Applicazioni in campo geofisico per i dati acquisiti dal sensore iperspettrale ASI-PRISMA e analisi dei requisiti scientifici per le nuove missioni ESA-SENTINEL e NASA-SBG

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OVERVIEW

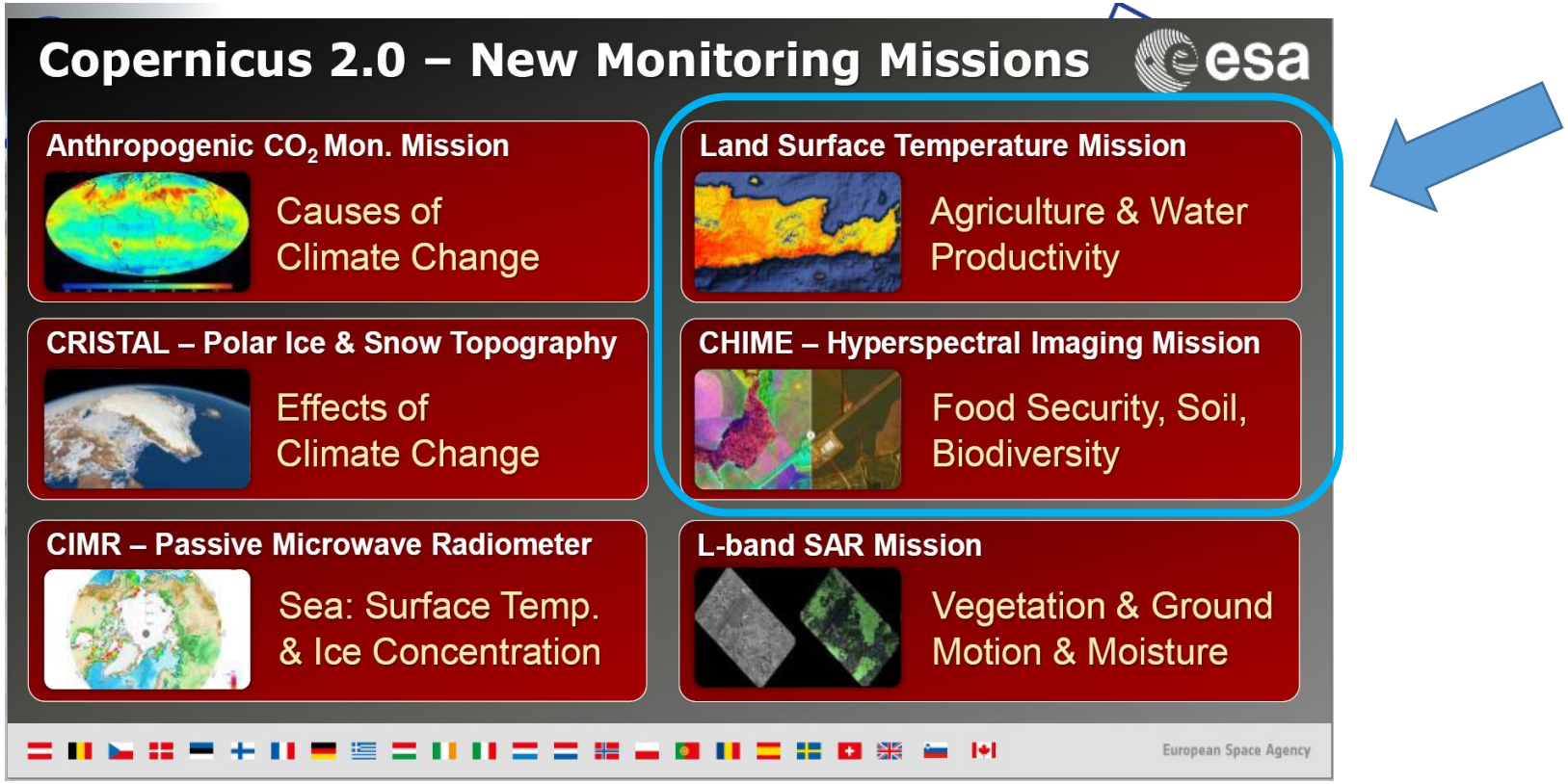
- ESA SENTINEL MISSIONS AND NEXT GENERATION
- ITALIAN CONTRIBUTE FOR OPTICAL MISSIONS
- INGV PRELIMINARY EVALUATION OF PRISMA DATA TO STUDY VOLCANIC PHENOMENA.
- ASI-JPL JOINT COOPERATION FOR THE NASA-SBG MISSION
- CONCLUSIONS

ESA NEW MISSIONS TO STUDY EARTH

In the last 2 decades a gigantic increase of space data have been acquired mostly at no cost for scientific and applicative communities

ESA earth observation missions program and sentinels for eu-copernicus services are very successful example

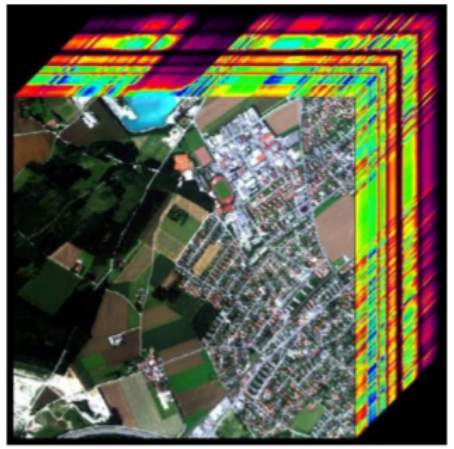
6 new ESA monitoring missions are under study in esa ingv is currently working in the **chime** and **land surface temperature** missions



Technical Concept of CHIME

Routine spectroscopic observations in contiguous spectral bands conducted at:

- Instrument: Pushbroom Imaging Spectrometer
  400 – 2500 nm, $\Delta\lambda \leq 10$nm,
- Revisit (temporal resolution) 10-15 days,
- GSD (spatial resolution): 20-30m,
- Sun synchronous orbit (LTDN 10:30 – 11:30),
- Nadir view covering land and coastal areas,
- High radiometric accuracy, low spectral/spatial misregistration.



Hyperspectral data cube
(courtesy DLR)

Spaceborne Heritage in Europe

- **EnMAP (DLR)** and **PRISMA (ASI)** being readied for launch
- **OHB (D)** and **TAS (F)** now active in Phase A/B1 studies for CHIME

MAIN CHARACTERISTICS FOR FUTURE THERMAL MISSIONS

Mission	Spatial resolution	Temporal Resolution	Local Observation Time	Thermal bands	Other bands
LSTM	30 – 50 m	1 – 3 days	13:00 at mid latitudes	3 -5	6 VNIR/SWIR 1 MIR (optional)
Landsat 9	100 m	16 days / 8 days (with Landsat 8/10)	10:00	2	9 VNIR/SWIR
TRISHNA	50 m	3 days	13:00	4	6 VNIR/SWIR
Surface Biology and	60 m	5 days	TBD	7	1 MIR

ITALIAN CONTRIBUTE TO NEW EO MISSIONS WITH OPTICAL INSTRUMENTS

The Italian Space Agency is implementing an articulated plan to support new EO missions which includes: instruments, satellite platforms, launchers and ground segment.

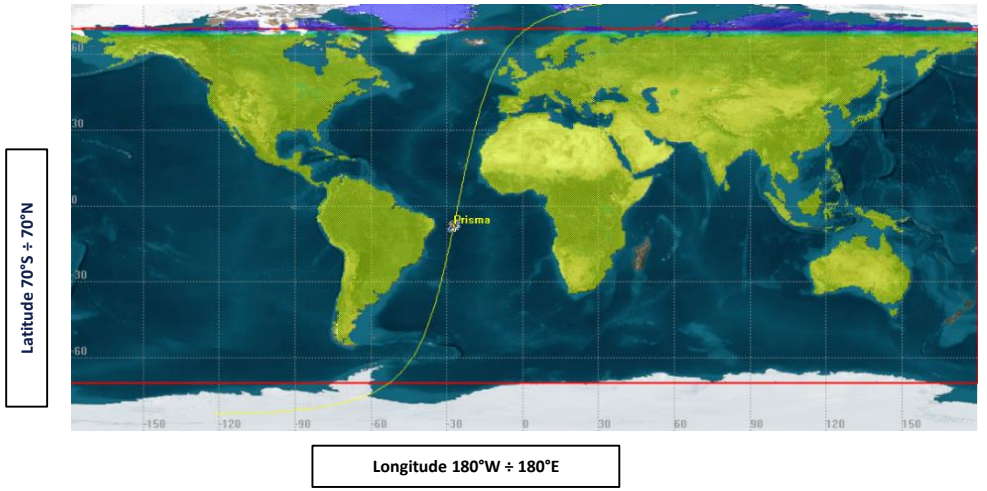
FOCUS ON OPTICAL MISSIONS

- HYPERSPECTRAL MISSIONS
- THERMAL INFRARED MISSIONS

PRISMA: PRecursore IperSpettrale della Missione Applicativa

Messa in orbita il 22-Marzo-2019

- National EO hyperspectral Mission fully funded by ASI.
- Realized by Italian Industries Consortium led by OHB Italia, Leonardo and Telespazio
- Mission conceived as a Pre-operational and technology demonstrator, with focus on
  - **Space qualification of PAN/HYP payload**
  - Development of PAN/HYP products up to Level 2D (BOA geocoded reflectance)



- PRISMA sensor operates in Pushbroom scanning mode
- Records the radiation reflected from the Earth surface (spectral cubes) in 400nm – 2505nm spectral window
  - **240 total bands in VNIR (#66, 400–1010 nm) & SWIR (#174, 920–2505 nm), partial spectral overlap**
  - High spectral Resolution (better of 14 nm)
  - Medium spatial resolution (30m) and swath (30km)
  - PAN camera offers added capability with 5m resolution

- **Primary mode – Manage user requests**
  - CALVAL sites (highest priority)
  - Nominal requests from all registered users, subject to quota and a priority level (depends by the user type)
  - Mission Manager can promote Nominal Requests already Accepted to Very Urgent, for insertion in next day plan
- **Background mission – Optimize system resources usage**
  - Generated to fill-up resources still available after planning of users requests or for systematic acqusitions

PRISMA MAIN CHARACTERISTICS

System Main Characteristics

Orbit	SSO 615 km 10:30 LTDN
Lifetime	5 years
Relook time	<7 days
Onboard Data Storage	448 Gbit
Downlink data rate	310 Mbps
Imaging capacity	200.000 km^2/day
	Pushbroom, strip ≤ 1800km
Pointing accuracy	0.5 km
Response time	< 14 days
	Acquisition latency < 9.5 days
	Processing latency < 4.5 days
Target access opportunities over the Primary AoI	duration/day: 235 minutes (average, off nadir pointing) distributed over the full daily orbits
Mass P/L + P/F	~ 830 kg (including contingency and balance masses)
Repeat cycle	29 days (430 orbits)
Average eclipse [minutes]	~ 34

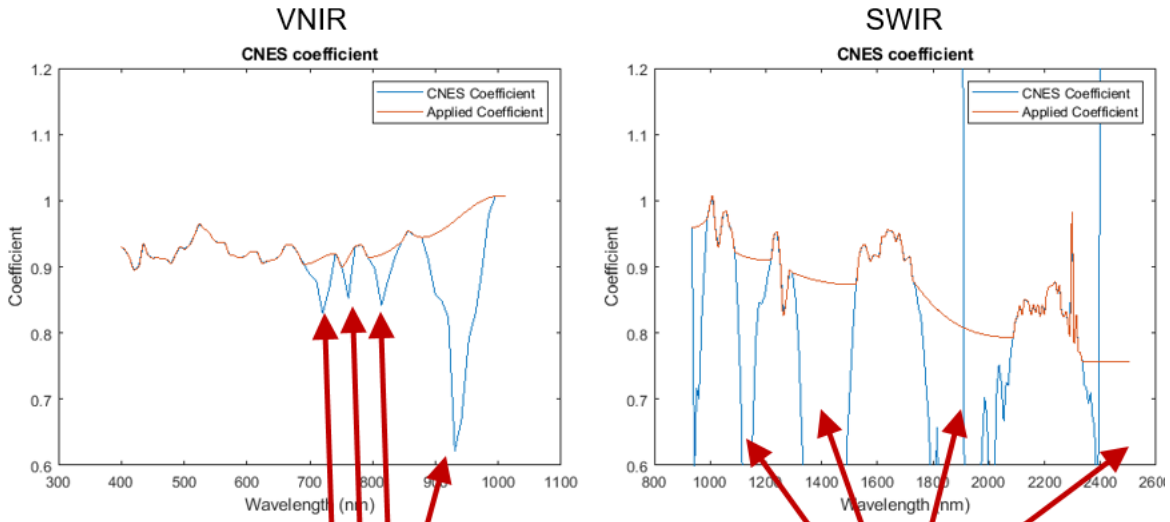
Instrument Main Characteristic

Swath / FOV /IFOV	30 km / 2.77° / 48 μrad
Ground Sampling Distance (GSD)	Hyperspectral: 30 m / PAN: 5 m
Spectral Range	VNIR: 400 – 1010 nm (66 spectral bands) SWIR: 920 – 2505 nm (174 spectral bands) PAN : 400 – 700 nm
Spectral Width (FWHM)	≤ 14 nm
Radiometric Quantization	12 bits
VNIR SNR	> 160:1 (450:1 at 650nm)
SWIR SNR	> 100:1 (>360:1 at 1550nm)
PAN SNR	> 240:1
Thermal Control System	Double stage passive radiator (1 for each channel) + stabilization heater
Mass	Optical Head: 175kg Thermal Shield: 25kg Main Electronics: 11kg
Power Consumption	Earth Observation /calibration: 90W Idle: 80W

PRISMA satellite shall be able to manoeuver in order to capture two images at a maximum distance of 1000 km in a single pass (from worst case left to right side looking and viceversa).

Radiometric Calibration

Calibrazione Radiometrica

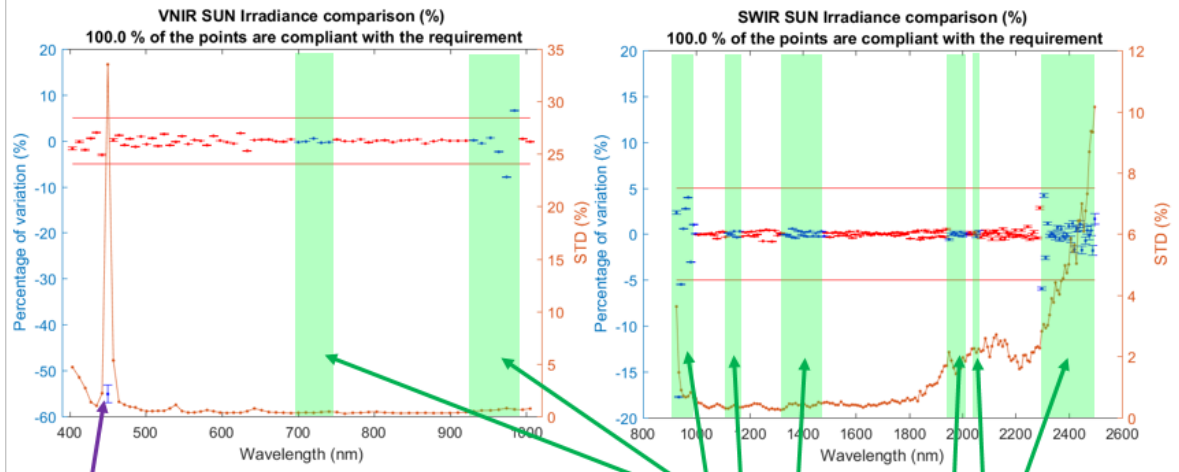


The coefficient has been interpolated over the atmospheric absorption spectral region.

Atmospheric absorption spectral region

Atmospheric absorption spectral region

Validazione tramite confronto irradianza Solare (SOI-B2)



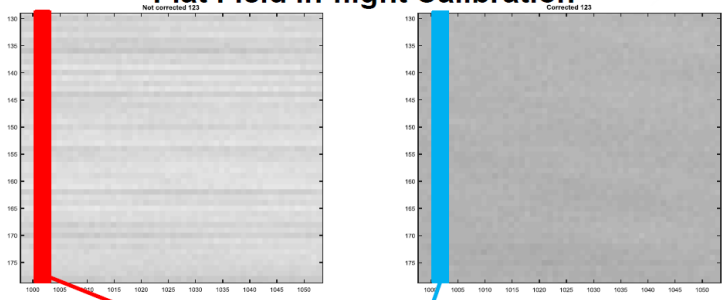
Regione con basso segnale sulle quali la misura di validazione risulta problematica. Il valore ottenuto a 450nm è falsato dal valore quasi 0 del segnale misurato e data la fisica del problema, per analisi si può considerare in linea con i risultati ottenuti sulle bande adiacenti

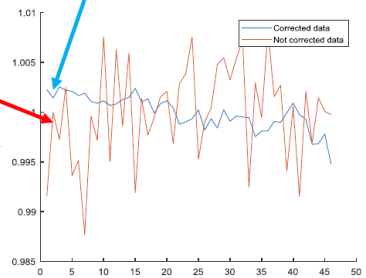
Il requisito di accuratezza radiometrica su queste regioni non è applicabile, poiché sono regioni di assorbimento atmosferico.

In-flight Flat field Calibration using PICS and Radiance

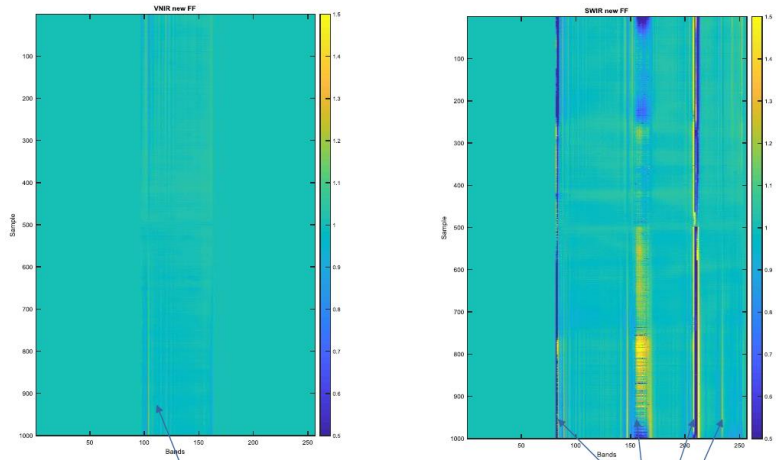
LEONARDO ELECTRONICS

Flat Field in-flight Calibration





Comparison between the raw signal (red line) along 50 pixel of the FOV and the corrected signal (Blue line).

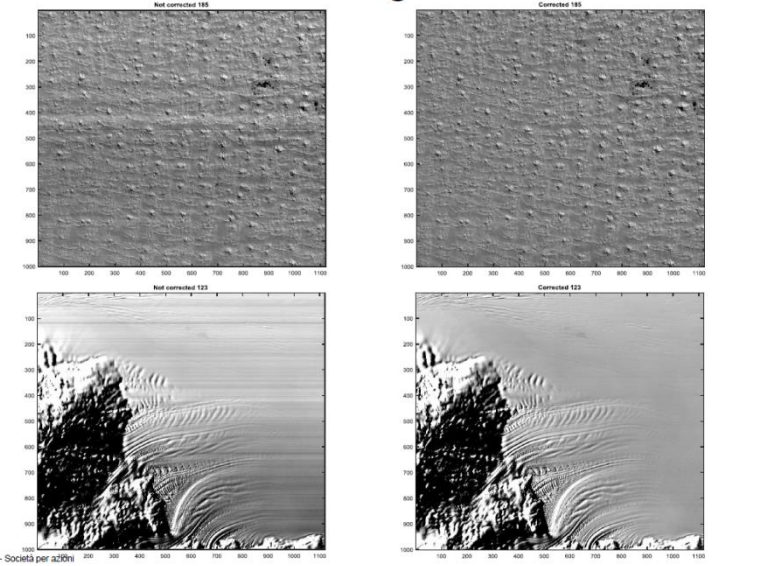


Atmospheric absorptions

Atmospheric absorptions

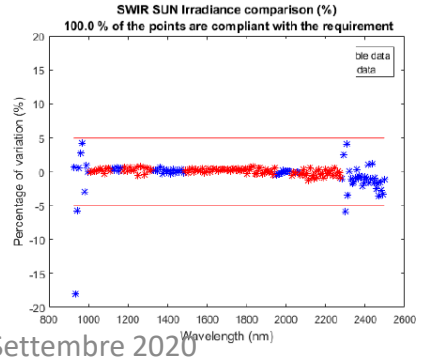
LEONARDO ELECTRONICS

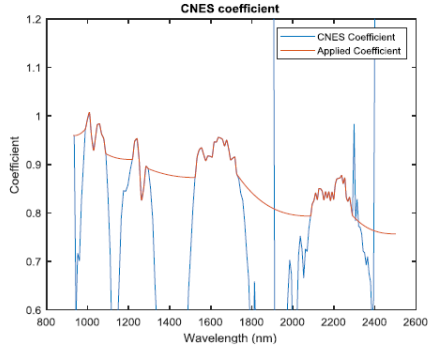
Flat Field in-flight Calibration



LEONARDO ELECTRONICS

Radiance Calibration





PRISMA DATA INFORMATION AND ACCESS

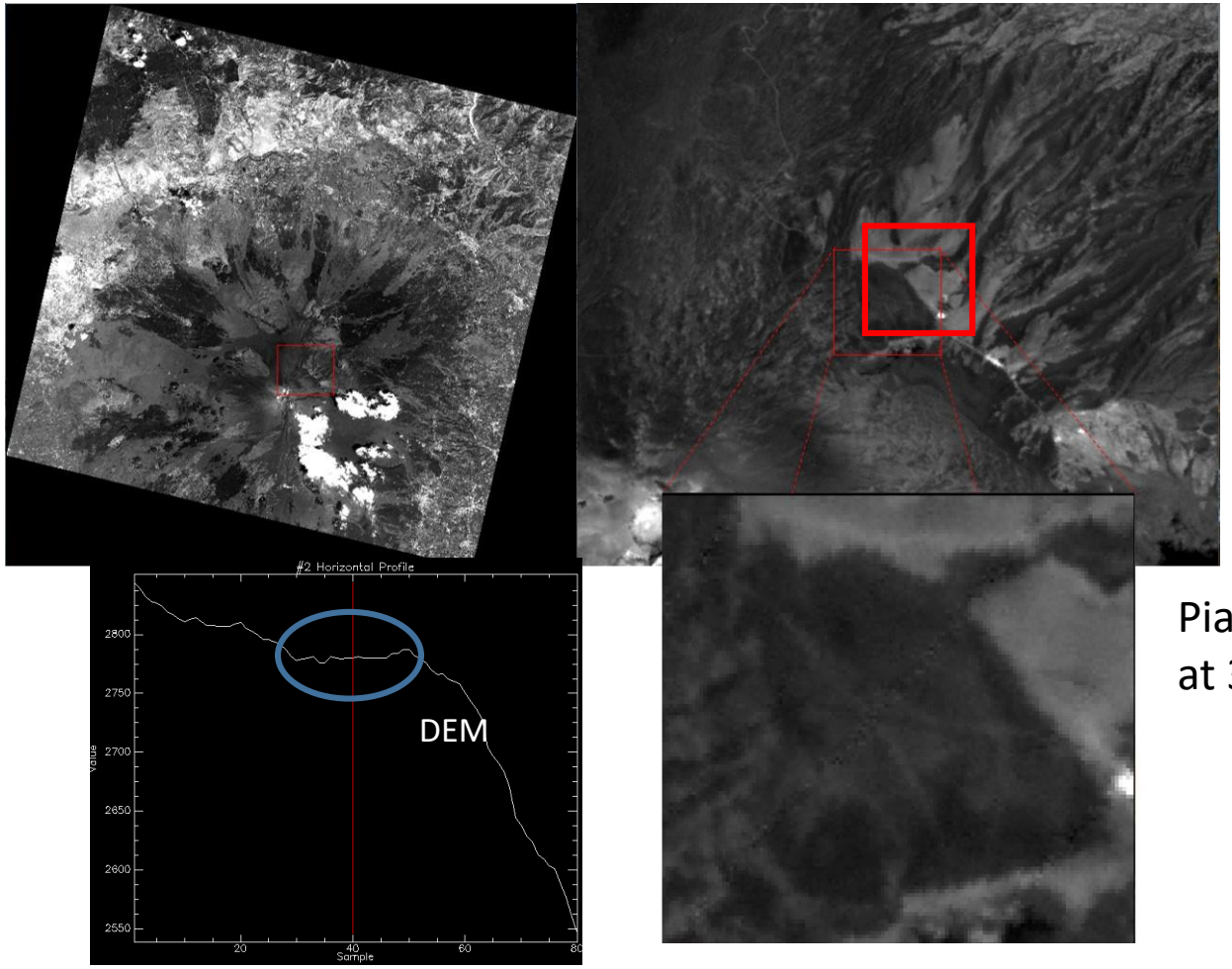
https://www.asi.it/en/earth-science/prisma/

To access the data You need to create an account which permits to access the PRISM archive and submit requests for new acquisitions

https://prisma.asi.it

ANALYSIS OF PRISMA DATA OVER CAL/VAL SITES IN VOLCANIC AREAS

INGV IS PRT OF THE PRISMA ADVISORY BOARD (PAGE) AND STARTED TO EVALUATE THE DATA QUALITY AT THE

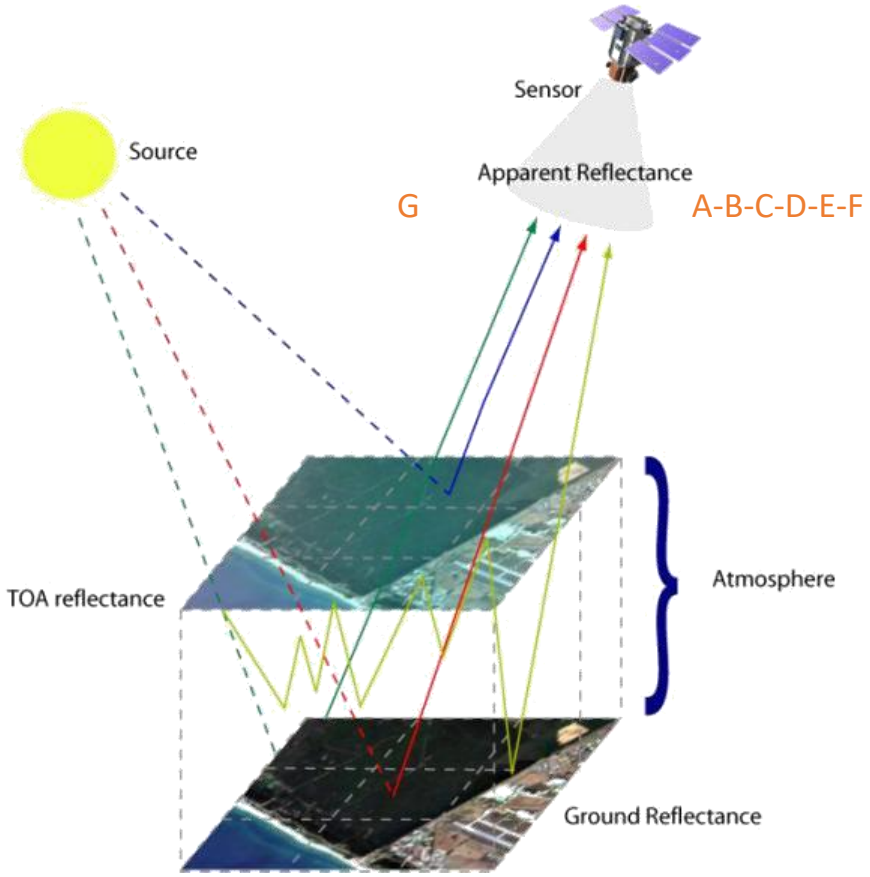


PRISMA image acquired sul piano delle Concazze (Mt. Etna)
31 July 2019

Piano delle Concazze area is located at 3000 m asl with a very homogenous surface

APPLAY ATTMOSPHERIC CORRECTION TO RETRIEVE GROUND REFLECTANCE

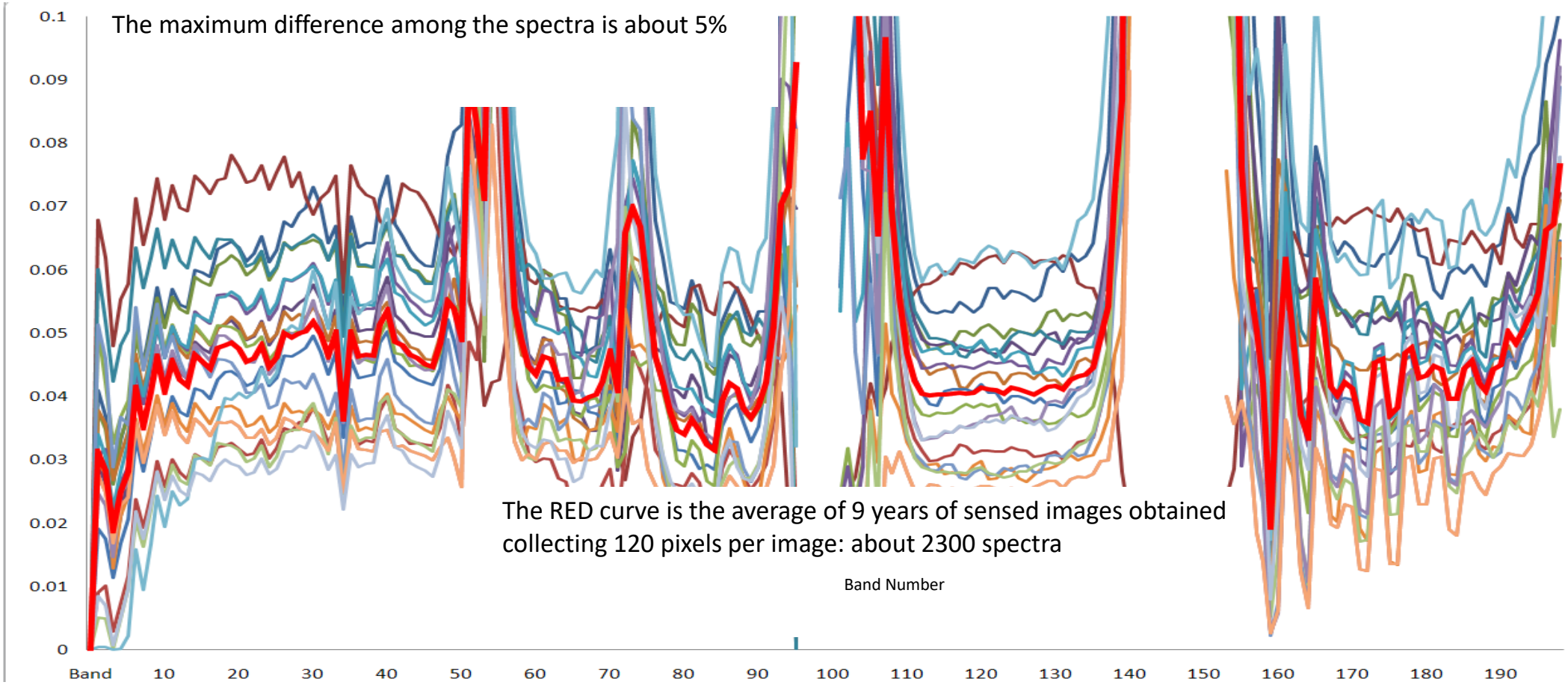
Retrieval of ground reflectance using atmospheric correction procedure based on S6 and MODTRAN



A. The sun radiance that reaches directly the pixel viewed by the sensor (target) and that is directly reflected by the target to the sensor;
B. The sun radiance that reaches directly the pixel viewed by the sensor (target) and that is reflected by the target to the sensor following a multiple scattering path;
C. The sun radiance that reaches the target following a multiple scattering path and that is directly reflected by the target to the sensor;
D. The sun radiance that reaches the target following a multiple scattering path and that is reflected by the target to the sensor following a multiple scattering path;
E. The sun radiance that directly reaches the surface surrounding the target and that is reflected by the surface to the sensor following a multiple scattering path;
F. The sun radiance that reaches the surface surrounding the target following a multiple scattering path and that is reflected by the surface to the sensor following a multiple scattering path;
G. The sun radiance that is directly scattered by the atmosphere to the sensor without reaching the ground.

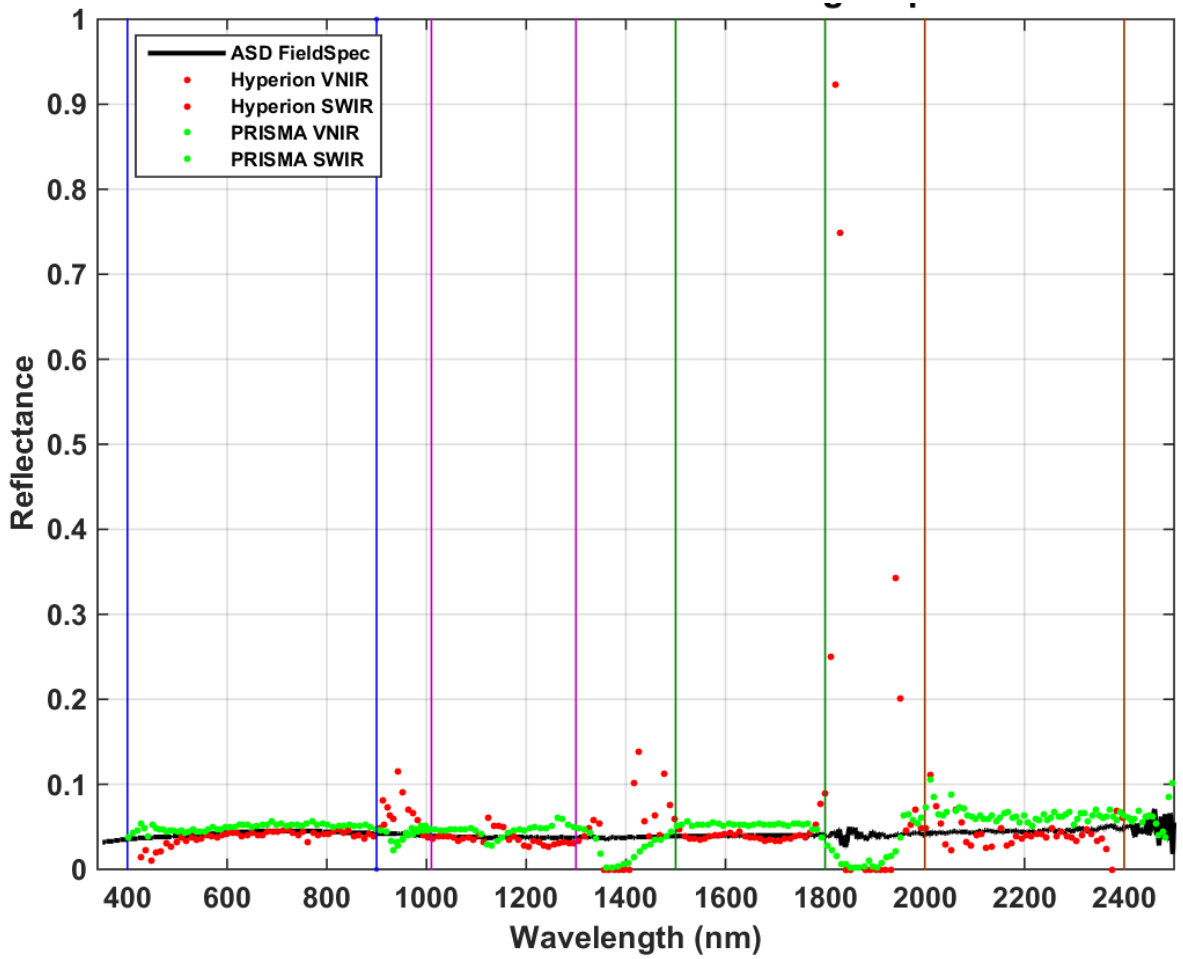
All of these terms, with the exception of **G**), are also influenced by the orientation of the surface with respect to the sun illumination direction.

Piano delle Concazze has been used for CAL/VAL activities and INGV has a reflectance history based over 10 years of Hyperion acquisitions



The RED curve is the average of 9 years of sensed images obtained collecting 120 pixels per image: about 2300 spectra

Comparison of PRISMA/Hyperion reflectances and ground truth on Piano delle Concazze



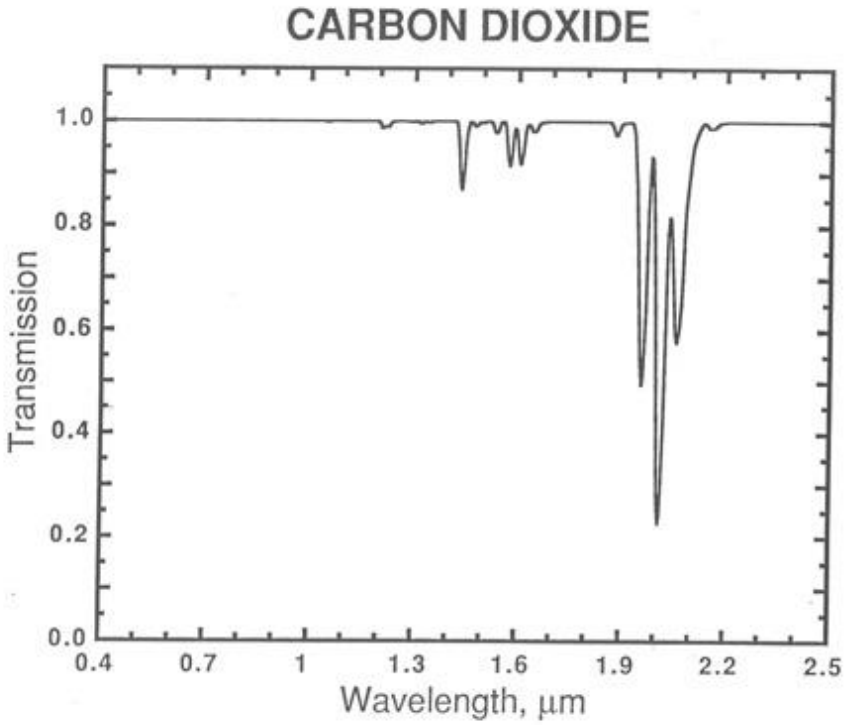
Intervallo spettrale (µm)	Hyperion	FieldSpec convolved on Hyperion	PRISMA	FieldSpec convolved on PRISMA
0.4 - 0.9 (VNIR)	0.0376	0.0425	0.0492	0.0419
1.0 - 1.3 (SWIR)	0.0363	0.0379	0.0460	0.0378
1.5 - 1.8 (SWIR)	0.0400	0.0397	0.0519	0.0397
2.0 - 2.4 (SWIR)	0.0423	0.0453	0.0645	0.0454

Volcanic CO2 mapping using SWIR channels

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

The CIBRW retrieval alghoritm

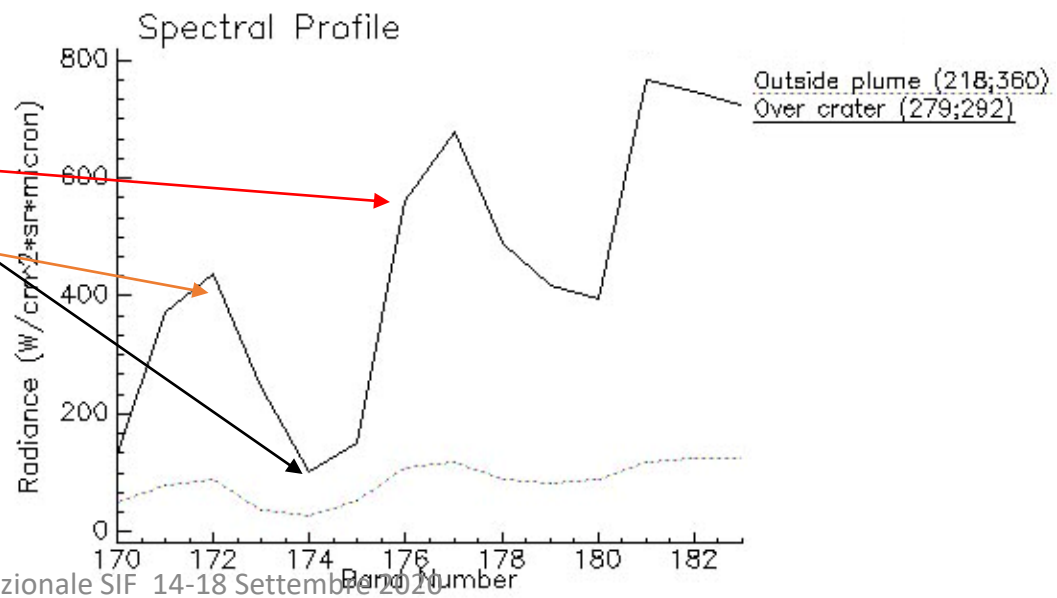
In order to retrieve the tropospheric volcanic plume Carbon Dioxide abundance, an inversion technique has been developed for remote sensing hyperspectral data (*Spinetti et al., 2008, RSE*). The algorithm is based on the assumption that there is a relationship between the dip in the atmospheric spectrum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

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

- $[CO_2]$ 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:

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

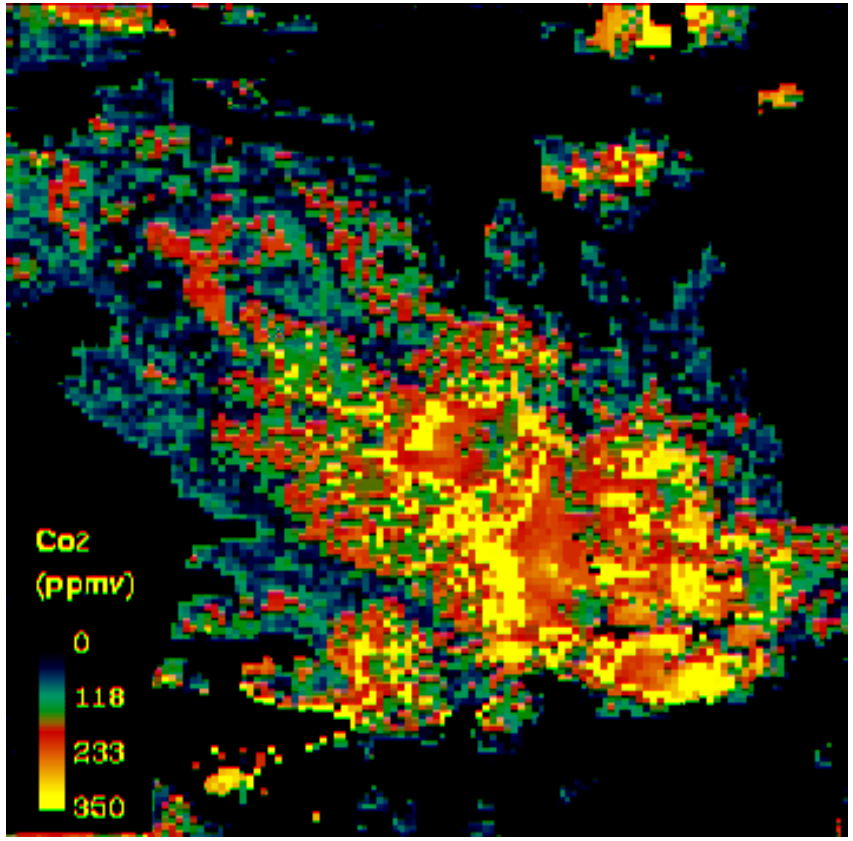
- R_a is the radiance corresponding to the minimum of absorption
- A and B are the weighting constants
- R_1 and R_2 are the radiances of the continuum



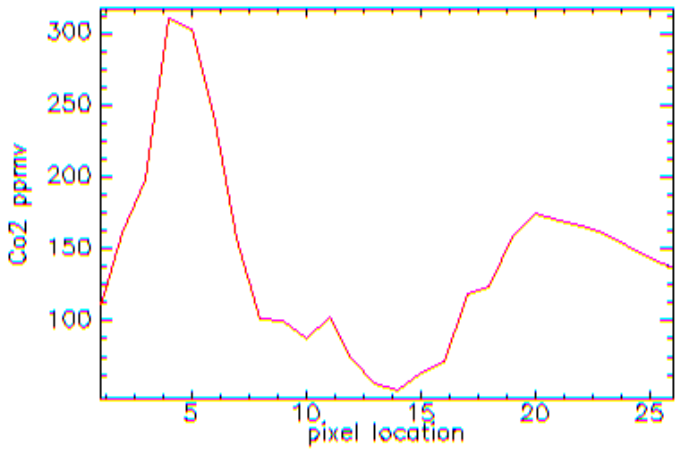
AVIRIS (Airborne Visible/InfraRed Imaging Spectrometer)

NASA-JPL

DATA
Pu'o'O, Hawaii



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



$\Phi_{CO2} = 396 \pm 138$ t d^{-1}

Accordance with ground sampling data

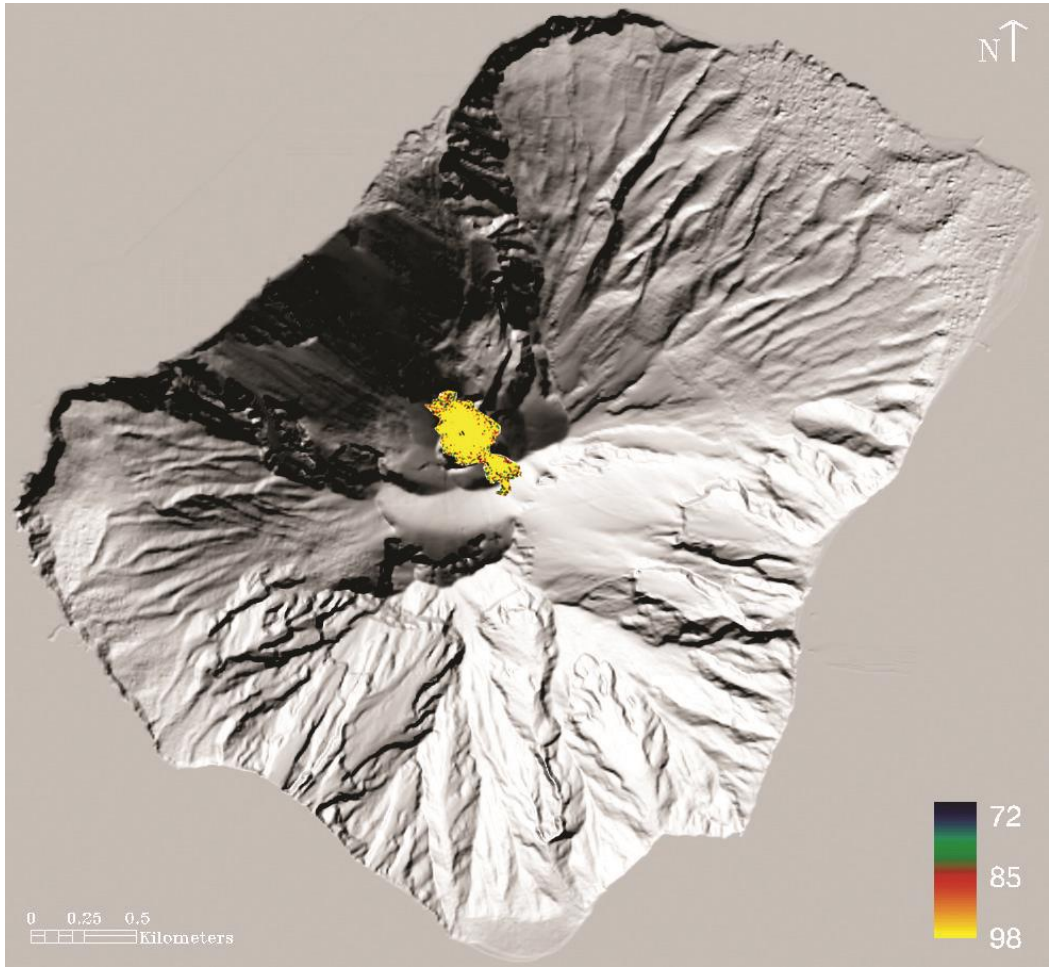
Figure 13. Lava from crater of Pu'u 'Ō'ō flows through west gap in cone. View eastward; photograph by J.P. Kauahikaua, taken October 20, 1997.

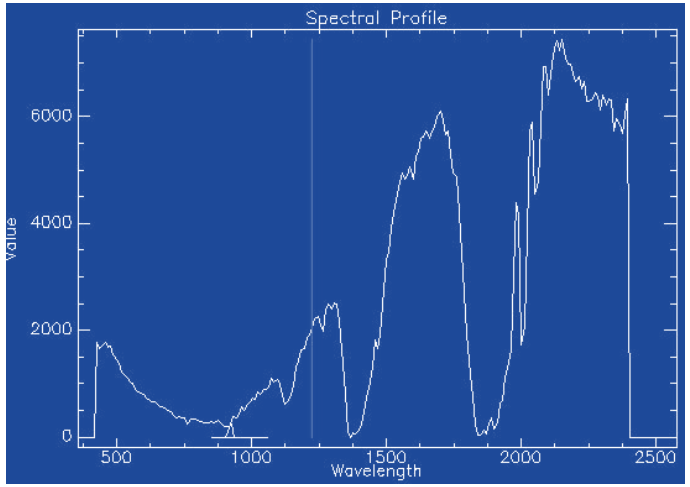
Figure 14. Crater of Pu'u 'Ō'ō. Fume rises from several vents on crater floor, which is covered with pāhoehoe erupted in 2002. View westward; photograph taken April 11, 2002.

Image acquired 26-April-2000

Retrieval of Carbon Dioxide from Radiating source

CO2 map emitted by active summit craters obtained with CIBRW technique on airborne hyperspectral images acquired on Stromboli in 1997.

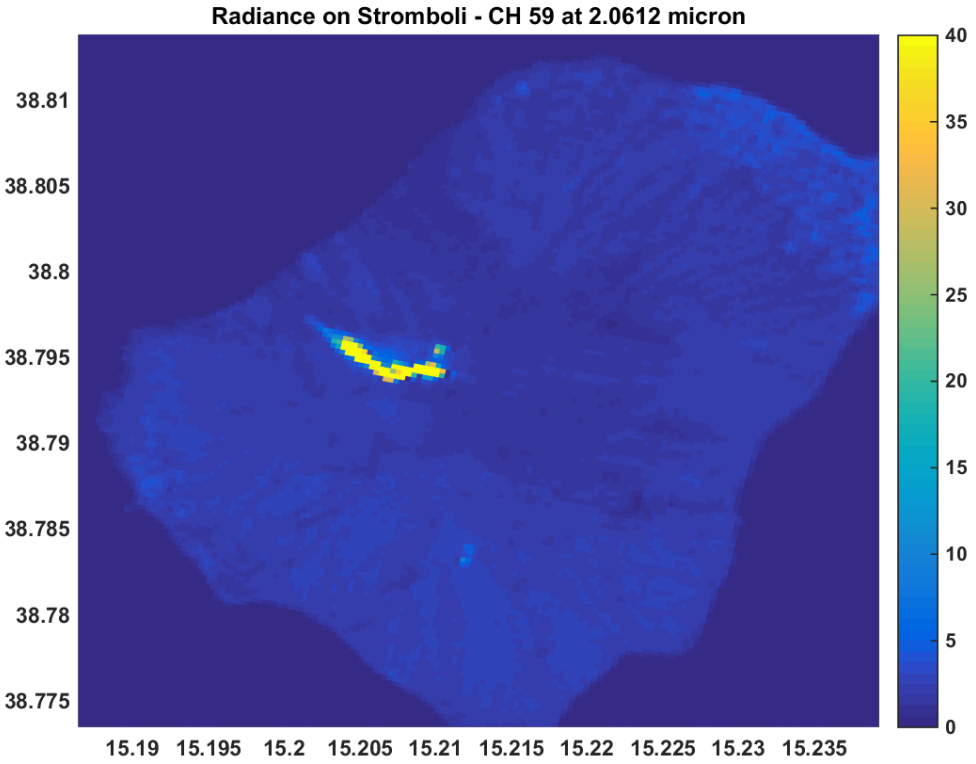




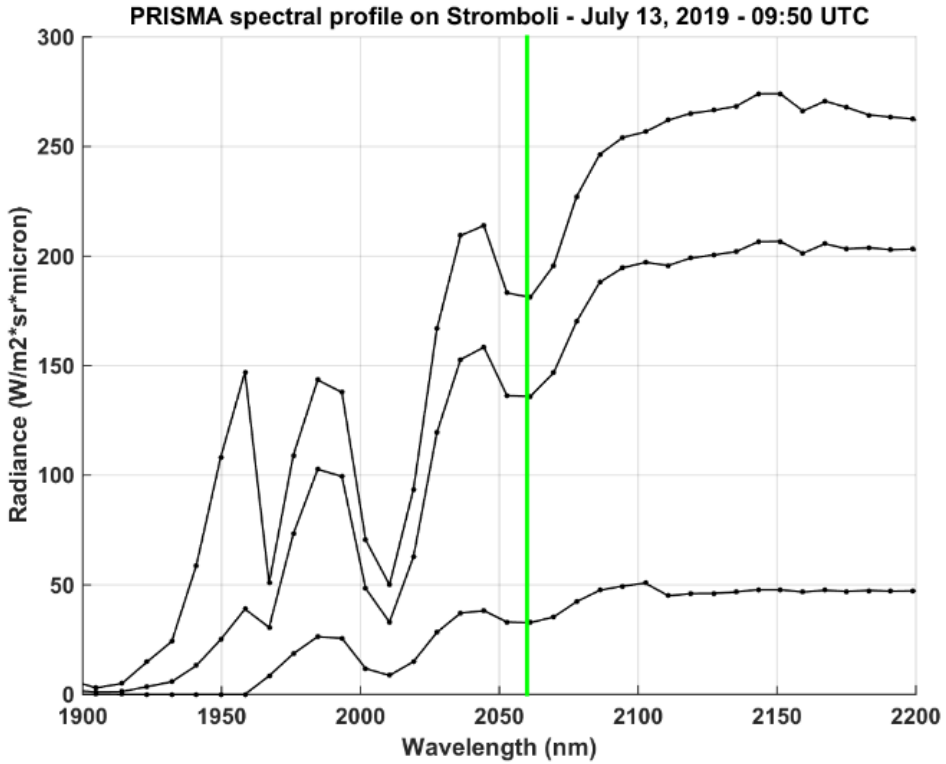
CO2 map @ 3 m res

Flight level 11500 ft 3.5 km

FIRST EVALUATION USING PRISMA DATA FOR CO2 mapping using SWIR channels



PRISMA RADIANCE SPECTRUM TO EVALUATE CO2 DETECTION

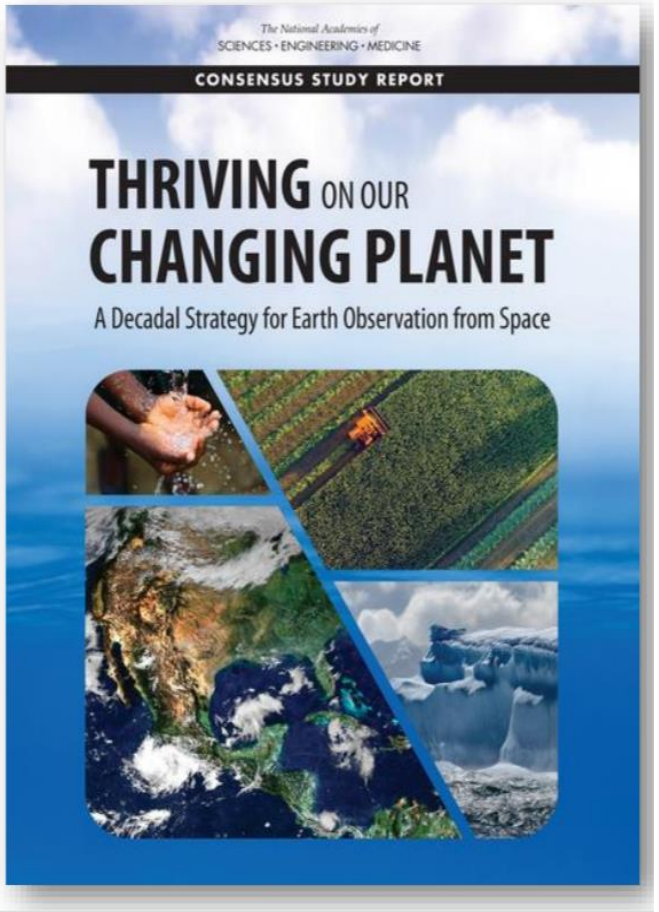


NASA NEW SCIENTIFIC MISSIONS TO STUDY EARTH ARE BASED ON THE LAST DECADEL SURVEY 2017

2017 Decadal Survey Snapshot

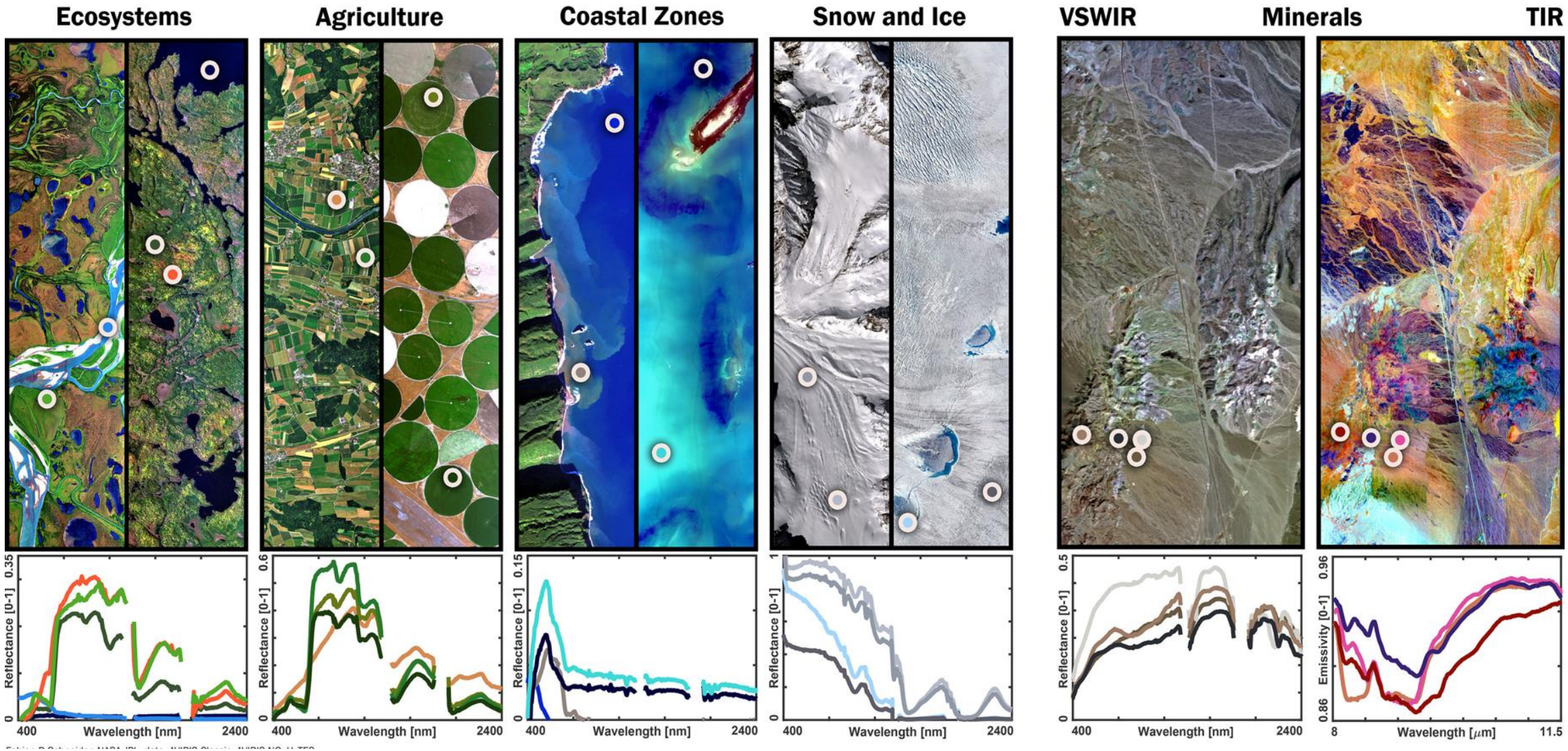
- Prioritizes observations rather than specific missions
- Identifies five "Designated" Observables
  - Aerosols; Clouds, Convection & Precipitation (ACCP)
  - Mass Change (MC)
  - Surface Biology & Geology (SBG)
  - Surface Deformation & Change (SDC)
- Introduces a new "Explorer" flight line
- Calls for "Decadal Incubation Program" on Planetary Boundary Layer (PBL) and Surface Topography and Vegetation (ST&V)

ESD is working with the community to translate the recommendations into an executable program and, for Flight, a portfolio of specific, realistic, launch-ordered missions and solicitations



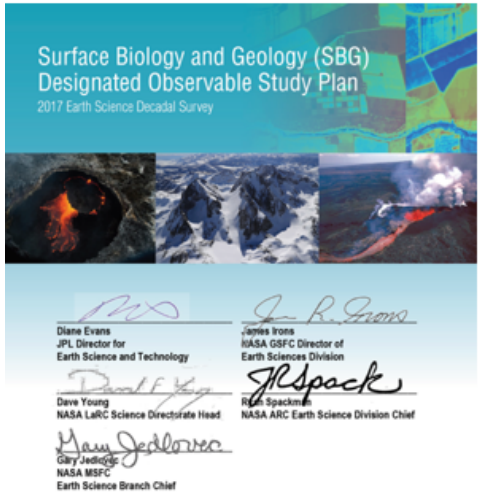
(https://essp.nasa.gov/essp/files/2018/02/2017-Earth-Science-Decadal-Survey.pdf)

SBG Science across five focus area and two critical spectral regions



THE MISSION SURFACE BIOLOGY AND GEOLOGY (SBG) will respond to many Science Objectives

- Leverages HYSPIRI pre-formulation study (HSI VSWIR+TIR mission concept)
- Capabilities derived from the Decadal Survey and shown in the SATM
- Three year Architecture Study Plan kicked off in August 2018
- *Global (mow-the-lawn), Event (pointing) and Change Detecting*



Performance Parameters	Spectral Range	Spectral	SNR or NeDT	GSD	Revisit	Coverage	Local Time for Acquisition
VSWIR	0.35 or 0.4 to 2.5µm	Resolution: 10nm or better Coverage: Continuous	SNR: VNIR: >400 SWIR: >250	30-45m	2-16 days	Global	10:30am to 1:30pm
TIR	8 to 12µm 3 to 5µm	Bands: >5 desired	NEdT: <0.2 K	40-60m	1-7 days	Global	Can vary across the diurnal cycle

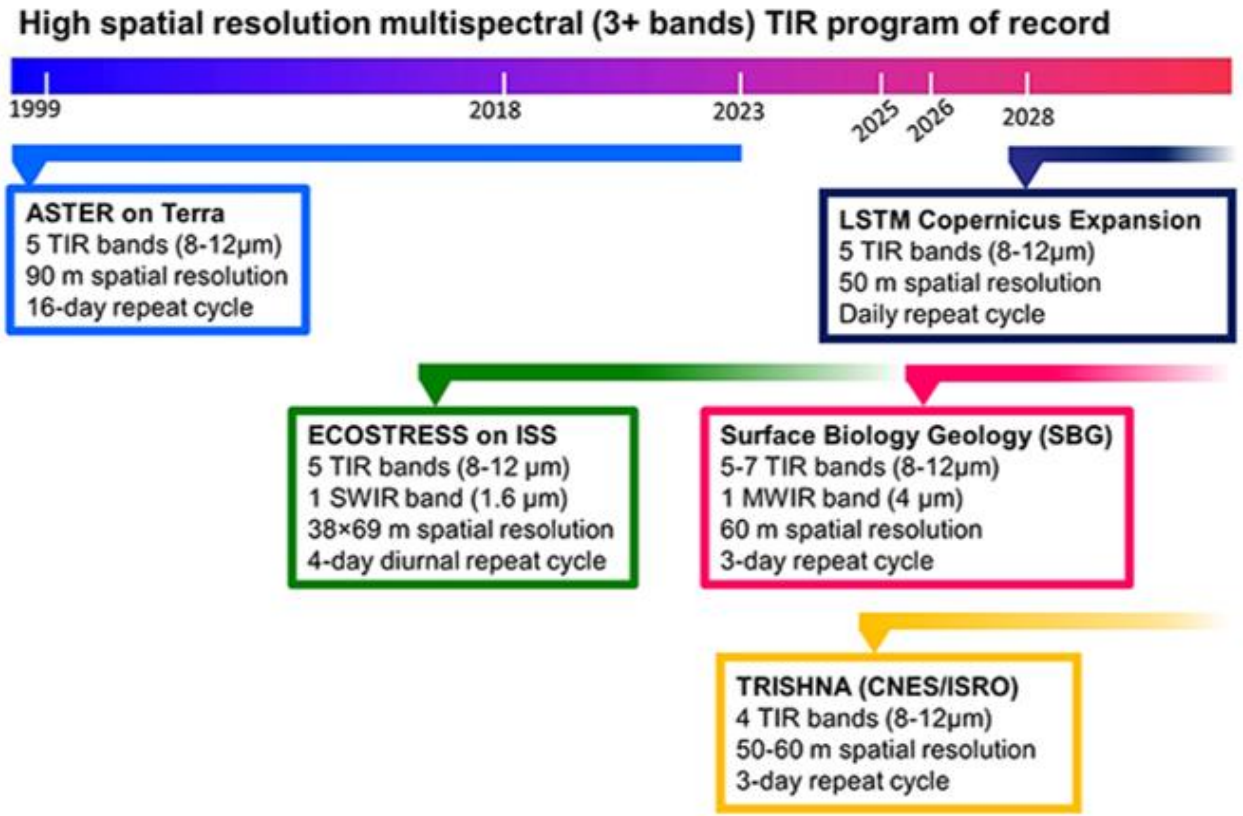
AGU 2019

Joint ASI-NASA-JPL joint mission study for NASA-SBG mission

in July 2018, the Italian Space Agency (ASI) and NASA-Jet Propulsion Laboratory (JPL) started a joint study to define a new TIR free-flyer mission concept.
ASI and JPL considered a number of previous studies performed in the past, including the following: HyspIRI TIR free-flyer, MTISS (2011) and TMAX study EE9 2017.

The present mission study carried out by the Joint team of ASI, JPL, INGV, INAF scientists has the aim to develop a very challenging space mission to respond to the observation requirements expressed by a very large scientific community.

The mission with a multispectral IR instrument is considered of high priority by the NASA's "Decadal Survey" plan, as well by ESA as one of the future Sentinels under study for the Copernicus program.

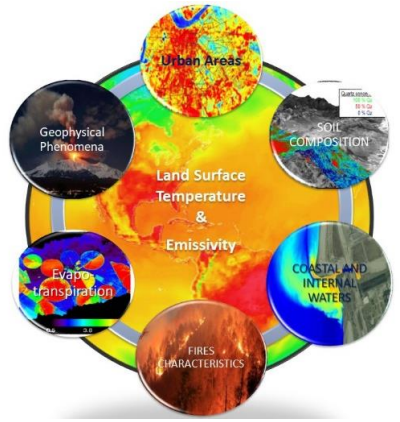


The JPL-ASI mission will fill a critical gap in the Mid and Thermal InfraRed science and represents a possible scientific precursor of ESA-LSTM mission and to other plenned missions.

Involvement of the Italian Scientific Community for mission requirements

The contribute of the Italian Scientific Community is fundamental to:

- Acquire information on the application that requires MWIR-LWIR observations
- Support the correct development of the MWIR-LWIR mission
- Explore opportunities for the international cooperation
- Networking opportunities for the national scientific community in EO issues



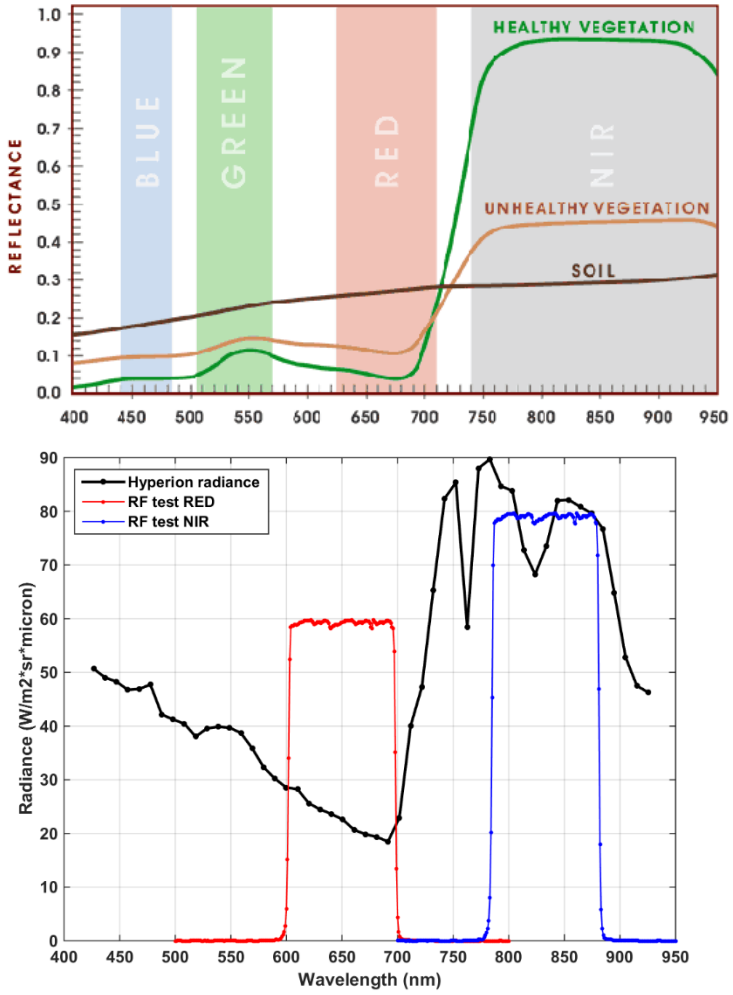
During 2018-2019, ASI and INGV organized two workshops to involve the Italian Scientific Community to acquire of the scientific and observation requirements for a MWIR-LWIR space sensor Information and presentation on the ASI-INGV workshops are available at https://www.asi.it/event/mwir-lwir-mission-study/.

The ASI-JPL mission study consider a SWIR-MWIR-LWIR sensor with 8 spectral channels and 1 VNIR camera with 2 spectral channels (Baseline)

PARAMETER	VF	TIR Baseline	VF	TIR Threshold	DS 2018 Science Requirement	ECOSTRESS Specification
Ground Resolution (m) @ nadir	A	<60	A	50	60	< 100
Orbit altitude (km) with 97.3 deg inclination		665		503		400
Equatorial Revisit (days)	B	3	C	4	<=5	variable
Half TFOV in degrees and TFOV in (km). No overlap between swaths		34.4 (935.1)		36.0 (747)	25.5 (from HysplRI)	26 (52)
Noise equivalent delta temperature (K) at 300K	A	<0.2	A	<0.2	<0.2 (from HysplRI)	<= 0.15 (3 bands)
Absolute accuracy (K) at 300K	A	0.5	A	0.5	<0.5 (from HysplRI)	0.5
Saturation range (K)		200-500		200-500	200-500 (from HysplRI)	200-435
Saturation – high temperature 4 µm band (K)		1200		1200	1200 (from HysplRI)	n/a
Daytime Overpass time (hh:mm)		1 pm		10:30 am -1:30 pm	10:30 am – 1:30 pm (from HysplRI)	variable
Nighttime imaging		Yes		Yes	YES (from HysplRI)	Required
Number of Bands spectral range: 1.3 – 12 µm	A	5 (TIR), 2 (MIR), 1 (SWIR)	A	5 (TIR), 2 (MIR), 1(SWIR)	5 (TIR), 1 (MIR) (from HysplRI)	5 TIR 1 @ 1.6 um for geolocation
Coverage		Land and coastal regions full resolution. Deep oceans at 1 km resolution		Land and coastal regions full resolution. Deep oceans at 1 km resolution	Land and coastal regions full resolution. Deep oceans at 1 km resolution (from HysplRI)	Land and coastal regions

VNIR camera under study (INAF coordinator)
has 1 channel in the VIS and I channel in the NIR are selected in order to produce NDVI maps for assessing vegetation coverage and characteristics

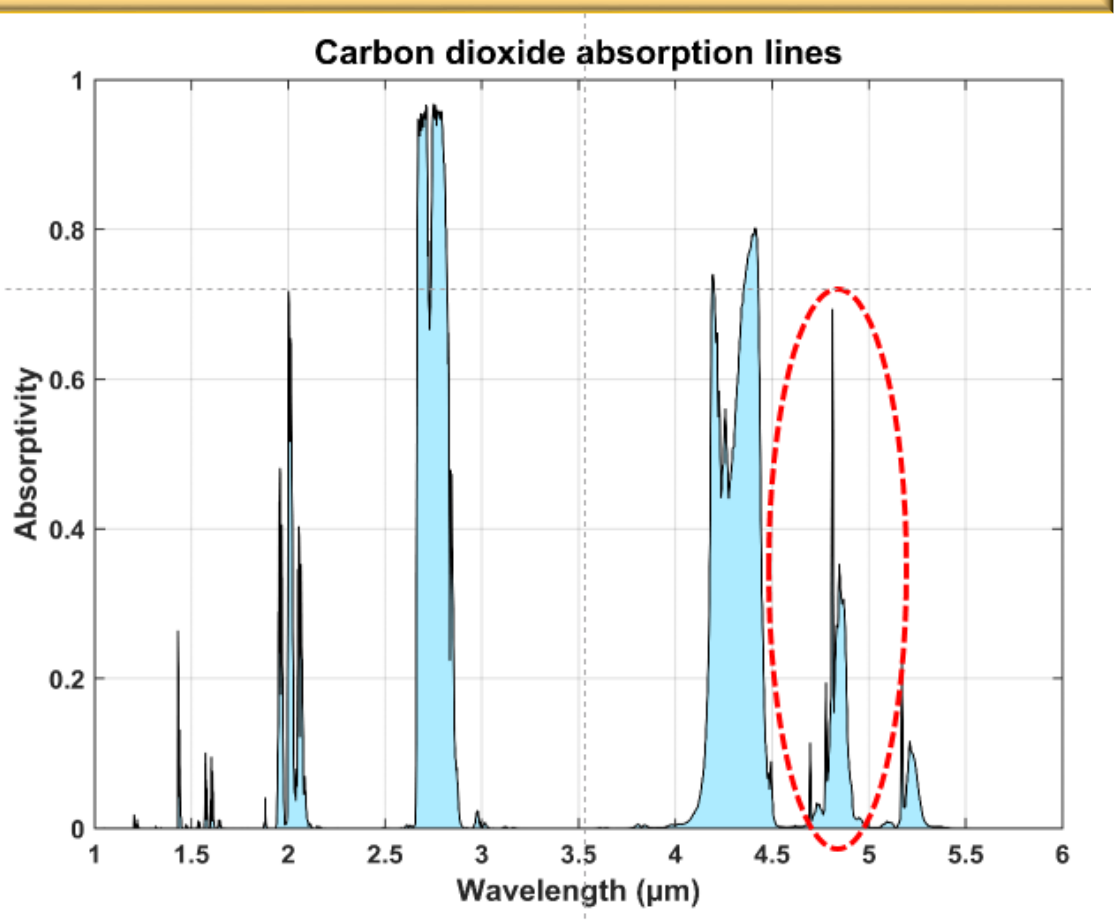
PARAMETER	VNIR Baseline	VNIR Threshold
Ground Resolution (m) @ nadir	<30	<25
Orbit altitude (km) with 97.3 deg inclination	665	503
Equatorial Revisit (days)	3	4
Half TFOV in degrees and TFOV in (km). No overlap between swaths	34.4 (935.1)	36.0 (747)
S:N (exact number is TBD)	~150:1	~150:1
Absolute radiometric accuracy (%) (exact number is TBD)	<10%	<10%
Saturation range (K)	?	?
Daytime Overpass time (hh:mm)	10:30 am -1:30 pm	10:30 am -1:30 pm
Nighttime imaging	No	No
Number of Bands	2	2
Band Centers (nm)	665, 835	665, 835
Band Width (nm)	40	40
Coverage	Land and coastal regions full resolution. Deep oceans at 1 km resolution	Land and coastal regions full resolution. Deep oceans at 1 km resolution
Data latency	2 days	2 days



Hyperion spectral profile on vegetation and RF's for testing

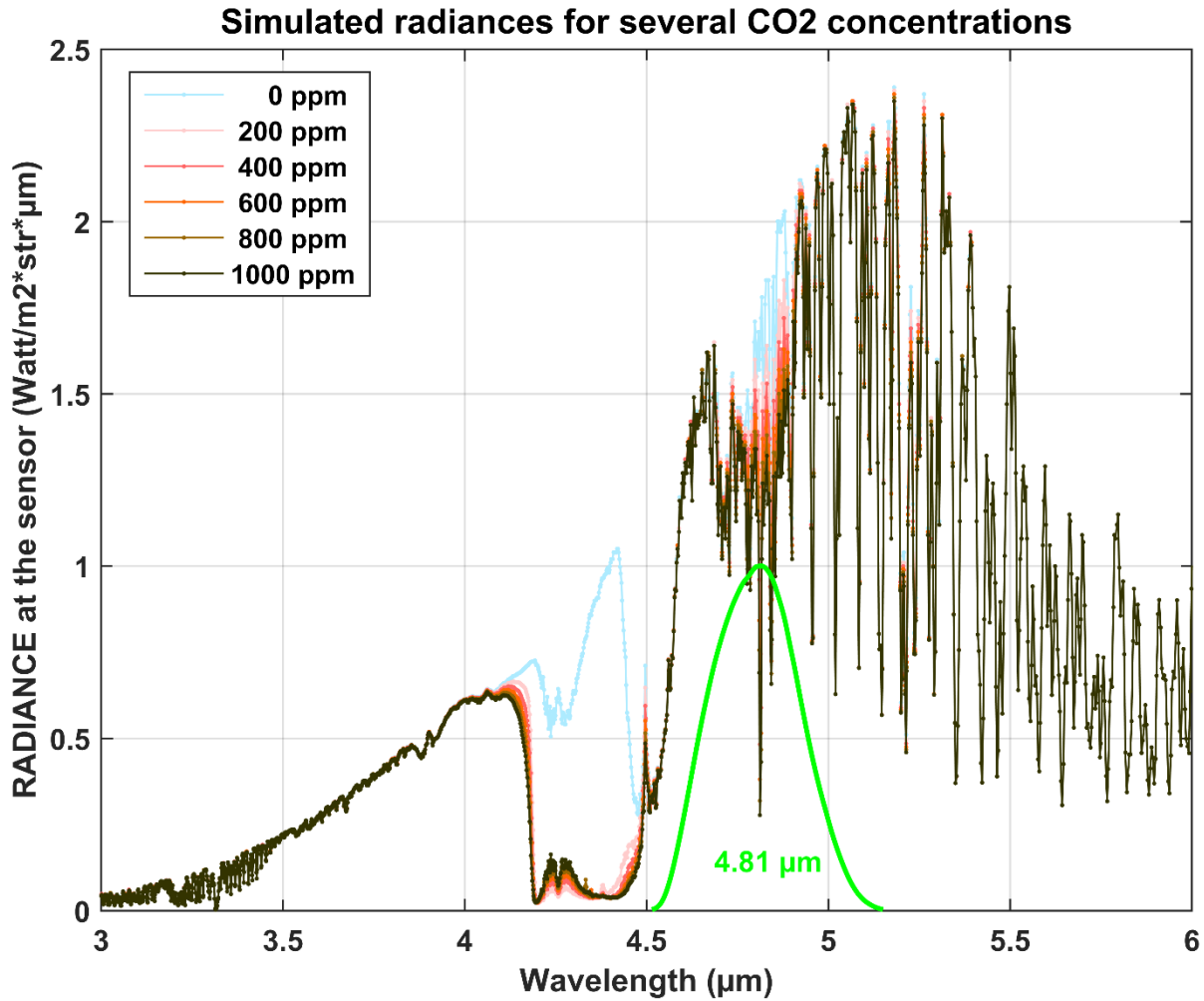
SBG TIR mission study may contribute to measuring CO_2 Emissions from point soureces using the absorption band at 4.8 µm

MWIR channels: estimate CO_2 **emissions from fires, volcanoes and industrial pants** is of high interest, the 4.8 µm, in the MWIR spectral range, has been investigated by means of model simulations to evaluate the radiometric requirements to measure different columnar concentration of CO_2



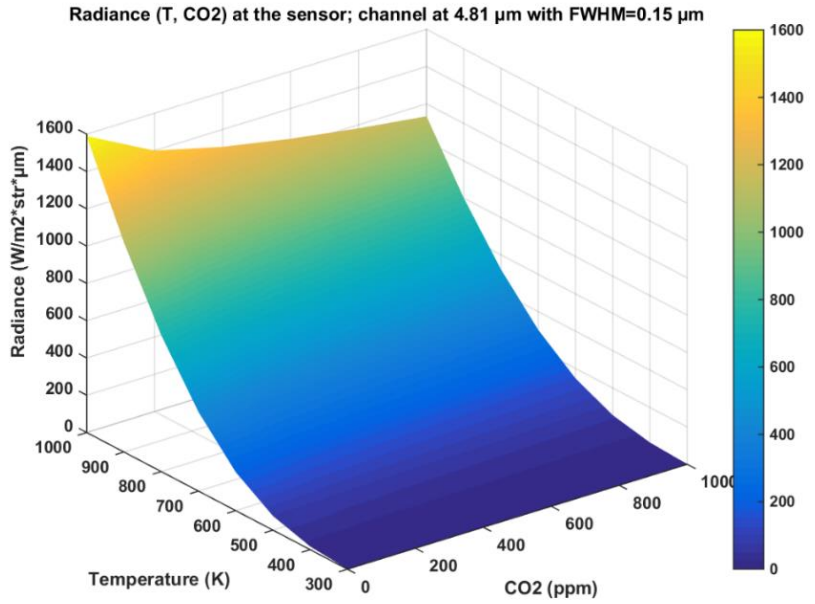
Sensitivity to the CO_2 concentration

EXP1 - EXP6: T=300 K; CO_2 = 0-1000 ppm (step 200 ppm)



Channel sensitivity to CO_2 concentration and surface temperature

First simulations analyses provide information on NEDT required for the carbon dioxide retrieval by employing the 4.8 µm channel with a FWHM=0.15 µm



NEDT (K) required	T=300 K	T=400 K	T=500 K	T=600 K
For 10 ppm abv bkg	< 0.046	< 0.095	< 0.150	< 0.211
For 20 ppm abv bkg	< 0.092	< 0.189	< 0.300	< 0.422
For 30 ppm abv bkg	< 0.139	< 0.283	< 0.450	< 0.632
For 40 ppm abv bkg	< 0.185	< 0.377	< 0.600	< 0.842
For 50 ppm abv bkg	< 0.230	< 0.471	< 0.750	< 1.052

For standard and intermediate temperatures

NEDT (K) required	T=700 K	T=800 K	T=900 K	T=1000 K
For 10 ppm abv bkg	< 0.285	< 0.368	< 0.459	< 0.558
For 20 ppm abv bkg	< 0.570	< 0.736	< 0.917	< 1.116
For 30 ppm abv bkg	< 0.854	< 1.103	< 1.375	< 1.673
For 40 ppm abv bkg	< 1.138	< 1.470	< 1.833	< 2.231
For 50 ppm abv bkg	< 1.422	< 1.837	< 2.289	< 2.787

For high temperatures

CONCLUSIONS

- In the next decade new satellite optical mission will be available to the scientific community
- Is very important to improve the capability to process large data volume acquired by hyperspectral and TIR sensor on satellite and consolidate retrieval algorithms to monitor Earth process and human activities
- Is also important to promote the international collaboration to share scientific goals and scientific and operational requirements for new satellite missions.
- Finally the prepare and train the new generation of space scientists

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HYDROSPHERE
GEOSPHERE
CRYOSPHERE
precipitation
condensation
wind waves
anthropogenic emissions
greenhouse effect
carbon dioxide
methane
aerosols
air density
clouds
solar radiation
incoming
reflected by surface
thermohaline circulation
primary production
oxygen
warm current
melting ice
land cover distribution and change
desertification
plants
transpiration
evaporation
erosion
THANK YOU