# Volcanic Carbon Dioxide Detection and Retrieval by using PRISMA Hyperspectral Satellite Data

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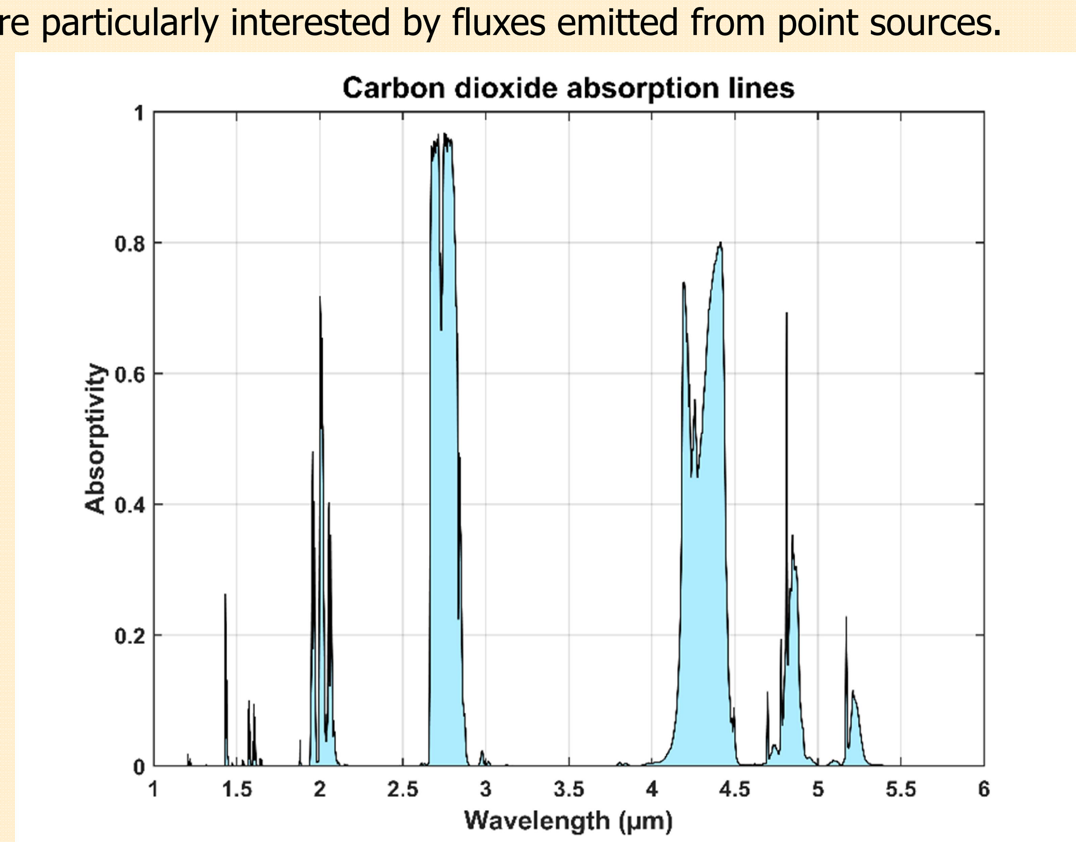
## Abstract

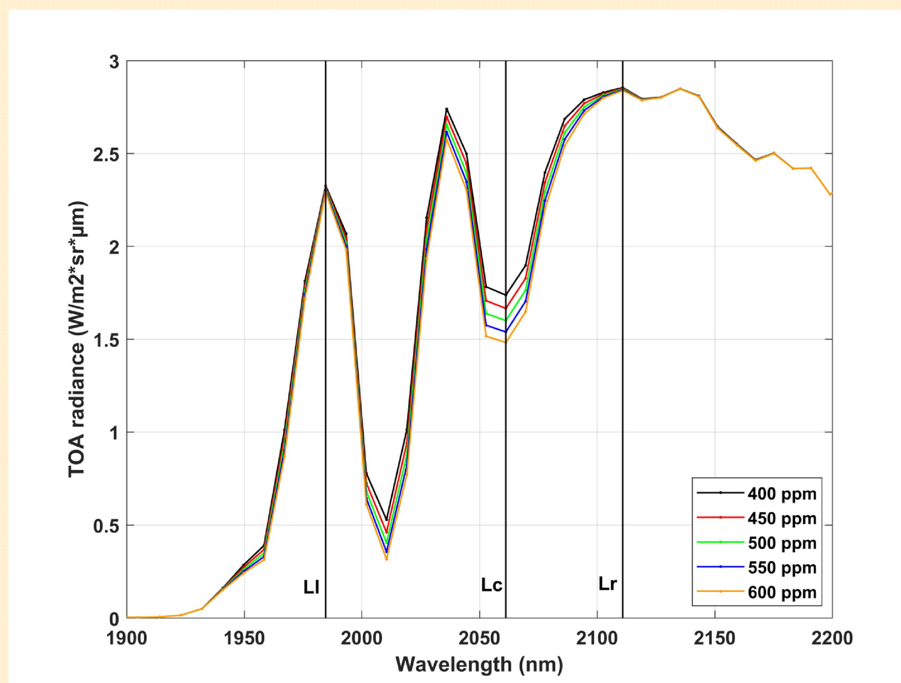
A large and fast view of volcanic plumes as detection and measurement of volatiles components exolving from craters is possible by using hyperspectral remote sensing if their absorption bands are in the sensor spectral range. In the present study the developed algorithm to calculate CO2 columnar abundance in tropospheric volcanic plume is presented. The algorithm is based on a modified CIBR 'Continuum Interpolated Band Ratio' remote sensing technique initially developed to calculate water vapor columnar abundance. The retrieval techniques exploit spectroscopy measurements by analysing gases absorptions features in the SWIR (Short Wave InfraRed) spectral range. Specifically, PRISMA (PRecursore IperSpettrale della Missione Applicativa) acquisitions are used for gases retrieval purposes. The PRISMA space mission was launched by the Italian Space Agency (ASI) on March 22, 2019; the on-board spectrometer is able to measure in the VNIR (0.4-1.0 μm) and SWIR (0.9-2.5 μm) spectral ranges, with a spatial resolution of 30 m. In this study, the inversion techniques is applied in order to compare its performances for CO2 detection and retrieval. The considered test site is Campi Flegrei volcano located in southern Italy and characterized by a persistent degassing and the additional test site is the Lusi mud volcano located in Java in Indonesia characterized by a persistent and cold degassing emissions.

## Framework

The availability of gases absorbing spectral channels in the satellite sensors allows measurements of CO2 column contents. Gas concentrations can be retrieved acquiring spectra in the CO2 absorption bands around 1.6 μm and 2.0 μm in the short-wave infrared (SWIR) spectral region (Spinetti et al., 2008), at 4.8 μm in the mid-wave infrared (MWIR) (Romaniello et al., 2020). Carbon dioxide absorption bands in the SWIR spectral range are sensitive down to the lowermost layers of the atmosphere which are particularly interested by fluxes emitted from point sources.



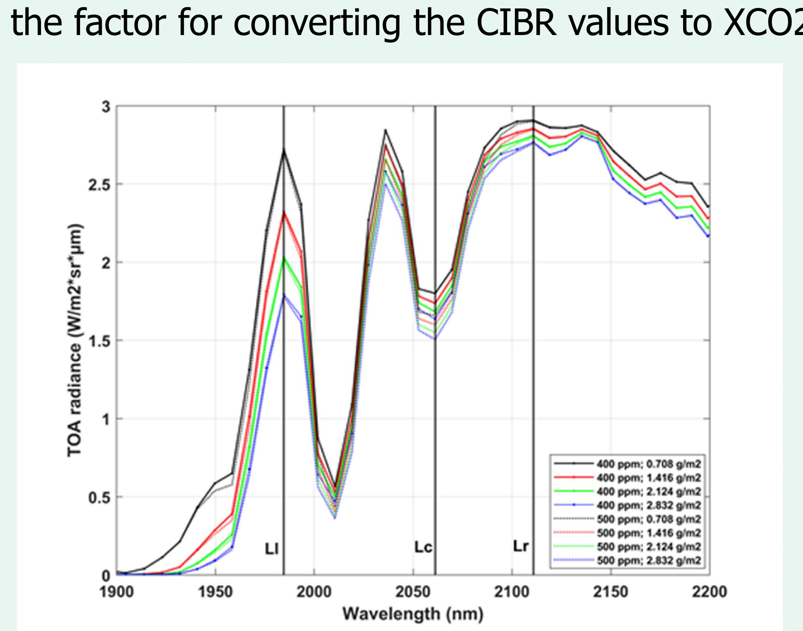

$CO_2$ absorption bands in the SWIR-MWIR spectral range (1-6 μm).




Simulated TOA spectral profiles convolved on PRISMA channels, for several CO2 column-averaged (400, 450, 500, 550, 600 ppm) and the standard H2O column-averaged corresponding to 1.416 g/m2 (US std 1976).

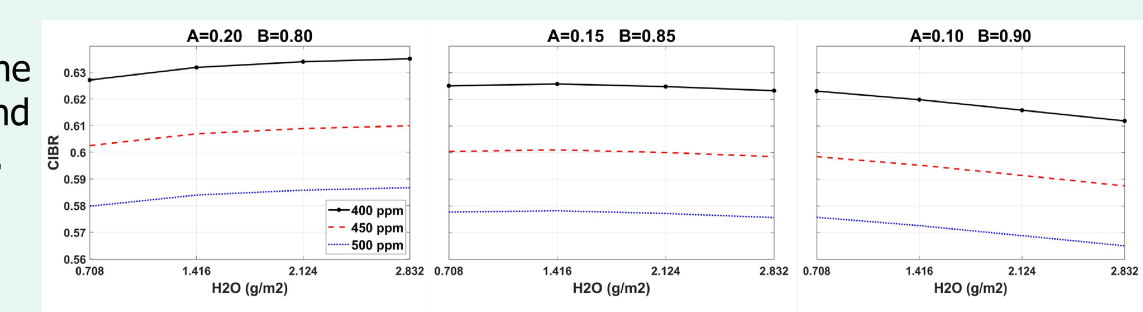
## Retrieval Algorithm

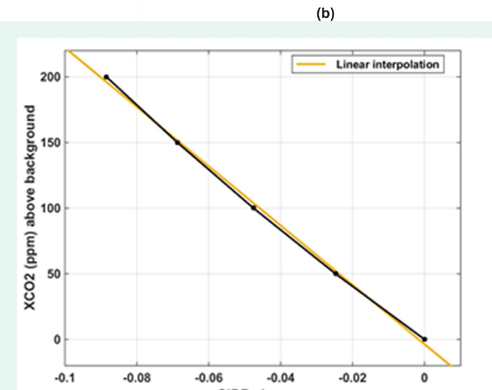
Model simulations are used to infer the best SWIR channels for CO2 retrieval purposes, the weight coefficients for a Continuum Interpolated Band Ratio (CIBR) index calculation and the factor for converting the CIBR values to XCO2 (ppm) estimations above the background.




$$CIBR = \frac{L_c}{A * L_l + B * L_r}$$

where:
L = Radiance at ch 37
$L_l$ = Radiance at ch 31
$L_r$ = Radiance at ch 39
A,B= weighing coefficients (a+b=1)

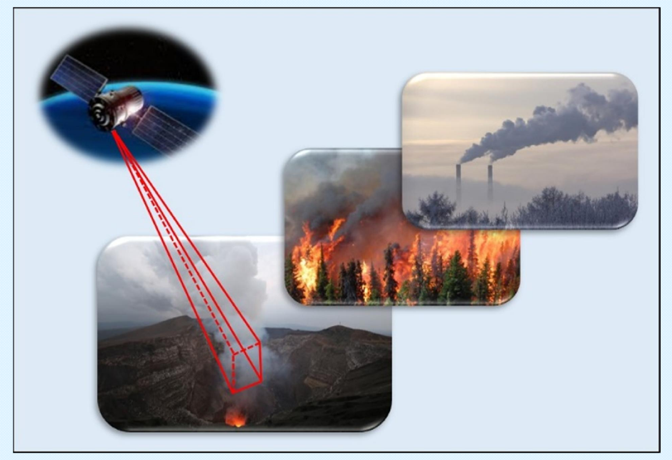


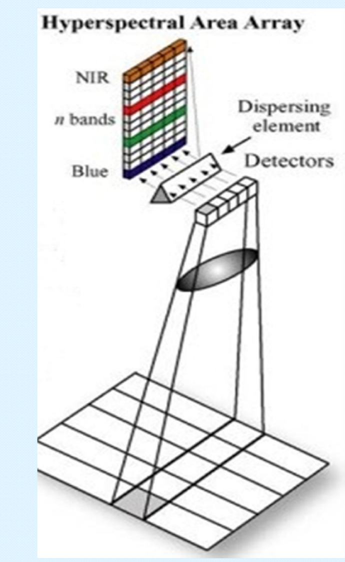

Modelled relation between CIBR changes and XCO2 enhancements

## ASI-PRISMA Hyperspectral Space Mission

The Italian Space Agency launched the hyperspectral imaging platform, PRecursore IperSpettrale della Missione Applicativa PRISMA, on March 22, 2019. PRISMA is a polar orbiting satellite in LEO and holds a panchromatic camera operating in the spectral range 0.4-0.7 μm, acquiring images at 5 m spatial resolution, and the hyperspectral payload sensor. The hyperspectral instrument based on a pushbroom scanning technique works in the range 0.4-2.5 μm with 66 and 173 channels in the VNIR (Visible and Near InfraRed) and SWIR (Short-Wave InfraRed) regions, respectively and a spatial resolution of 30 m. After three months of verifications its operational activity is started in June 2019 (http://prisma-i.it/index.php/en/).



PRISMA system provides the capability to acquire, downlink and archive images of all Hyperspectral/Panchromatic channels totaling 200,000 km2 daily over the the Primary Area of Interest in Longitude 180° W – 180° E and Latitude 70° S - 70° N. The characteristics are:
- acquisition capacity up to 223 images per day, with scene of 30 km x 30 km;
- continuous strip acquisition capacity up to 1800km;
- data acquisition, download and processing up to 0a level and storage of all data (hyperspectral/ panchromatic) up to a maximum of 200,000 km2 per day;
- daily processing capacity of 200 hyperspectral images (30 km x 30 km) up to Level 2d (from data already in the archive).
- Target access opportunity on Area of Interest:
- duration / day: 240 minutes - number of orbits / day: 15
- Agility: the system is capable of acquiring images distant 1000km in a single pass (with a total rotation left to right side looking and viceversa).

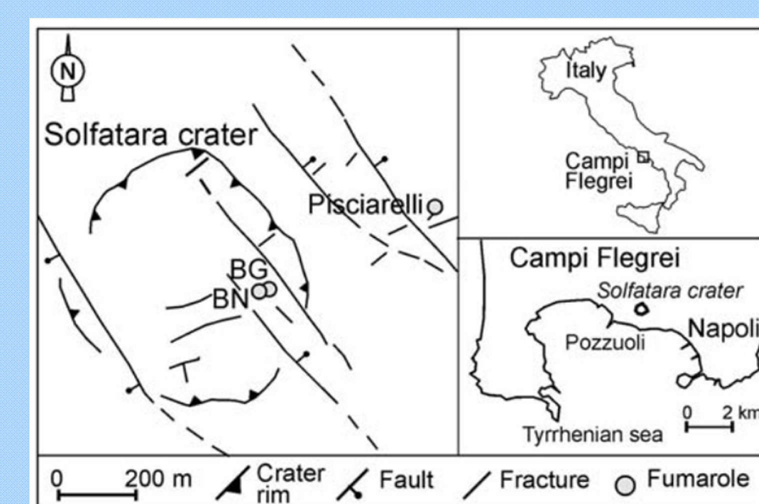



| Instrument Main Characteristics | |
|---|---|
| Swath / FOV | 30 km / 2.45° |
| GSD | • Hyperspectral: 30 m<br>• PAN: 5 m |
| Spatial Pixels | Hyperspectral: 1000<br>PAN: 6000 |
| Spectral Range | VNIR: 400 – 1010 nm<br>SWIR: 920 – 2505 nm |
| Spectral Resolution | ≤ 12 nm |
| Spectral Bands | VNIR: 66<br>SWIR: 171 |
| Radiometric Quantization | 12 bit |
| VNIR SNR | > 200:1 on 400 – 1000 nm<br>> 500:1 @ 650 nm |
| SWIR SNR | > 200:1 on 1000 – 1750 nm<br>> 400:1 @ 1550 nm<br>> 100:1 on 1950 – 2350 nm<br>> 200:1 @ 2100 nm |
| PAN SNR | > 240:1 |
| Absolute Radiometric Accuracy | Better than 5% |

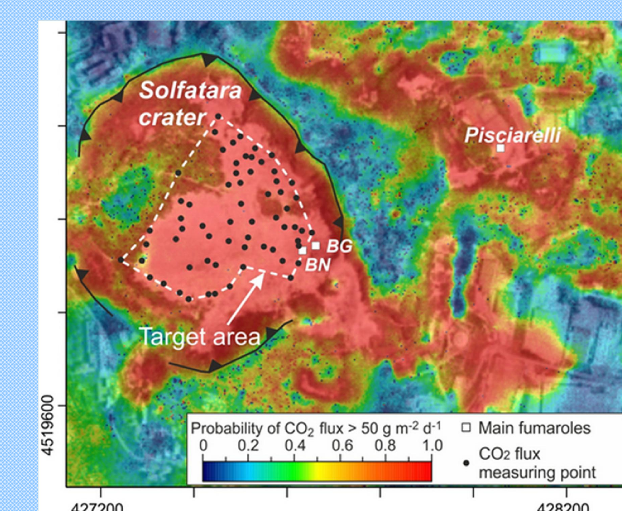
## VOLCANIC TEST SITES

The sites selected for testing the method are Solfatara area in the caldera of Campi Flegrei (Italy) and the LUSI volcanic area (Indonesia).The selects areas are characterized by gas emissions but have very different geological structures. Campi Flegrei is a caldera in an unrest period characterized while LUSI is a mud volcano with cold gas emissions.

### Campi Flegrei – La Solfatara - Italy

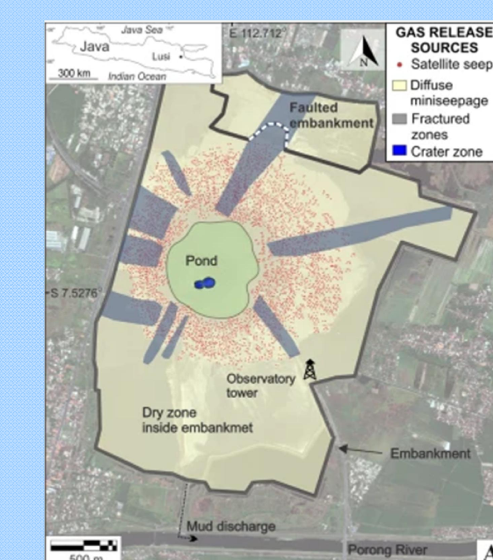



Campi Flegrei caldera Location map.




Map based on soil CO2 flux from 1998 to 2016 (Cardellini et al., 2017), illustrates the probability that the simulated CO2 flux is greater than 50 g m−2d−1 (Chiodini et al, 2021).

### Lusi – East Java - Indonesia

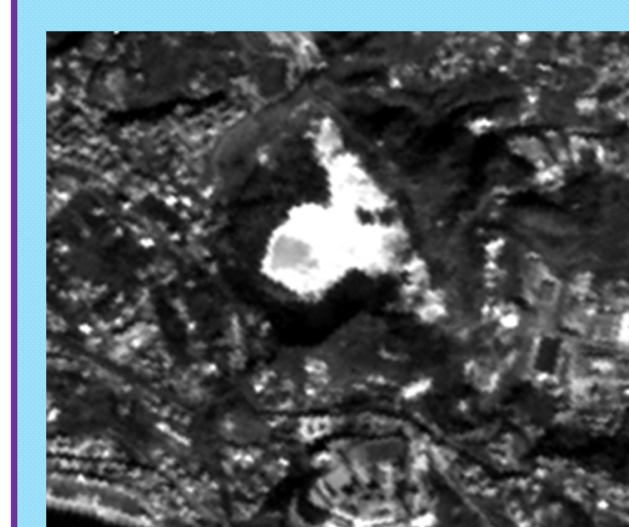


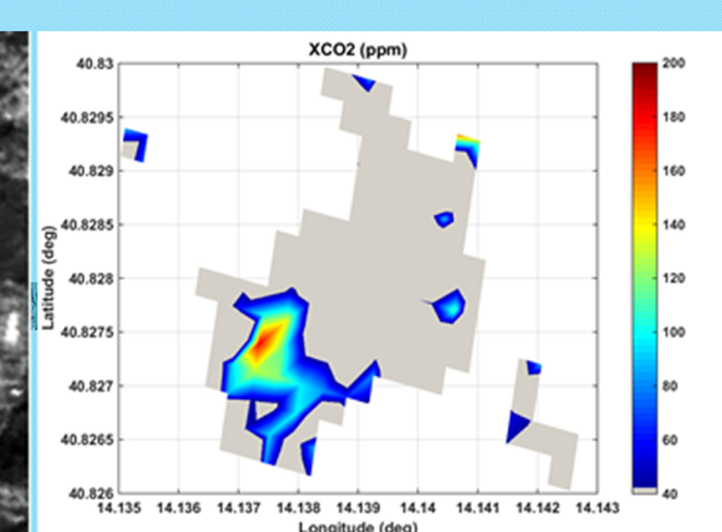

LUSI map (August 2014 and peripheral seeps structure (Mazzini et al., 2021).

Gas emissions at LUSI that discharge aqueous vapour (~98 vol.%) belonging to the hydrothermal component of the system and $CH_4$ and $CO_2$, (picture from Mazzini et al., 2021).

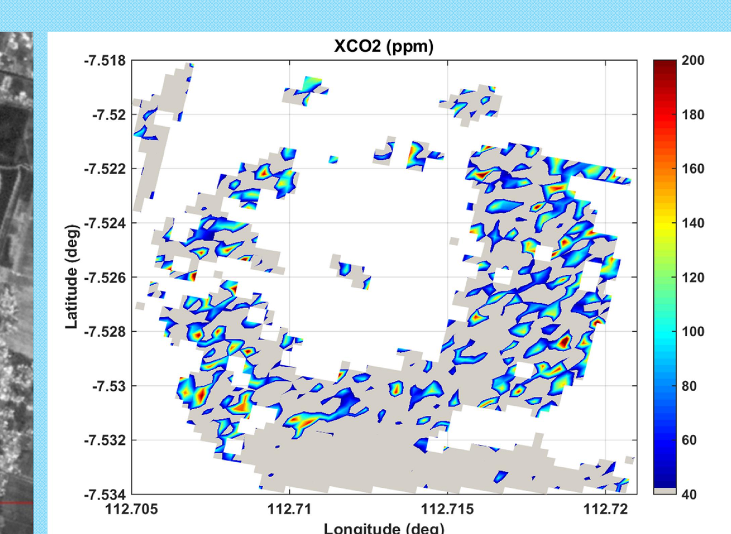
## RESULTS

The methodology developed is applied to the two considered test cases. Results of XCO2 retrieval are for LUSI and Solfatara, respectively; a graphical interpolation is applied to images to enhance the gas emitting points. White areas represent regions with Lr radiance less than 2 W/m2*sr*μm (so not considered for the retrieval), while grey areas include regions with XCO2 values up to 40 ppm that is the minimum detectable.






PAN image acquired on February 18, 2021




PAN image acquired on August 14, 2020

**References:** *Romaniello V, Spinetti C, Silvestri M, Buongiorno MF. (2021). A Methodology for CO2 Retrieval Applied to Hyperspectral PRISMA Data. Remote Sensing; 13(22):4502. DOI 10.3390/rs13224502*