Forum TERATEC 24

# The Volcano Space Observatory : an interdisciplinary web portal for the monitoring of volcanic activity and atmospheric hazards

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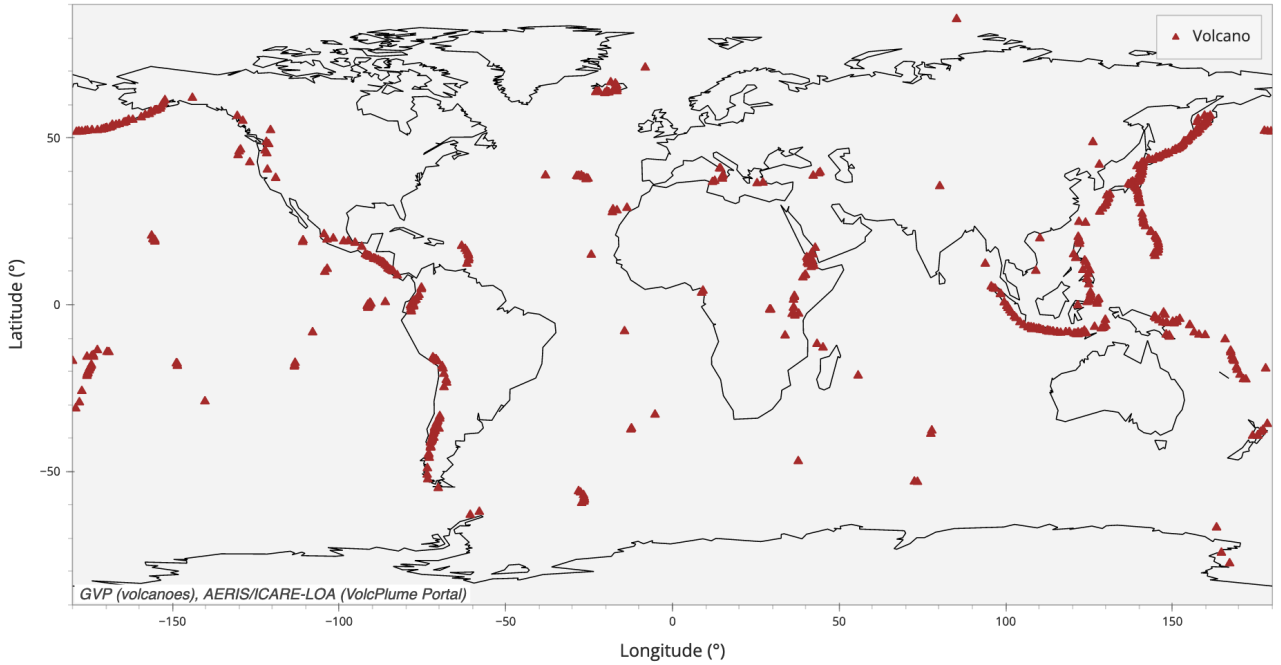
(3) Univ. Lille, ICARE Data & Services Center

# Most active volcanoes are remote and unmonitored

- Most active volcanoes in the word are remote and not monitored.




- If a volcano observatory is present, instruments can be destroyed or dysfunctioning in case of explosive eruption (ex. Soufriere St. Vincent, Antilles, Apr 2021)

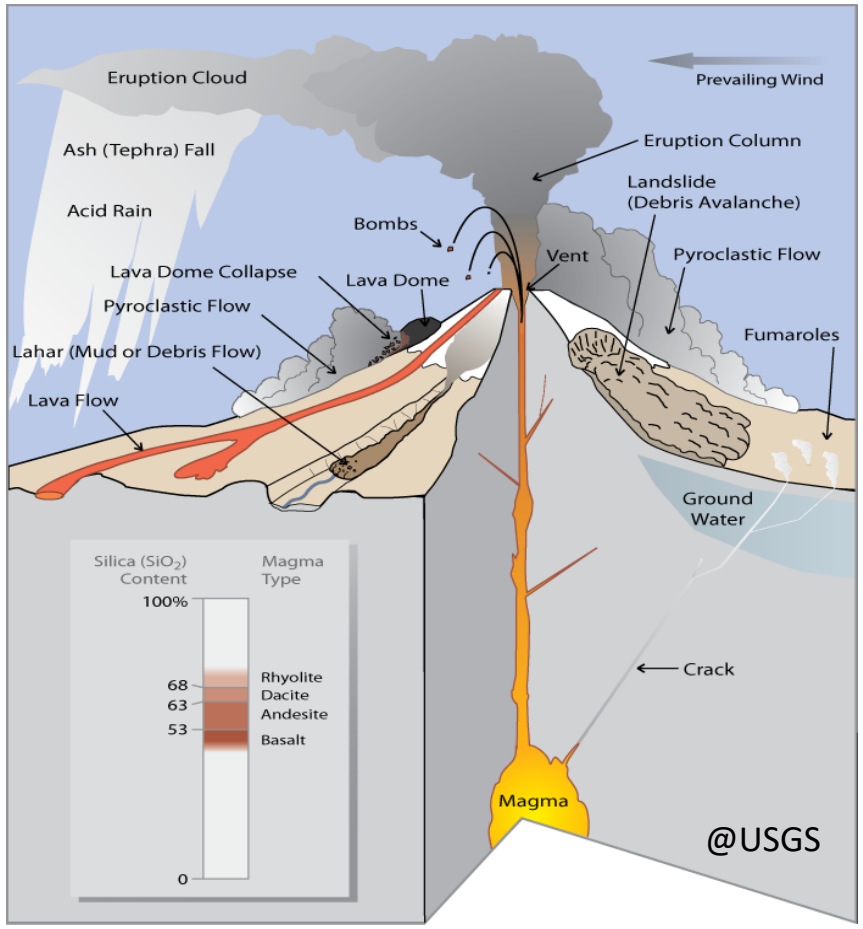
- More broadly, we need a stronger coordination between in situ/ground monitoring and satellite-based monitoring.

# Local & atmospheric hazards produced by volcanoes

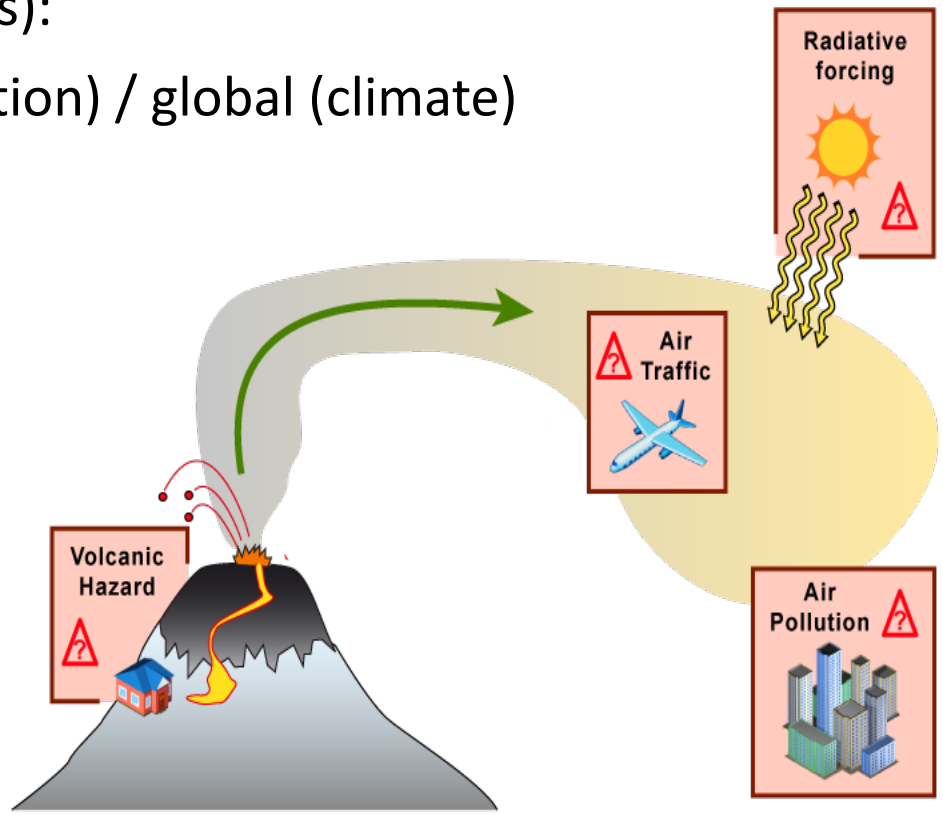
Various volcanological & atmospheric hazards over multiple geographical scales:

- Lava flows: local
- Pyroclastic flows: local (sometimes regional)
- Tephra / ash: local => regional (aviation/VAAC)
- Volcanic gases: local => regional/continental (air pollution)
- Aerosols (sulfate aerosols):

  local / regional (air pollution) / global (climate)




Local volcanic hazards

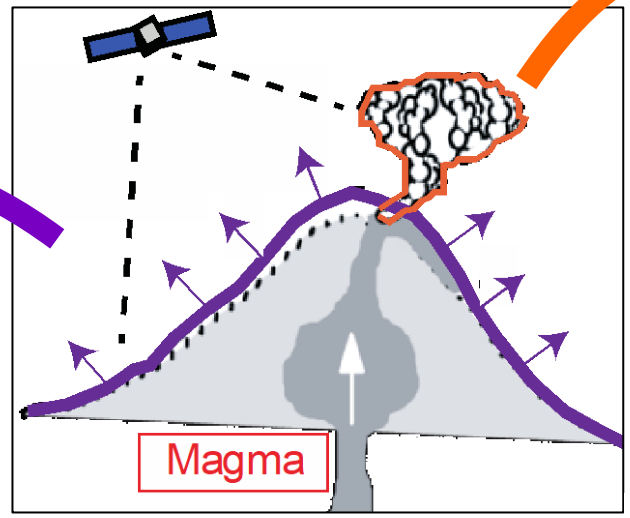



Large-scale hazards

# From space: access to gas-particle emissions & ground deformation (also thermal activity)

## Ground deformation

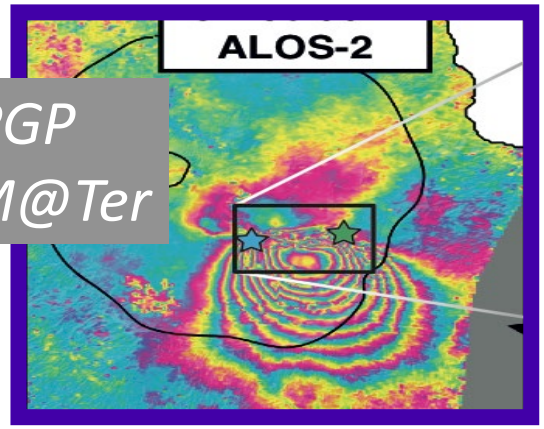
Access to:
- transport & magma storage
- volume budget




## Gas-particle emissions

Access to:
- Magma composition, depth
- mass budget
- flux

### InSAR




*IPGP ForM@Ter*

20 km

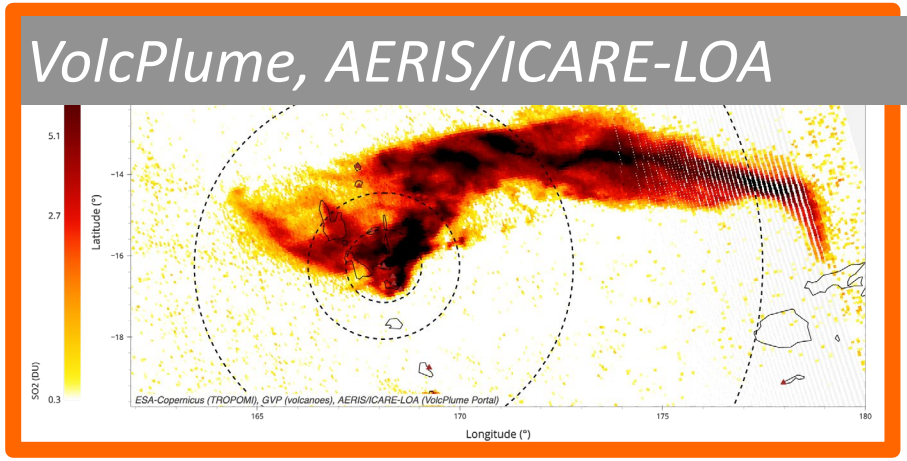
pixel size = 1–100 m

Revisit time: ~ 6 days

### Topography


### TROPOMI/IASI/OMPS – $SO_2$

*VolcPlume, AERIS/ICARE-LOA*




1000 km

pixel size = 5–25 km

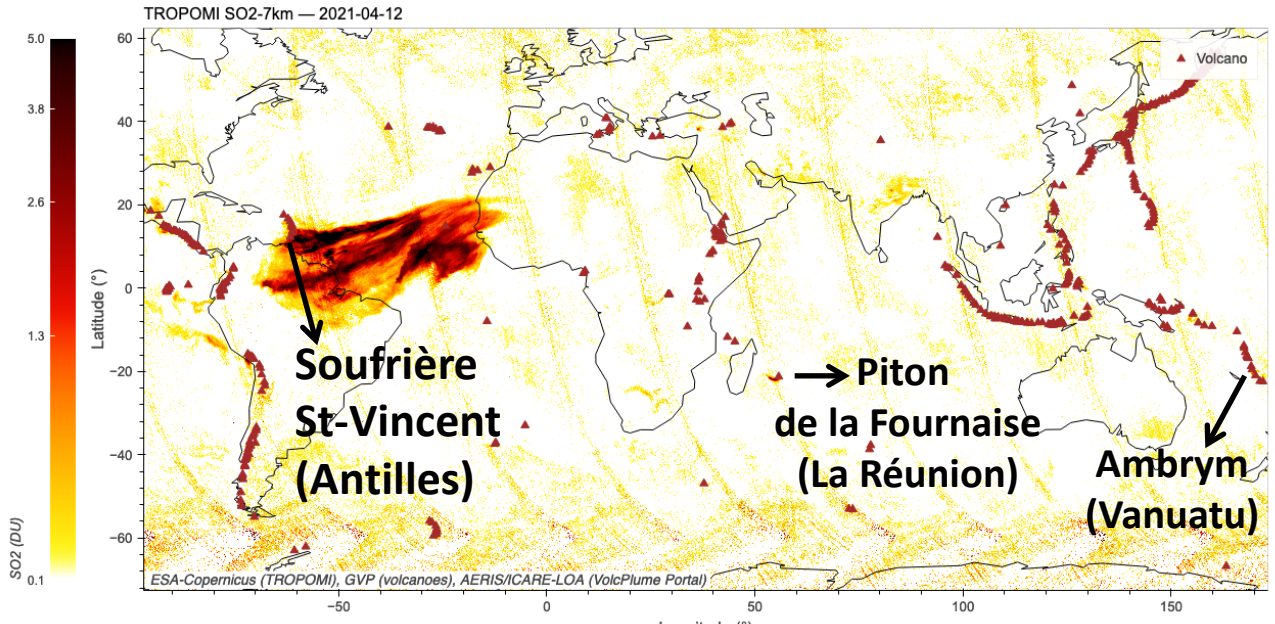
Revisit time: 12 or 24 hours (LEO)
(20 min for GEO)

# Four volcanic case-studies

- **Ambrym volcano, Vanuatu (2004-today)**:
  - Remote volcano with difficult access, poorly monitored from the ground, poorly-populated island
  - Long-term (multi-decade) degassing and lava lake activities, abrupt cessation after eruption in 2018 (mainly sub-terranean or sub-marine)

- **Soufrière St-Vincent volcano, Lesser Antilles (Dec 2020-Apr 2021):**
  - Volcanological Observatory (UWI-SRC), densely populated island, but many instruments destroyed or dysfunctioning during the ash-rich explosive eruption (thick ash deposits, electrical failures, etc)
  - Harsh meteorological conditions during eruption

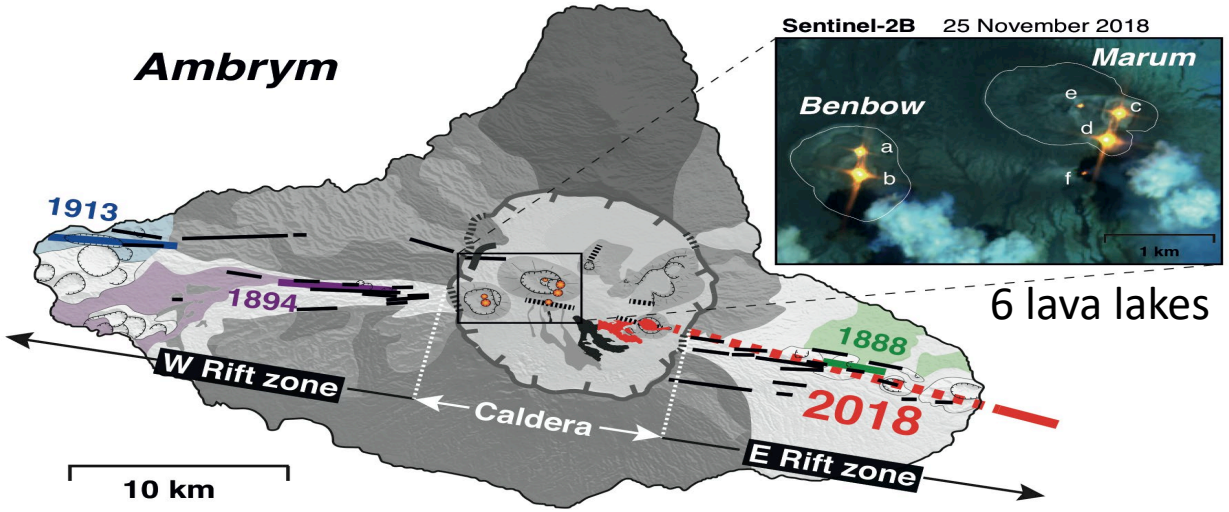
- **Piton de La Fournaise volcano, La Réunion (Sept-Oct 2022 & 2023):**
  - Volcanological Observatory (IPGP/OVPF)
  - Effusive eruptions usually
  - Events of air pollution
- **Hunga Tonga (2022):** a record breaking eruption with an impact on climate



# Multi-year activity of a volcano from space

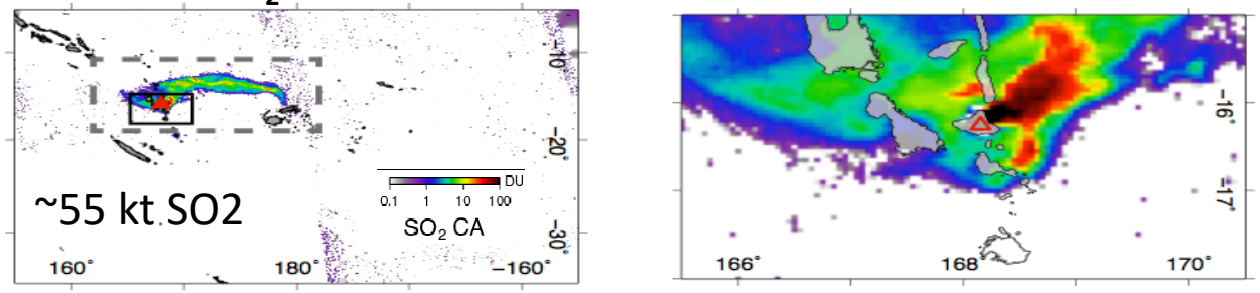
## Ambrym volcano (Vanuatu)

### Multi-decade lava lake activity




Shreve et al. 2019

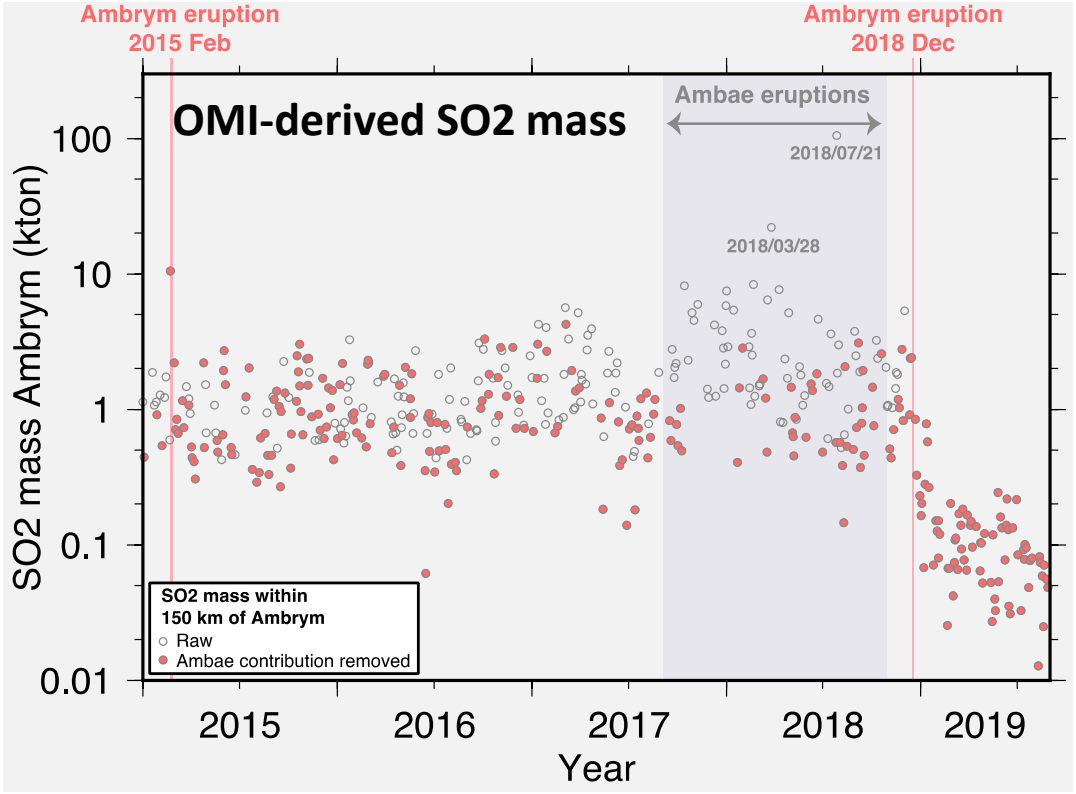
### TROPOMI $SO_2$ – 16 Dec 2018




### Degassing during the 2018 eruption before its cessation

1st worldwide $SO_2$ volcanic emitter (Carn et al. 2017)

### Multi-year sustained degassing activity before 2018 eruption

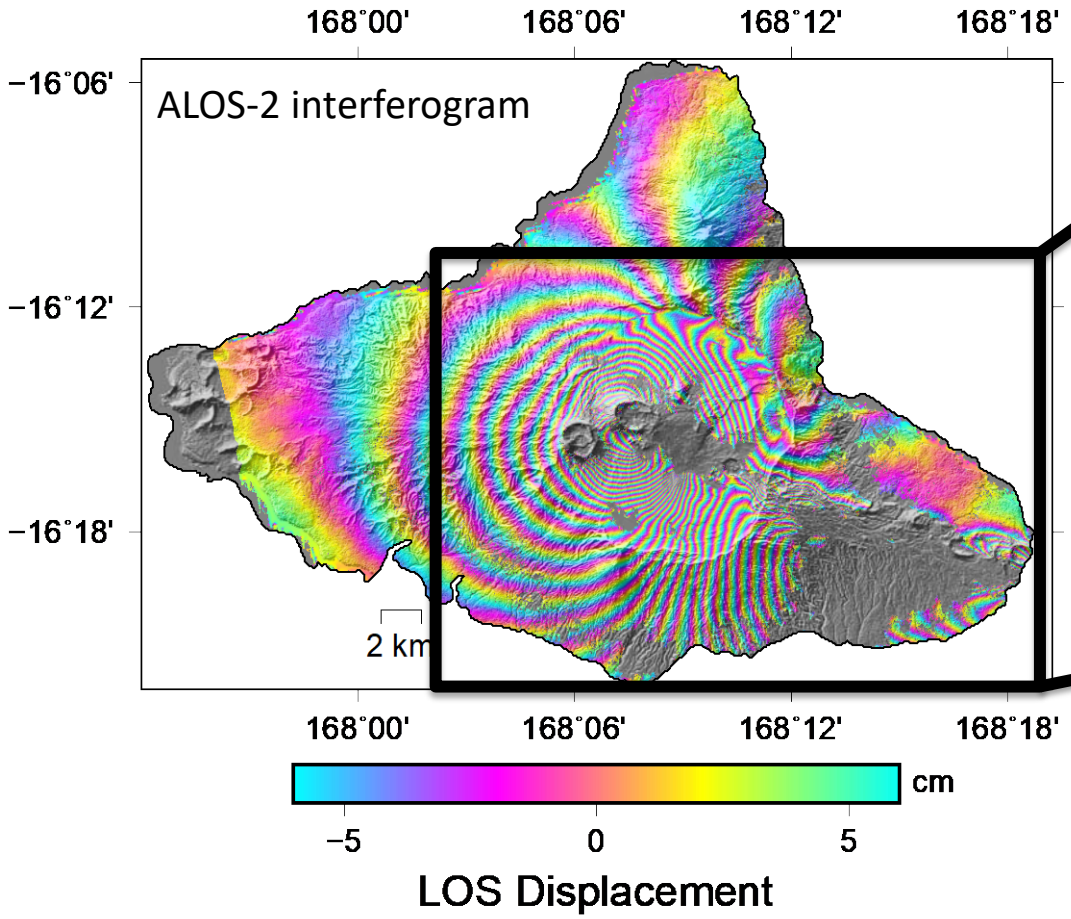



Shreve et al. 2022

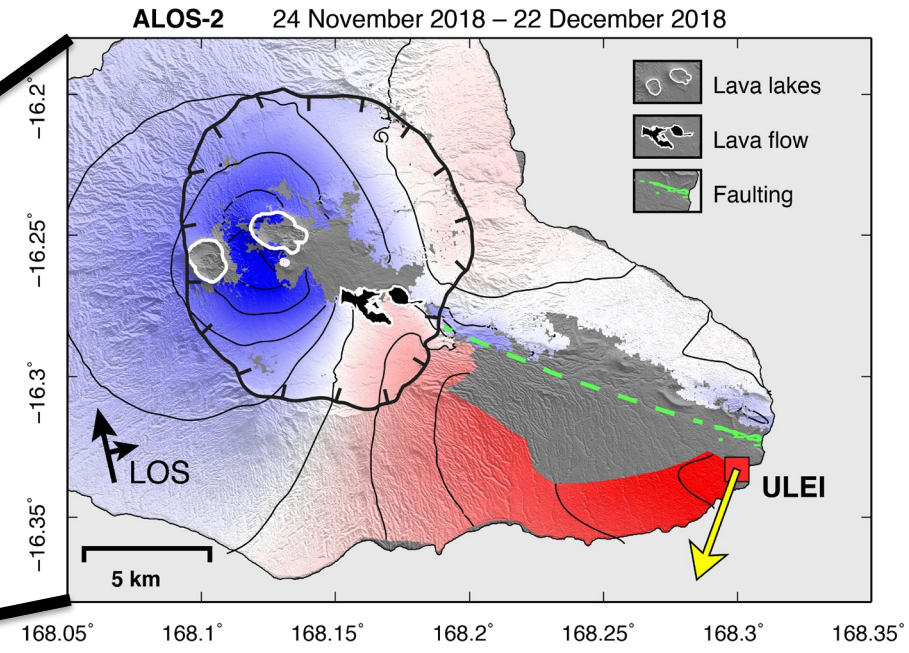
# Cessation of degassing & lava lake activites coincides with a major magma intrusion detected by InSAR

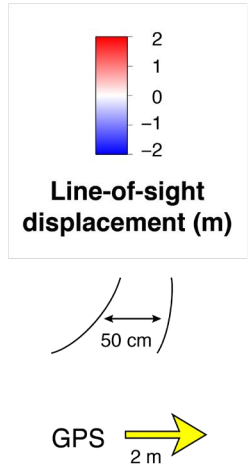
Ambrym volcano (Vanuatu)

## InSAR: Interferometric Synthetic-Aperture Radar (ALOS-2, Sentinel-1)




## Deformation after phase unwrapping




**Subsidence: 2 meters in caldera**
**Coastal uplift: 3 meters**
**Volume of magmatic dike intrusion: 0.5 km³**

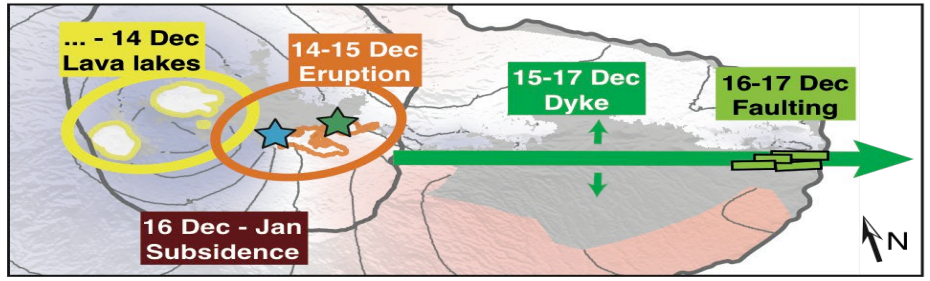
Shreve et al. 2019

➔ **A quasi-silent eruption, with moderate gas emissions, but a major magma intrusion at shallow depth !**

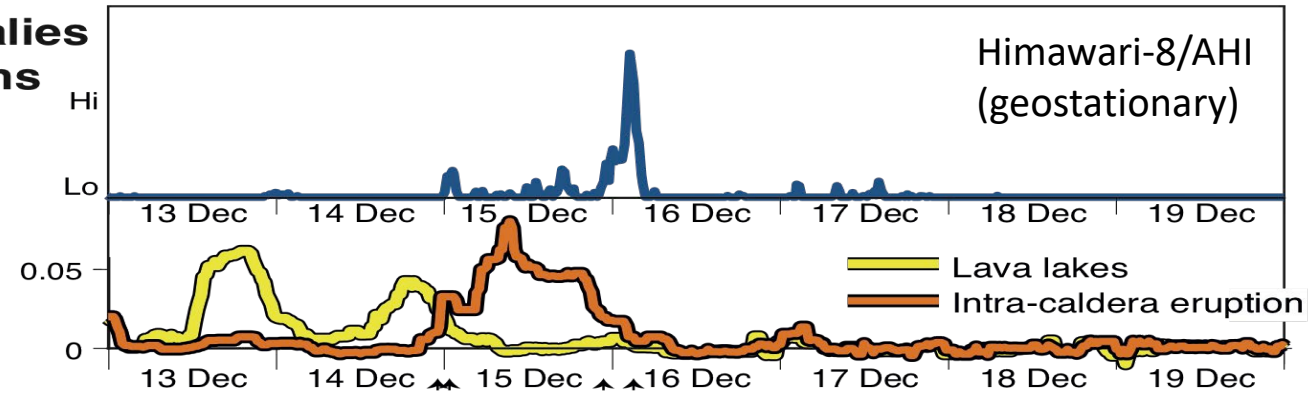
# High time resolution monitoring of the eruptive activity from space

## Ambrym volcano (Vanuatu)

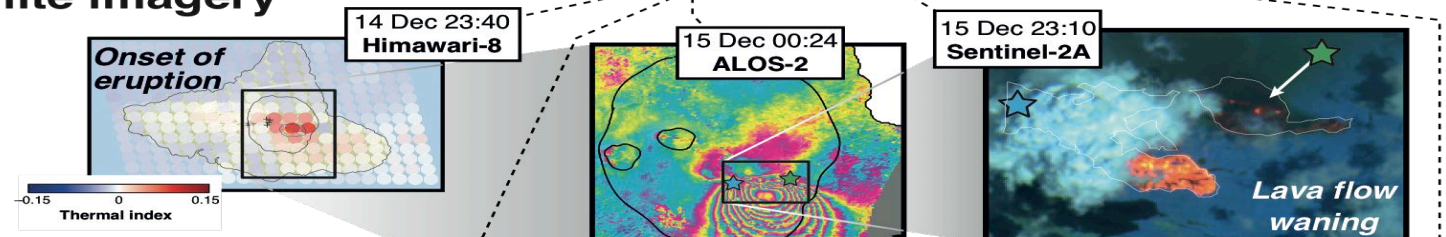
**Deformation**




**Thermal anomalies & $SO_2$ emissions**




**Satellite imagery**




**Ground observations**

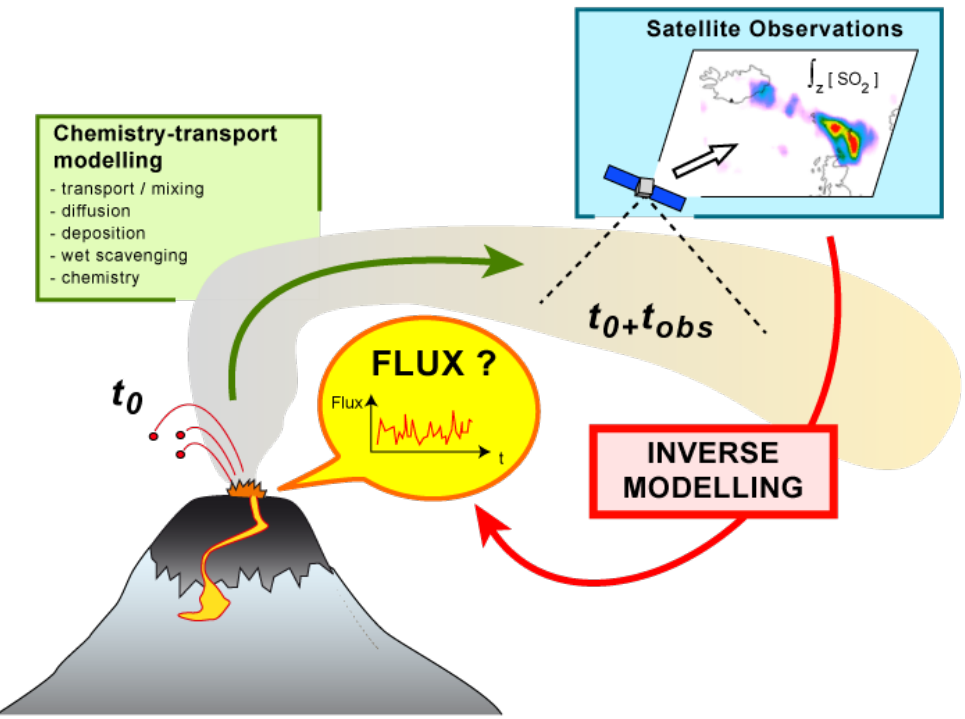

- Lava lake drainage coincident with:
  - intra-caldera dike
  - intra-caldera eruption/lava flow
- Then 2nd major magma dike that propagates at shallow depth out of caldera until the sea coast

**Shreve et al. 2019**

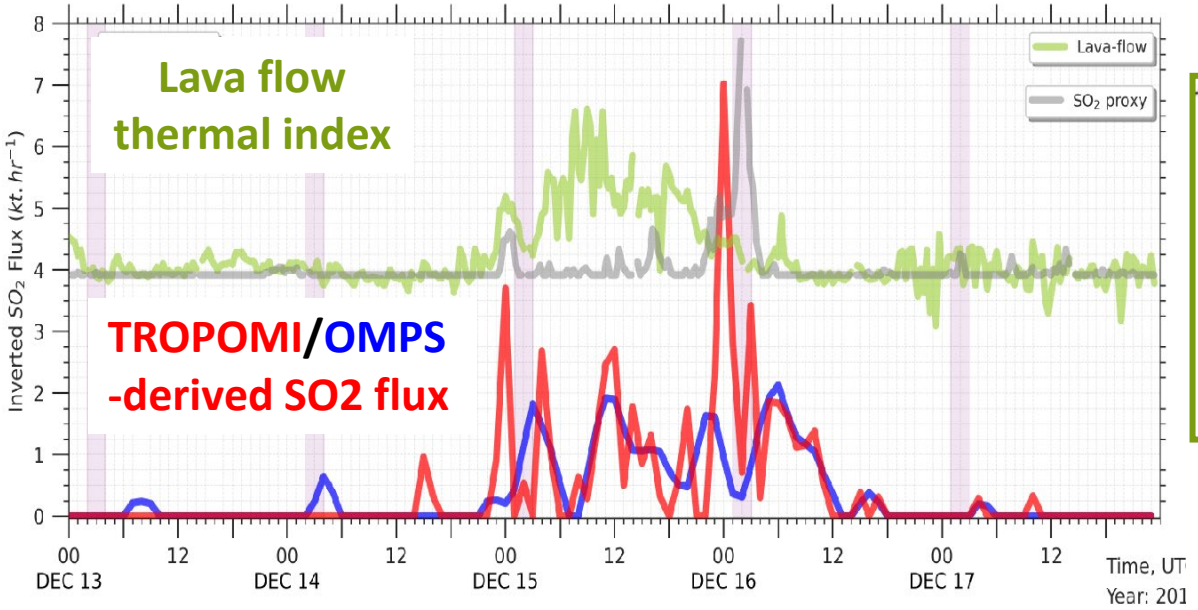
# SO2 degassing at high time resolution derived from TROPOMI observations (by inverse modeling)

Ambrym volcano (Vanuatu) - 2018

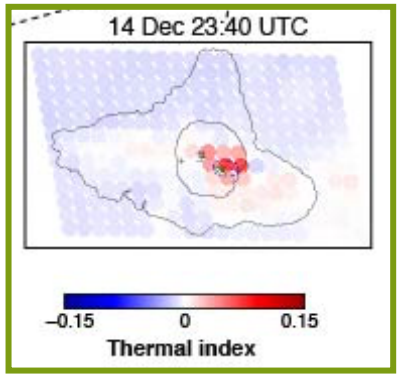
**Inverse modeling**
**using a chemistry-transport model**



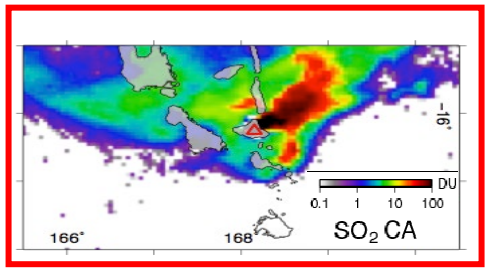

Boichu et al. (2013, 2015)




**HIMAWARI-8/AHI lava flow pixels**




**TROPOMI SO2**




16 Dec 2018

**Behera et al. (Egusphere 2023)**
doi.org/10.5194/egusphere-2023-2545

# **VolcPlume Portal:** multi-scale NRT 4D monitoring & analysis of volcanic plumes

**ANR & AERIS projects - PI: M. Boichu (LOA), main software engineer: T. Mathurin (AERIS/ICARE)**

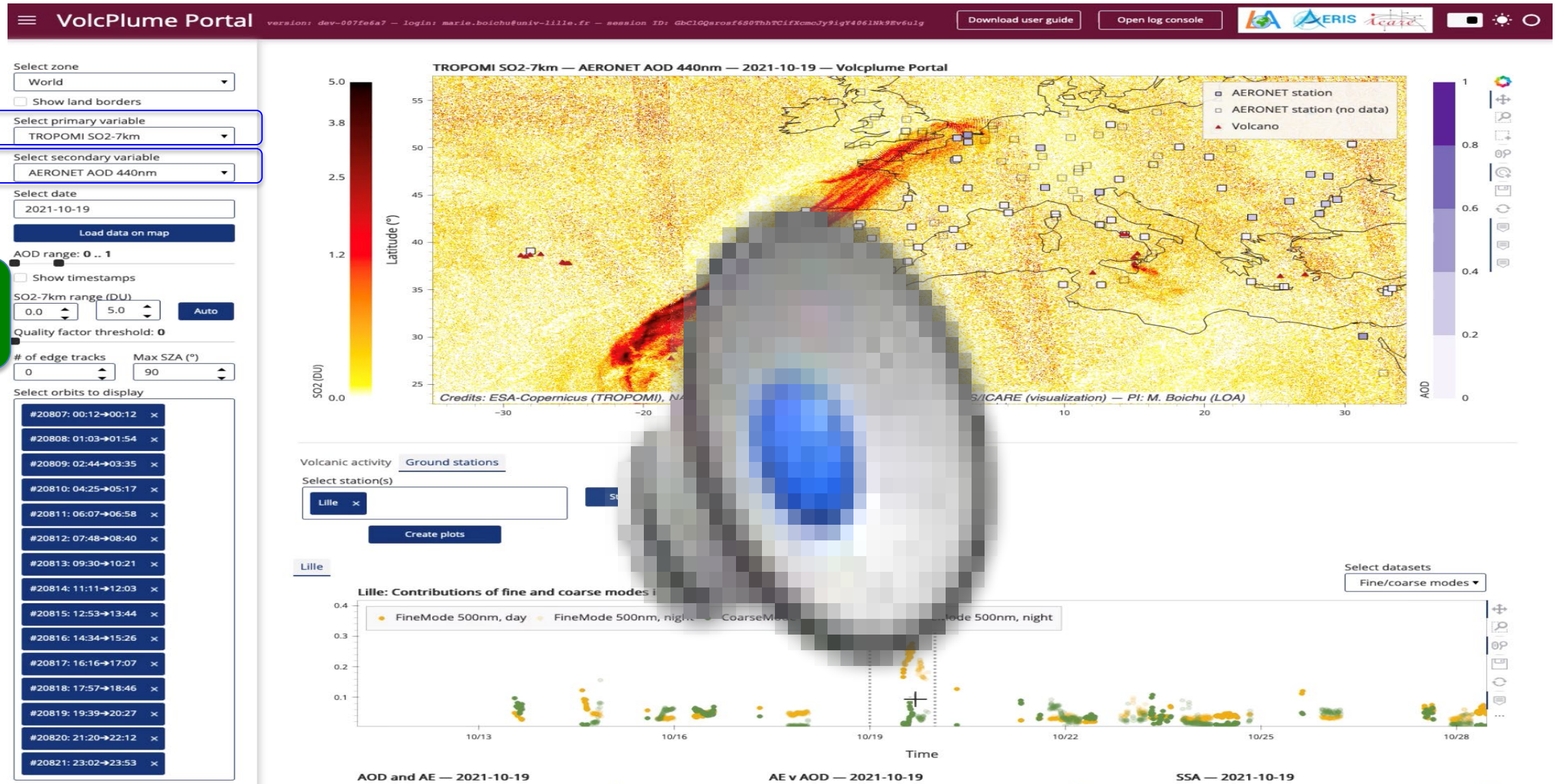
https://volcplume.aeris-data.fr (public access) - https://www.icare.univ-lille.fr/volcplume/

**Satellite**

**Ground**

remote sensing + in situ

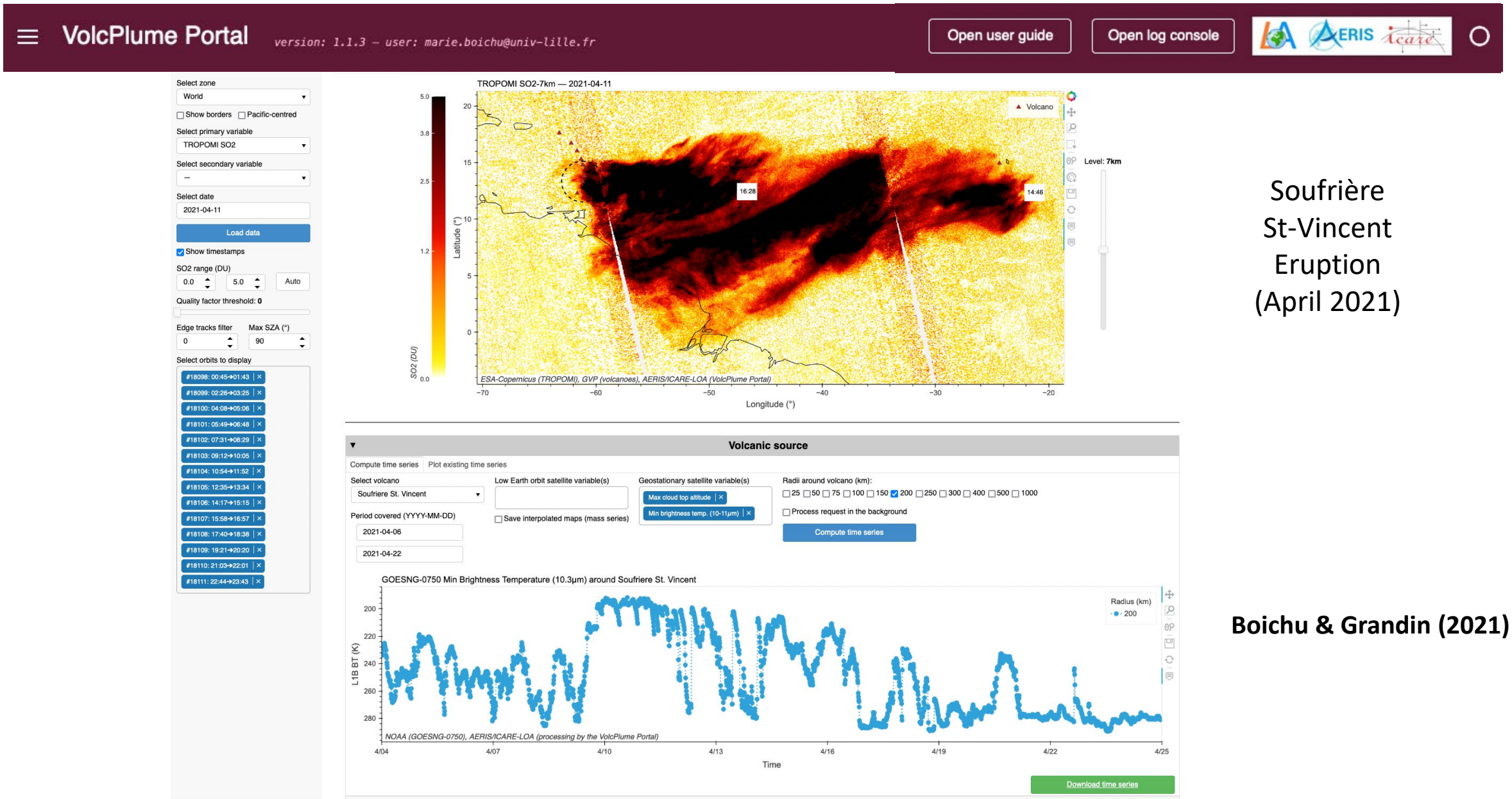
- Gas ($SO_2$)
- Particles
- Clouds




Boichu & Mathurin, 2022, https://doi.org/10.25326/362

# Near real time monitoring from space of explosive activity

## Soufrière St-Vincent (Apr 2021, Lesser Antilles)

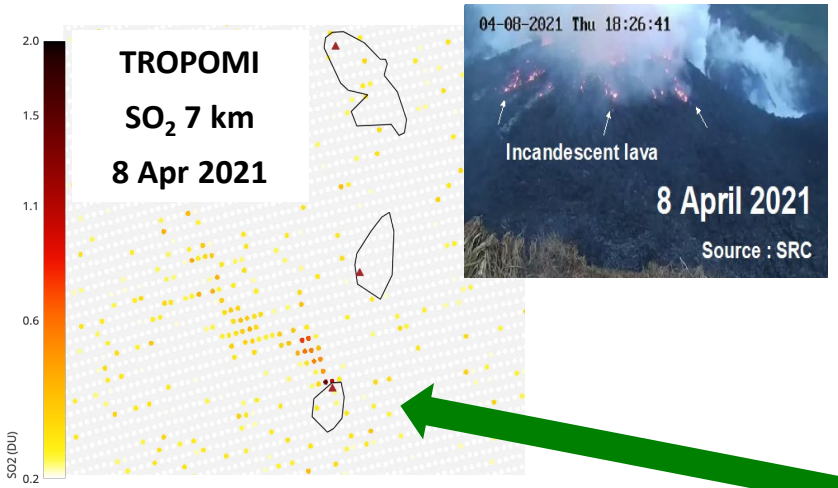



Soufrière
St-Vincent
Eruption
(April 2021)

**Boichu & Grandin (2021)**

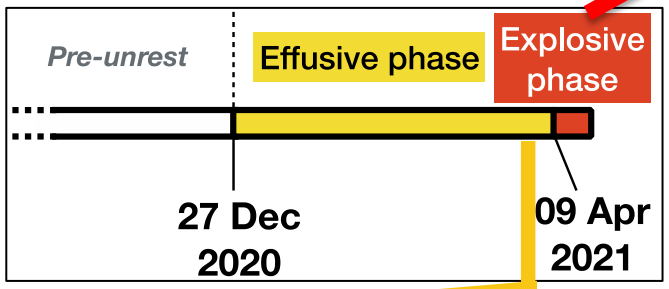
# Near real time monitoring from space of precursory degassing & explosive activity - Soufrière St-Vincent (Apr 2021, Lesser Antilles)

8 Apr 2021:
**Precursory $SO_2$ degassing detected from space one day before explosion**



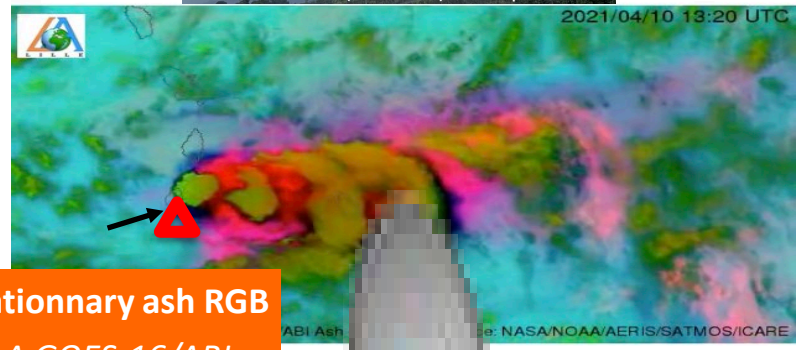




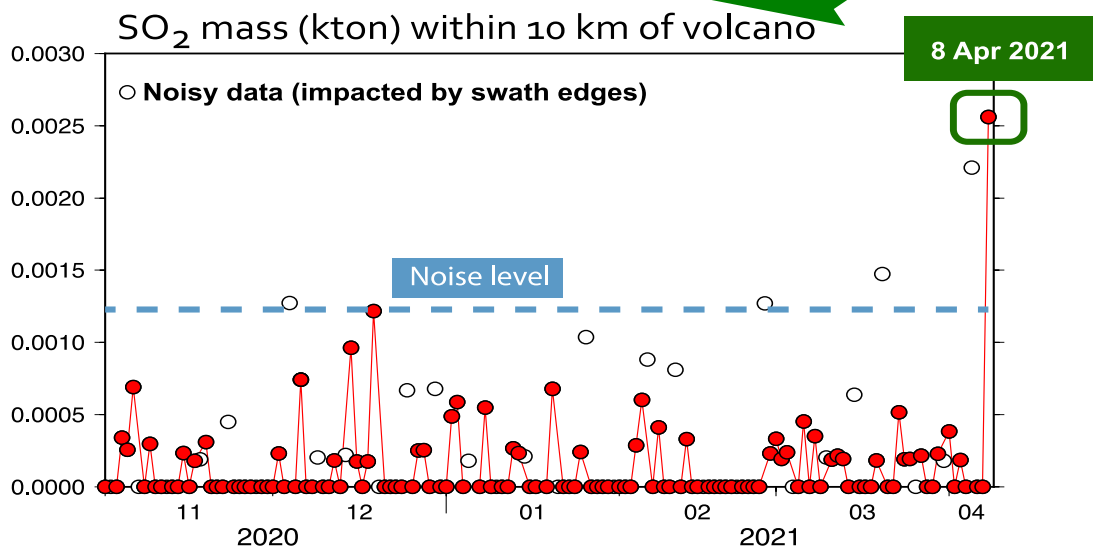


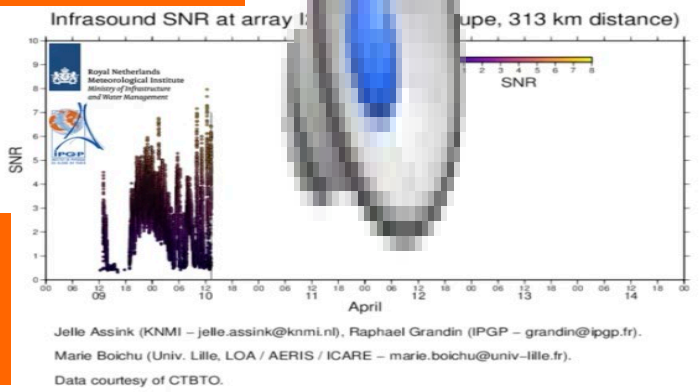

9–14 Apr 2021:
**Near Real Time monitoring of explosive activity**


From the ground




**Geostationnary ash RGB**
*NOAA GOES-16/ABI*



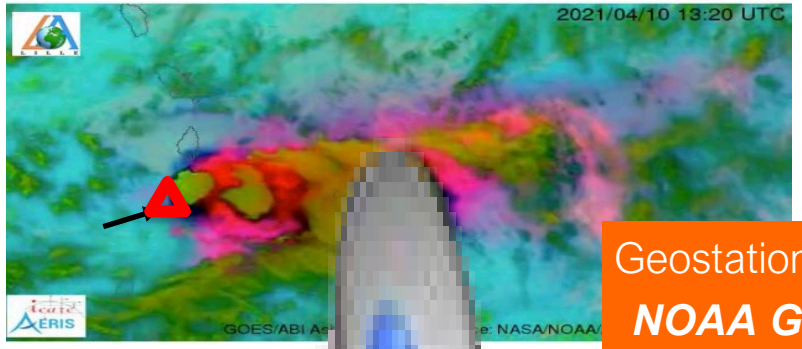

**Infrasounds**
***CTBTO***
*(KNMI/IPGP)*

**Boichu & Grandin (2021)**

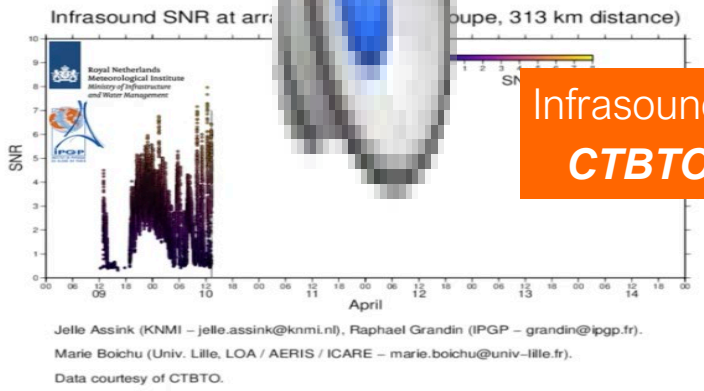
**Synergistic analysis of geostationary & infrasound data**

# Monitoring of explosive activity, summit destruction, pyroclastic flows and ash deposits

## Soufrière St-Vincent (Apr 2021, Lesser Antilles)



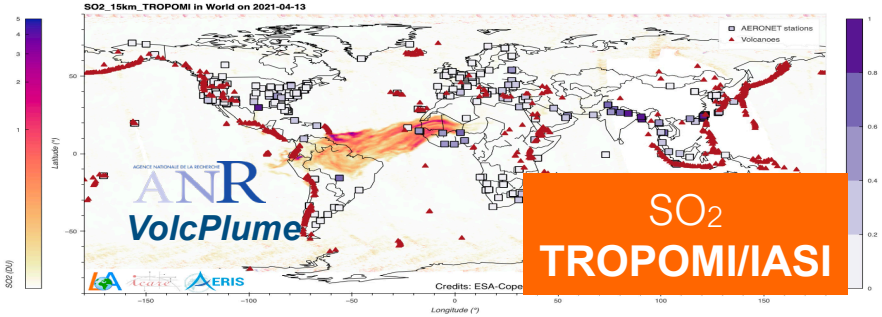

Geostationnary obs
***NOAA GOES-16***



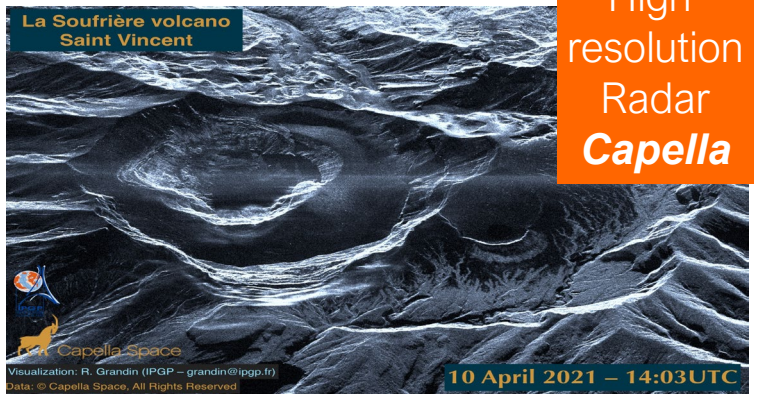

Infrasounds
***CTBTO***

## Remote sensing

- **Multispectral**: ash/gas monitoring
  → eruptive dynamics / air traffic (VAAC) ✈ & air quality
- **Radar**: see through plumes → morphologie du cratère
- **Visible**: deposit volumes → ash mud hazards
- **Infrasound**: «hear » explosions → explosive dynamics




$SO_2$
**TROPOMI/IASI**



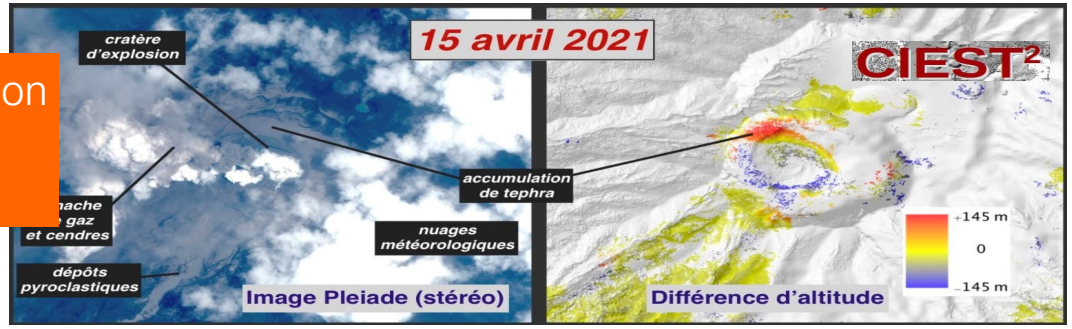

High resolution Radar
***Capella***

Data Terra/inter-poles:

AERIS ForM@Ter

**Horizon Europe FAIR-EASE project**
**« Volcano space observatory » Pilot**
(LOA, Univ Lille & IPGP, Univ Paris)

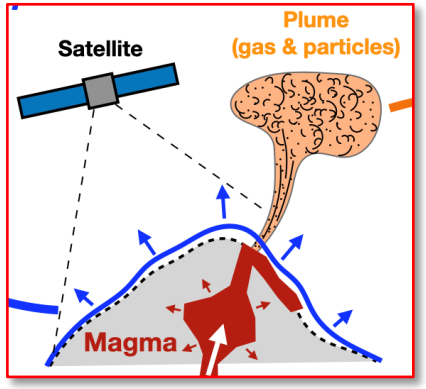
High resolution visible
***Pléiades***

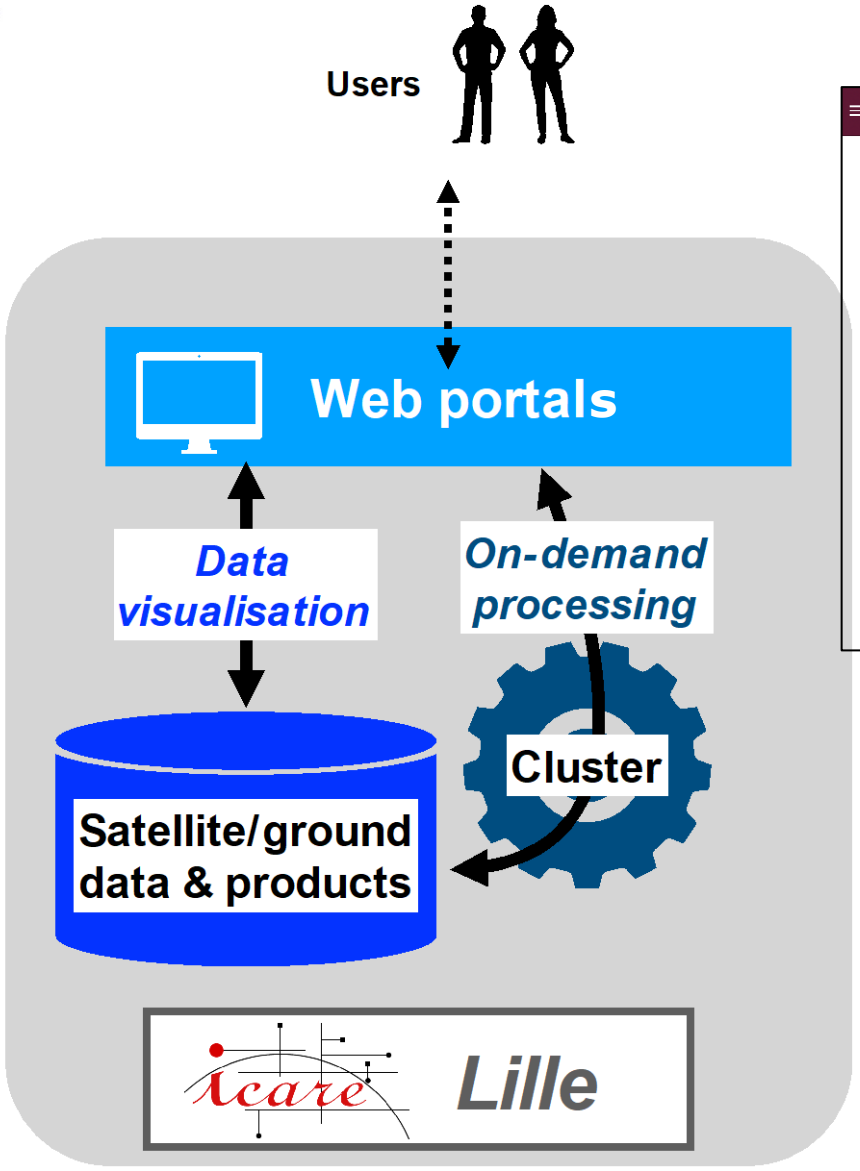


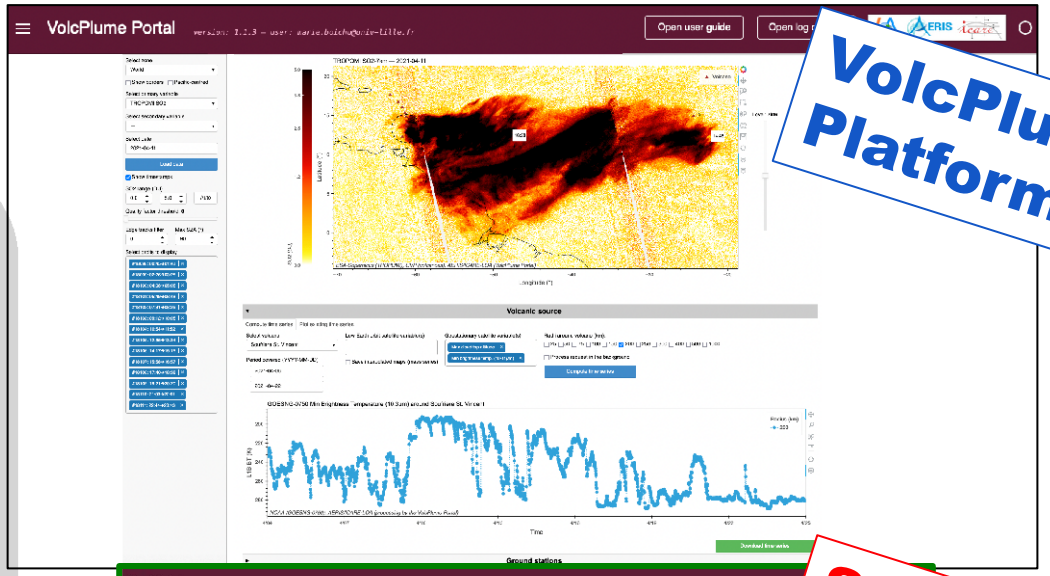

Atmospheric Sciences & Solid Earth-Volcanology project

# Volcano Space Observatory Pilot

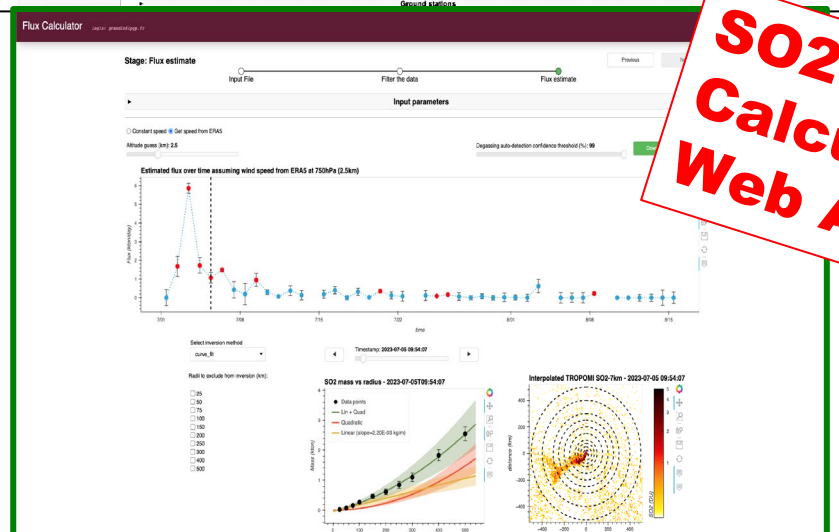
eosc | FAIR-EASE
Building Interoperable Earth Science & Environmental Services




VolcPlume Platform



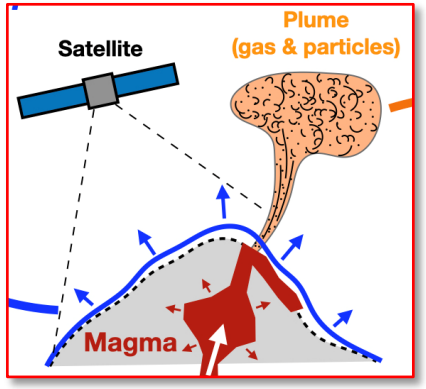

SO2 Flux Calculator Web App

EUROPEAN OPEN SCIENCE CLOUD

# Volcano Space Observatory Pilot

eosc | FAIR-EASE
Building Interoperable Earth Science & Environmental Services

IPGP | Université Paris Cité | ForM@Ter




Users

On-demand processing

Web portal

Cluster

Subsetting

boto3 + rasterio

/s3

Copernicus Data Space Ecosystem

PROGRAMME OF THE EUROPEAN UNION

opernicus

esa

icare

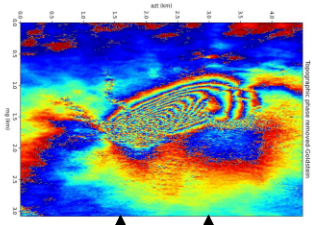
AERIS

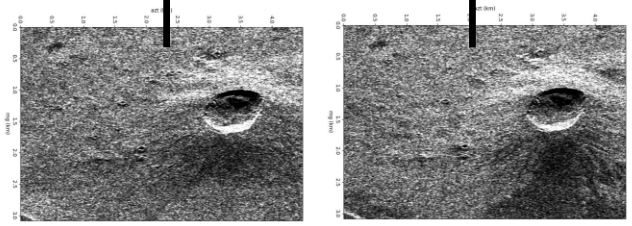
***Heavy data:***
subsetting required,!
ideally *before* download!
!
***Combinatorial explosion:***
suited for parallel computing

« EOS-SAR »
processing chain

KAYRROS

Interferogram





Datatake 1 Datatake 2

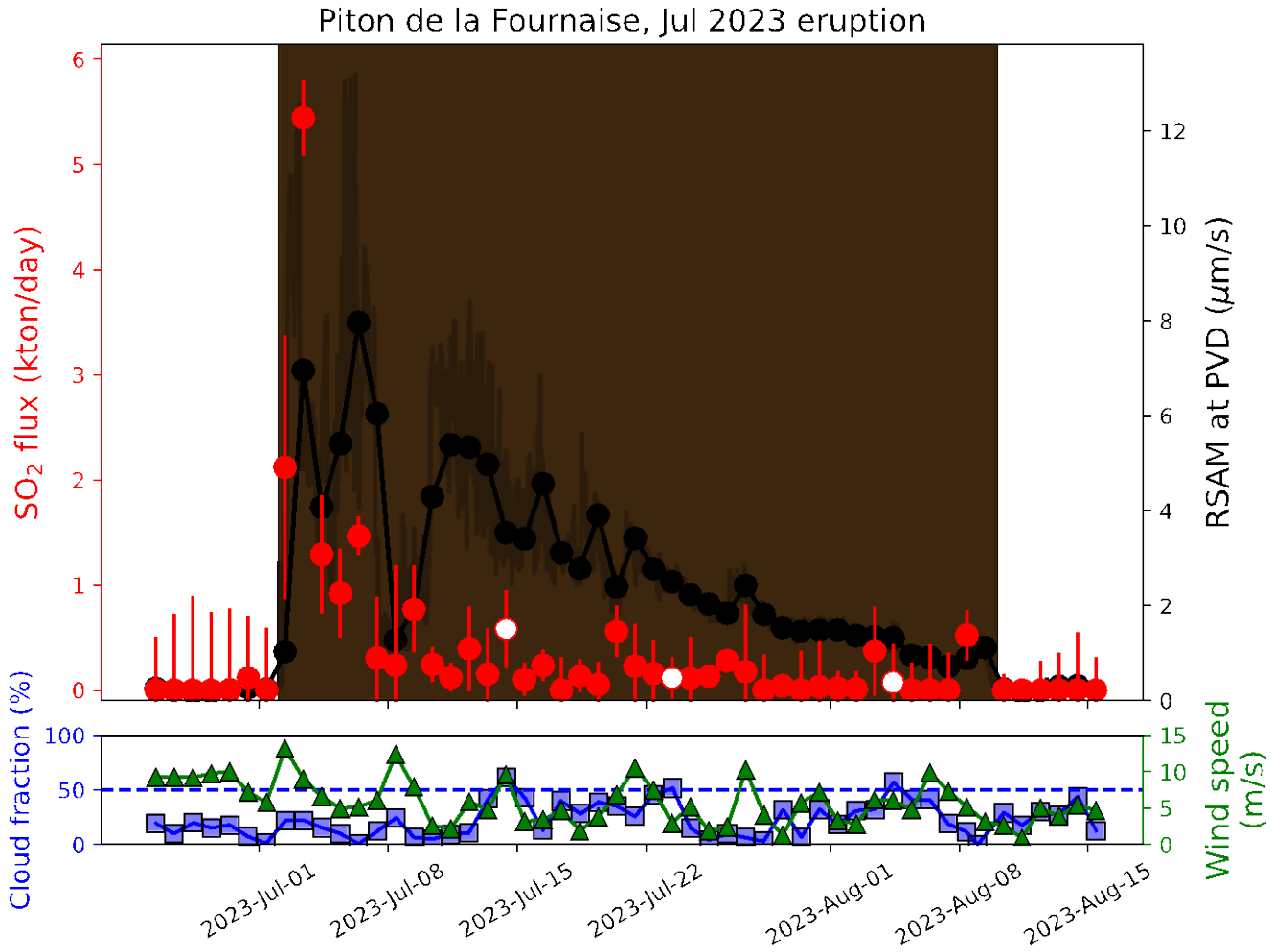
EUROPEAN OPEN SCIENCE CLOUD

# Degassing from space: an additional tool to monitor the volcanic activity

## Piton de La Fournaise (La Réunion, July 2023)

Volcano Space Observatory Pilot

eosc | FAIR-EASE



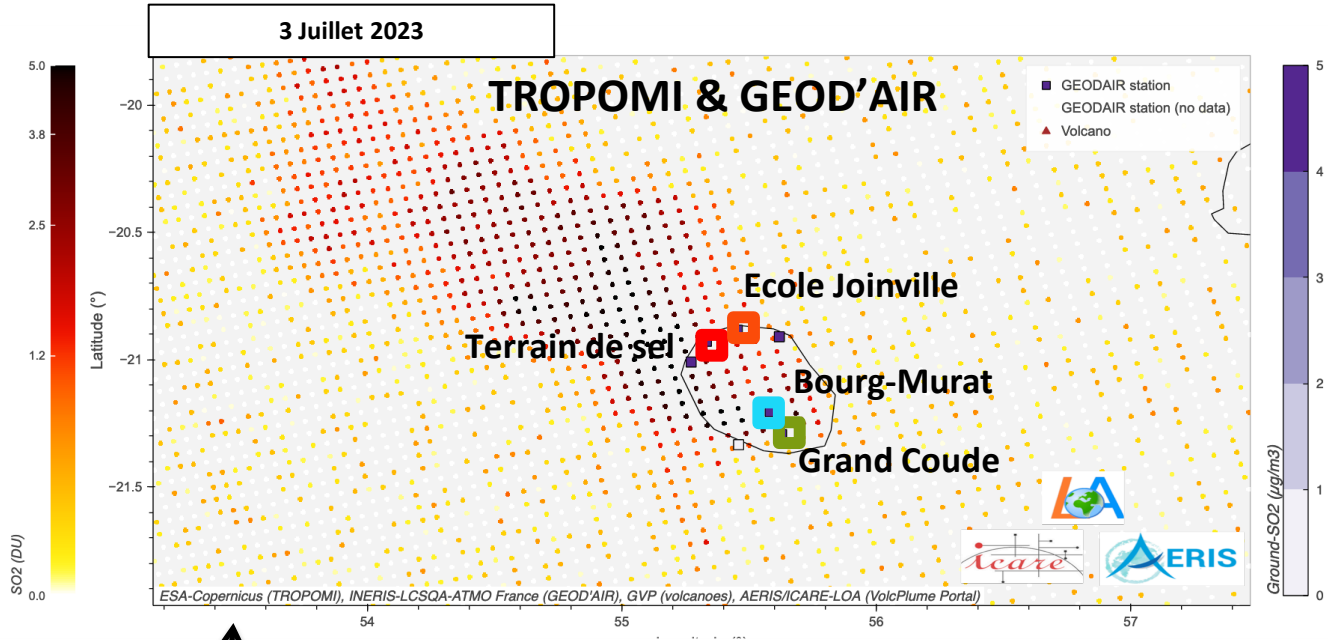

**Grandin, Boichu et al., 2024**
10.22541/essoar.170067242.21872660

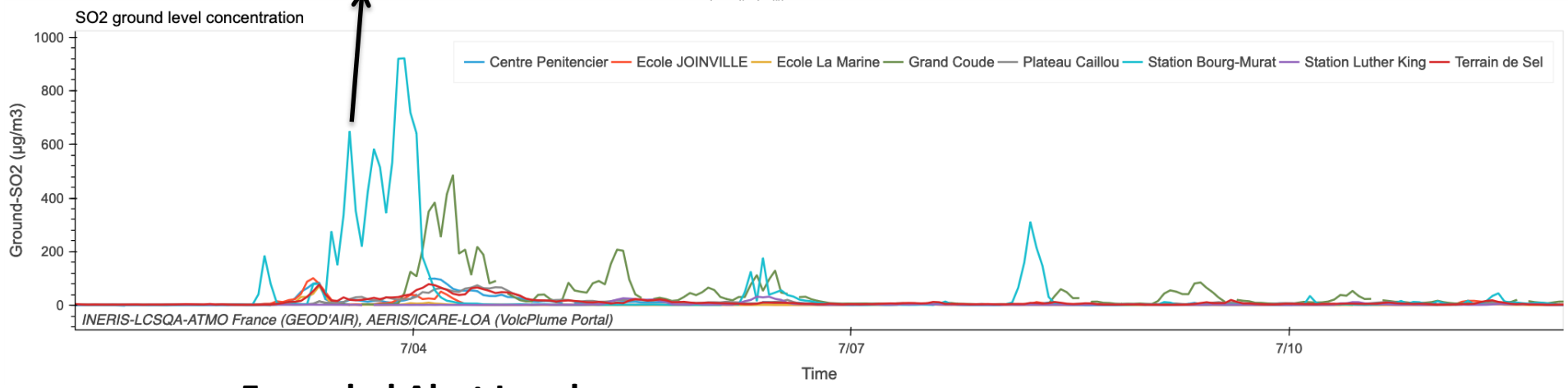
- Broad correlation between seismic activity and SO2 degassing derived from satellite observations => tracking degassing from space is an additional tool to follow the volcanic activity

- SO2 flux calculator: can be massively deployed for automatic detection of volcanic degassing from space

# Air pollution

## Piton de La Fournaise (La Réunion, July 2023)



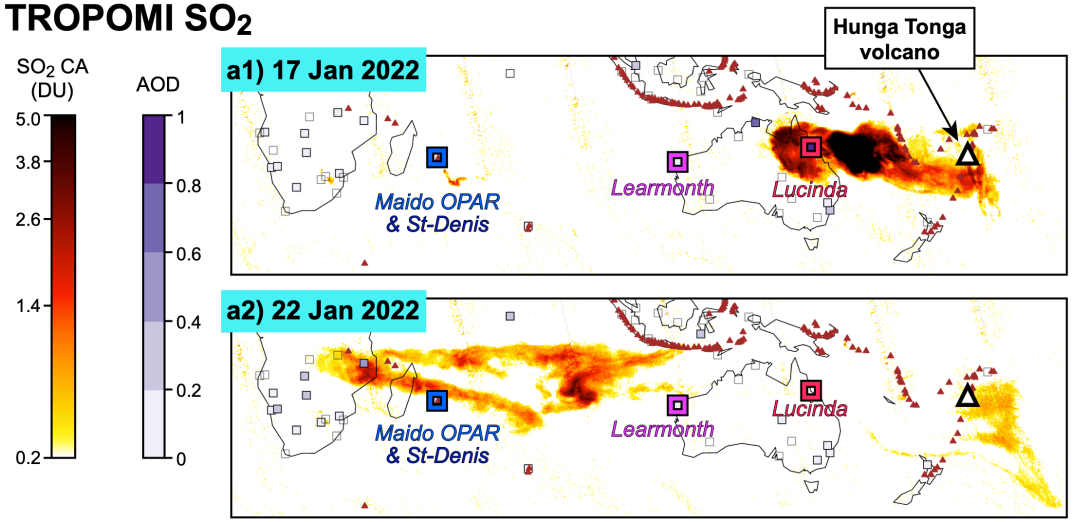

**Exceeded Alert Level**
**(> 500 ug/m3 during 3 hours)**

Boichu & Grandin, Data Terra & AERIS web releases:
https://www.aeris-data.fr/leruption-du-piton-de-la-fournaise-observee-par-la-plateforme-web-volcplume/
https://www.data-terra.org/en/news/fairease-observe-volcanoes/

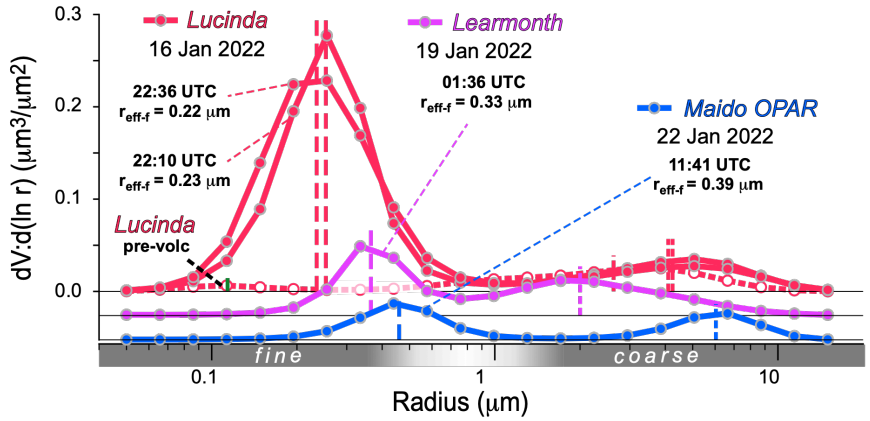
# Growth and persistence of Hunga Tonga stratospheric sulfate aerosols: impact on climate (Hunga Tonga, 15 Jan 2022)


## A record-breaking eruption in the satellite era !

### TROPOMI $SO_2$

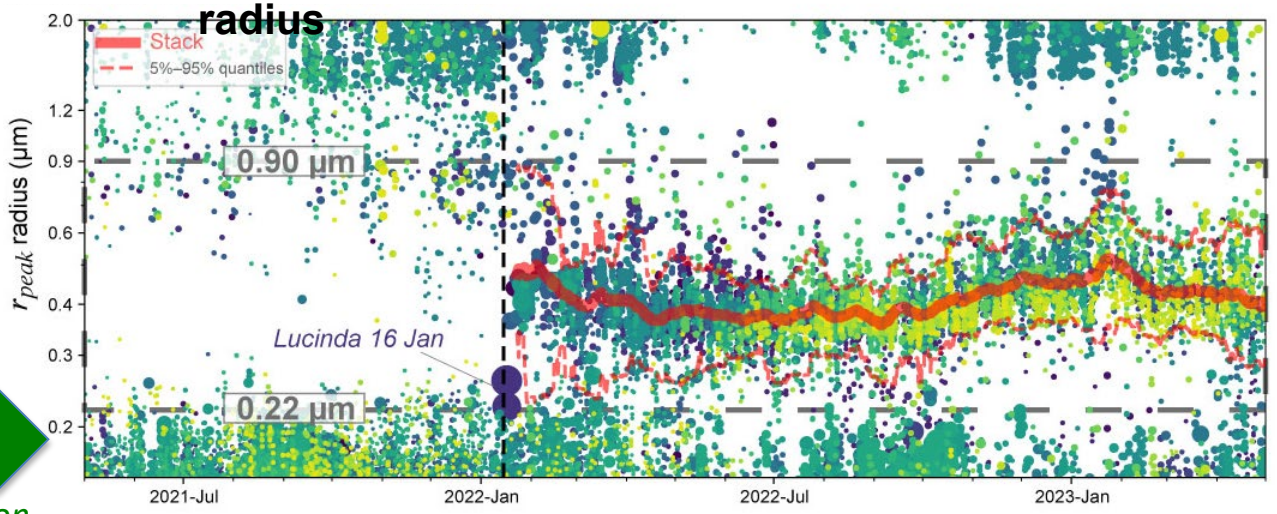



### Aerosol volume size distribution (AERONET)




*Multi-station analysis of AERONET network data (**VOLCPLUME**)*

### Fine mode aerosol radius




## Key results

- Faster growth than for other stratospheric eruptions.
- Stratospheric aerosols persist for >1.4 yrs as identified at 20 AERONET stations of the southern hemisphere.
- 1 yr after eruption:
  Hunga Tonga aerosols smaller than Pinatubo particles
  **=> an enhanced climate impact ?**

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# Conclusions & perspectives

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- Fast progress in remote sensing: increasing spectral/spatial/temporal resolutions of satellite data, open access to multiple ground networks…
- Challenge to jointly process so many data and enable their fast and interactive visualisation

- We are developing **open access web services** for interactively aggregating and jointly analysing satellite observations from **Solid Earth and Atmospheric Science** communities **for the near-real-time monitoring of volcanic activity**

=> **VolcPlume Platform** and **Volcano Space Observatory Portal** for interactive and fast analysis of data to retrieve SO2/particle emissions (flux, altitude) combined with ground deformation

- Can be a support for institutions in charge of atmospheric hazards (air quality, air traffic/VAAC, climate)
- Can be a support for Volcanological Observatories, especially during crises