Consiglio Nazionale delle Ricerche

IMAA ISTITUTO DI METODOLOGIE PER L'ANALISI AMBIENTALE

Normalized Hotspot Index (NHI): an original algorithm for mapping, monitoring and characterizing high temperature events related to natural, environmental and anthropic hazards

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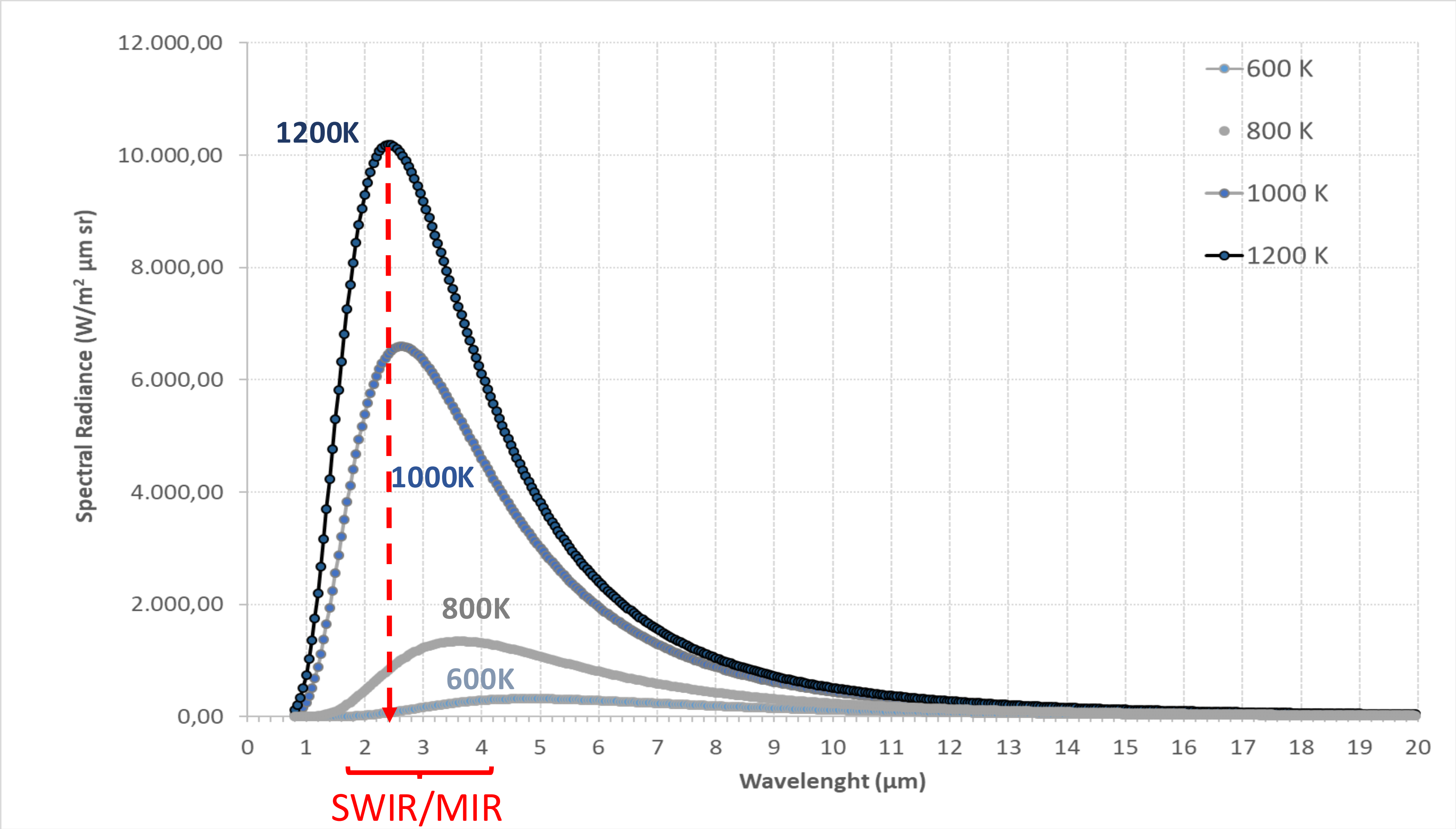
"Tecnologie satellitari e analisi multi-rischio: l'esperienza dei progetti I4DP_SCIENCE e prospettive future", ASI, Roma, 27-28 Maggio 2025

Main Objective

Identifying, mapping, monitoring and characterizing high temperature features related to natural, environmental and anthropic hazards

Background: Planck curves at different magmatic temperatures



Wien's law

$$\lambda_{max}\,[\mu m] = \frac{2898}{T[K]}$$

High-temperature features (e.g., lava flows; lava lakes) emit the maximum of thermal radiation in the **SWIR/MIR bands** based on their temperature

Problem: Solar reflected radiance!

The NHI (Normalized Hotspot Indices) algorithm

$$NHI_{SWIR} = \frac{L_{2.2} - L_{1.6}}{L_{2.2} + L_{1.6}} \qquad NHI_{SWNIR} = \frac{L_{1.6} - L_{0.8}}{L_{1.6} + L_{0.8}}$$

A Multispectral approach, proposed for Sentinel-2/MSI and Landsat/OLI, using SWIR (@1.6µm and @2.2µm) & NIR (@0.8µm) Top-Of-Atmosphere radiances

A thermal anomaly is detected if(*):

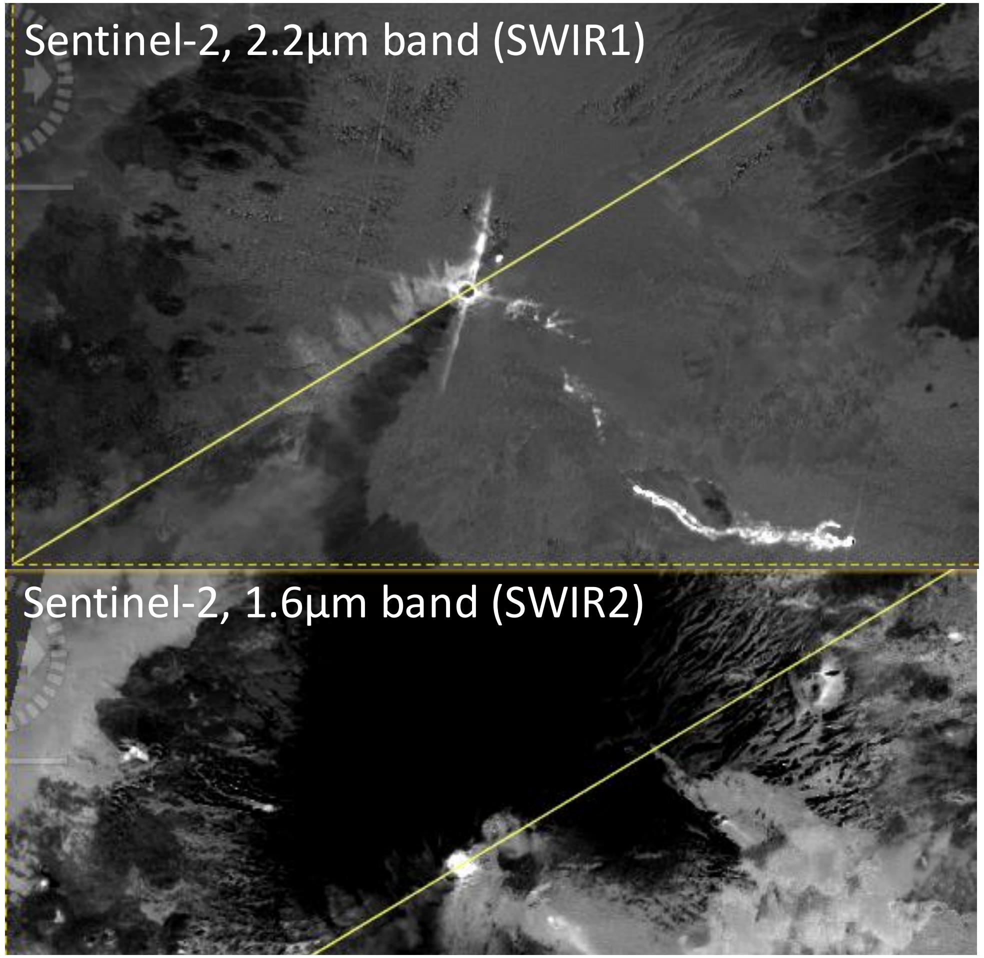
$$\left\{ \begin{array}{l} NHI_{SWIR} = \dfrac{L_{2.2} - L_{1.6}}{L_{2.2} + L_{1.6}} > 0 \\ \text{OR} \\ NHI_{SWNIR} = \dfrac{L_{1.6} - L_{0.8}}{L_{1.6} + L_{0.8}} > 0 \end{array} \right.$$

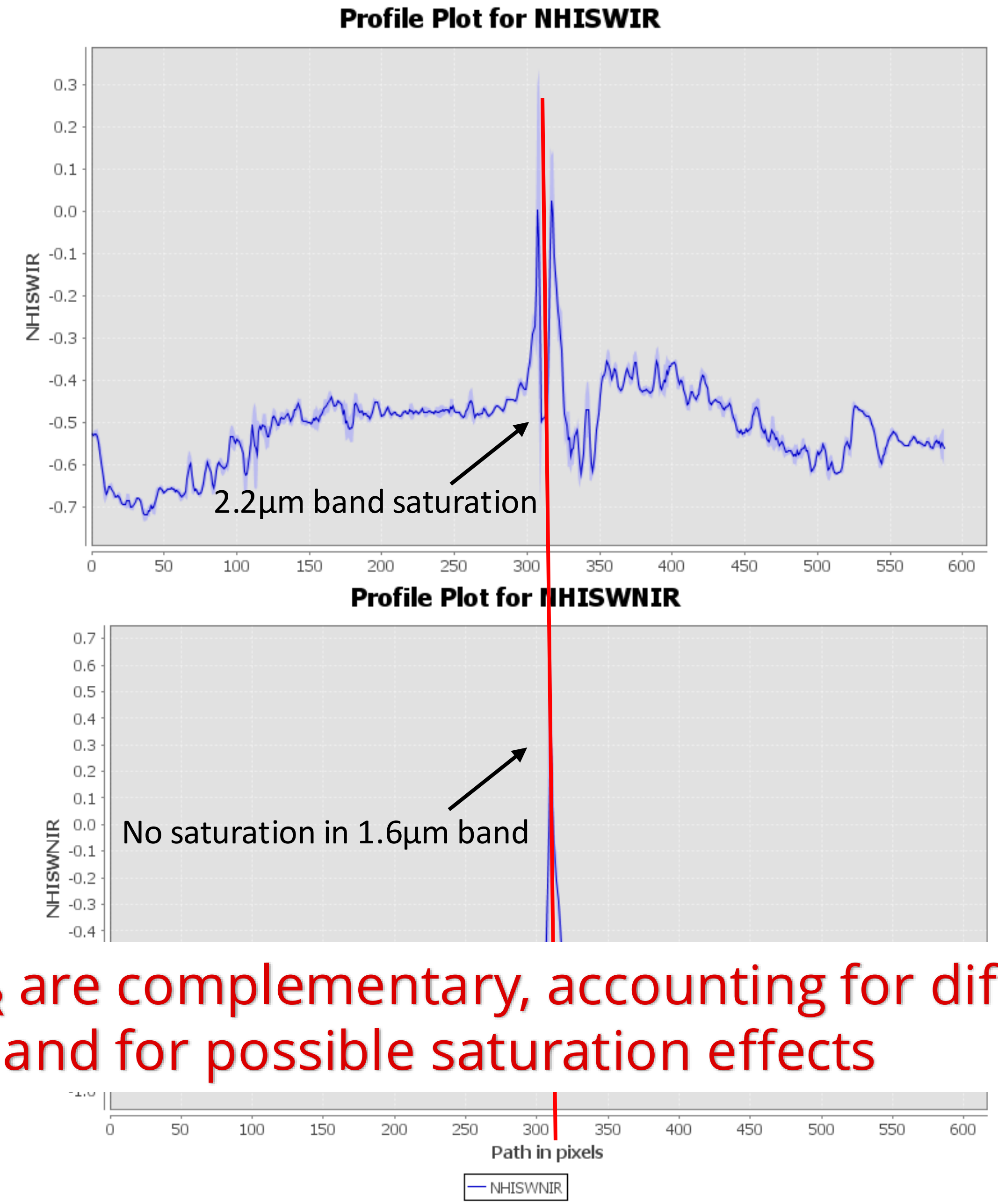
To account for hot sources at different temperatures/sizes, saturation effects, etc.

Marchese et al., Remote Sens. 2019, 11, 2876

(*) but lower, automatically derived, thresholds can be used to increase sensitivity

The NHI (Normalized Hotspot Indices) algorithm



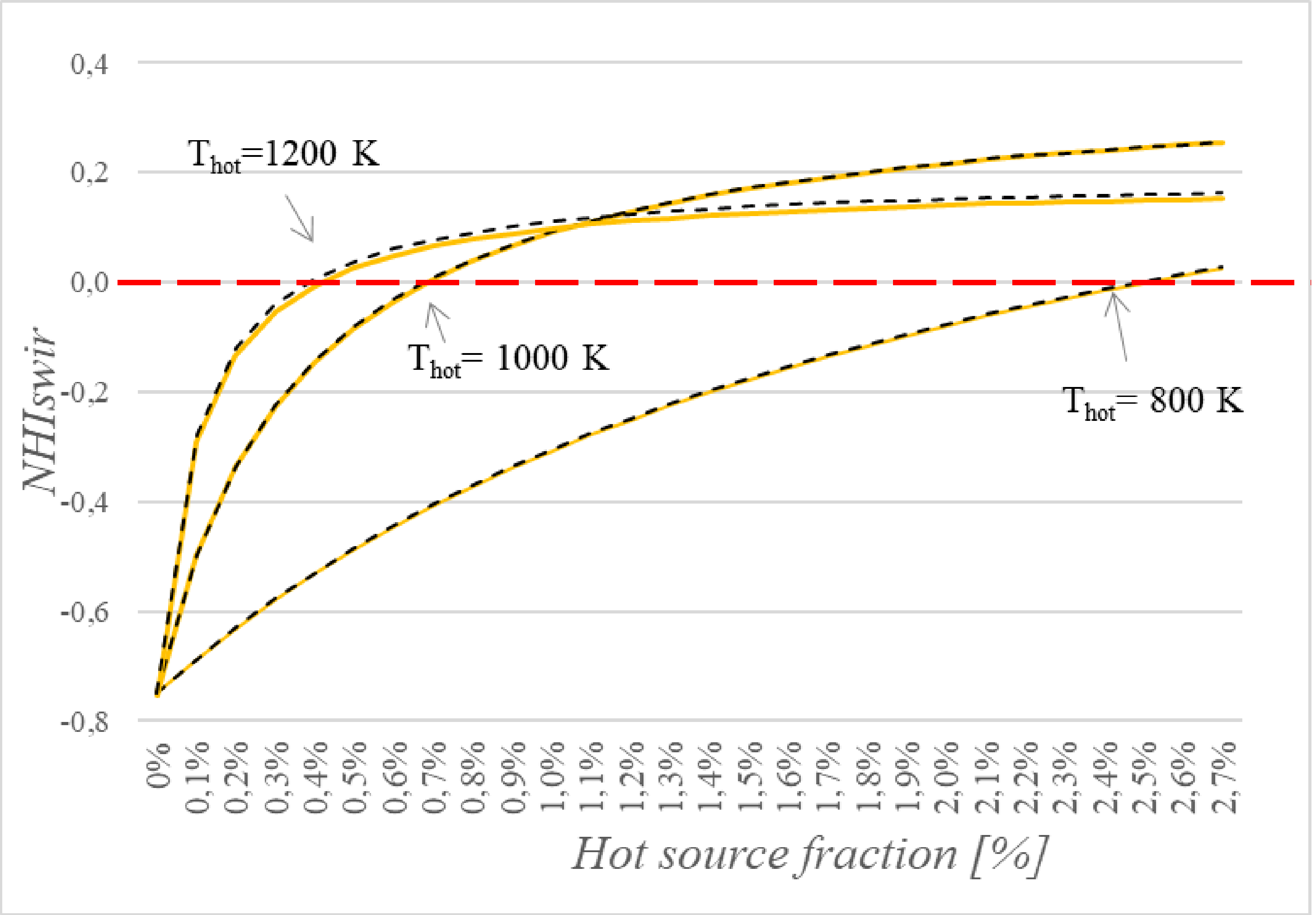


The two indices, NHI_{SWIR} and NHI_{SWNIR} are complementary, accounting for different target temperatures/sizes and for possible saturation effects

Marchese et al., Remote Sens. 2019, 11, 2876

NHI sensitivity

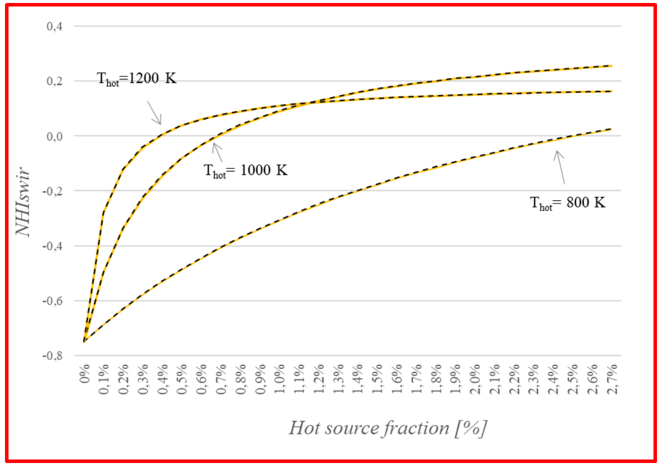
Simulated NHI_{SWIR} values for different hot source fractions



NHI shows a high sensitivity toward hot sources of very small size

Hot sources occupying pixel fraction from ~2.5% (@T=800K) up to 0,4% (@T=1200K) are potentially detectable by NHI>0 (even smaller fractions can be detected with lower thresholds)

NHI sensitivity for different space systems



Approxymate minimum size (in m^2) of hot sources detectable by NHI on sensor data at different spatial resolutions

Sensor/resolution	1200 K	1000 K	800 K
S-2 @20m	1,6	3,2	10
L8/9 @30m	3,6	7,2	22,5
S-3 @500m	1000	2000	6250
VIIRS @750m	2250	4500	14062,5
MODIS @1000m	4000	8000	25000
SEVIRI @3000m	36000	72000	225000

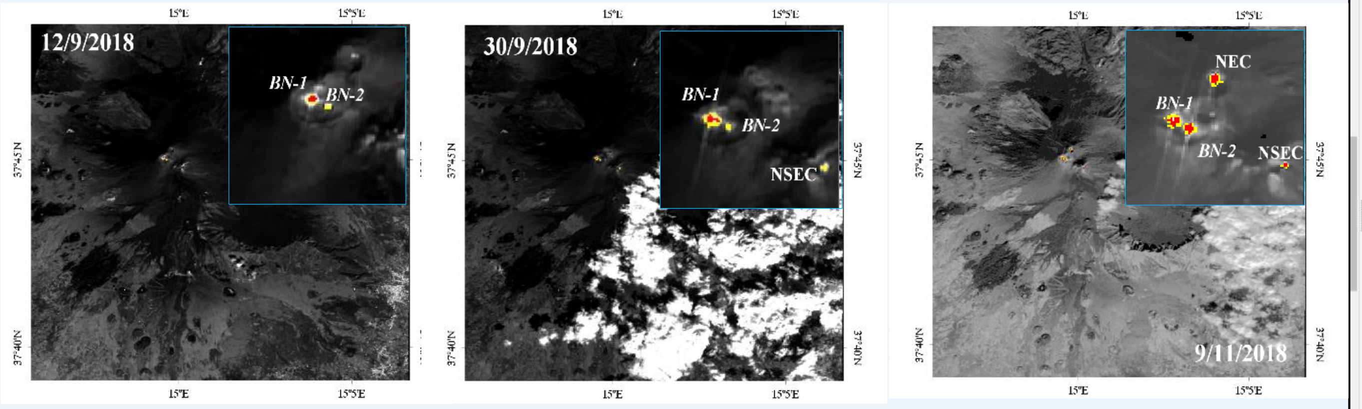
Landsat (L8/9) and Sentinel-2 (S-2) offer the best spectral and spatial characteristics for mapping volcanic hotspots by means of NHI, in spite of a lower temporal resolution.

However, properly integrating all the operational missions (L8+L9+S2A+S2B), a Virtual Constellation can be obtained with a **global median average of revisit intervals of 2.3 days** (Li & Chen 2020)

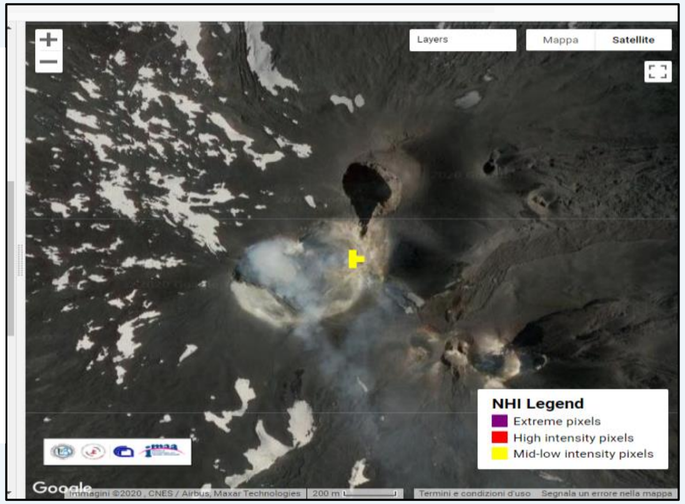
NHI for active volcanoes: Thermal anomaly detection&Mapping

Accurate localization of active vents

Etna (Italy) - September-November 2018

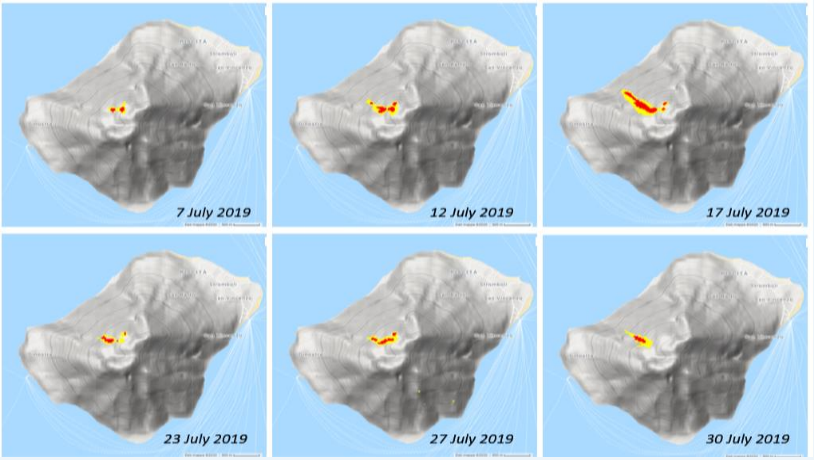


Etna (Italy)- July 2016

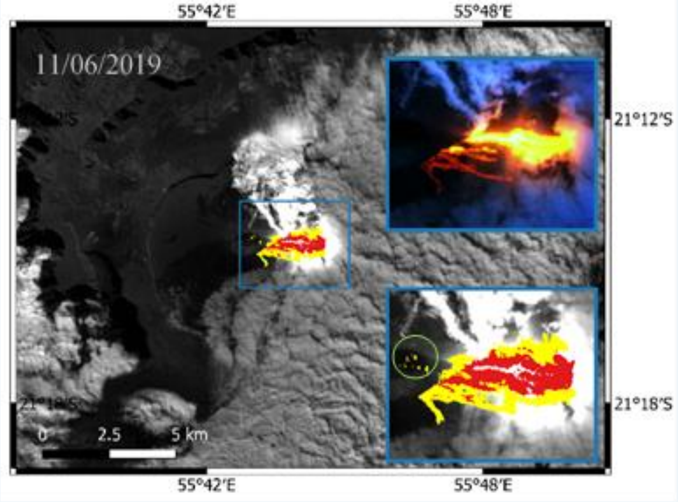


Detailed mapping of lava flows/lakes

Stromboli (Italy) – July 2019



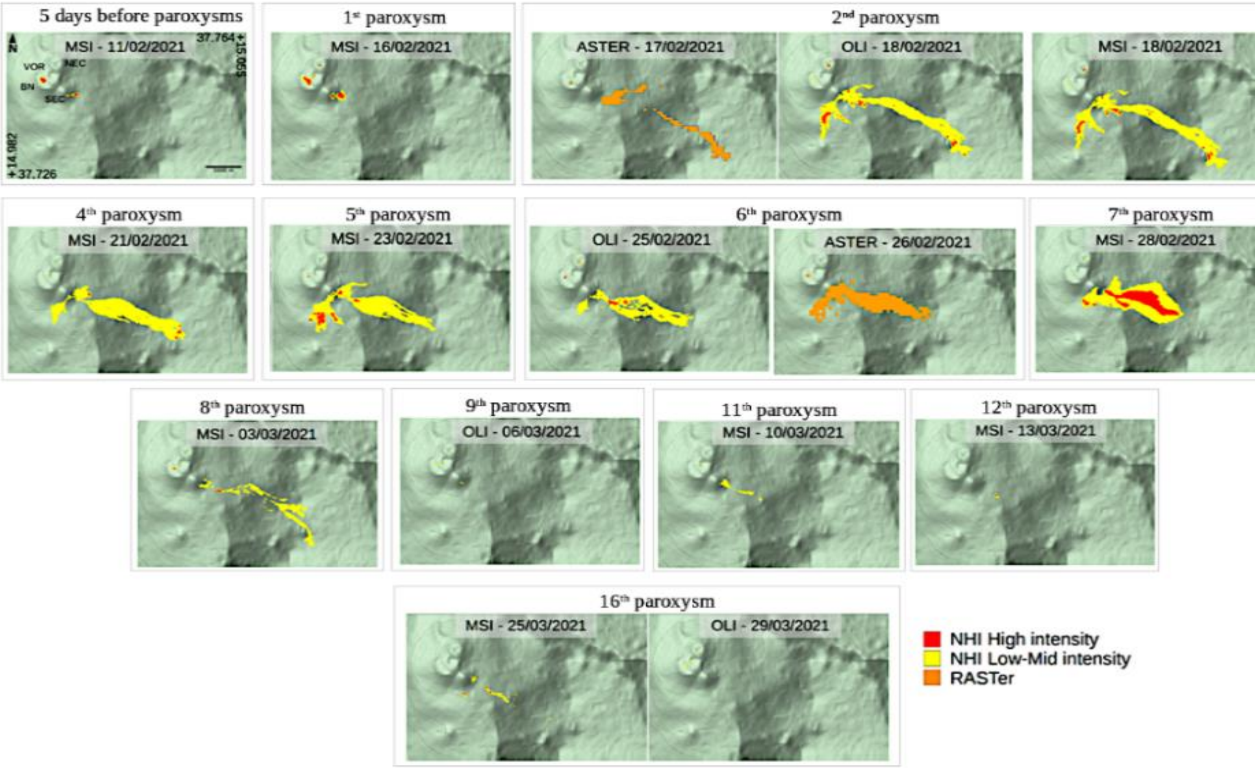
Piton de La Fournaise 11 June 2019



Genzano et al, 2020
Marchese et al., 2019

NHI for active volcanoes: Monitoring eruption evolution

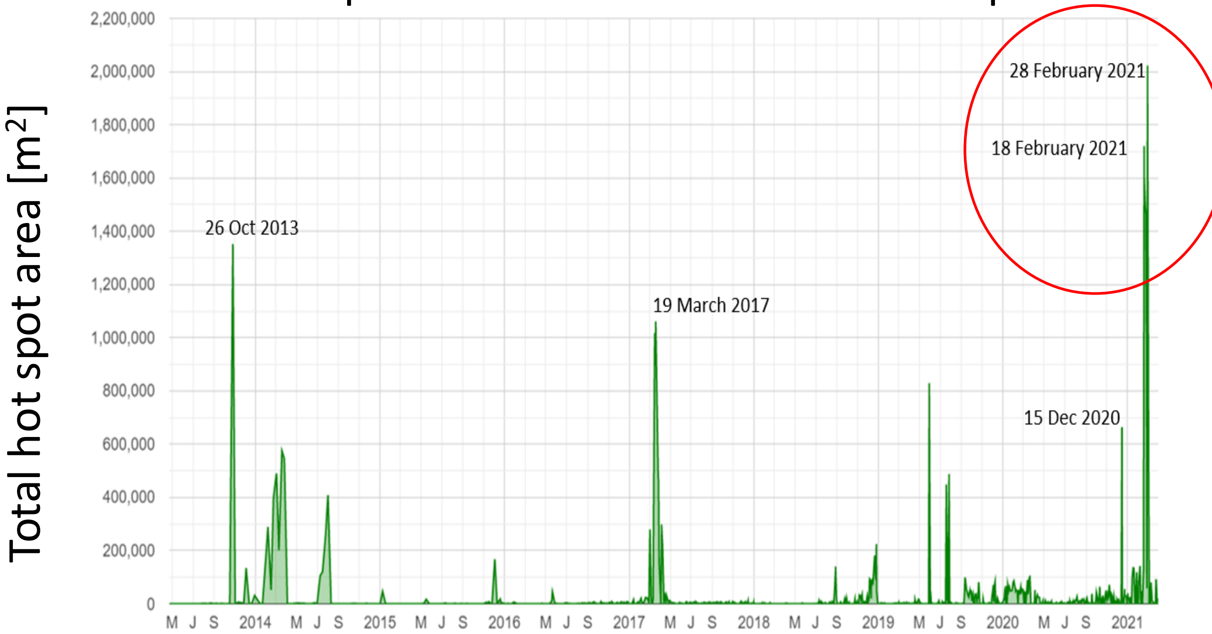
Mt. Etna (Italy) paroxysms of February-April 2021



During Feb- early Apr 2021, 17 paroxysms occurred at Mt. Etna.

The NHI tool enabled a **near continuous and accurate lava flow mapping** by fully integrating Landsat& Sentinel observations

Total hot spot area observed in Oct 2013- Apr 2021



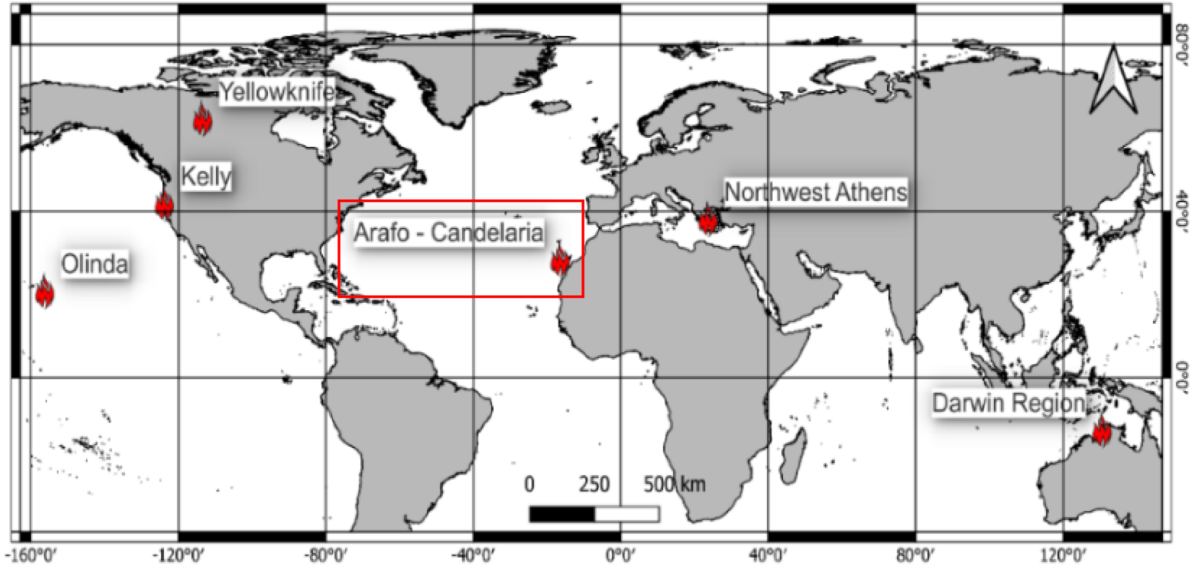
The long-term time series analysis of the total hot spot area revealed that **thermal anomaly observed during some of those paroxysms was the most extended since 2013**

Marchese et al., 2021

NHI for active fire detection: Mapping fires at Global scale

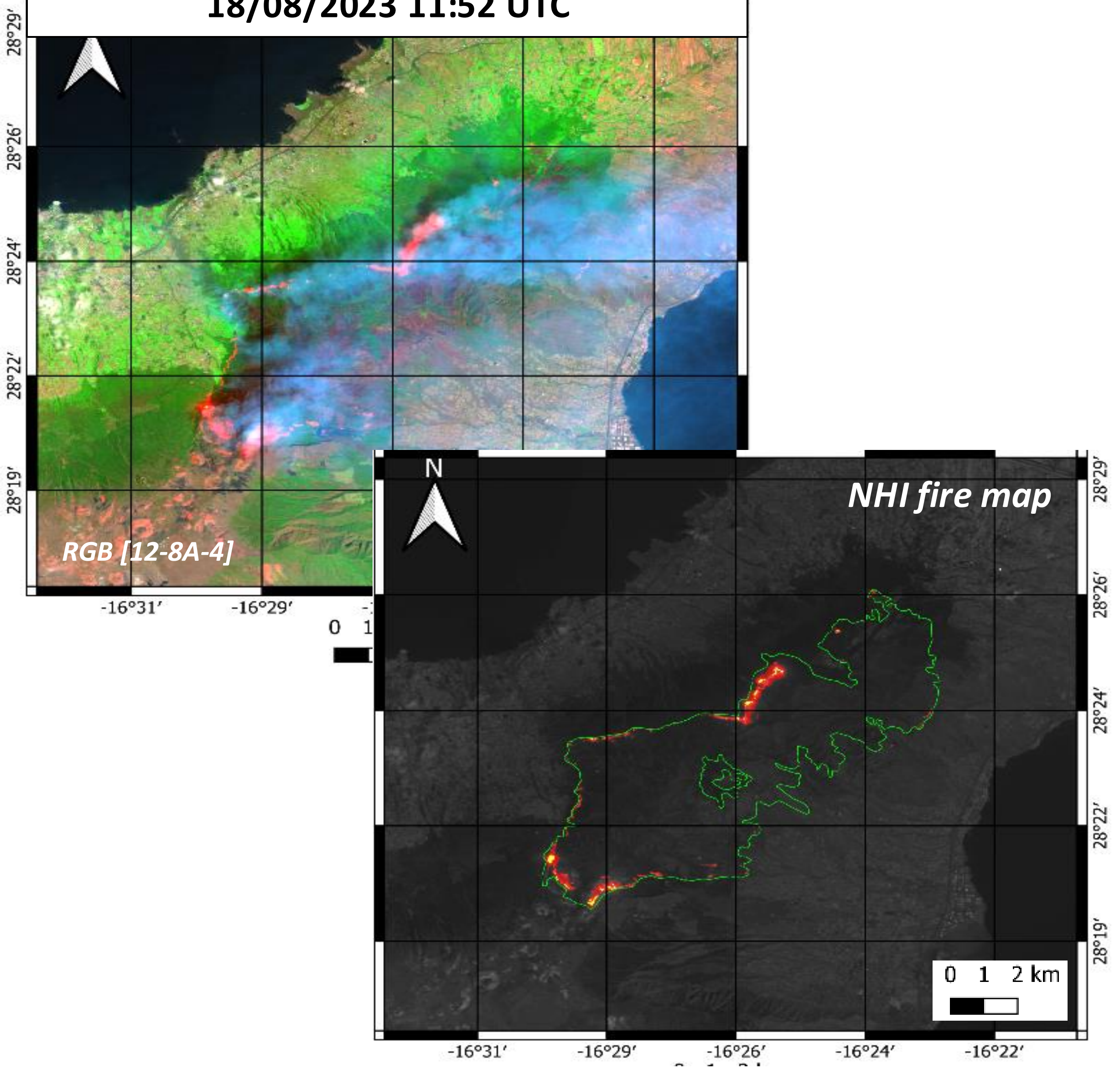
6 Big fires recently investigated worldwide

(Mazzeo G. et al. 2025)



Fire Location	Climate	Vegetation cover	Tot Burned area (ha)	Satellite scenes
North Attica (Greece)	Mediterranean	Forest	6193	23 August 2023
Tenerife (Spain)	**Mediterranean**	**Forest**	**15**	**18 August 2023**
Hawaii (USA)	Tropical	Tall Grass	438	8 August 2023
California (USA)	**Temperate**	**Forest**	**32,9**	**15–30 August 2023**
Darwin Region (Australia)	Tropical	Savannah	440	13 July 2023
Yellowknife (Canada)	Subarctic	Boreal Forest	50,75	9 August 2023

Arafo Candelaria (Tenerife-Spain), 18/08/2023 11:52 UTC

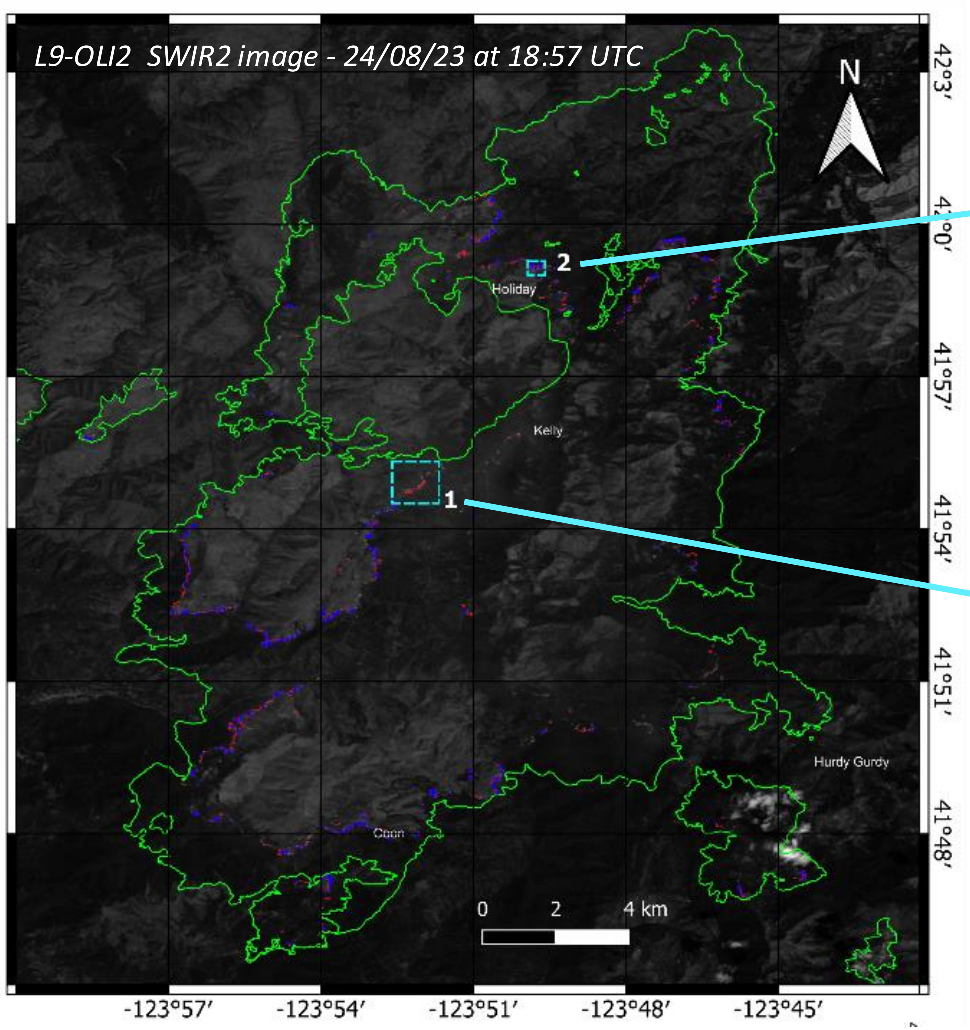


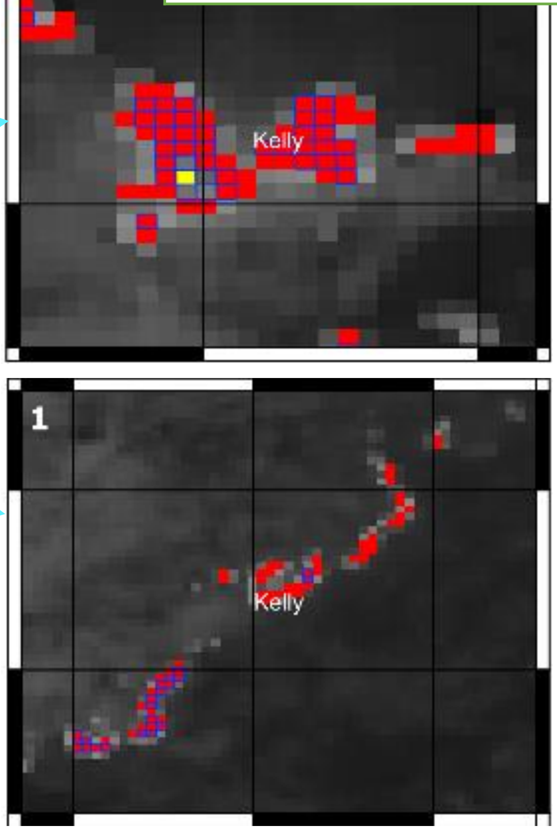
NHI for active fire detection: Comparison

Comparison with other operational products

Landsat Fire and Thermal Anomaly – LFTA (*Schroeder et al. 2016*)

Fire Location	Satellite overpass	Common fire pixels	Only NHI-F	Only LFTA
Yellowknife	09/08/2023 18:45 UTC	48.3%	51.1%	0.6%
Kelly	**24/08/2023 18:57 UTC**	**46.0%**	**53.5%**	**0.5%**





Common detection

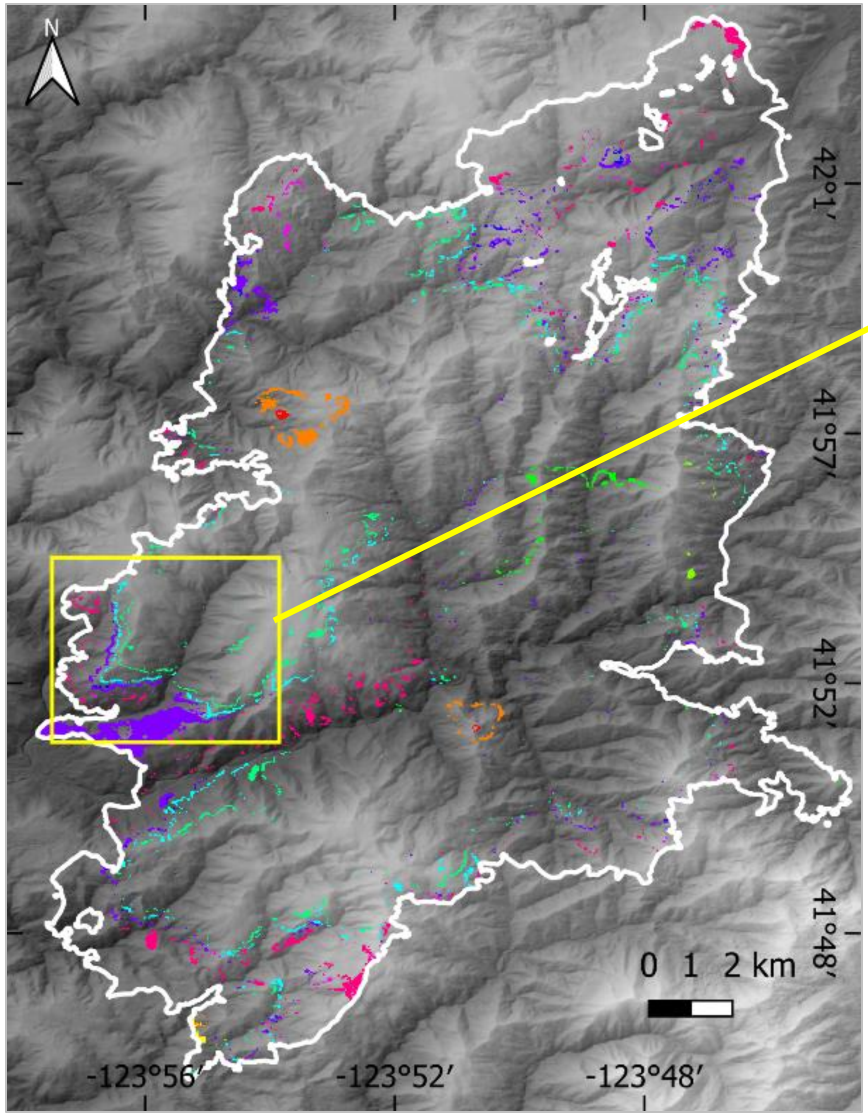
Unique NHI-F detection

Improved sensitivity → better fire front mapping capability

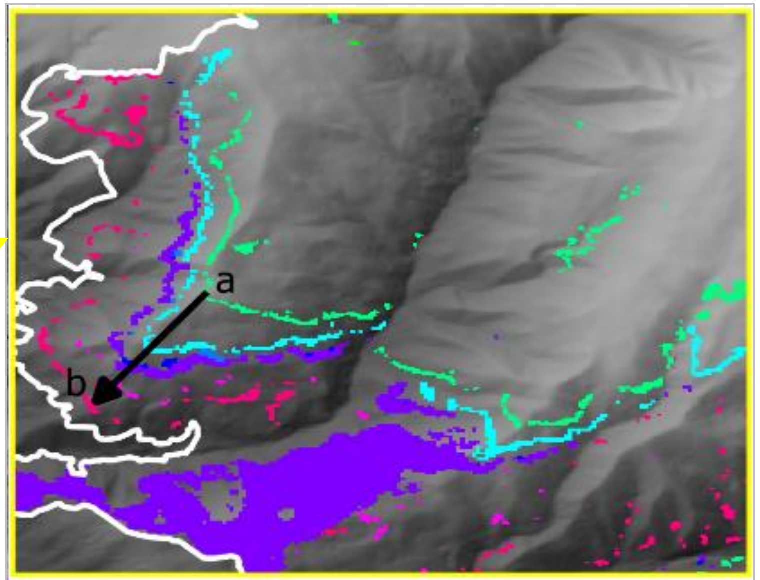
*LFTA (blue bordered pixels) and NHI (red pixels) detections performed for **Kelly fire (California), 24/08/23 at 18:57 UTC**, in green the fire perimeter (WFIGS), in background*

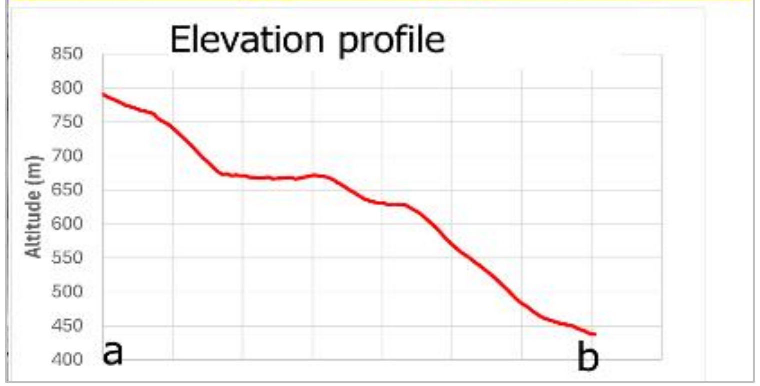
NHI for active fire detection: Fire spread rate estimation

NHI-F fire pixels map from both daytime and night-time satellite scenes on 15–30 August 2023, for **Kelly fire (California)**



Fire front **displacement (about 1600m)** between 18 and 30 August 2023, with the prevailing wind direction (black arrow)





Kelly fire
S2 15/08/2023 18:59 UTC
L8 16/08/2023 18:57 UTC
L8 17/08/2023 06:03 UTC
L9 18/08/2023 05:56 UTC
S2 18/08/2023 19:09 UTC
S2 23/08/2023 19:09 UTC
L9 24/08/2023 18:57 UTC
L9 25/08/2023 06:03 UTC
S2 25/08/2023 18:59 UTC
L8 26/08/2023 05:56 UTC
S2 28/08/2023 19:09 UTC
S2 30/08/2023 18:59 UTC

Fire rate of spread ~ 9.5 m/h

NHI for industrial sites: Gas Flaring

The Gas Flaring: A Global Challenge

Incomplete combustion

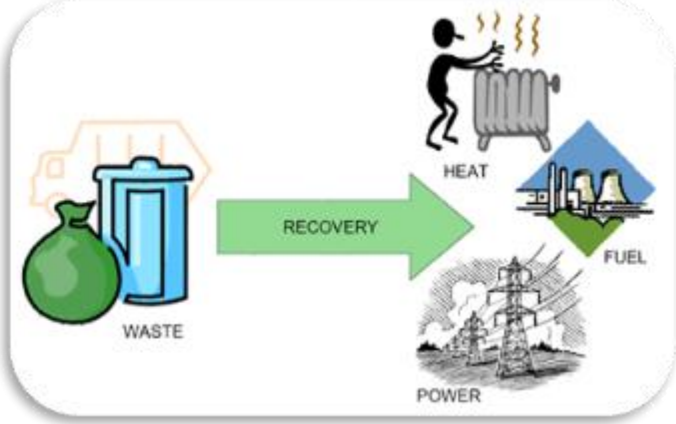
Most GFs are important source of greenhouse gas (GHG) emissions (**CO_2 and methane**)

Over **350 million tonnes of CO2e emissions** annually (~ **12% in the form of unburnt methane**)

Gas Flaring

burning of the natural gas associated with oil extraction

Waste of Clean Energy



Global Warming

Climate Change

NHI for industrial sites: Gas Flaring catalogue at global scale

a) Select the temporal window to visualize the detected gas flaring sites

- [x] GFs 2013-2021
- [x] GFs 2013-2022
- [x] GFs 2013-2023

2013-2021
2013-2022
2013-2023

b) Download GF catalogues

GFs_2013-2021

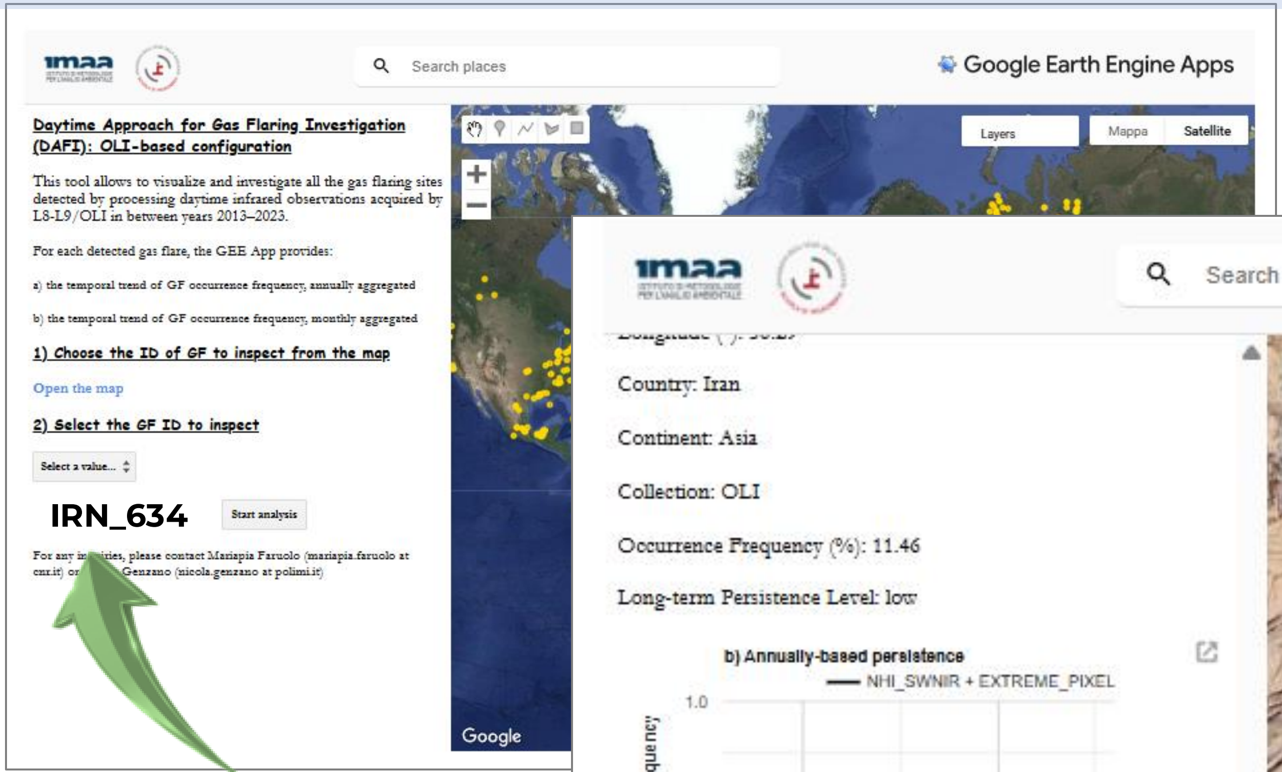
GFs_2013-2022

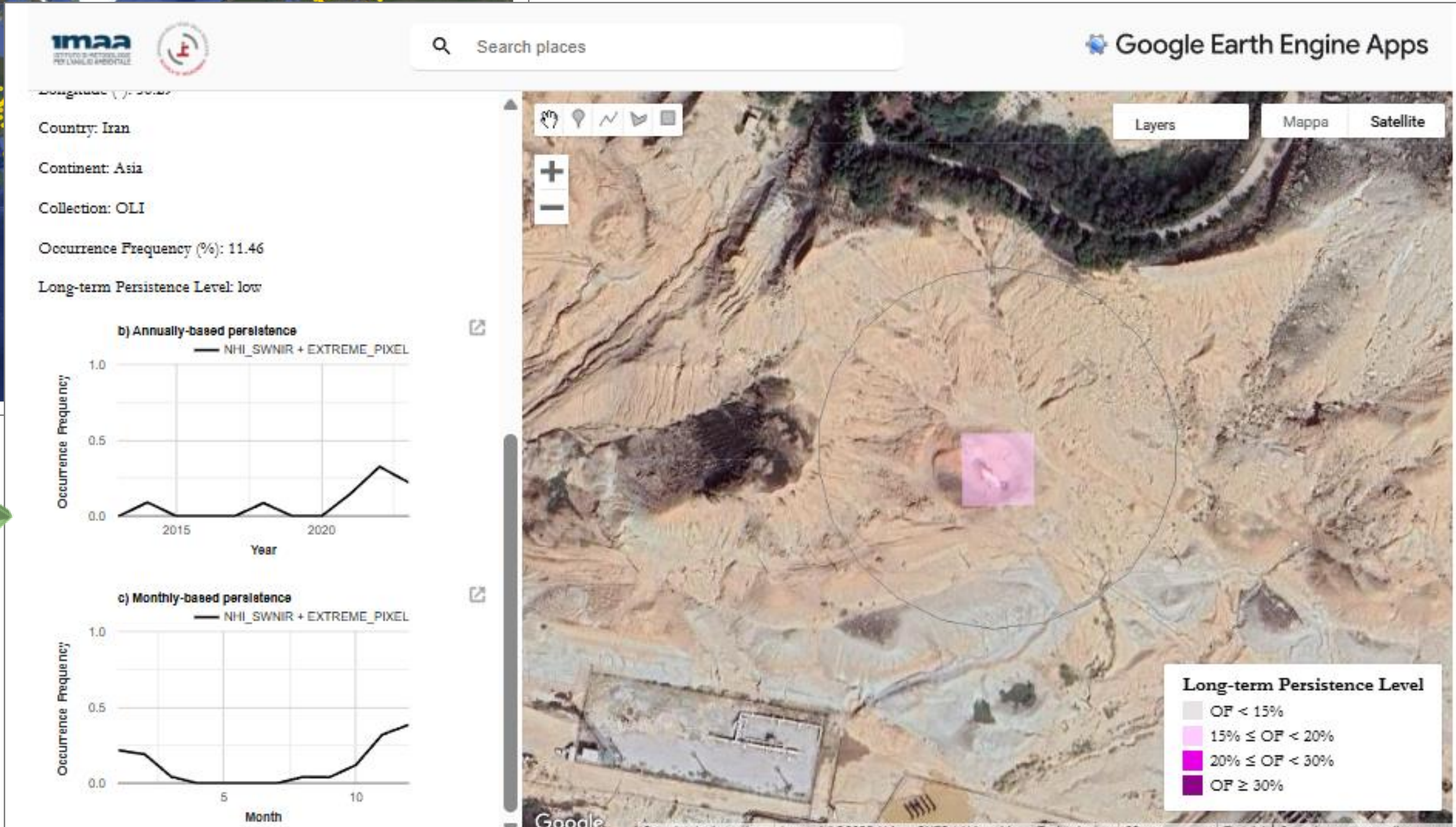
GFs_2013-2023

GFs_2013-2024 - available soon

Periodic updating

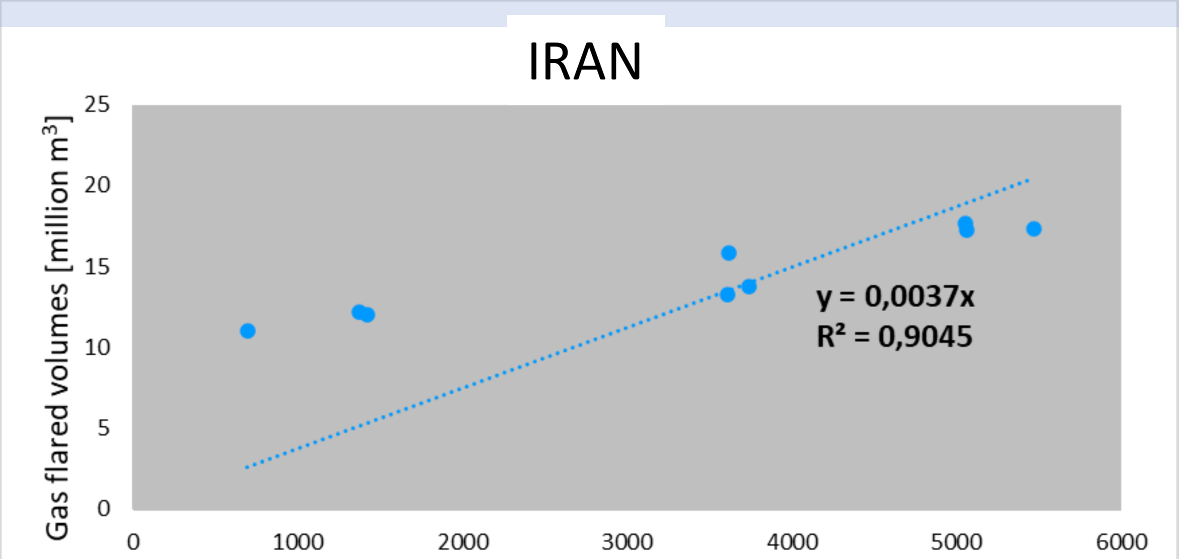
NHI-F for industrial sites: Gas Flaring characterization

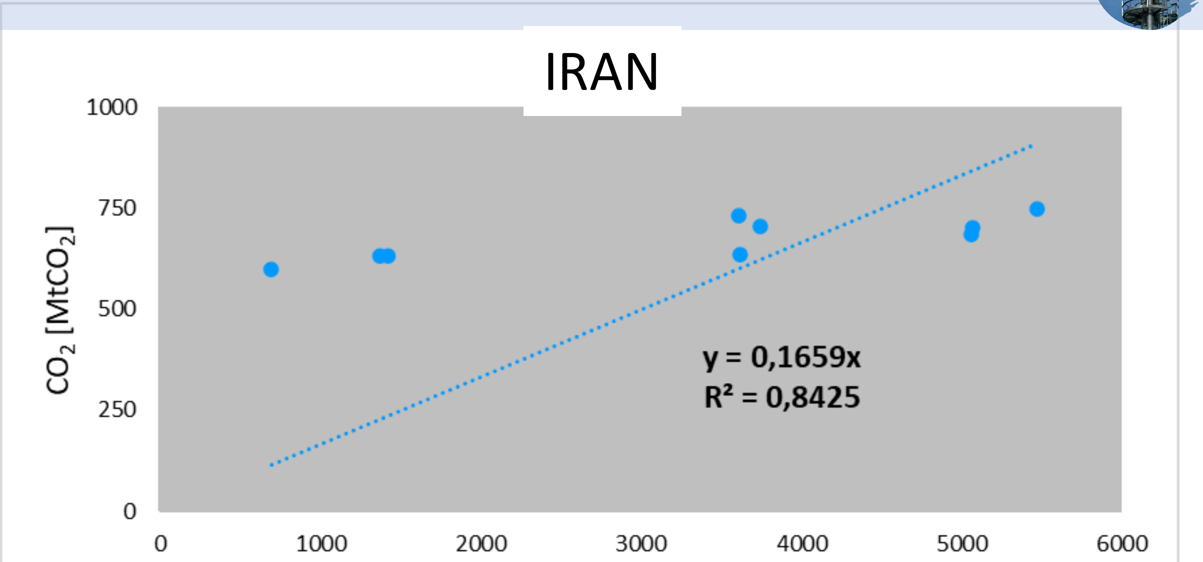




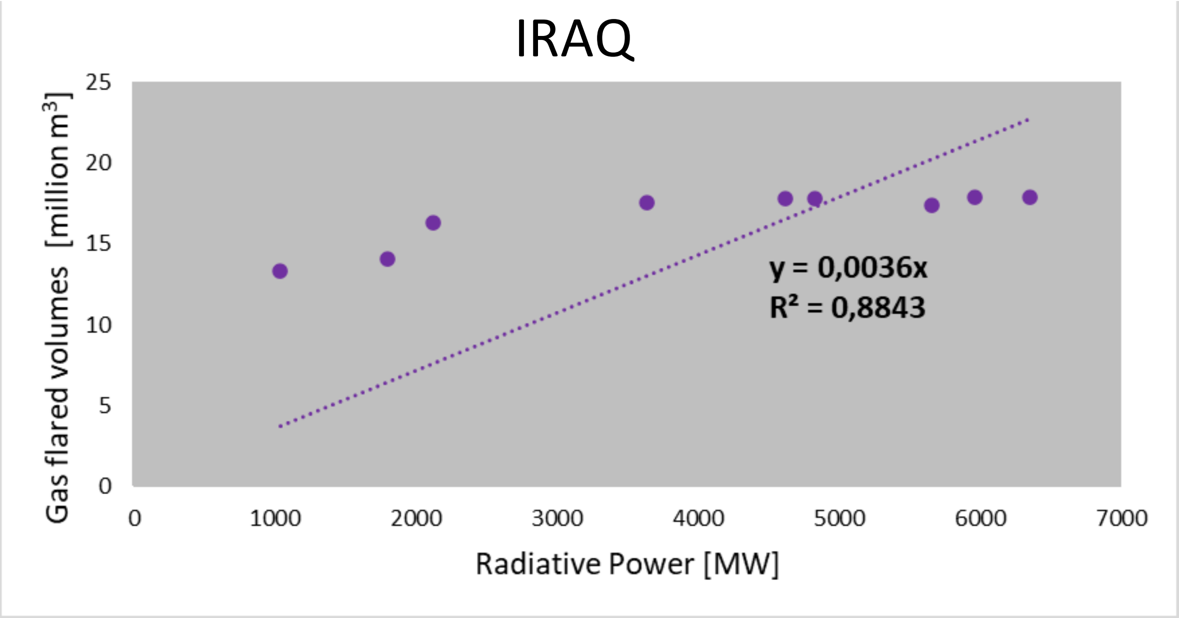
Time persistency and Occurrence frequency

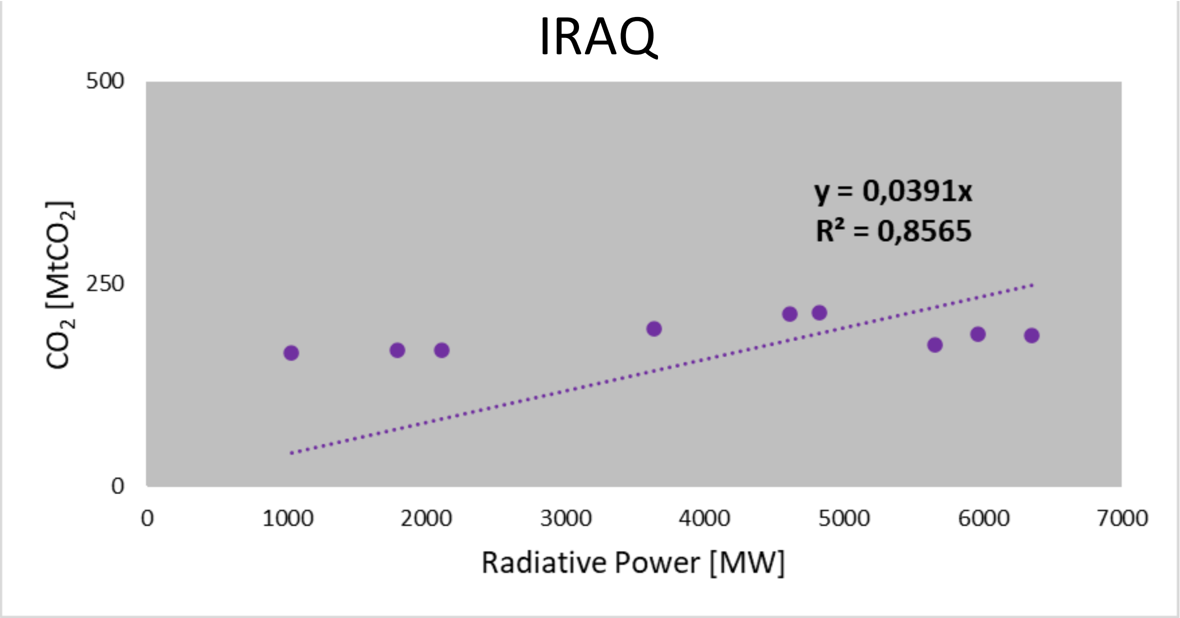
NHI-F for industrial sites: Gas Flared Volume estimation





High correlation factor for both CO_2 (R^2 > 0,84) and Total Volumes (R^2 > 0,88)

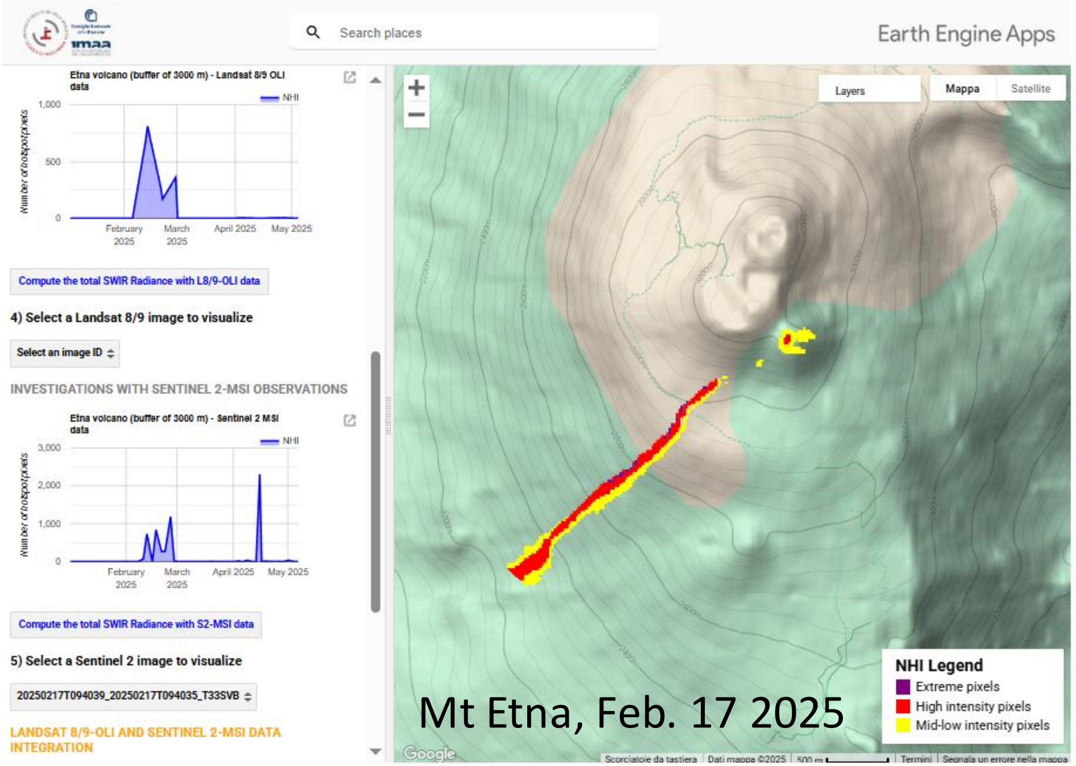




Source CO_2: Global Carbon Atlas; Source gas flared volumes: EOG, https://eogdata.mines.edu/products/vnf/global_gas_flare.html#catalog

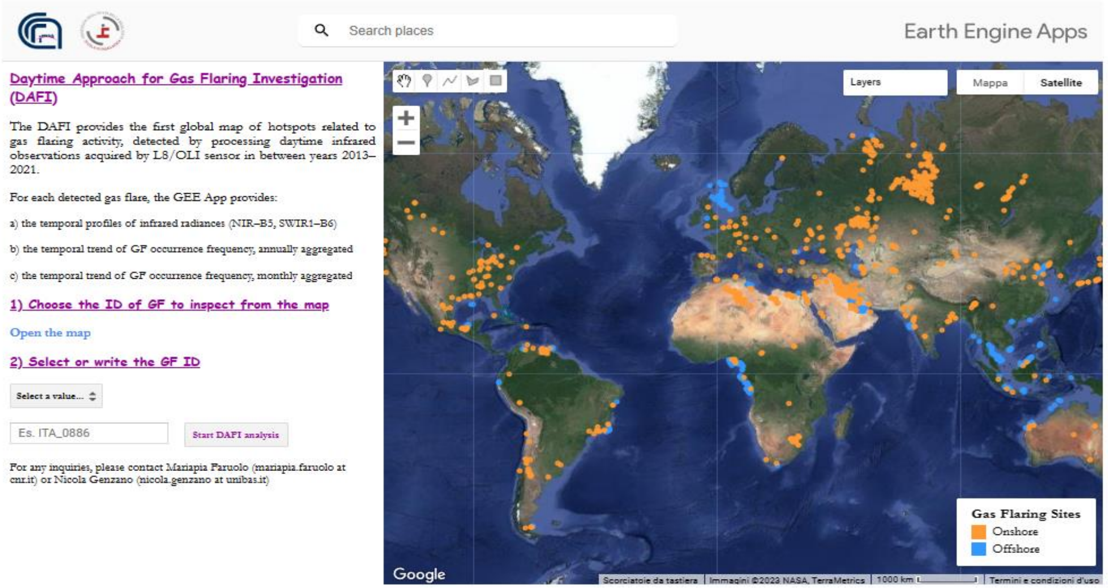
Open tools for sharing satellite products

NHI (Normalized Hotspot Index) Tool: an open platform for mapping and monitoring thermal activity of ~1400 volcanoes at global scale



Freely available at:
https://nicogenzano.users.earthengine.app/view/nhi-tool

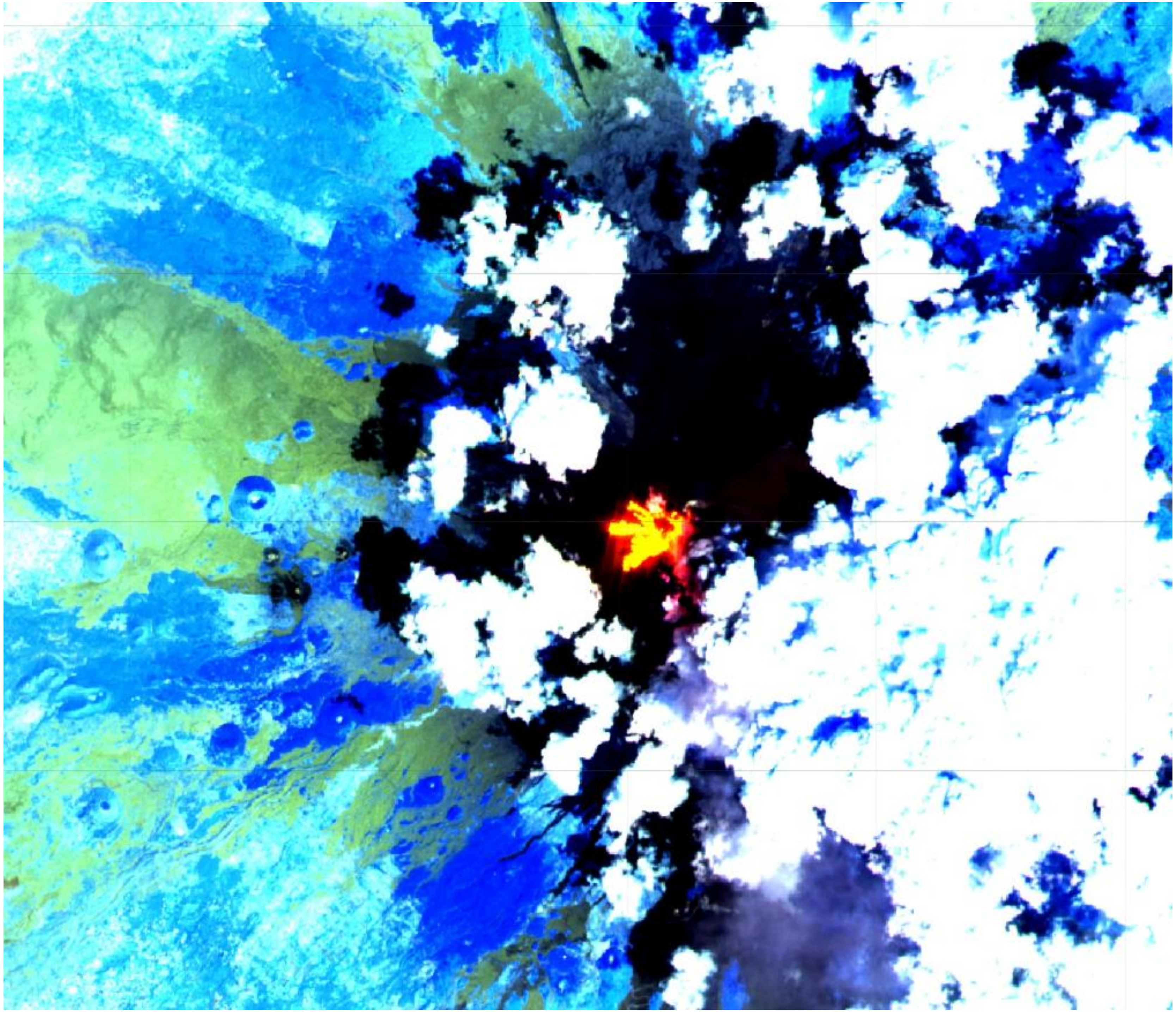
DAFI (Daytime Approach for gas Flaring Investigation): a GEE App for worldwide gas flaring mapping, analysis and characterization



Freely available at:
https://sites.google.com/view/flaringsitesinventory)

Tema di R&D per il futuro:

To improve hot source investigation and characterization capability from space by exploiting a multi-mission, multi-sensor, integrated satellite system (e.g., LEO+GEO)



THANK YOU FOR YOUR ATTENTION

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