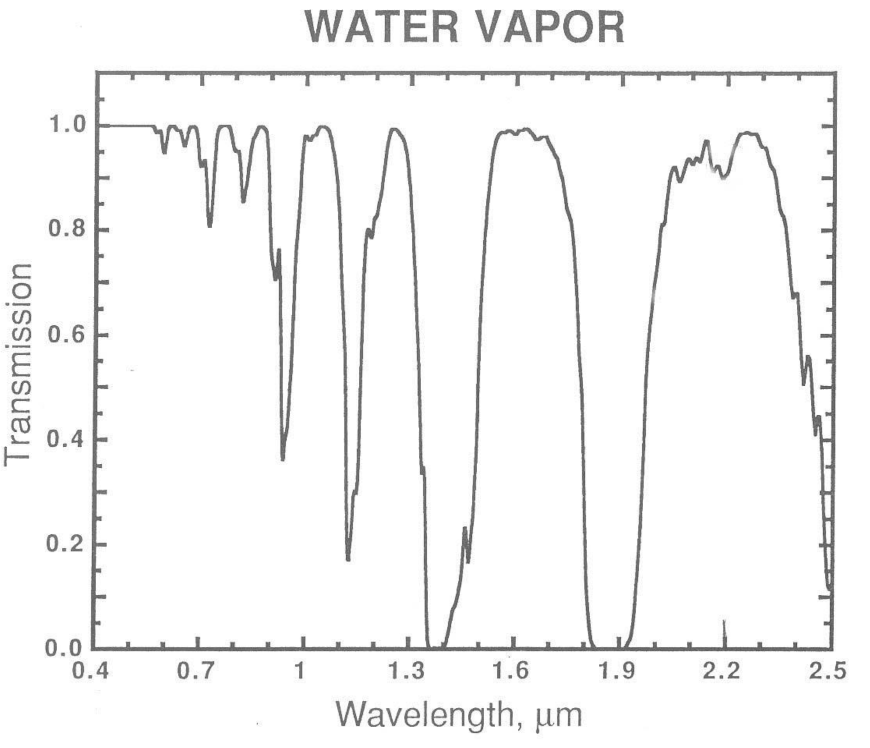
Atmospheric transmisson simulated using Modtran with the only presence of CO_2 in standard condition with 10 nm of spectral resolution

Water Vapour absorptions in the VNIR-SWIR spectral range

Water Vapour Absorption lines are present in the spectral range of hyperspectral imaging spectroradiometer:

weak absorption
940 e 1125 nm

very strong absorption
1350 e 1900 nm



Atmospheric transmisson simulated using Modtran with the only presence of water vapour in standard condition

The CIBRW retrieval alghoritm

In order to retrieve the tropospheric volcanic plume Carbon Dioxide abundance, an inversion technique has been developed for remote sensing hyperspectral data (*Spinetti et al., 2008, RSE*). The algorithm is based on the assumption that there is a relationship between the dip in the atmospheric spectrum curve, due to the gas absorption, and the gas concentration in the atmospheric column. The retrieval is based on solving the equation:

$$CIBRW = \exp\left(-\alpha(w) \cdot [CO_2]^{\beta(w)}\right)$$

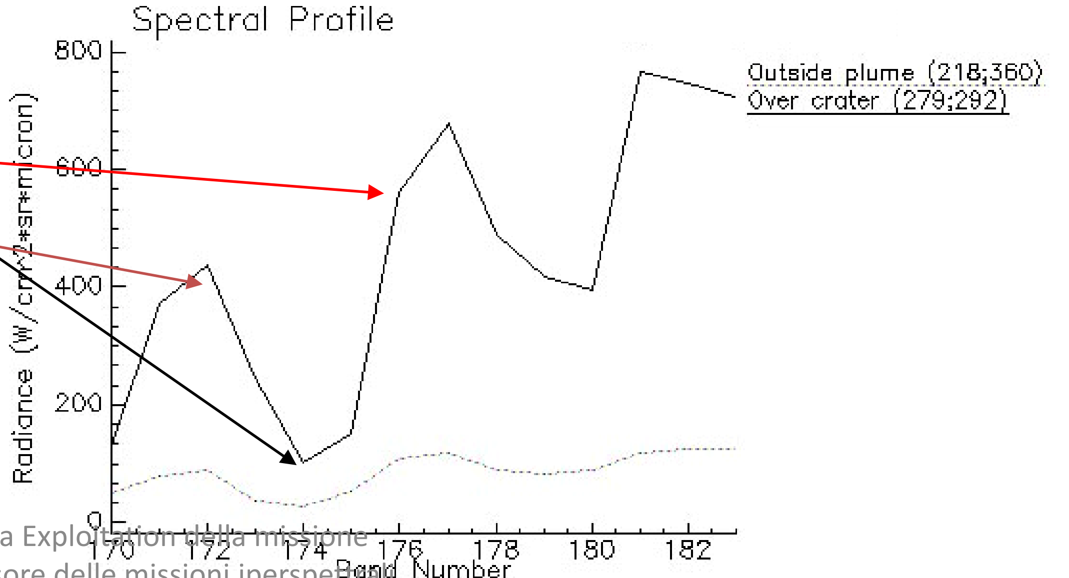
- $[CO_2]$ is the unknown carbon dioxide columnar abundance ($kg \cdot m^{-2}$);

- α e β parameters related to the model variables, volcanic water vapor abundance and volcanic aerosol presence;

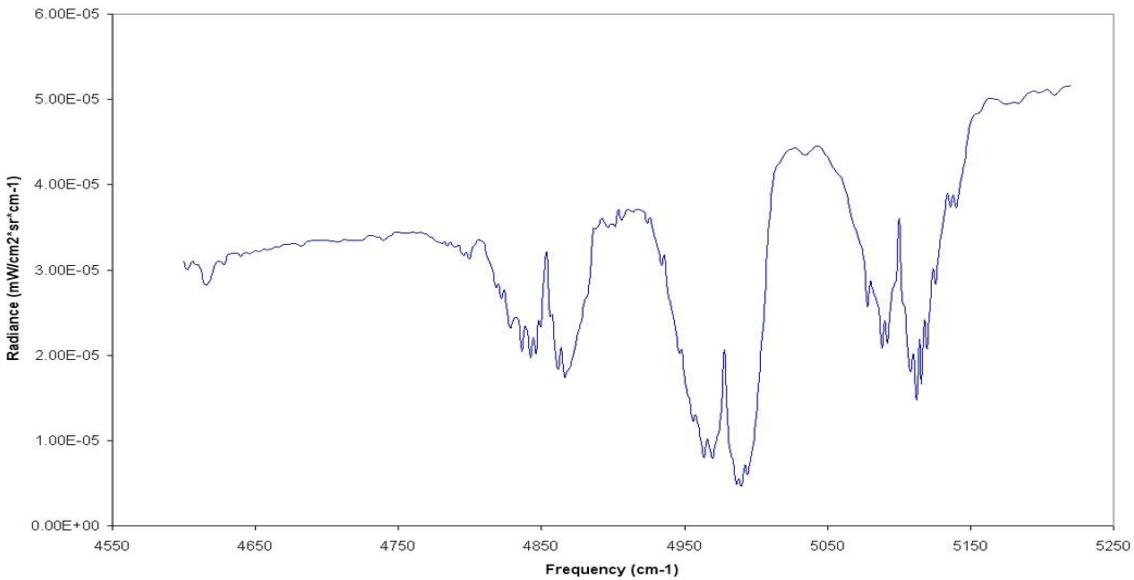
- CIBR is given by the following ratio:

$$CIBR = \frac{R_a}{A \cdot R_1 + B \cdot R_2}$$

- R_a is the radiance corresponding to the minimum of absorption
- A and B are the weighting constants
- R_1 and R_2 are the radiances of the continuum

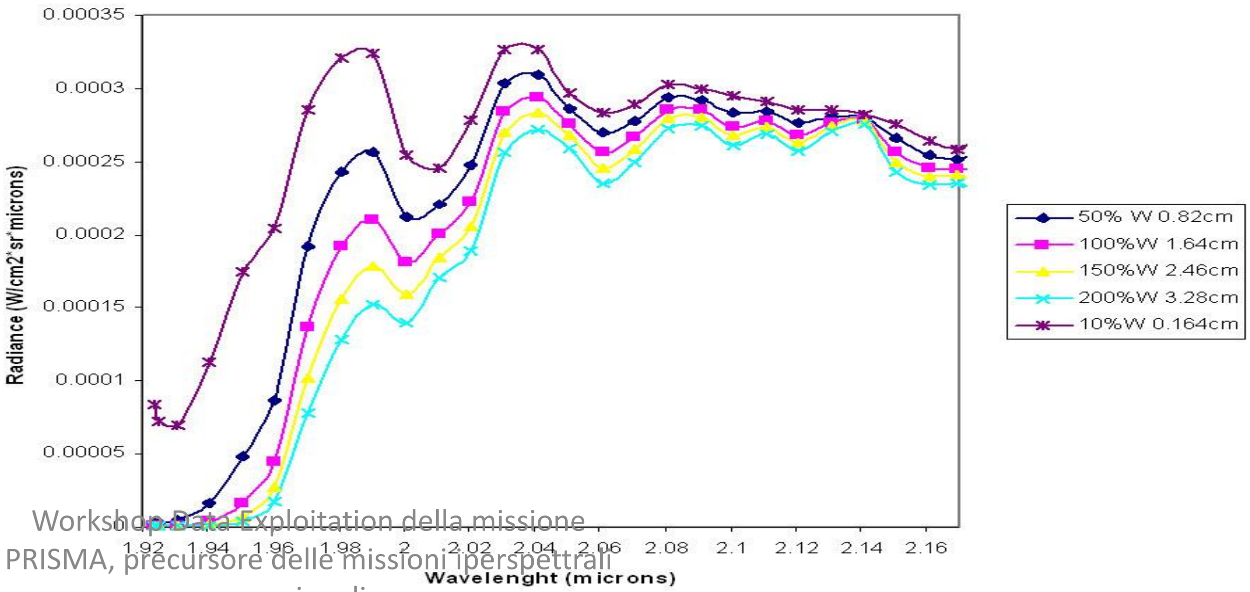


The water vapour influence



Considering 10 nm of spectral resolution, CO_2 lines partially overlap with the water vapor lines. The presence of water vapor influences the CO_2 absorption bands cancelling the signal of the first CO_2 absorption band and modifying the other two bands depending on the amount of water vapor.

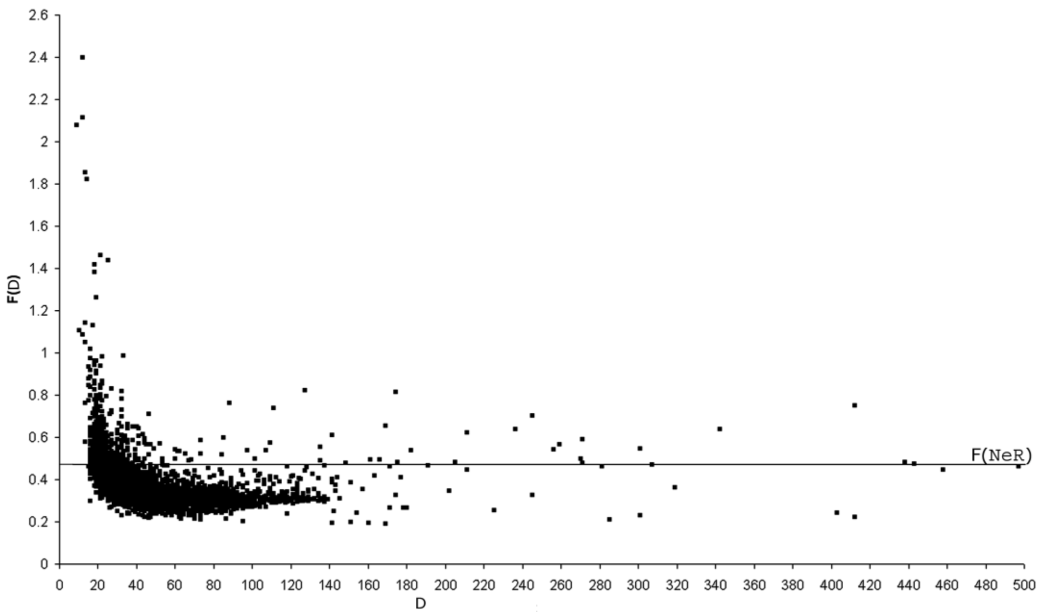
Modtran Radiance simulation at standard atmospheric conditions with the atmospheric concentration of CO_2 and the presence of different values of water vapour in the atmospheric column.



Signal Sensitivity Analysis

In order to quantify the signal sensitivity with respect to the CO2 absorption line variations, a sensitivity function F(D) has been defined:

$$F(D) = \left| \frac{D(\lambda)|_{\lambda=\lambda_m}}{D(\lambda)|_{\lambda=\lambda_{C1}} + D(\lambda)|_{\lambda=\lambda_{C2}}} \right|$$



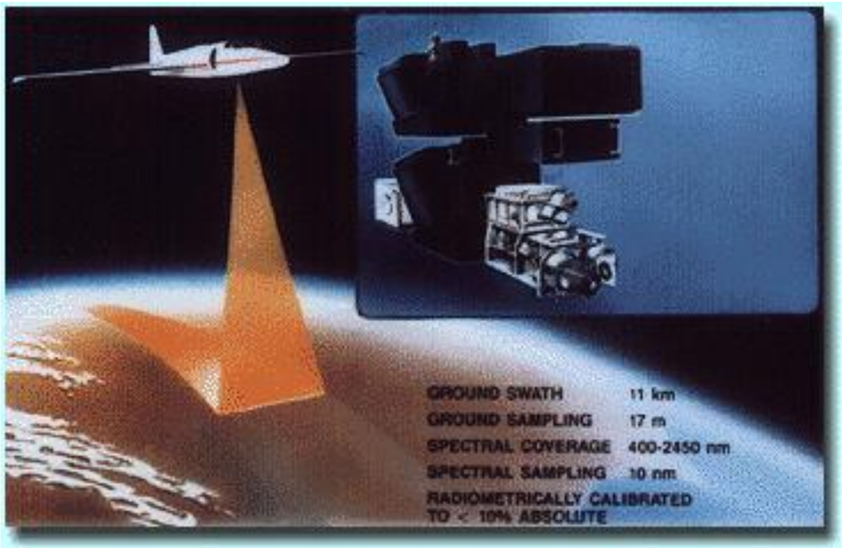
λ_m= 2011nm is the CO2 absorption channel; λ_{c1} = 1981nm and λ_{c2} = 2031nm are channels in the continuum;
$D = (R_{Plume} - R_{Atm})$ where R_{Plume} is the volcanic plume radiance and R_{Atm} is the atmospheric radiance outside the plume

The CO2 retrieval is possible only if the signal contains the information on volcanic CO2 above the atmospheric background, i.e. where F(D) assumes values greater than the noise equivalent radiance:

$$F(D) > F(NeR)$$

AVIRIS

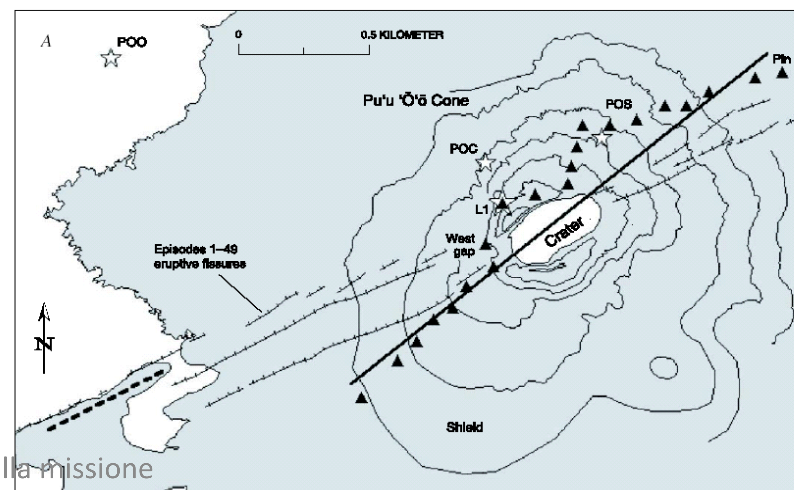
Airborne Visible/InfraRed Imaging Spectrometer



"Whisk broom" scanning

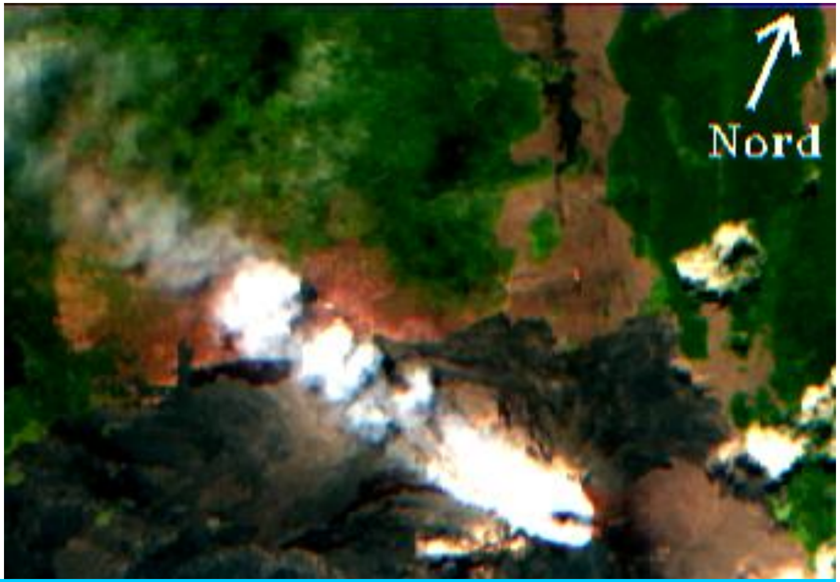
Spectral coverage	**400-2450 nm**
Spectral sampling interval	**9.6-9.9 nm**
Spectral channel width	**9.8 12.5 nm**
Number of spectral channel	**224**
Number of pixel scan line	**614**
Number sca/sec	**12**
IFOV	**1.0 mrad**
Rad. Calib. accuracy	**6%**
In-flight stability	**1%**
Spectral calib.accuracy	**2+- nm**

Airborne campaign on Kilauea Volcano Hawaii



Water vapour abundance map of Pu'o'O Vent plume at Kilauea volcano

AVIRIS campaign April 26th 2000

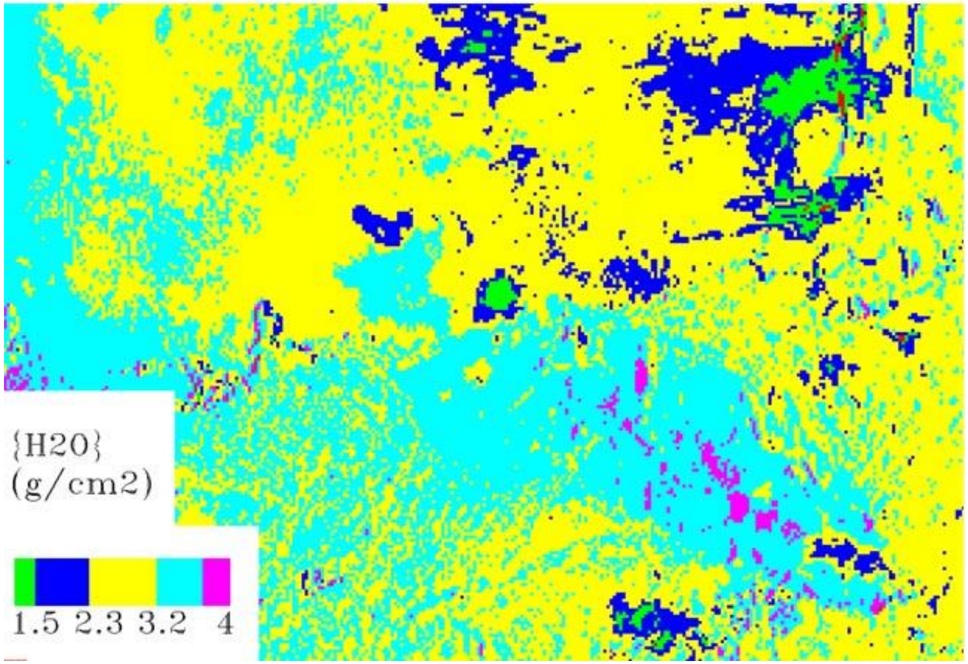


Pixel dim.

20x20 m^2 @ crater

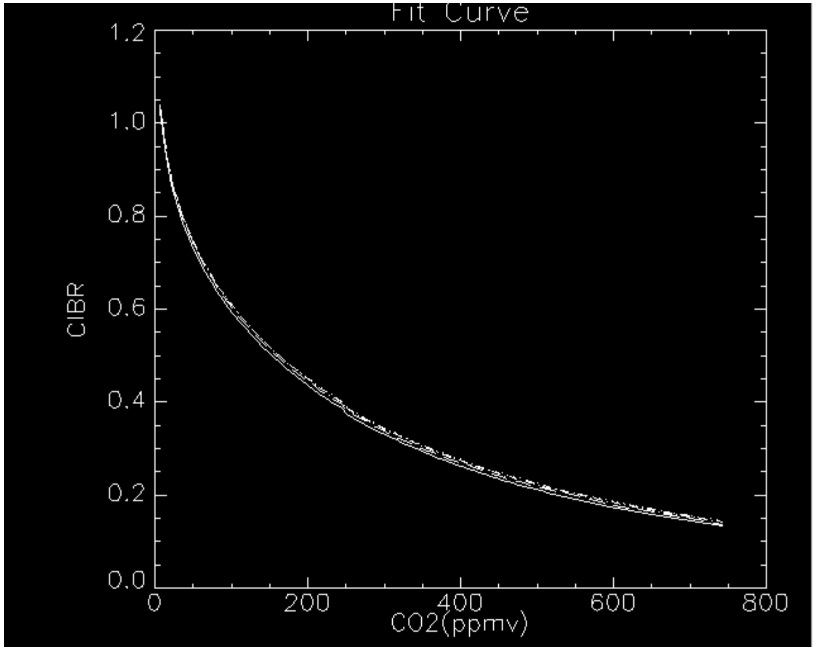
R 676.31± 0.11nm
G 529.43 ± 0.11nm
B 452.08 ± 0.11nm

Water vapour map retrieved using 940 nm absorption band

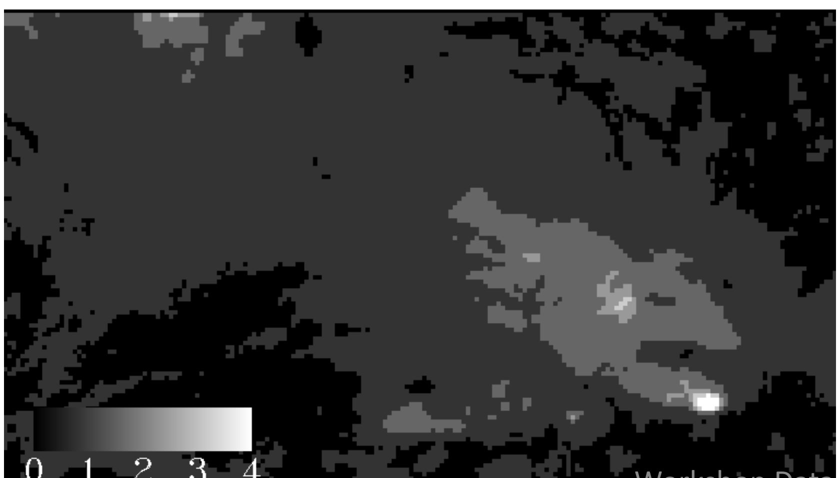


Spinetti and Buongiorno 2004, IEEE Trans

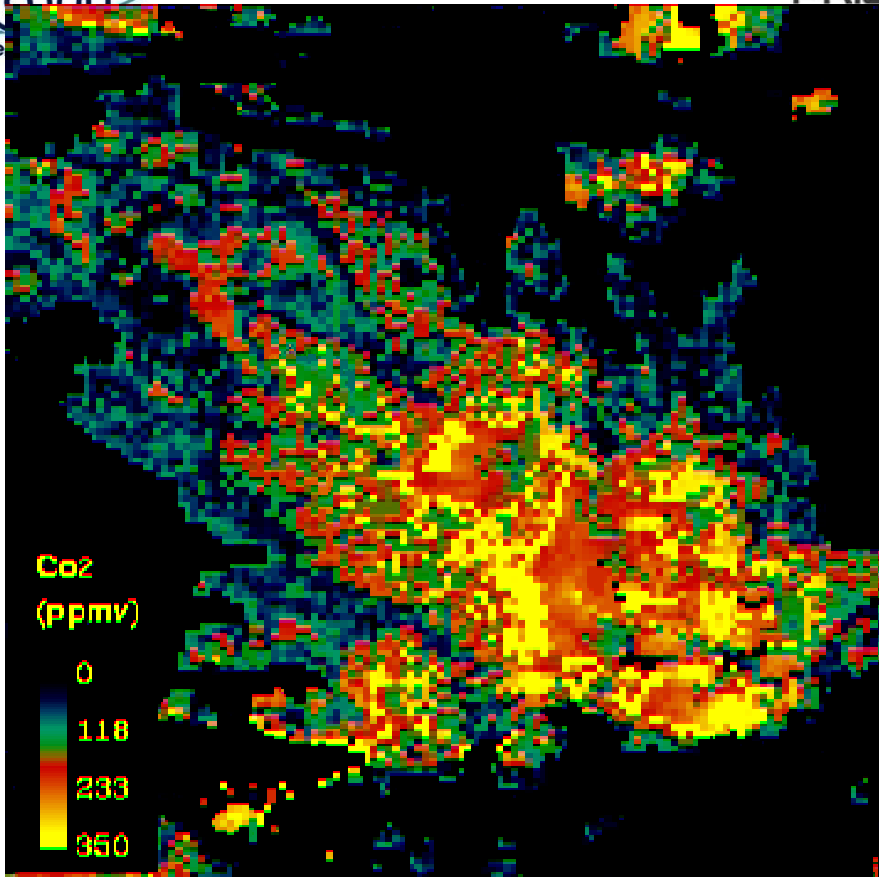
Paramaters α and β depending on water vapour content



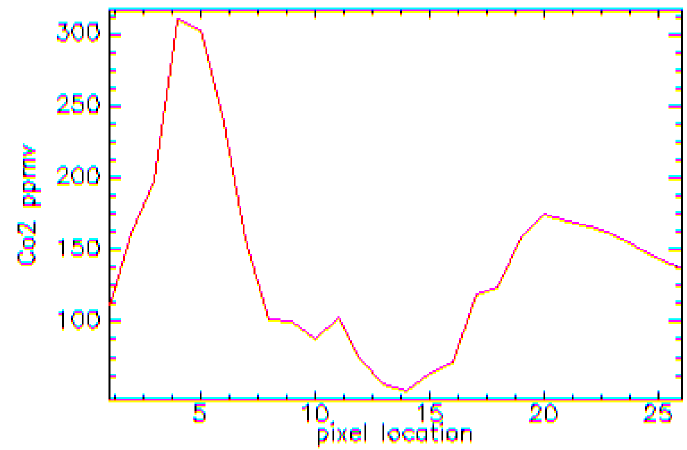
Index	W (g/cm2)	$\alpha(w)$	$\beta(w)$	Correlation fit (R^2)
0	2.3	0.0160669	0.740992	0.989785
1	2.8	0.0141277	0.759783	0.986303
2	3.2	0.0133723	0.766998	0.984544
3	3.4	0.0135917	0.763602	0.984492
4	4	0.0141354	0.756234	0.985672



Map of CO_2 abundance in the Pu'o'O Vent plume



26-4-00



Φ_{CO2} = 396±138 t d^{-1}

Accordance with ground sampling data

Figure 13. Lava from crater of Pu'u 'Ō'ō flows through west gap in cone. View eastward; photograph by J.P. Kauahikaua, taken October 20, 1997.

Figure 14. Crater of Pu'u 'Ō'ō. Plume rises from several vents on crater floor, which is covered with pāhoehoe erupted in 2002. View westward; photograph taken April 11, 2002.

VOCANIC GAS EMISSIONS PRODUCTS FROM PRISMA

Algorithms: Review of the CIBRW modified algorithm
development of new algorithm LIR based on hyperspectral sensors data in the SWIR range

Objective: Analysis of the absorption bands of CO_2 and CH_4 in volcanic plumes and degassing cold fumaroles

Products: maps to show degassing areas in volcanic zones
CO_2 concentration and flux in volcanic plumes

L'Algoritmo APDA-LIR

The Atmospheric technique Pre-Corrected Differential Absorption Technique APDA as evolution of CIBR. The algorithm is based on the pre-correction following equation of radiative transfer in the case of a sensor that acquires ia large number of spectral channels

$$L(\lambda) = \rho(\lambda)\frac{1}{\pi}\{E_0(\lambda)\cos(\sigma)\tau_1(\lambda)\tau_2(\lambda)\} + L_{atm}(\lambda)$$

Where: L (λ) and 'the spectral radiance for a channel, r (λ) and' the reflectance of the ground including the adjacency effects; E0 (λ) and 'irradiance exo-atmospheric; s and 'the angle subtended by the normal to the line joining the sun-earth; t1 (λ) and 'the atmospheric transmittance relative to the path sun-ground; t2 (λ) and 'the atmospheric transmittance relative path to ground-sensor; LATM (λ) and 'the total upwelled atmospheric radiance. The terms of transmittance can be separated into terms that depend on the content from the aerosol content in the gas and water vapor.

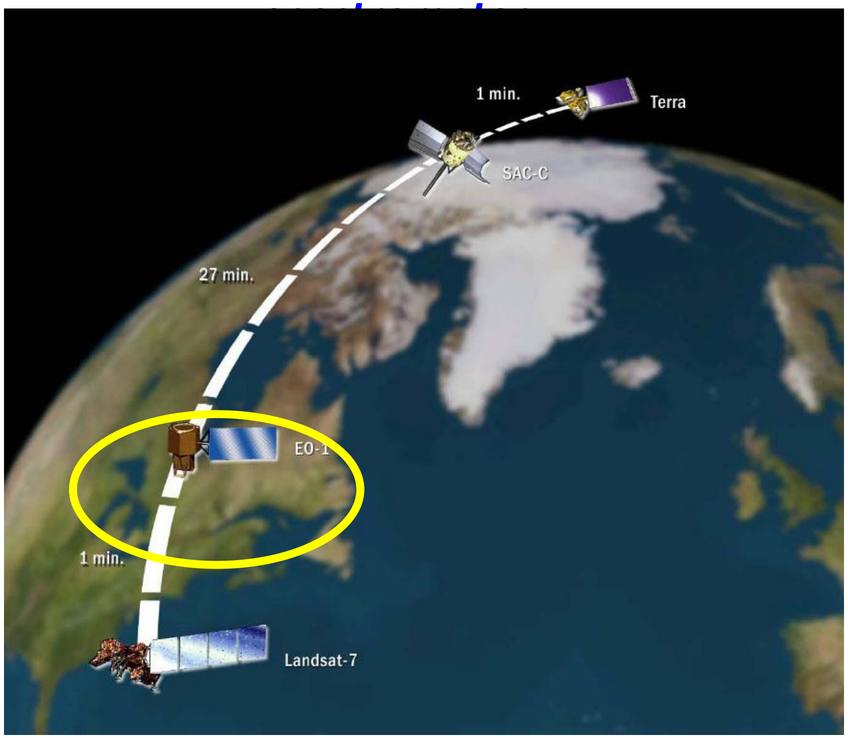
The technical innovation is based on the use of a large number of channels given large number of spectral features typical of a gas absorptions. The previous equation CIBR was transformed in the new equation RAPDA:

$$RAPDA = \frac{\left[L_m - L_{atm,m}\right]i}{LIR\left(\left[\lambda_r\right]j, \left[L_r - L_{atm,r}\right]j\right)_{\left[\lambda_m\right]i}}$$

Where with 'm' is the index of absorption spectral channel; LATM is the upwelling radiance; LIR ([x], [y]) refers to a linear regression y = ax + b for the points y = Lr - LATM, r x = lr evaluated. The linear regression calculated between the' features' of absorption spectrum and i and j indices refer to the spectral channels.
Based on three channels the above equation returns the CIBR but the term LATM correction

HYPERION

hyperspectral spaceborne imaging



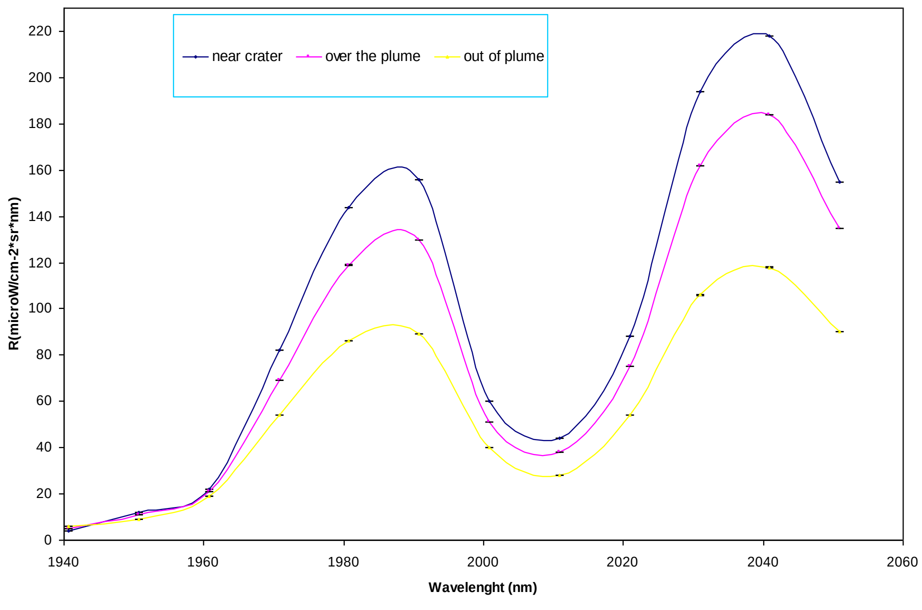
Morning constellation
709 km orbit
EO-1 launched on 2000

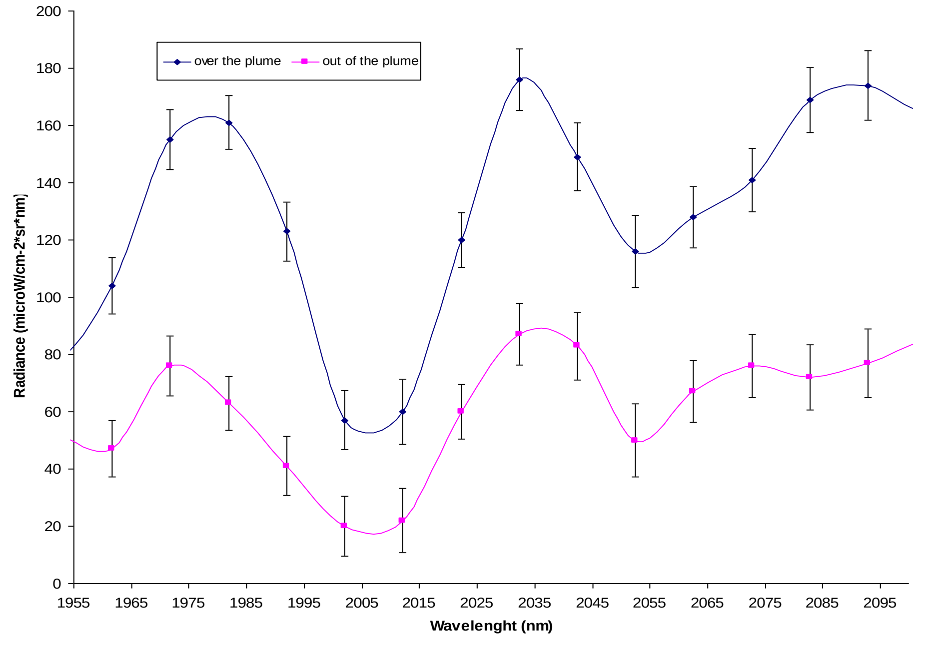
"Push broom" scanning
242 channels 400 – 2500 nm. 10 nm nominal channel bandwidth.
224 Hz frame rate. 12 bit data encoding.
0.61 degrees total field of view. 42.4 microrad Instantaneous Field of View.
On-board Accuracy Radiometry 3.40% VNIR SNR (550 - 700nm) 140- 190 SWIR SNR (~ 1225nm) 96 SWIR SNR (~ 2125nm) 38

Signal Sensitivity Analysis

Sensitivity function

$$F = \frac{|(R_{Plume} - R_{Atm})|_{ch174}|}{|(R_{Plume} - R_{Atm})|_{ch172} + (R_{Plume} - R_{Atm})|_{ch176}|}$$



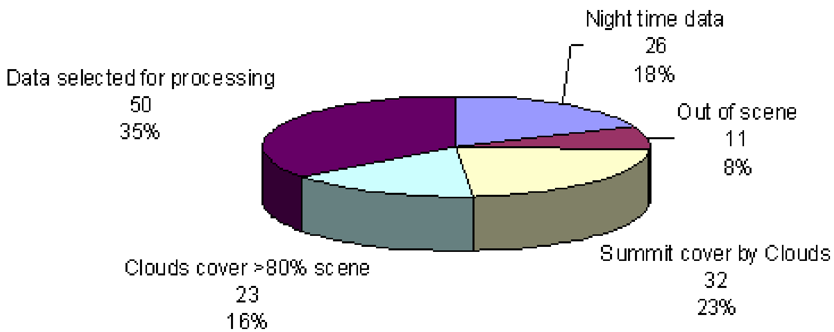


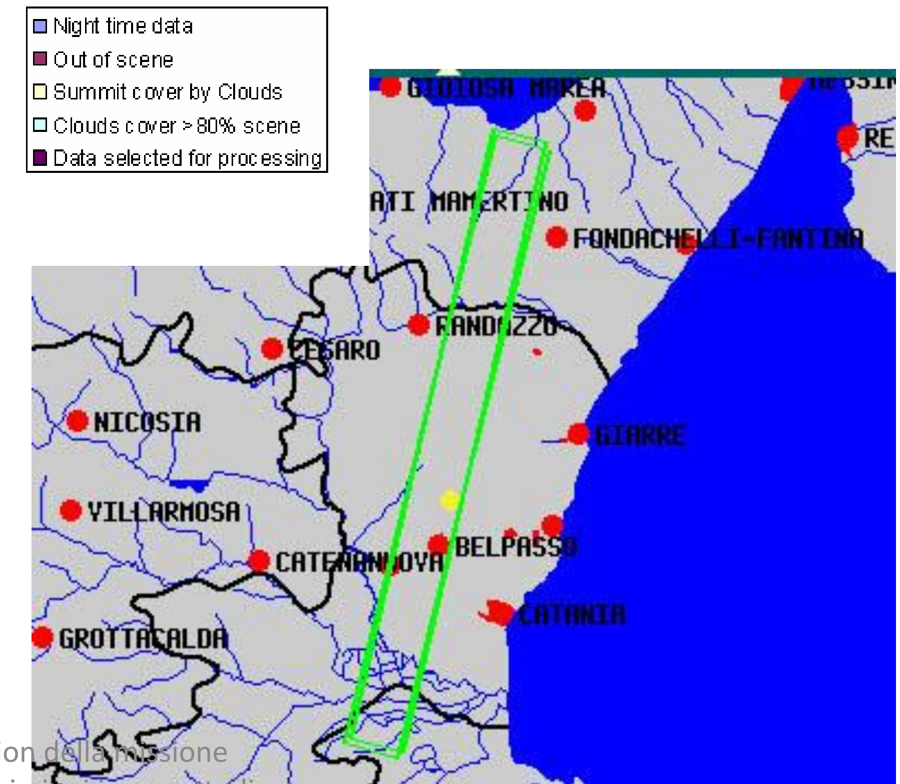
F(min) ≥ NeΔR

Hyperion data have a very limited sensitivity compared to Aviris

Hyperion data analysis

Task 2.6.1 Retrieval of carbon dioxide analysis of the acquired series of Hyperion Data Etna since 2001 in order to identify the data set to be analyzed between the eruptions and pre-eruptive phases.



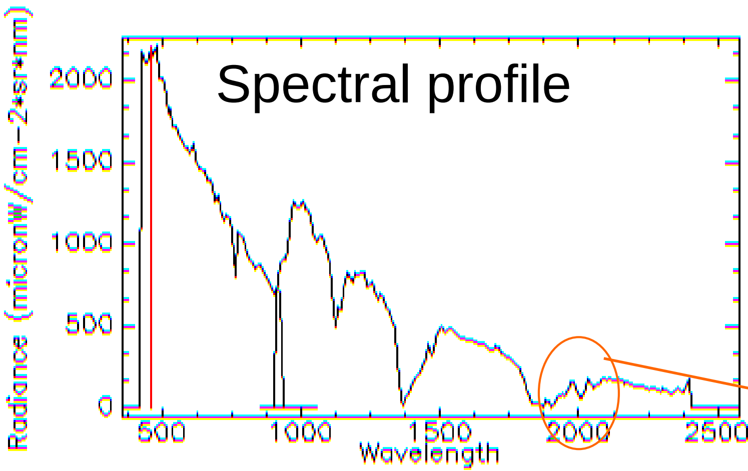


Total area of Etna Hyperion acquisitions: 142 Data

Which can be used in the summit area, day and no cloud cover are 50 data for 35% of total acquisitions since 2001.

Swath width 7.5 km

Hyperion data analysis

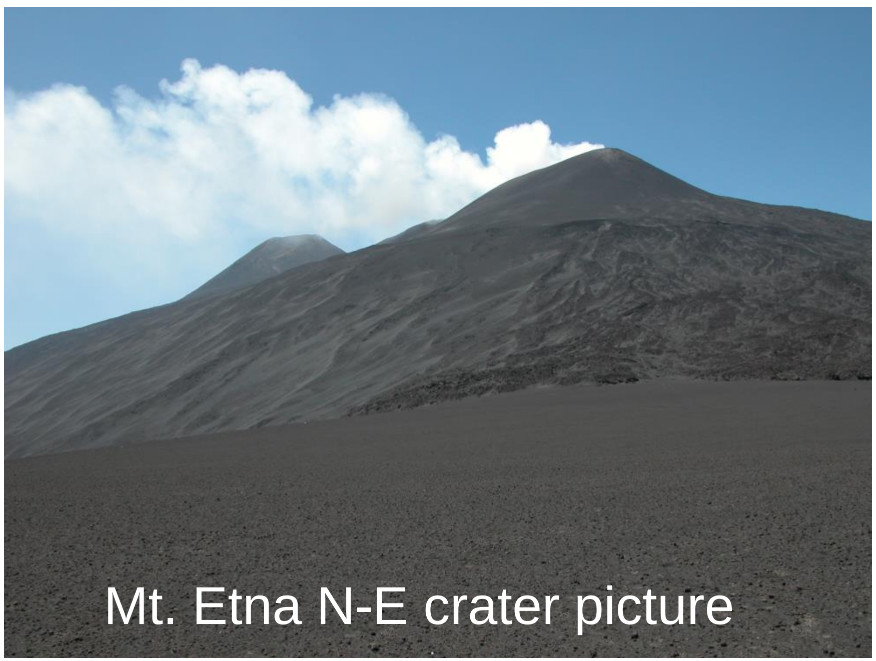


Mt. Etna volcano

R
G
B

Pixel dim.
30*30 m^2

Hyperion 19-7-03



Mt. Etna N-E crater picture

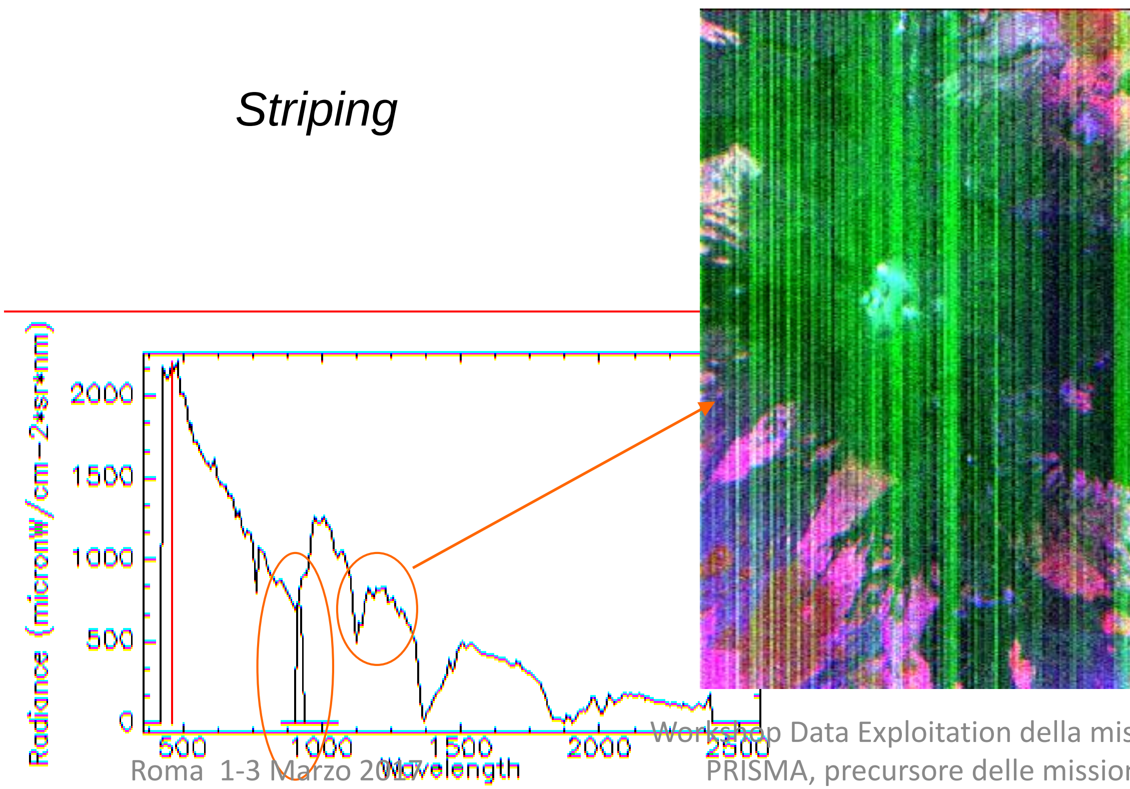
Hyperion data anlysis to retrieve H_2O e CO_2

The absoprtion band at 940 nm is located in and overlap zone between two spectrometers which gives a lower sensitivity

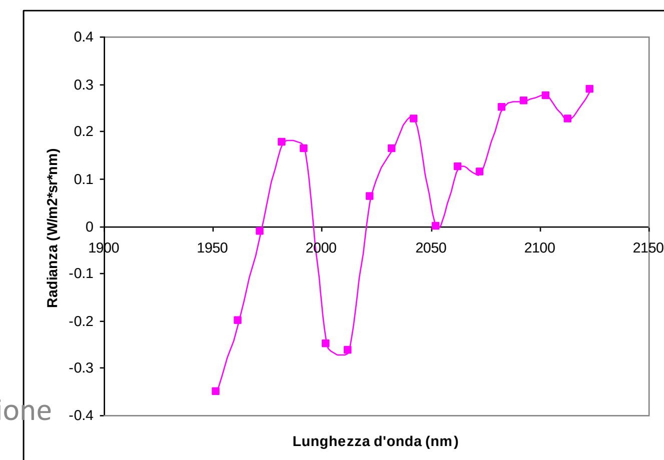
A strong Striping is visible when the albedo <5% and atmospheric transmittance <10%

We observed on calibrated data pixels with radiances <0

Striping

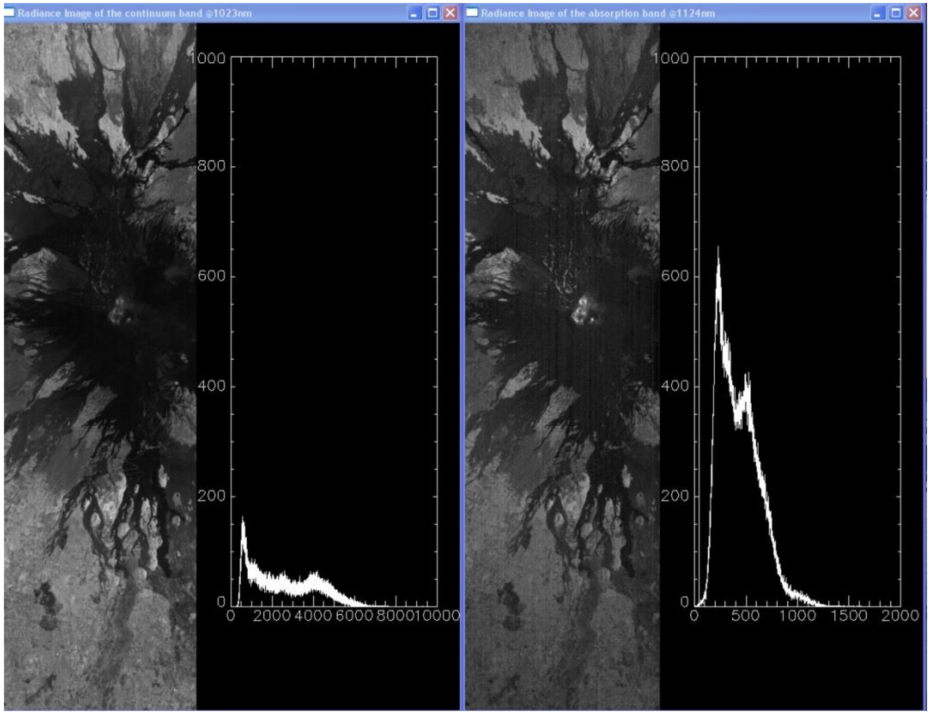


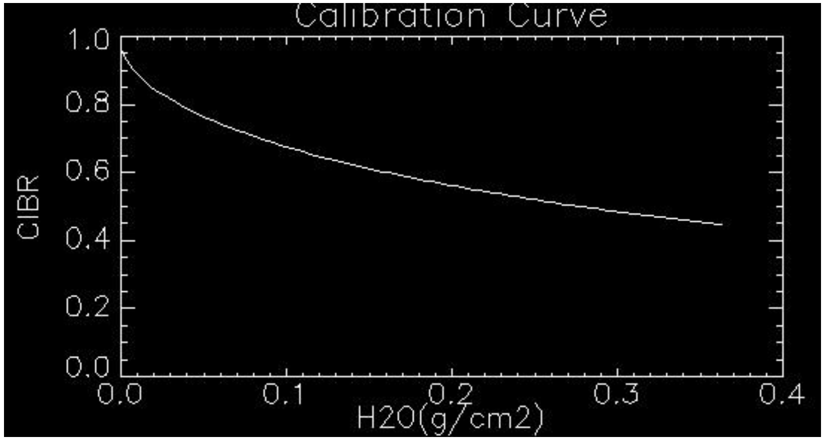
Radiometric calibration



Water vapor

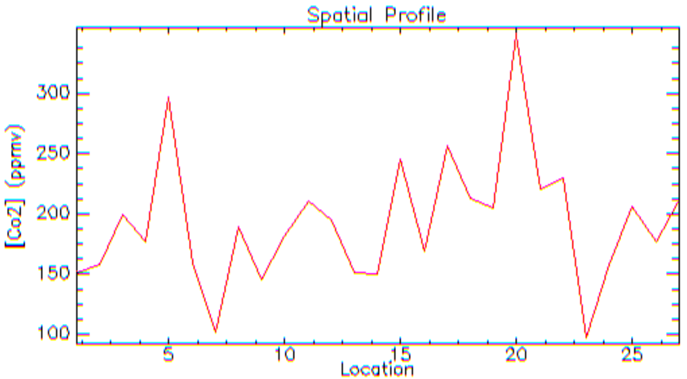
Hyperion acquisition Etna June 26, 2012 application of the algorithm CIBR
To retrieve the water vapor content in volcanic plume

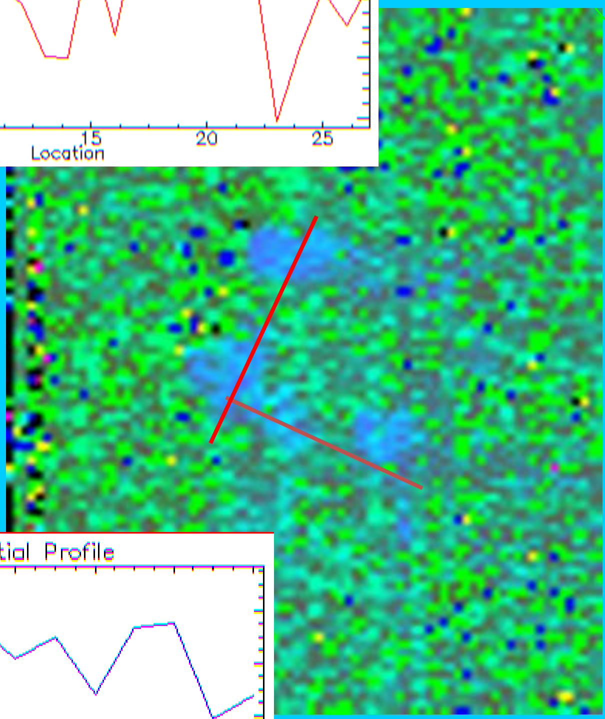


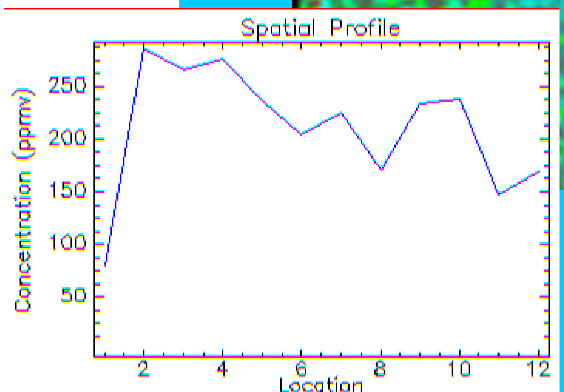


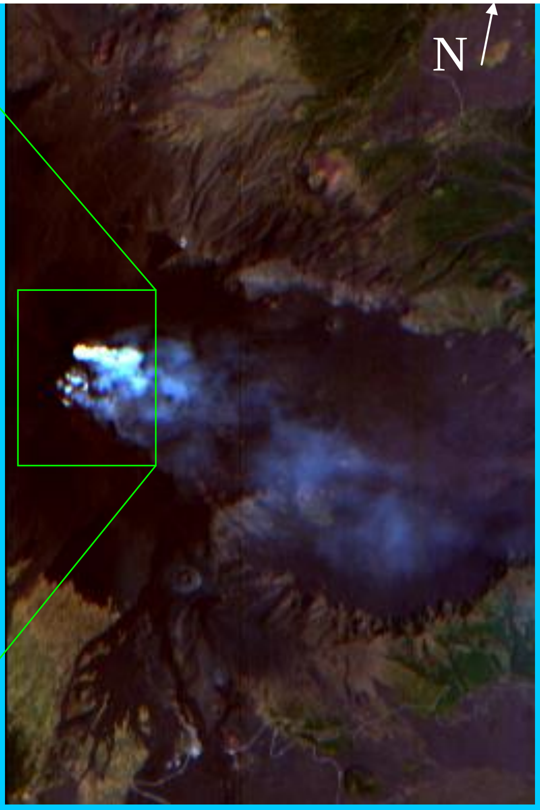
Mt. Etna CO_2 plume

For the end of August 2001 the CO2 map detecting two of the degassing crater after an intense period of eruption. After 2 month another intense eruptive activity started at Mt. Etna 2002-2003 eruption.





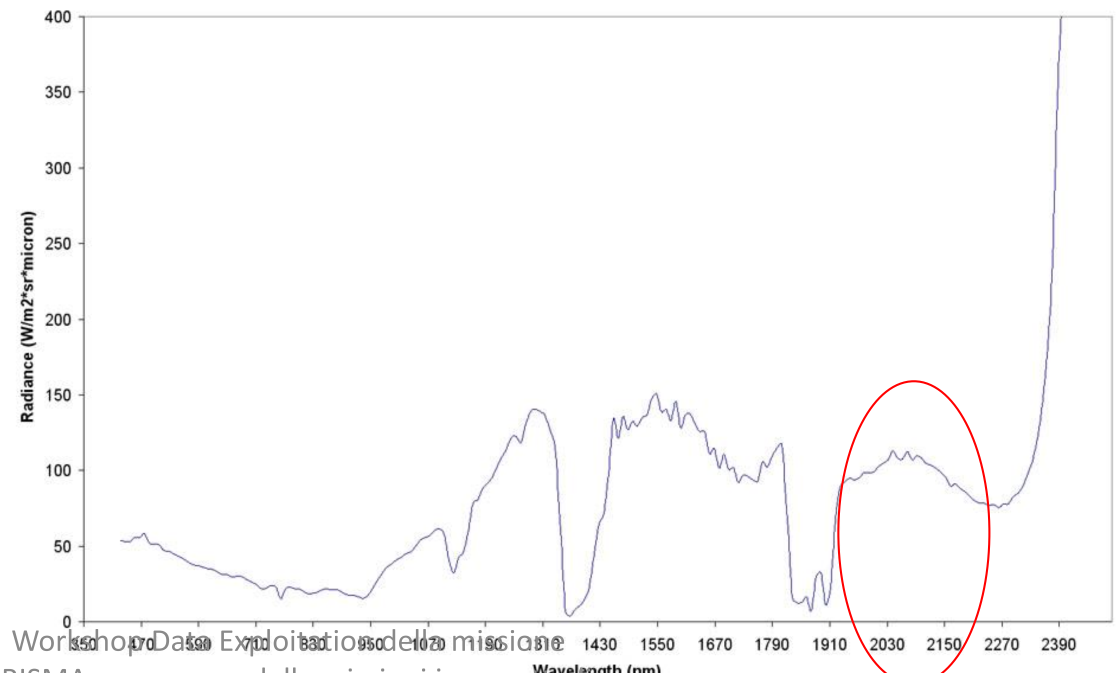




Hyperion 30-8-2001

Contributo radiativo

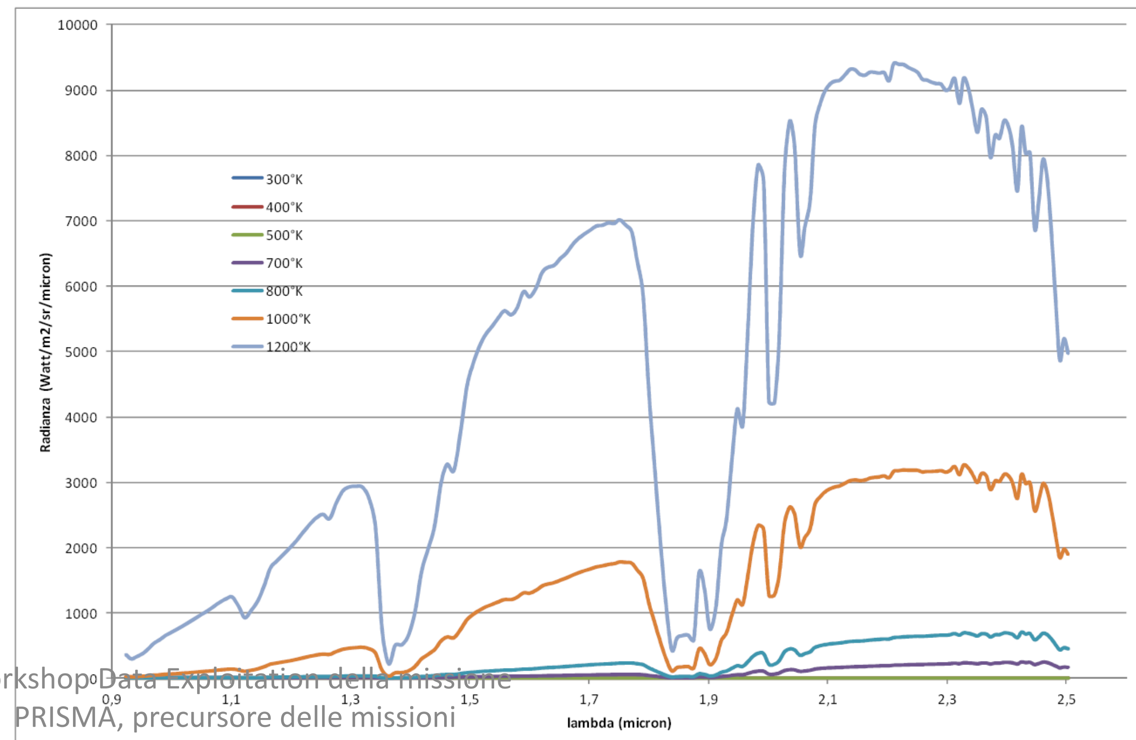
In eruptive phases, from Hyperion data you were identified in which the scenes and 'present a lava flow as active radiating surface in the bands 2 mm below the area of the plume dispersion near the summit area (eruption 2006). However, most of the areas identified have saturation of the signal in the spectral range of the SWIR. The saturation annihilates the absorption bands of the gases present in the spectral region of interest. In fact the high temperatures of an active lava flow make that the pre-set gains in the sensor are not good to record the signal.



Hyperion 25-8-2006

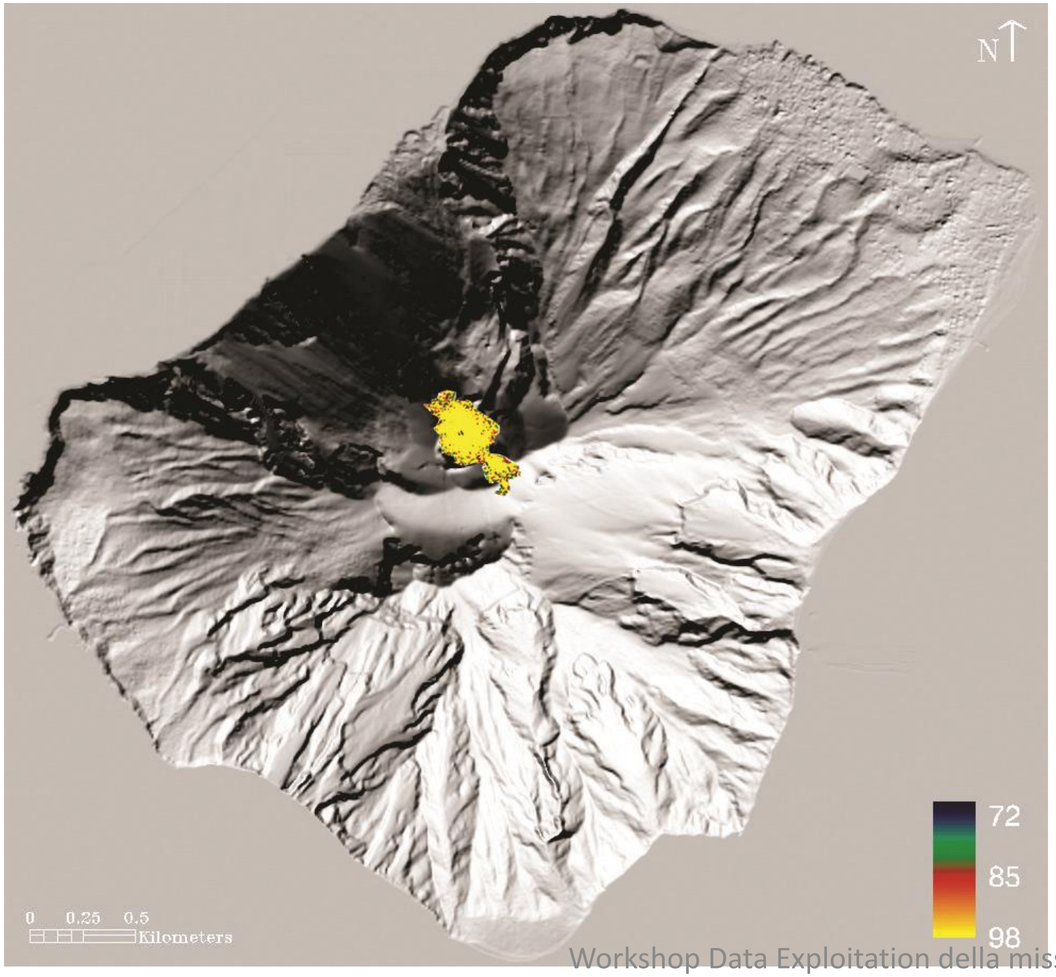
Radiating source

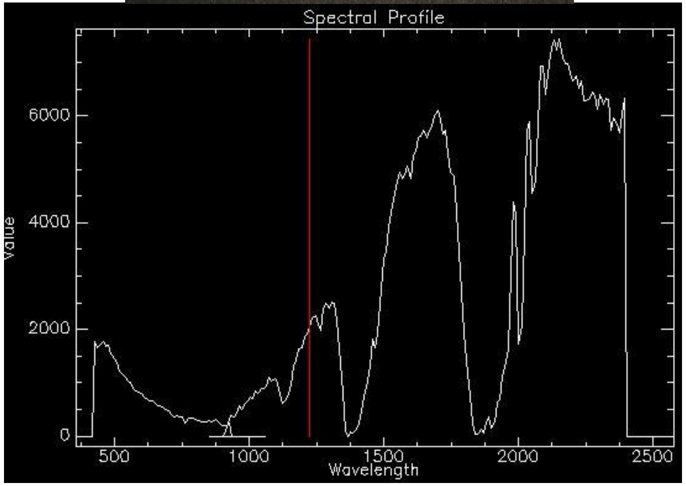
The radiating source is represented by an hot spot in a scene. The radiance shows an increment in the CO2 lines. This appends during Strombolian explosions. Temperature has been derived using the plank equation applied to radiance data. The temperature of the plume has been used as input in the Modtran simulations.



Retrieval of Carbon Dioxide

CO2 map obtained with CIBRW technique on MIVIS images acquired on Stromboli during the campaign MVRSS measures 97





CO2 map @ 3 m res

Flight level 11500 ft 3.5 km

Mt. Etna airborne hyperspectral data campaign 2012

Hyperspectral data acquired by two different spectrophotometers operating, respectively, in the VNIR and the SWIR and covering spectral range between 400 nm and 2500 nm.

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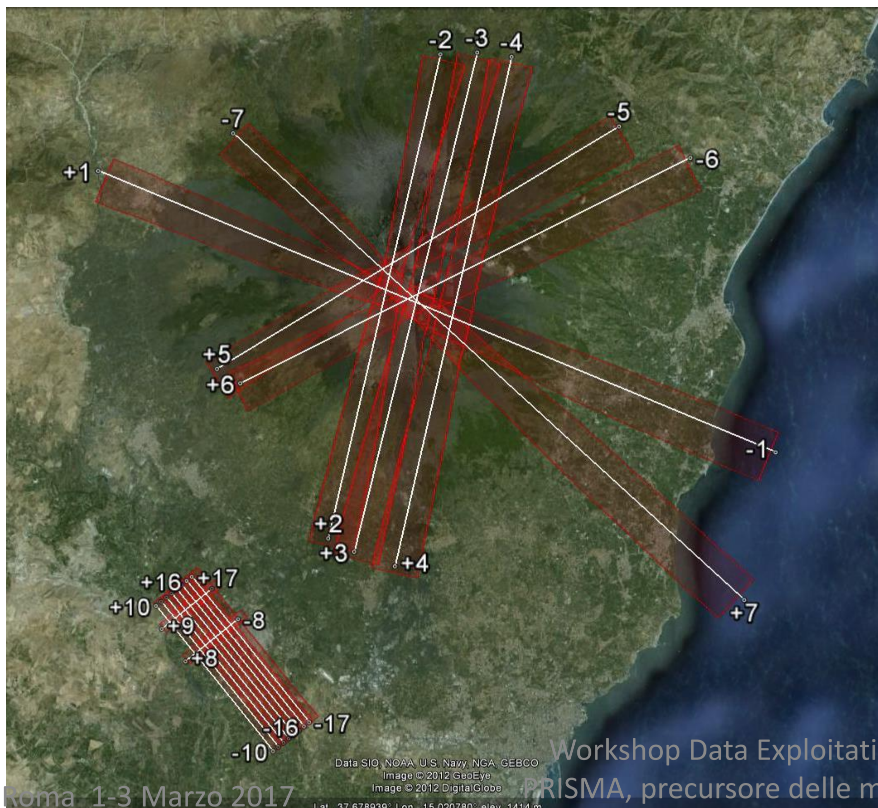
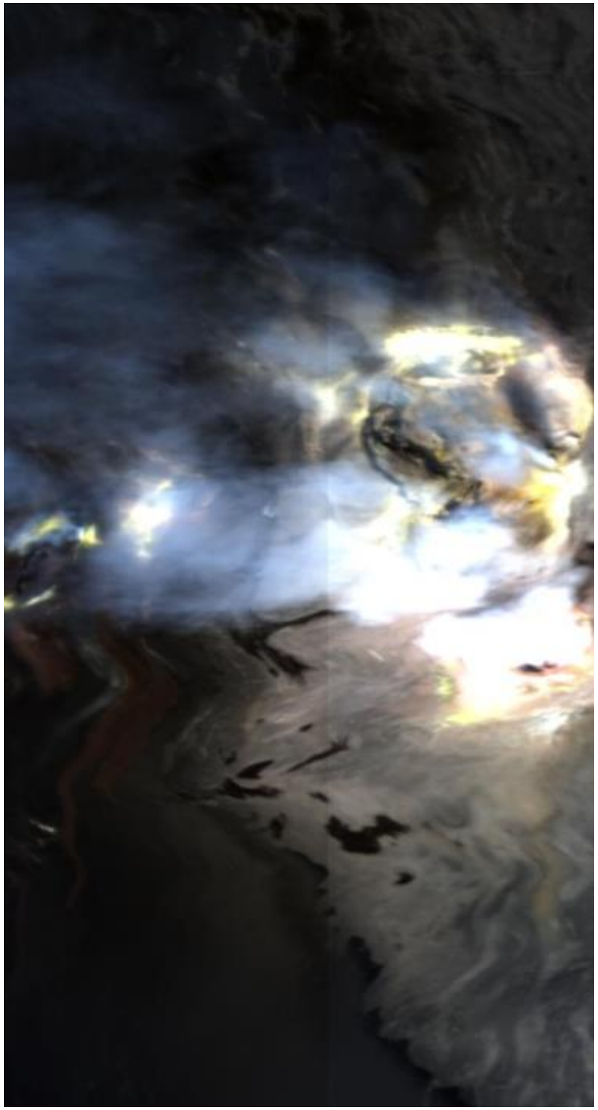
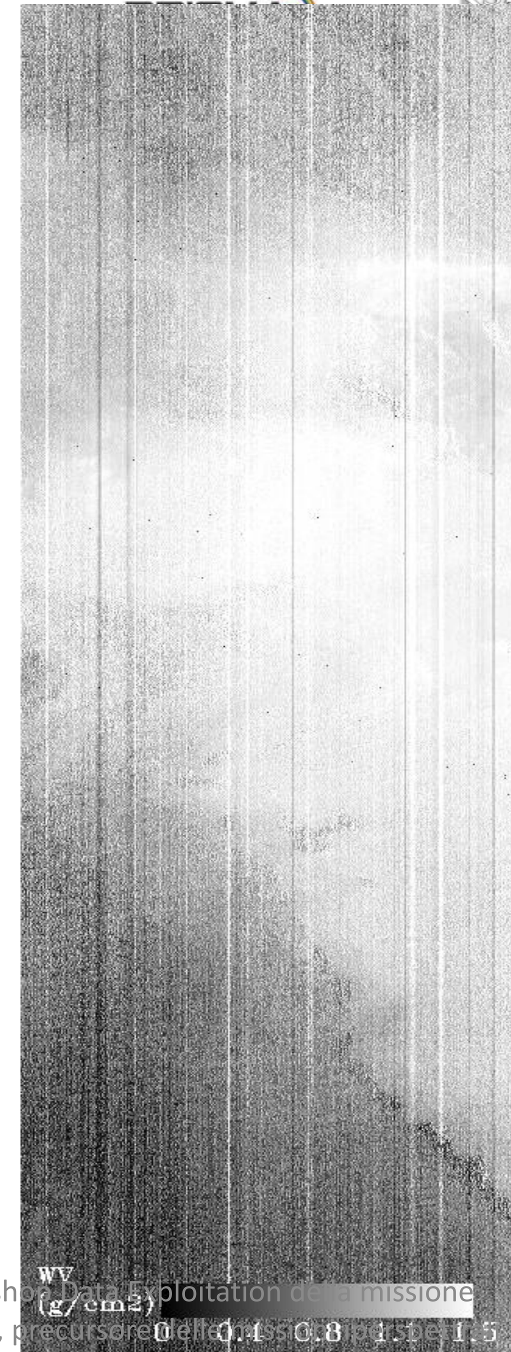


CARATTERISTICHE SISTEMA IPERSPETTRALE		
	VNIR	SWIR
Spectrometer Name	ImSpector V10E /Specim	ImSpector N25E /Specim
Spectral Range	400-1000 nm	1000-2500 nm
Spectral Resolution	2.8 nm	10 nm
Spectral Sampling	1.2 nm	6.3 nm
Spectral bands	504	239
Spatial pixels	1024	320
Digital resolution	12 bit	14 bit
FOV	68.64°	36°
Focal length	9 mm	15 mm

Finestra di volo
dal 25/06 al 26/06 2012
(Hyperion ed ASTER).

Results -LIR





Conclusions

1. The measurement of the carbon dioxide in a volcanic plume has been possible using airborne data in particular AVIRIS, MIVIS Specim but instrument SNR and influence of the water vapor content , areosols and topographic height are critical parameters
2. The Hyperion satellite data shows a lower sensitivity, which limits the range of measurable concentrations;
3. Radiometric requirements , SNR and saturation for PRISMA sensor represent crucial issues when retrieval are made in volcanic environment with albedo less than t5%;
4. The position of the 940nm band is very important to estimate water vapor content and is crucial that is not placed in the overlap area of the two spectrometers as for Hyperion which prevents the correct use for the retrieval
5. The calibration procedures and data quality are critical to retrieve gases


Thank
you
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Geofisica e Vulcanologia
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