UV satellite measurements of volcanic emissions in space and time

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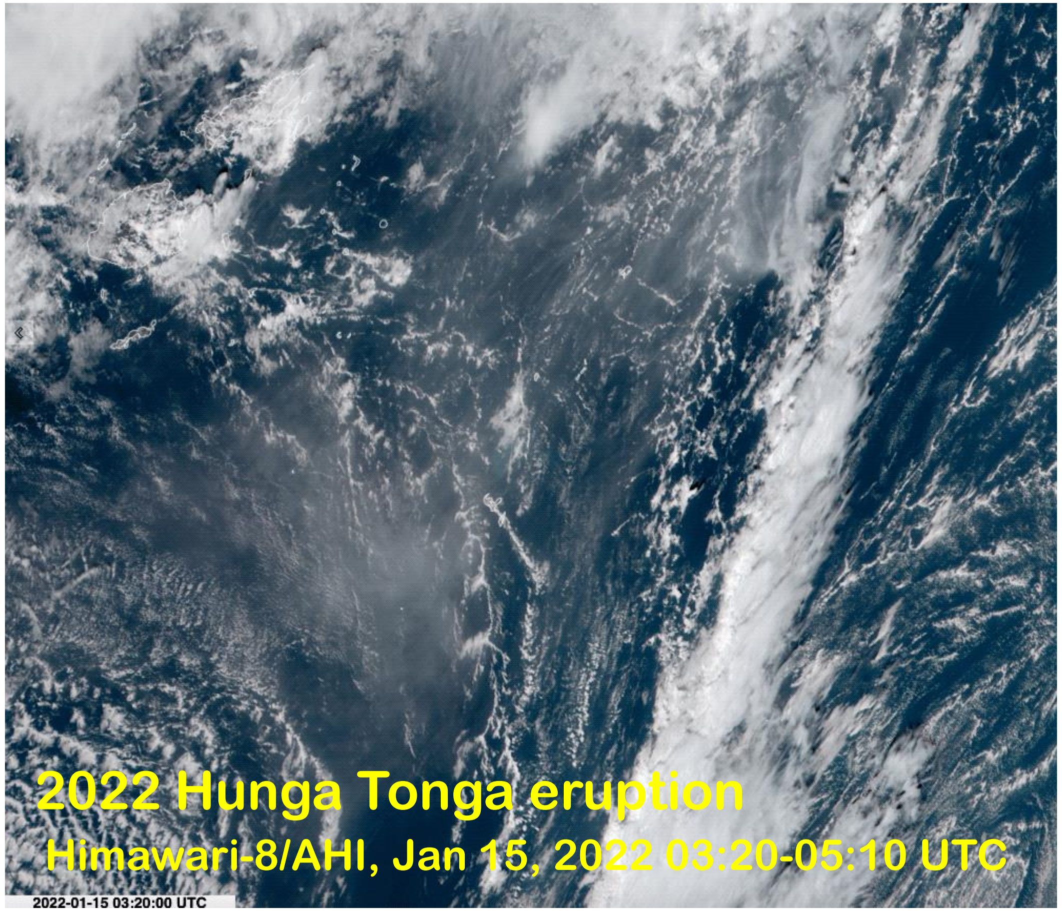
Etna from Taormina
Thomas Cole, 1843

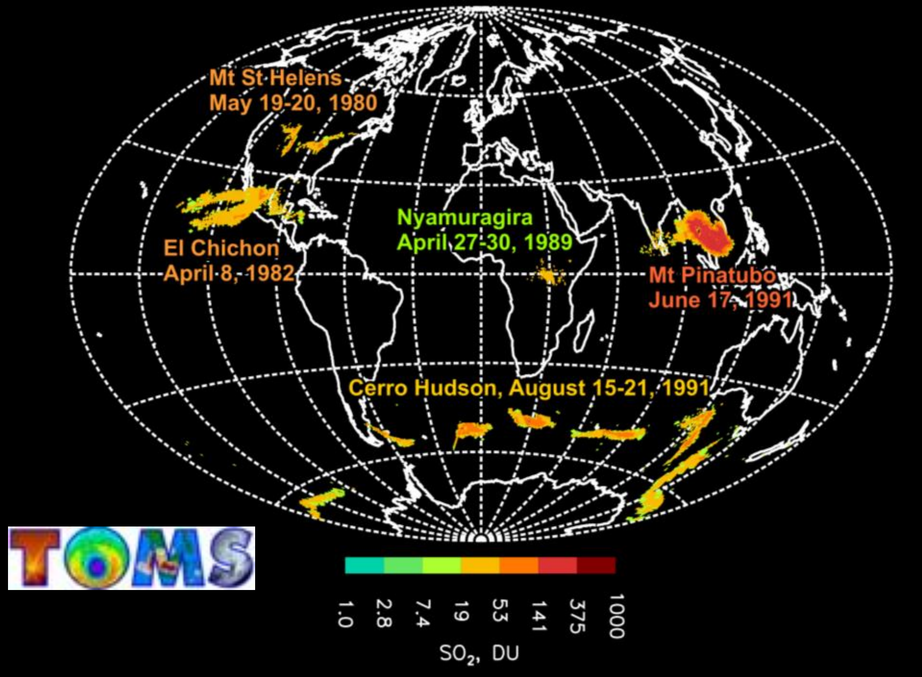
Variable timescales of volcanic activity

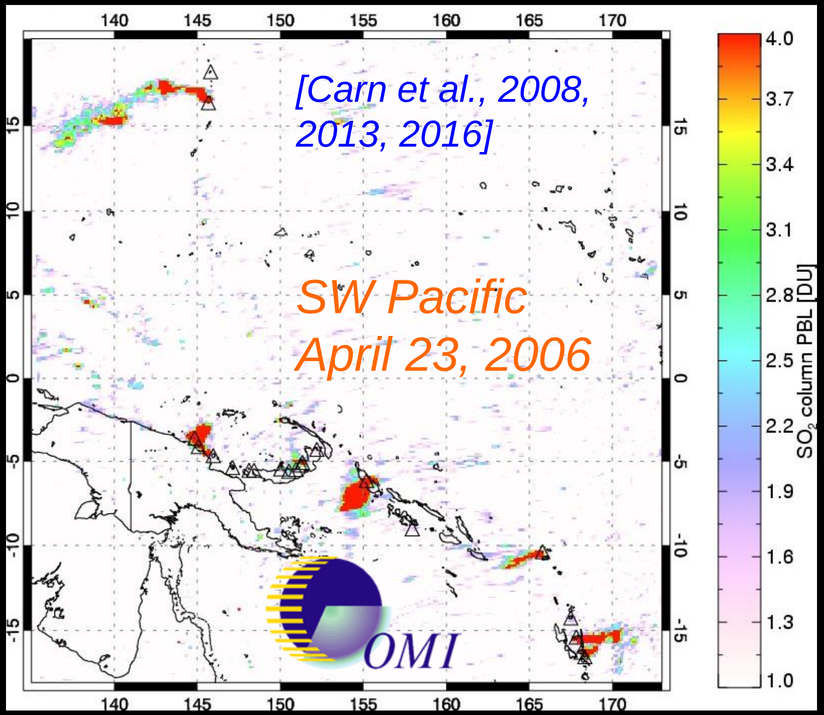


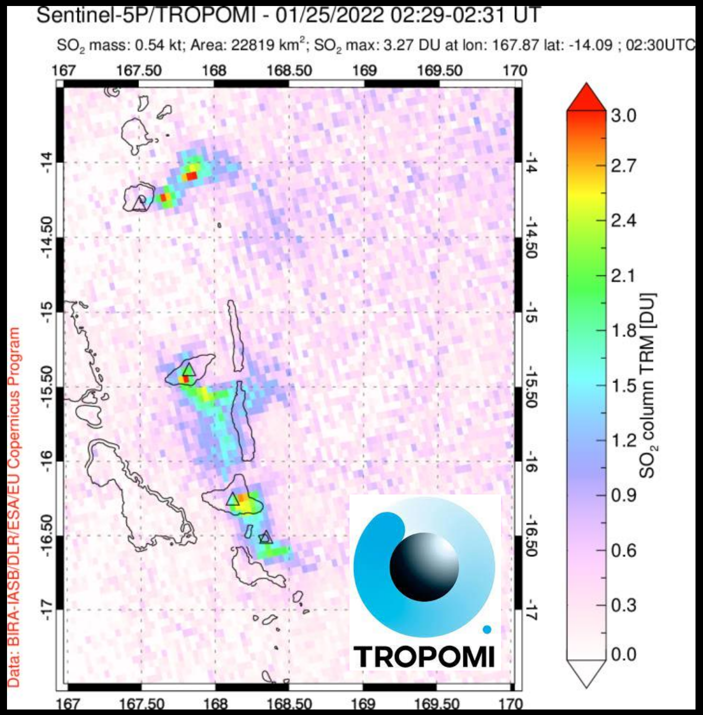
Rapid explosive volcanic eruptions

Long-term, persistent volcanic degassing; e.g., Etna

NASA and ESA UV satellite remote sensing of volcanic SO_2







NASA **1978-2005**
Total Ozone Mapping Spectrometer (TOMS)

esa **1995-2003**
Global Ozone Monitoring Experiment (GOME)

2004- → 2025?
Ozone Monitoring Instrument (OMI) NASA

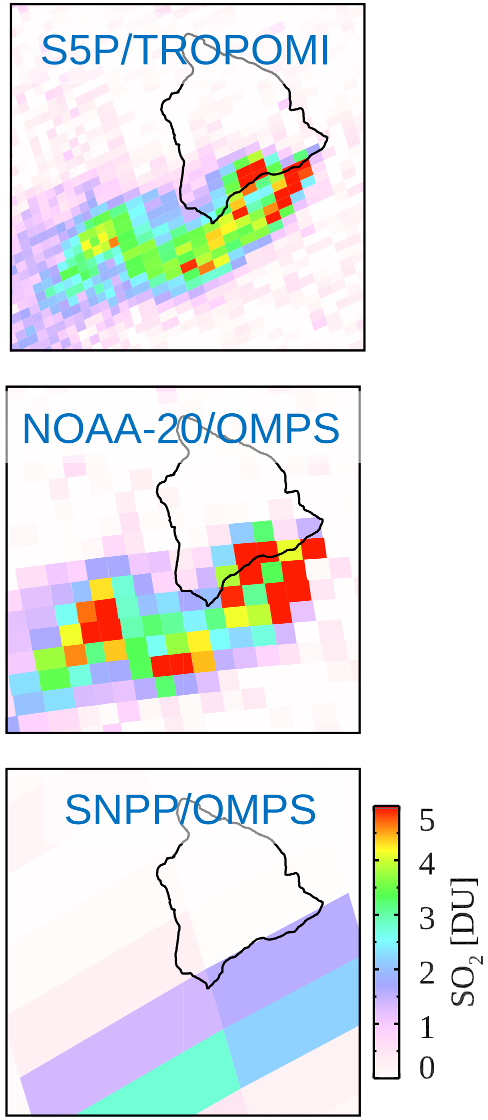
esa **2006-**
GOME-2

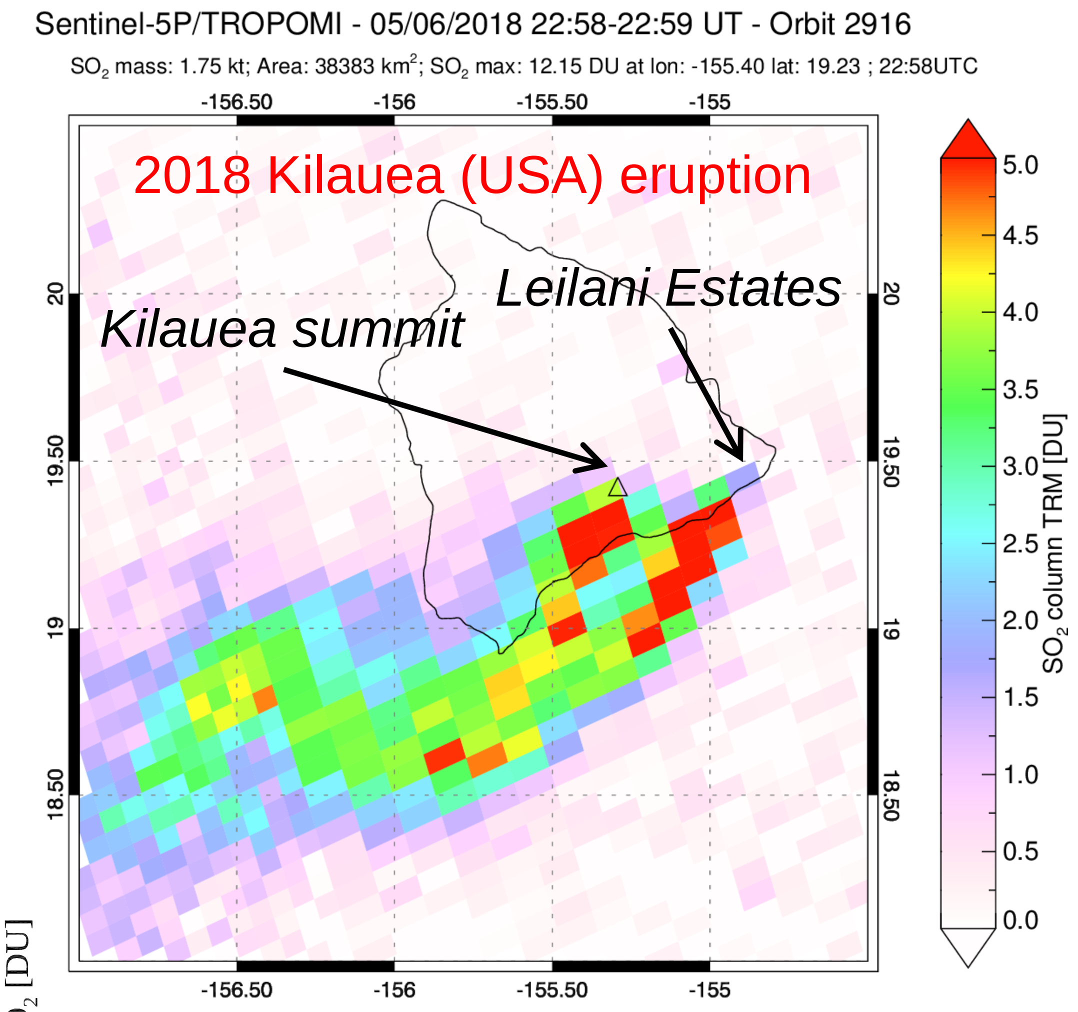
2012- & 2017- NASA
Ozone Mapping and Profiler Suite (OMPS)

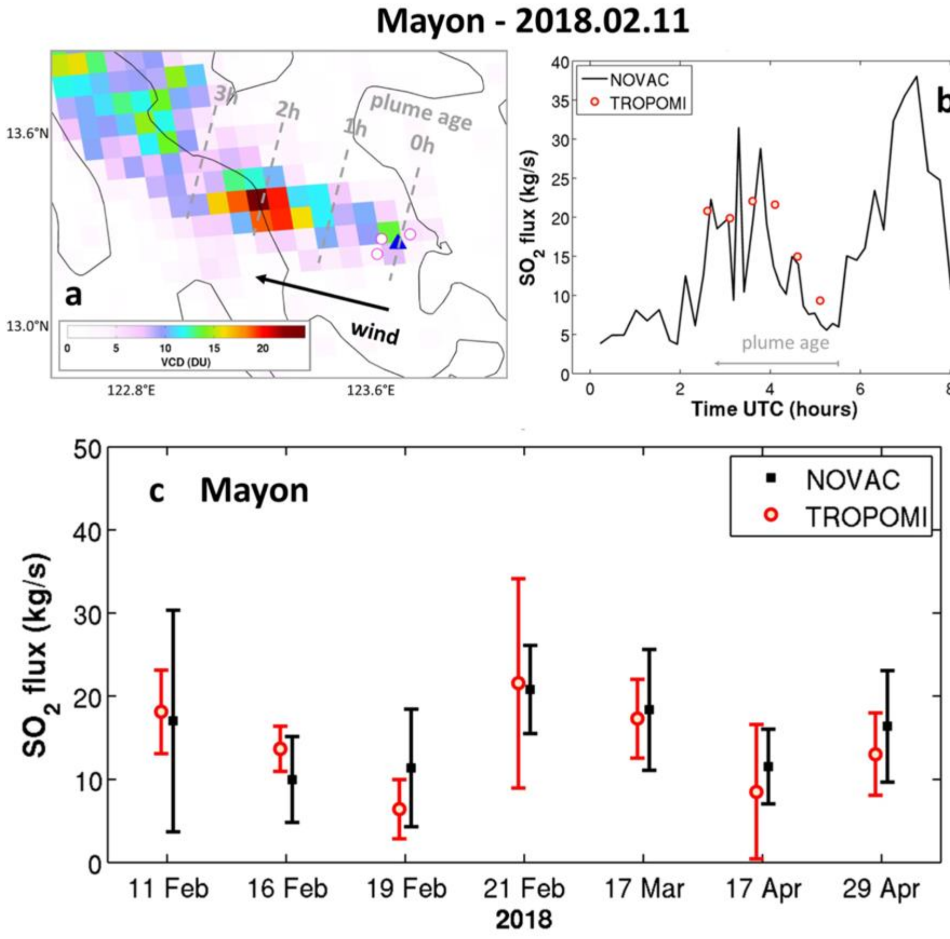
2015- NASA
DSCOVR/ EPIC

2017- esa
Sentinel 5P TROPOMI

Advantages of high TROPOMI spatial resolution







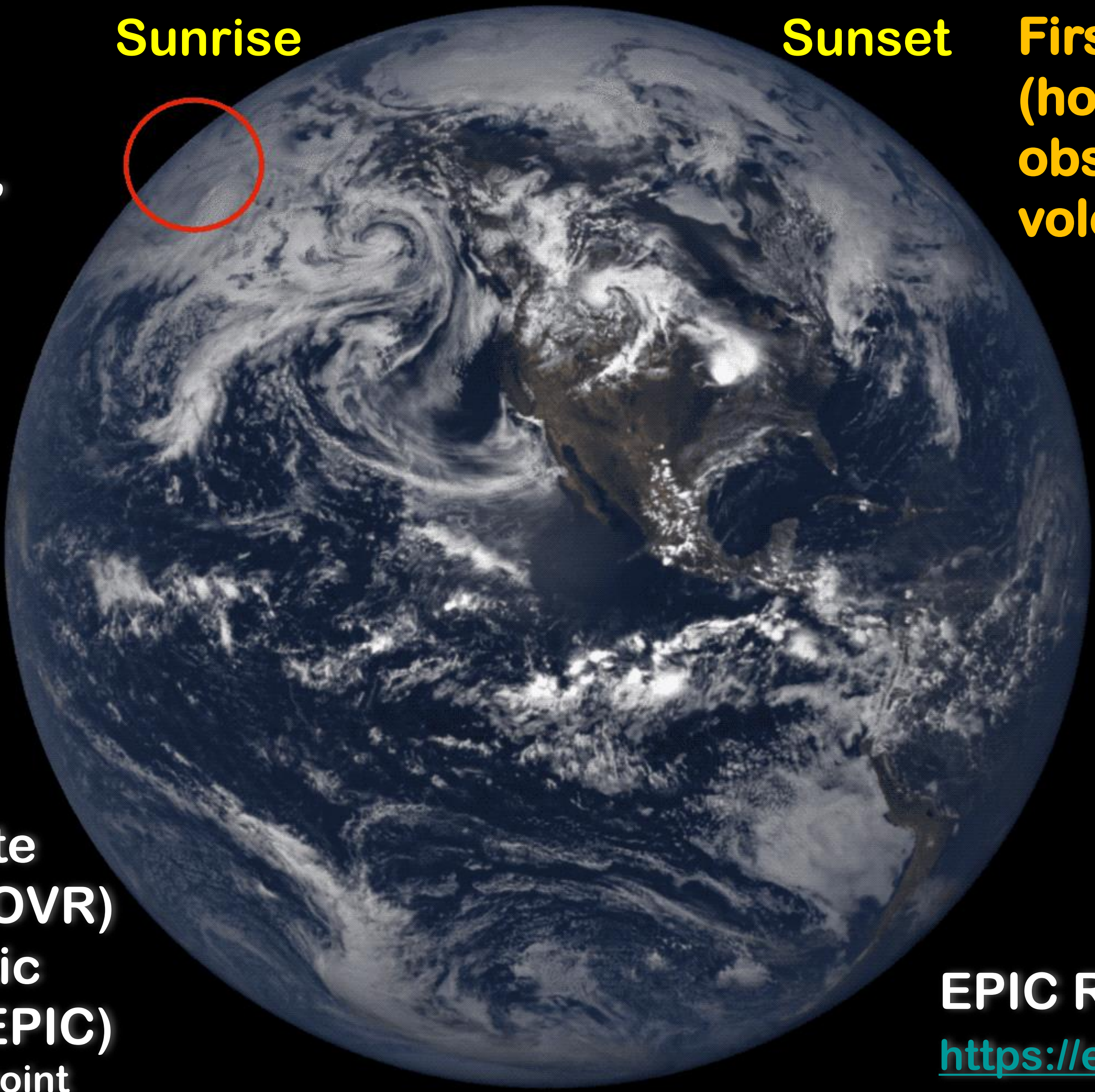
- Improved volcanic plume resolution with 5.6 x 3.5 km pixel size – aids SO_2 source identification and SO_2 flux analysis

Theys et al., 2019; Queisser et al., 2019

Raikoke eruption (Kuril Islands, Russia) – June 21, 2019

Sunrise

Sunset



First high-cadence (hourly) UV observations of volcanic eruptions

Carn et al., 2018, 2022
Marshak et al., 2018
Fisher et al., 2019

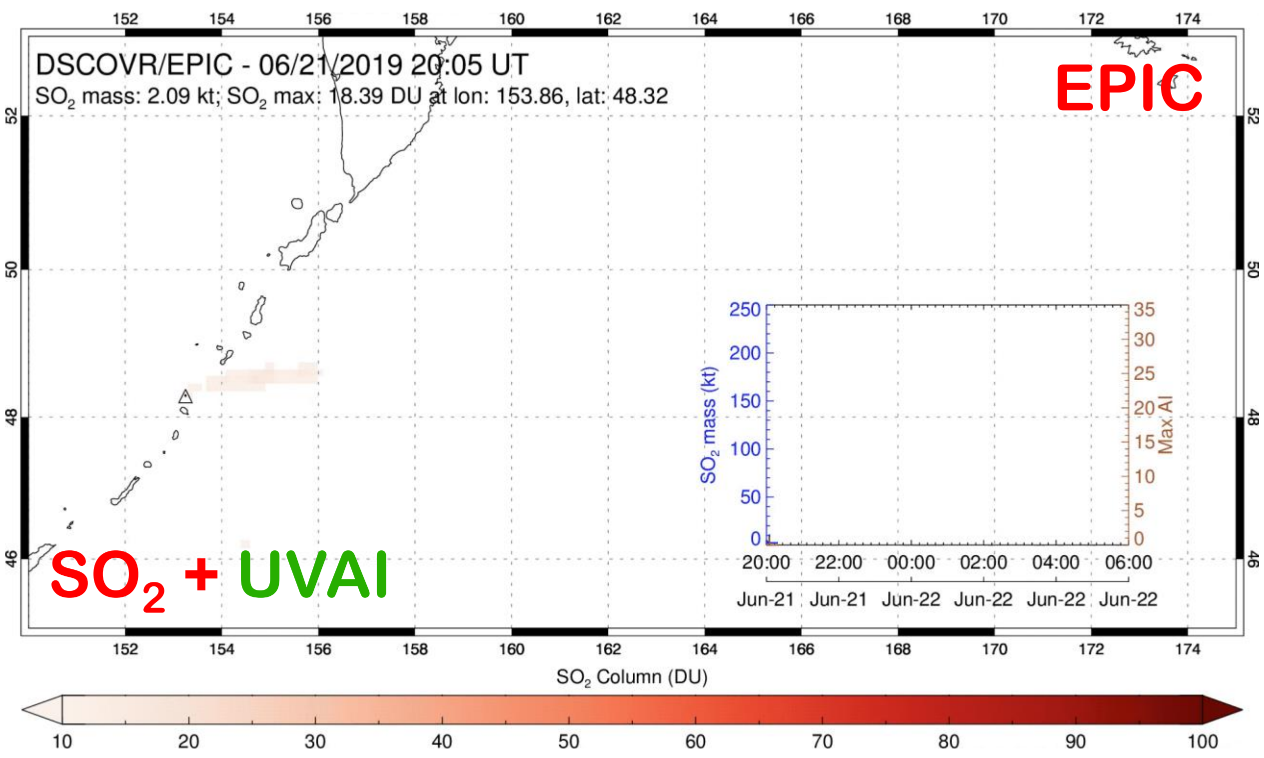
International Space Station

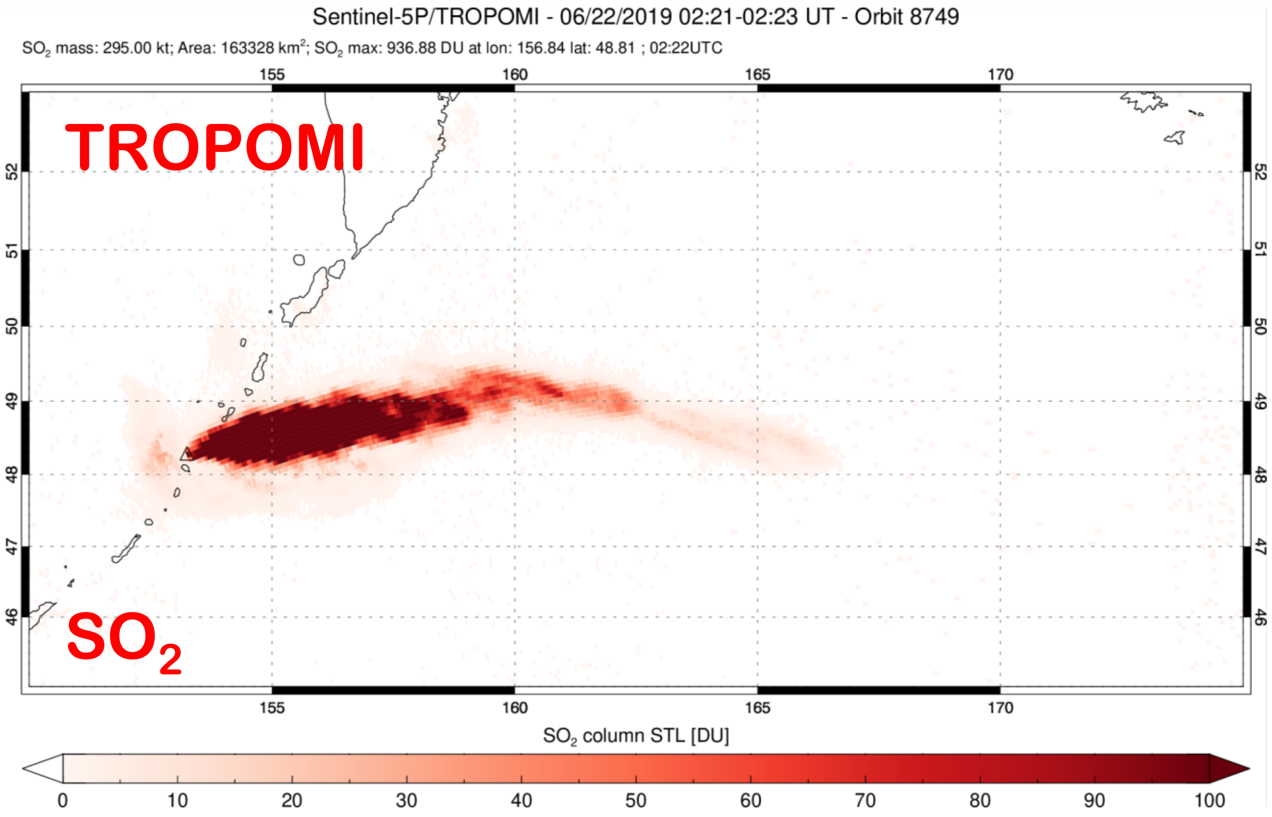
Deep Space Climate Observatory (DSCOVR) Earth Polychromatic Imaging Camera (EPIC)
L1 Earth-Sun Lagrange point

EPIC RGB images
https://epic.gsfc.nasa.gov/

EPIC and TROPOMI observations of the Raikoke erruption

2019 Raikoke (Kuril Is) eruption



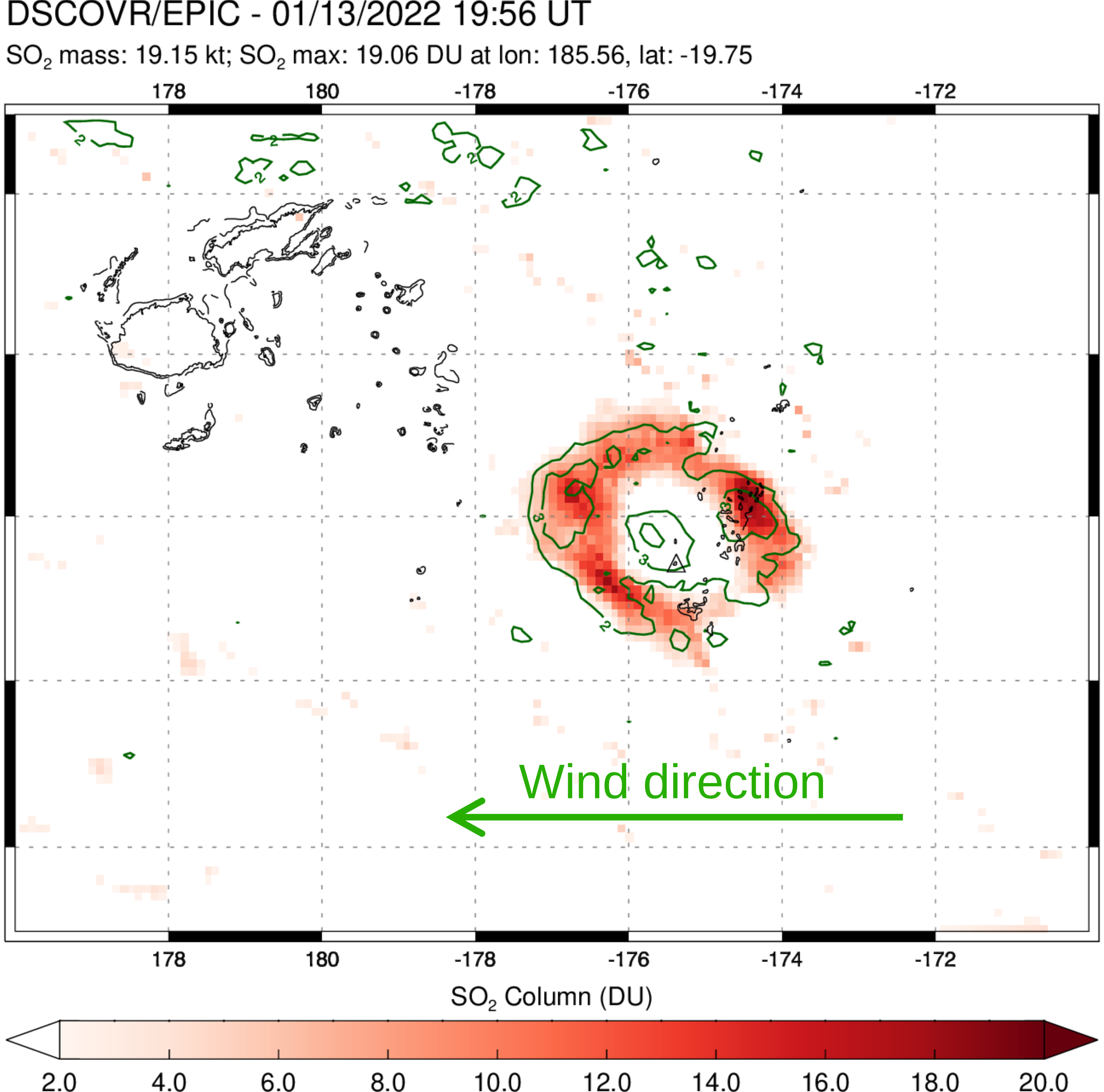


- DSCOVR/EPIC Level 2 SO_2 columns and UV Aerosol Index (UVAI)
- Hourly UV measurements of volcanic SO_2 and ash for large eruptions since mid-2015
- New insight into volcanic eruption processes (e.g., pre-eruptive gas accumulation, SO_2 emission rates)
- Similar information obtainable from inversion of LEO SO_2 data (e.g., Cai et al., ACP, 2022), but affected by wind shear, accuracy of meteorological data etc.

Jan 13, 2022 Hunga Tonga eruption

SO$_2$ retrievals
UVAI contours

- High-cadence EPIC SO$_2$ imagery permits the first UV-based analysis of volcanic umbrella cloud spreading and volume flux in the 13 January 2022 HTHH eruption (*Carn et al.*, 2022)



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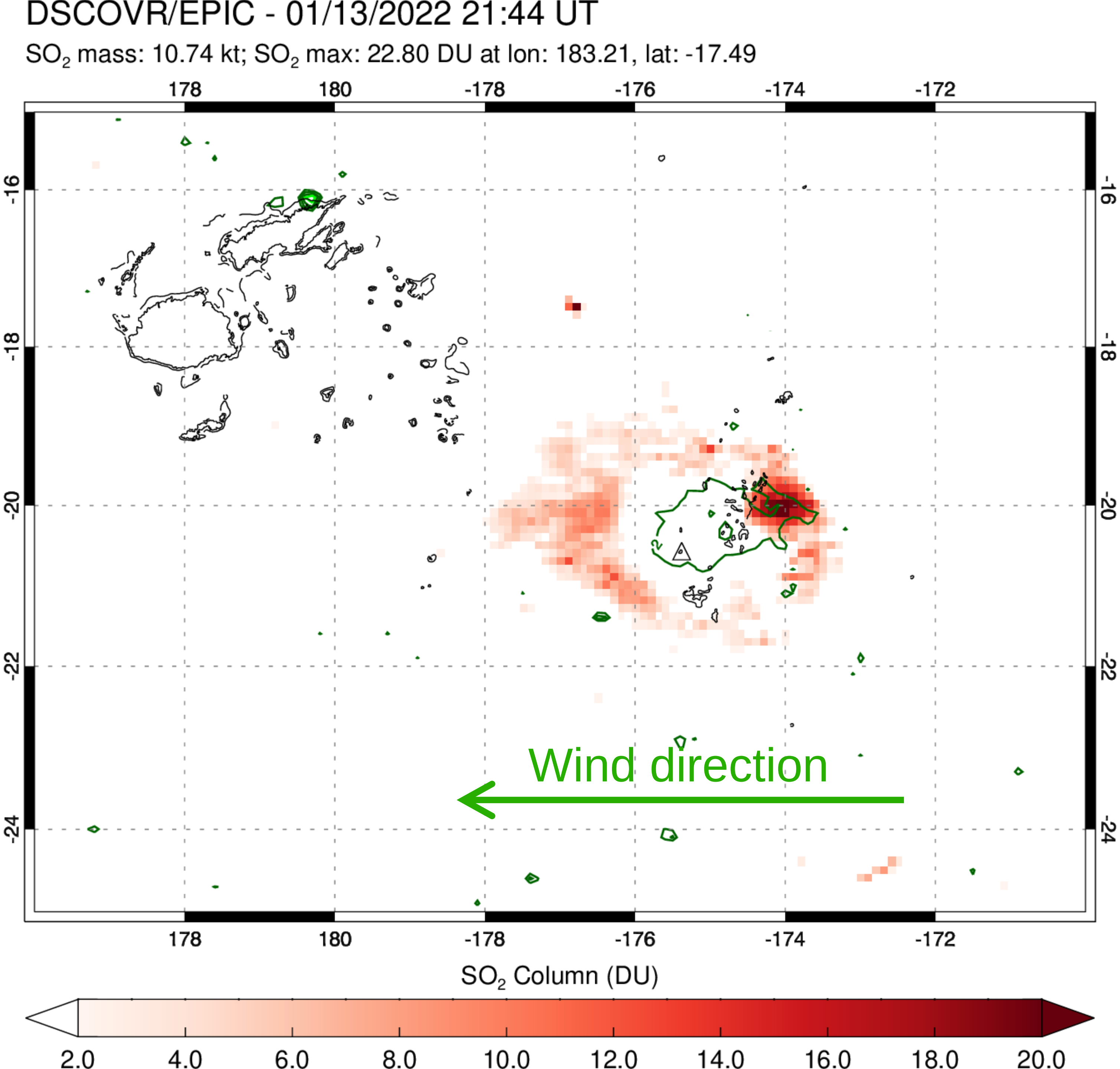

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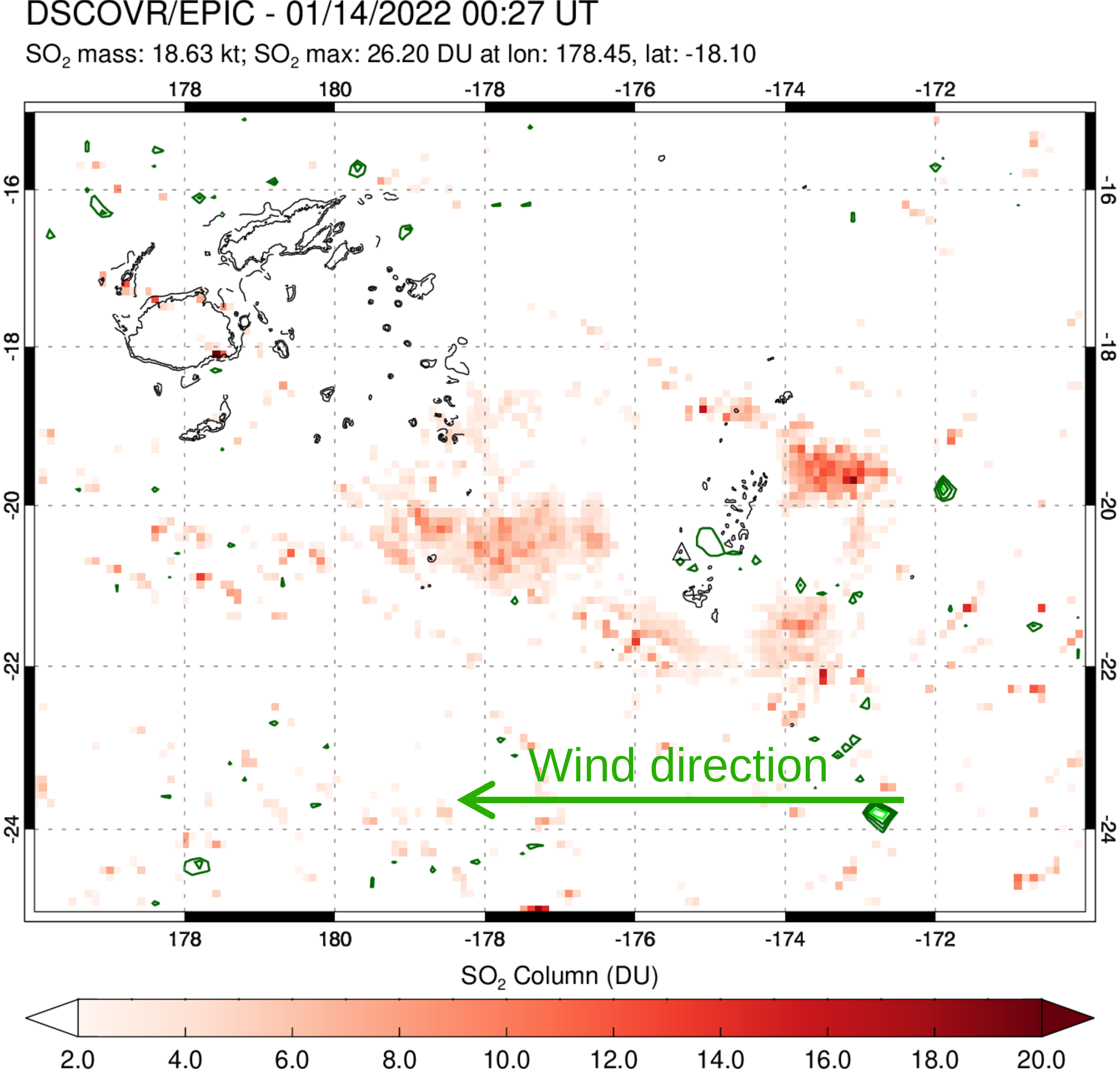
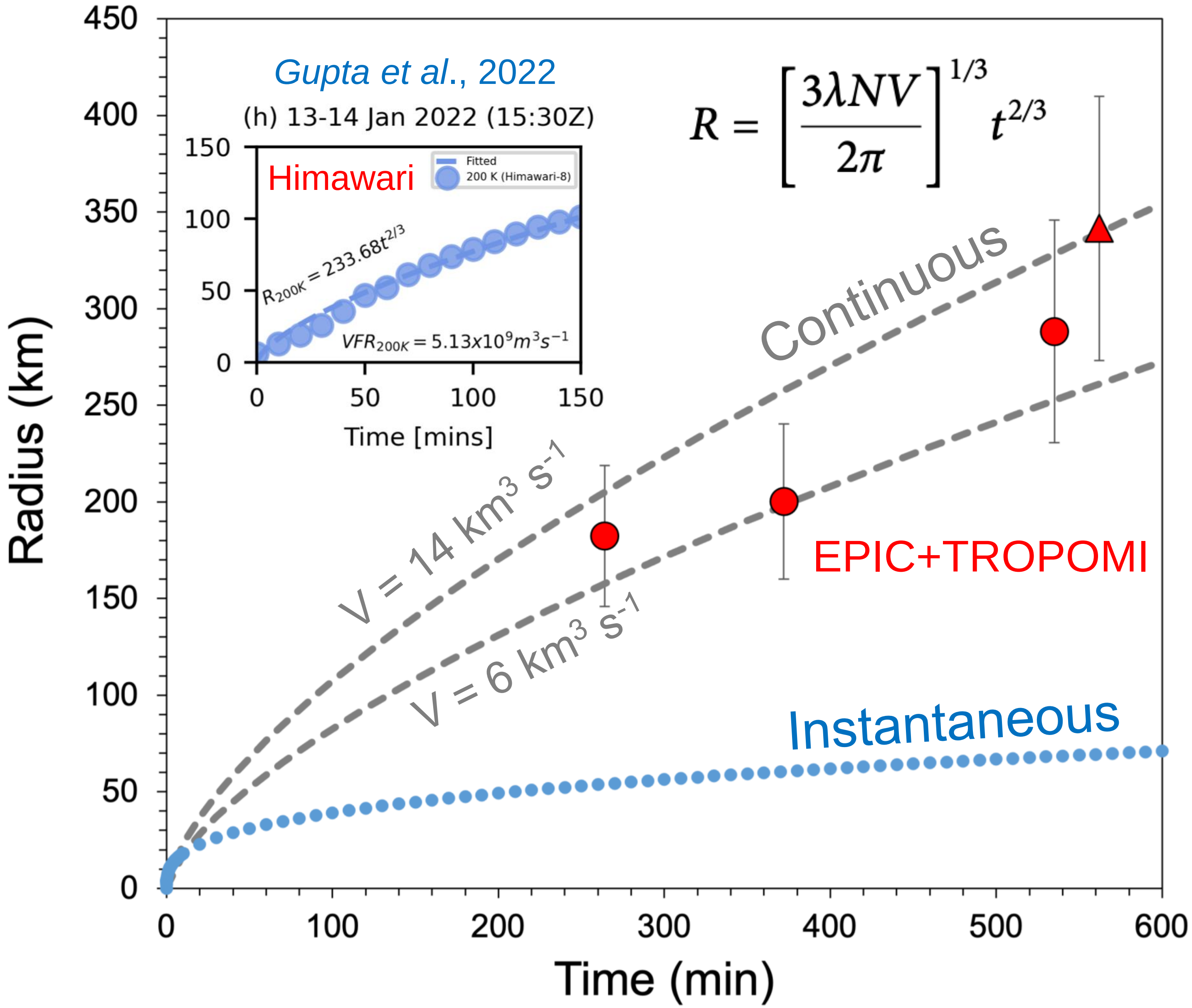
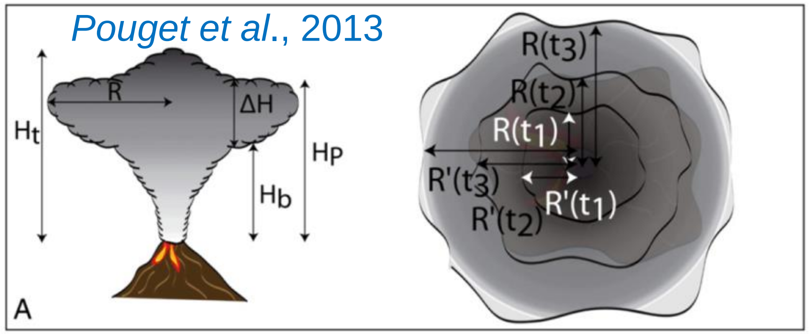
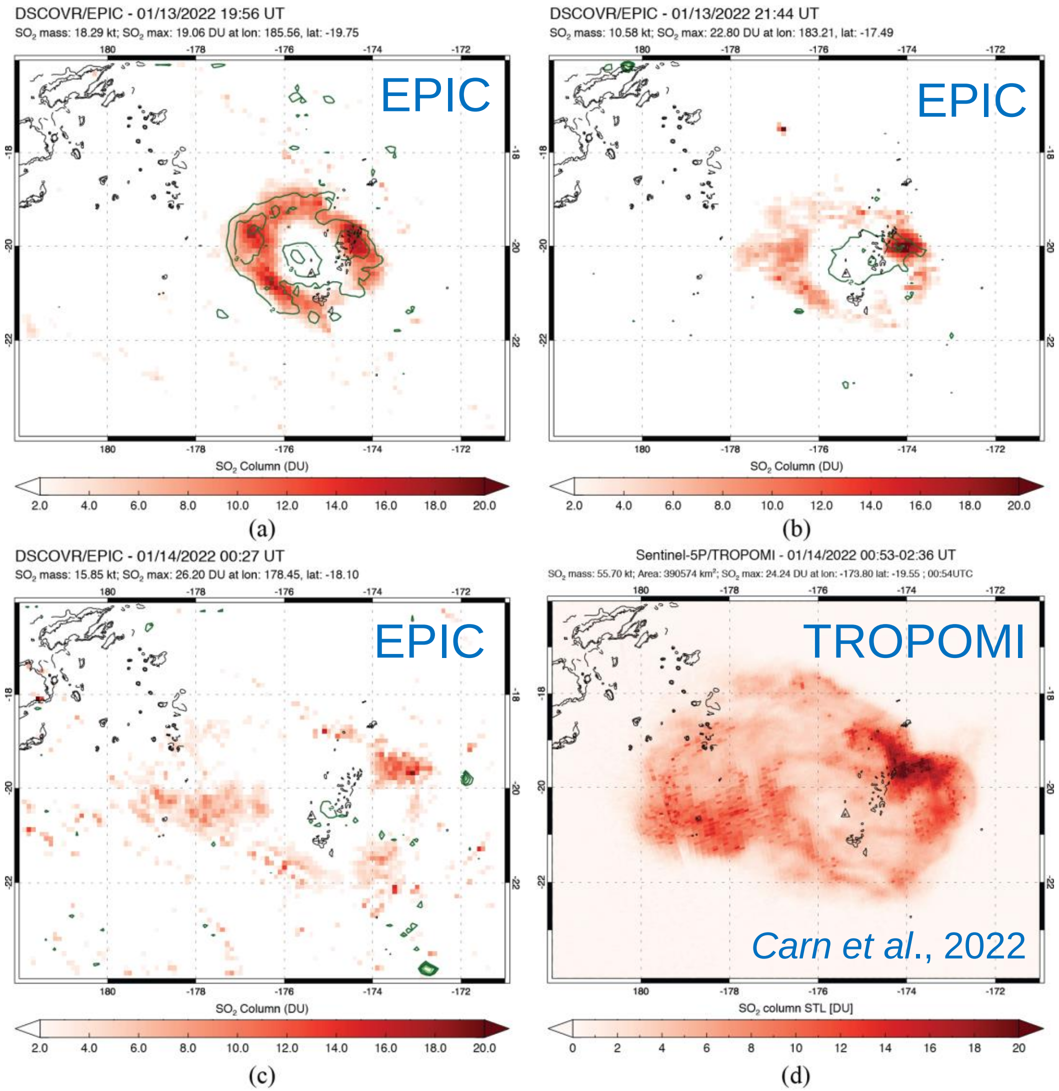


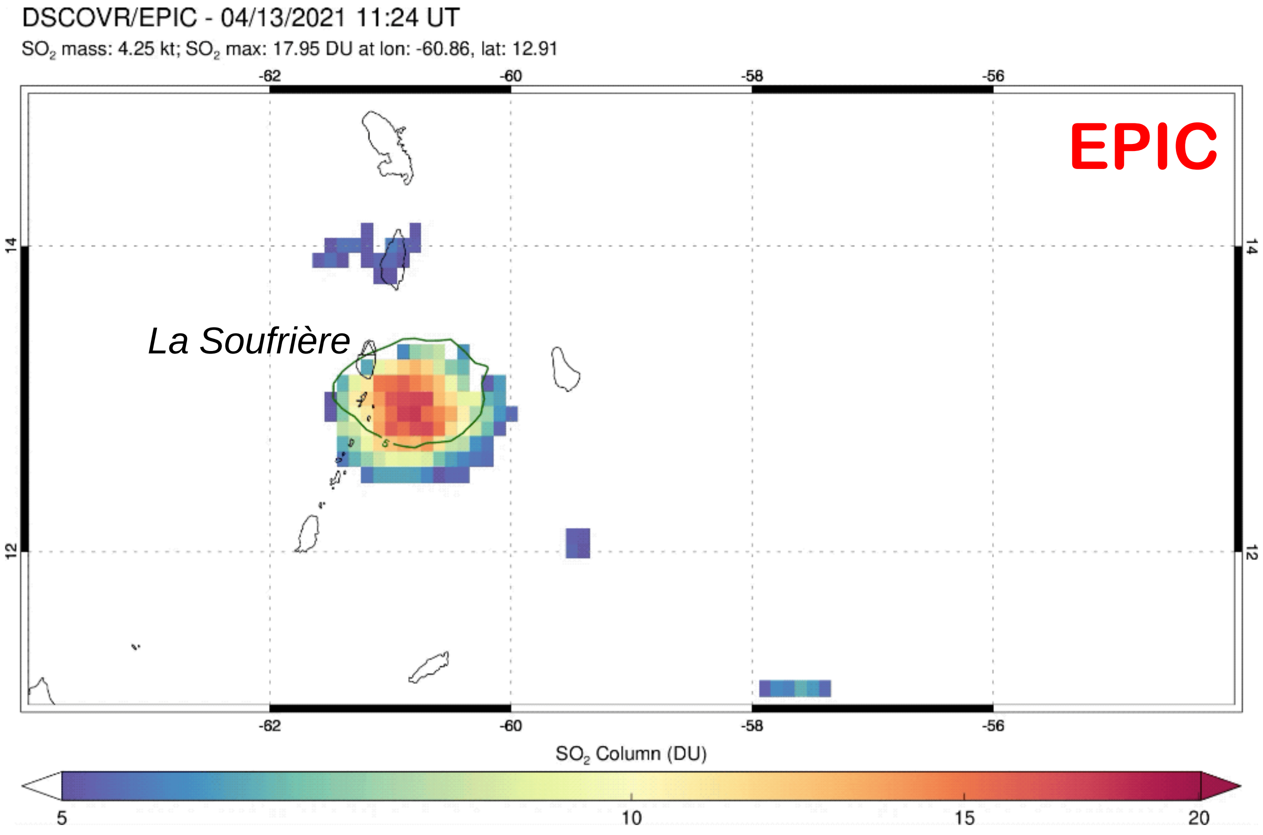
Umbrella cloud analysis with UV SO_2 data

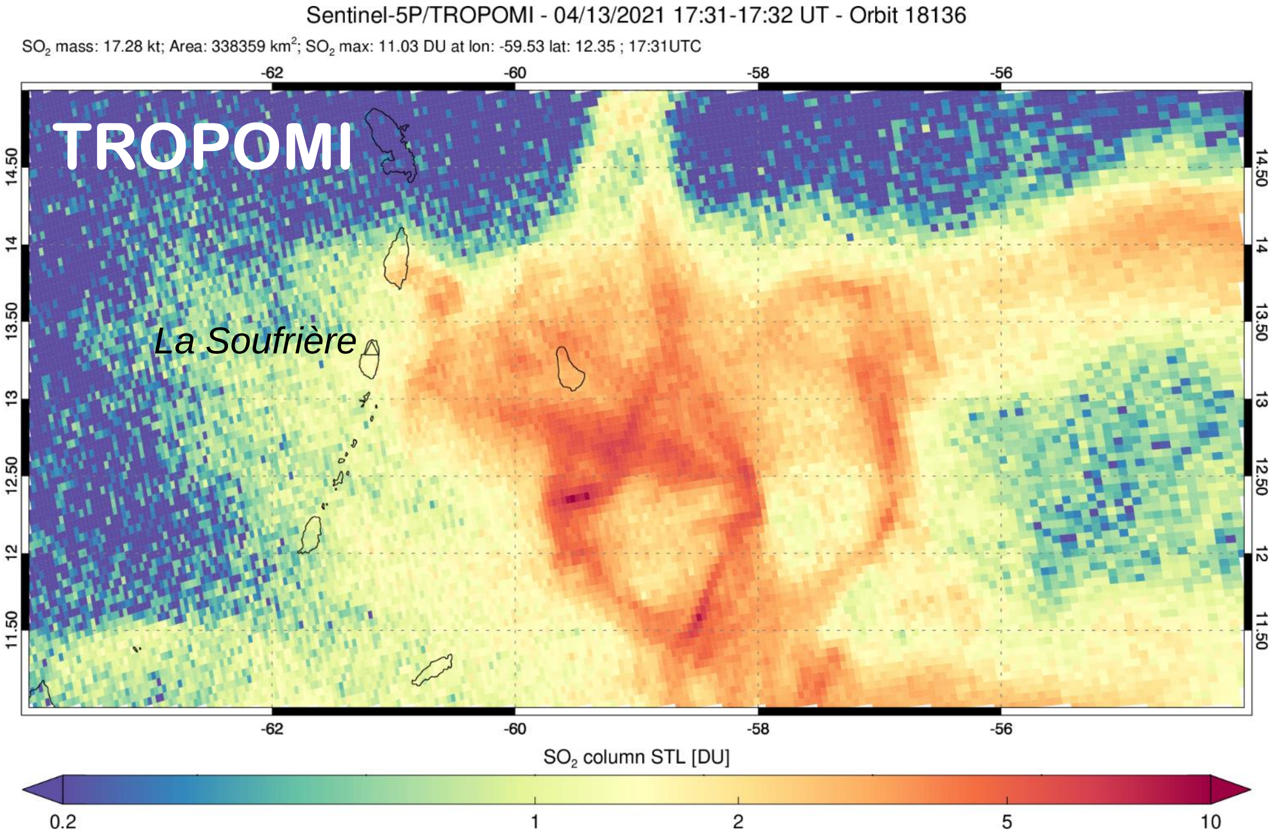






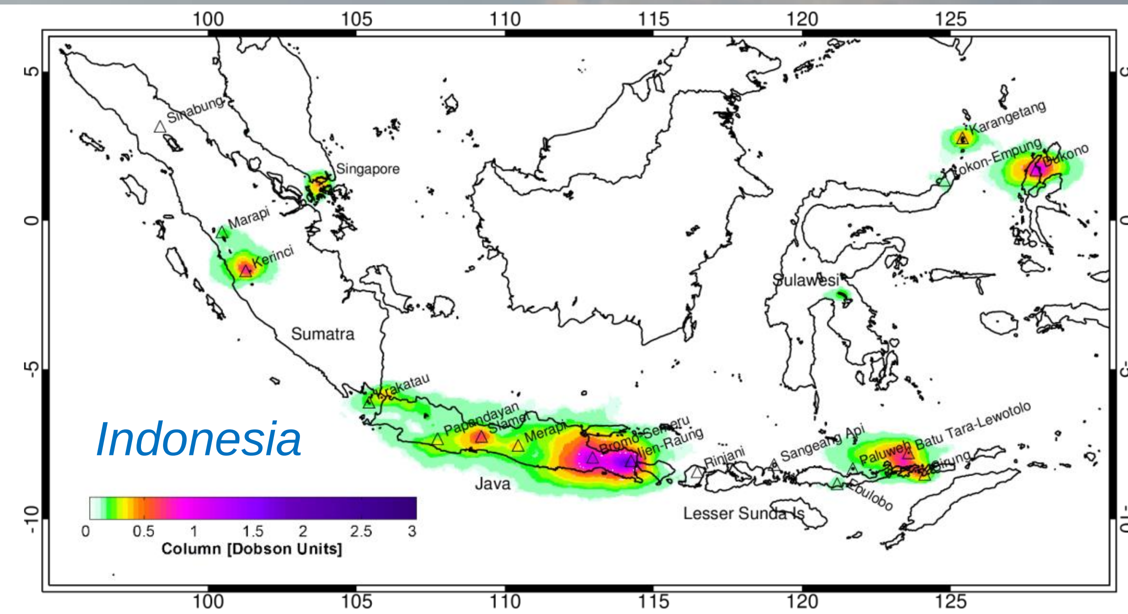
Multiphase eruptions: 2021 La Soufrière (St Vincent)

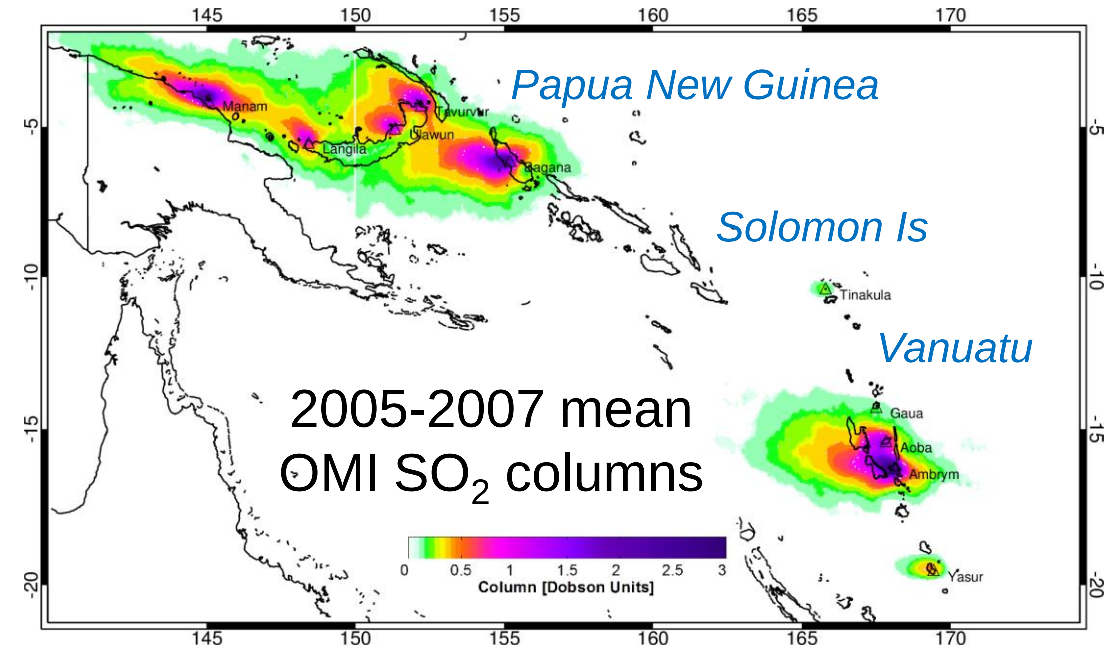


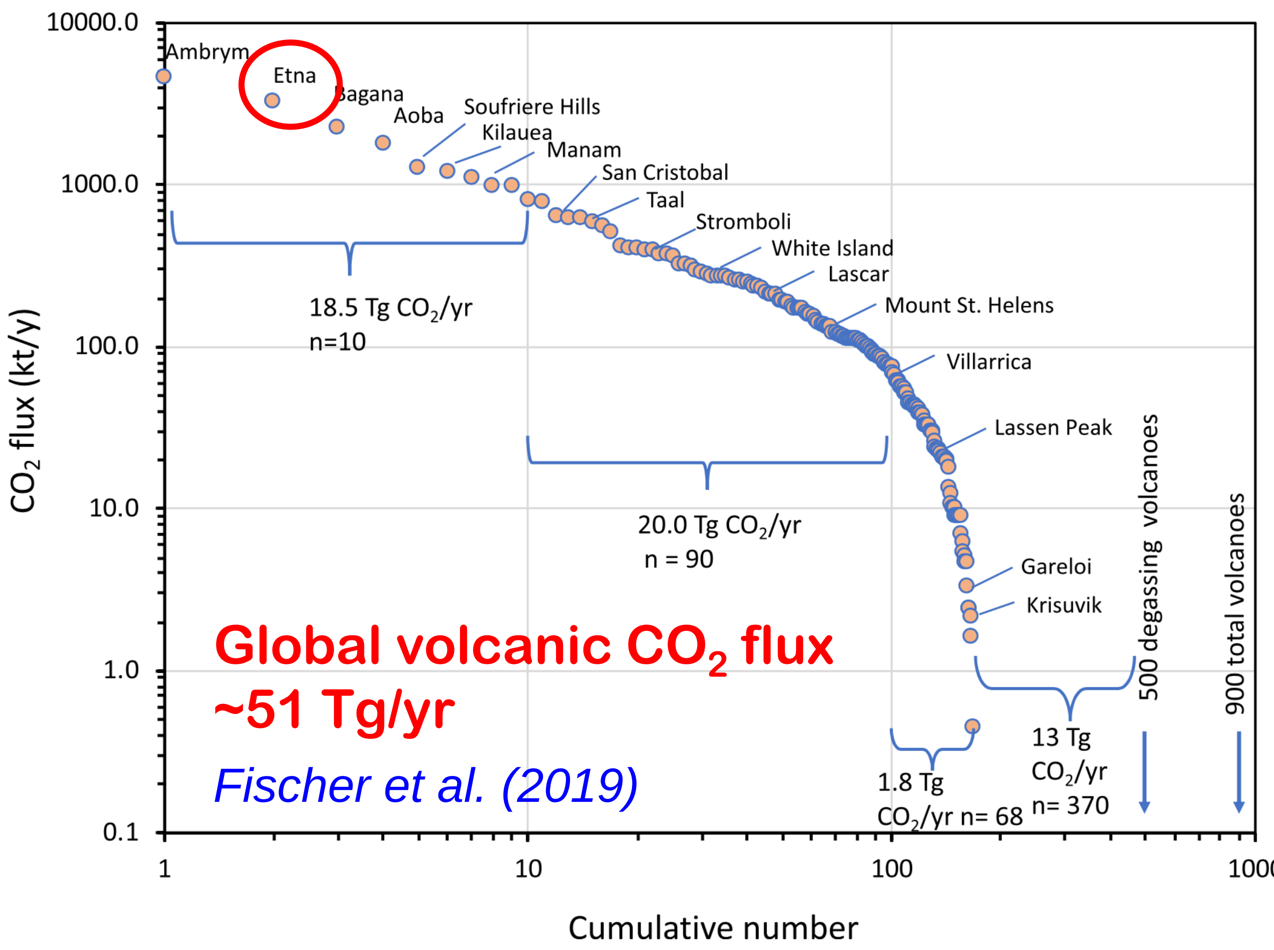


- 2021 La Soufrière (St. Vincent) eruption (April 9-13, 2021): 30 discrete explosive events
- April 13, 2021: large UTLS background SO_2 columns from prior eruptions (TROPOMI image)
- High-cadence EPIC imagery tracks SO_2 cloud (transient increase in SO_2 columns) from new eruption
- Lower SO_2 sensitivity of EPIC advantageous for reducing background interference

Long-term average volcanic SO_2 emissions from OMI



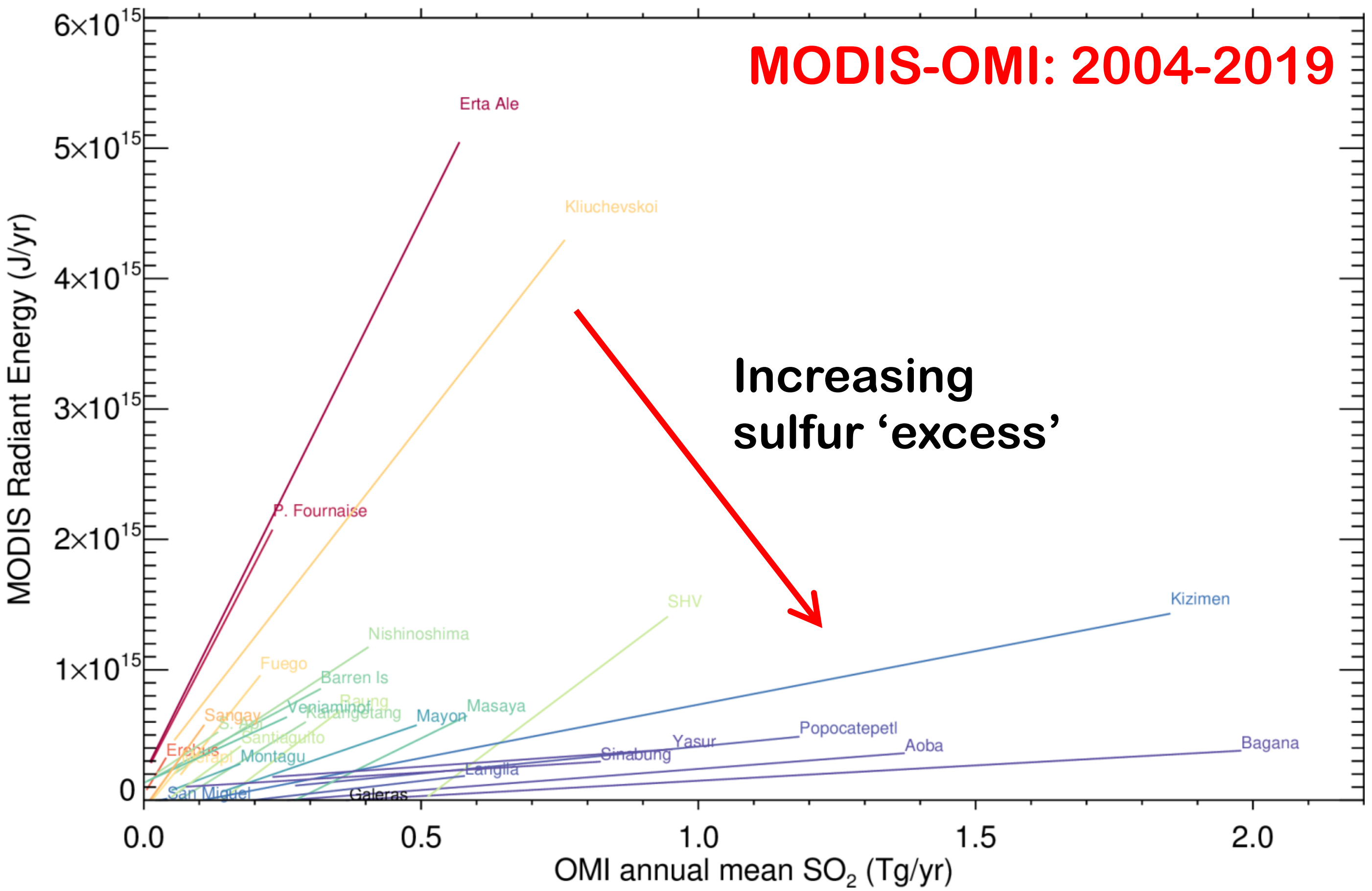


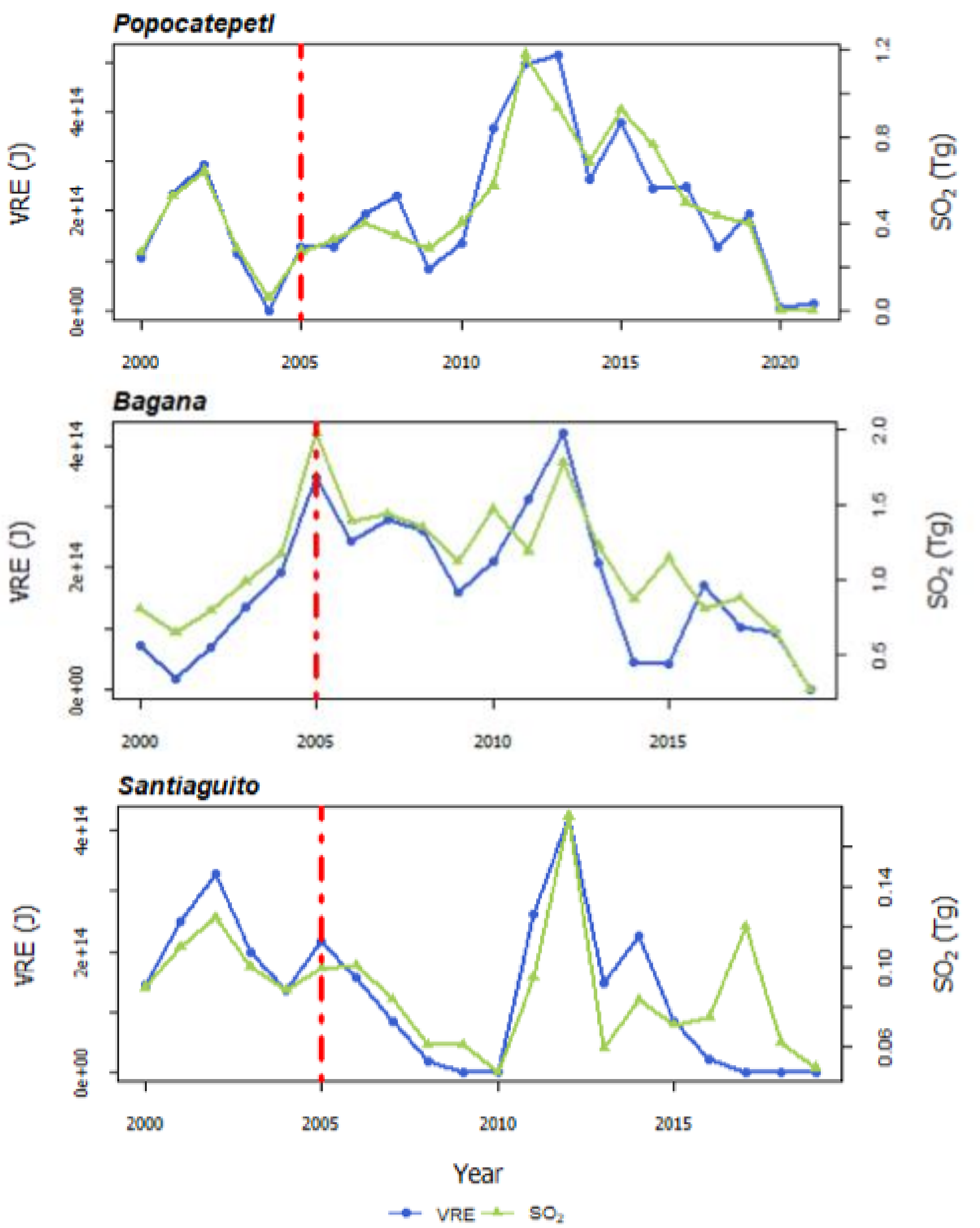


- Globally, 90-100 volcanic SO_2 sources quantified using NASA Aura/OMI data (2004 – present).
- Total SO_2 flux of 23+/-2 Tg/yr (~63 kt/day); ~80-90% of total SO_2 flux from passive + eruptive degassing.

Fioletov et al. (2016); Carn et al. (2017)

SO_2 emissions and heat flux

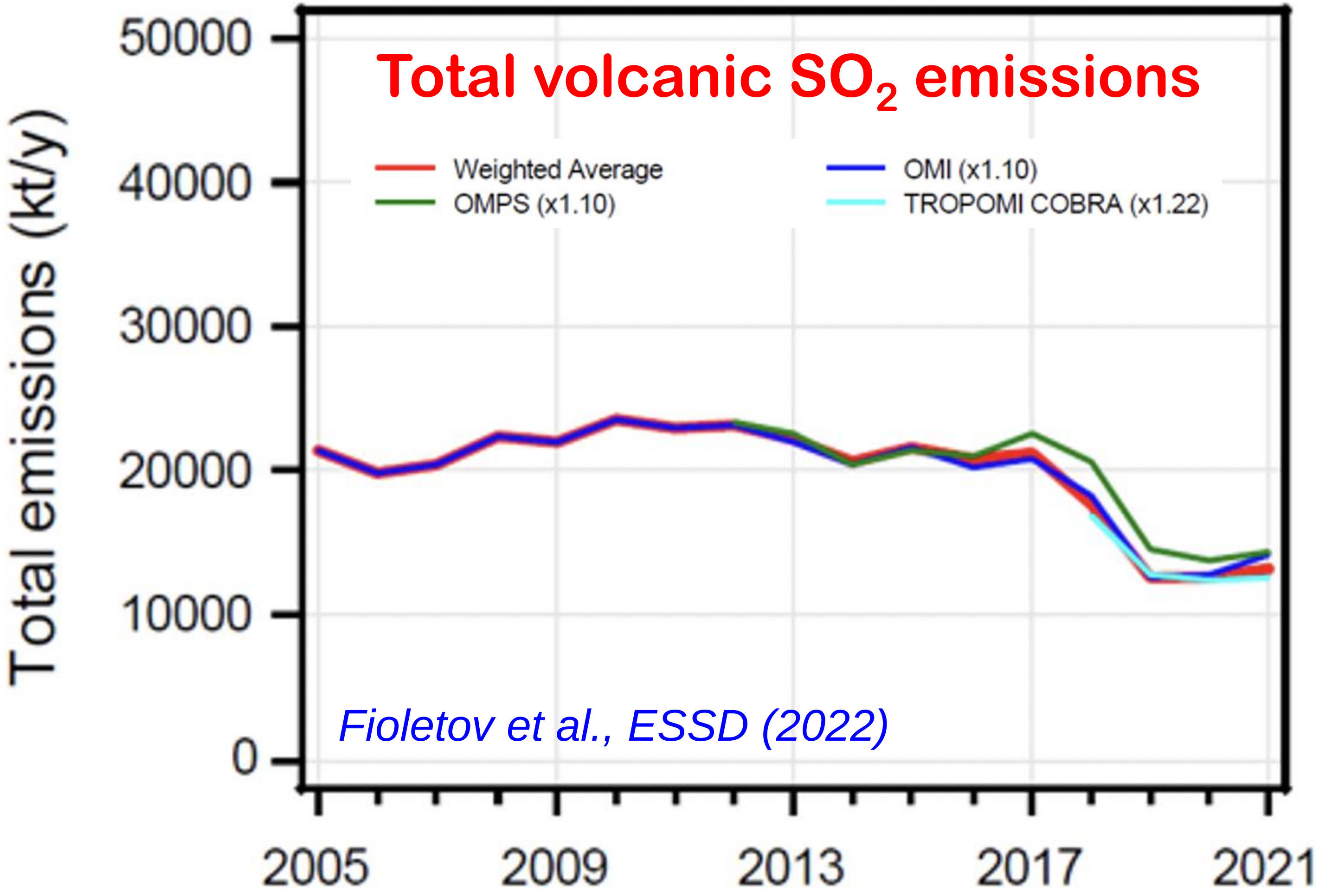


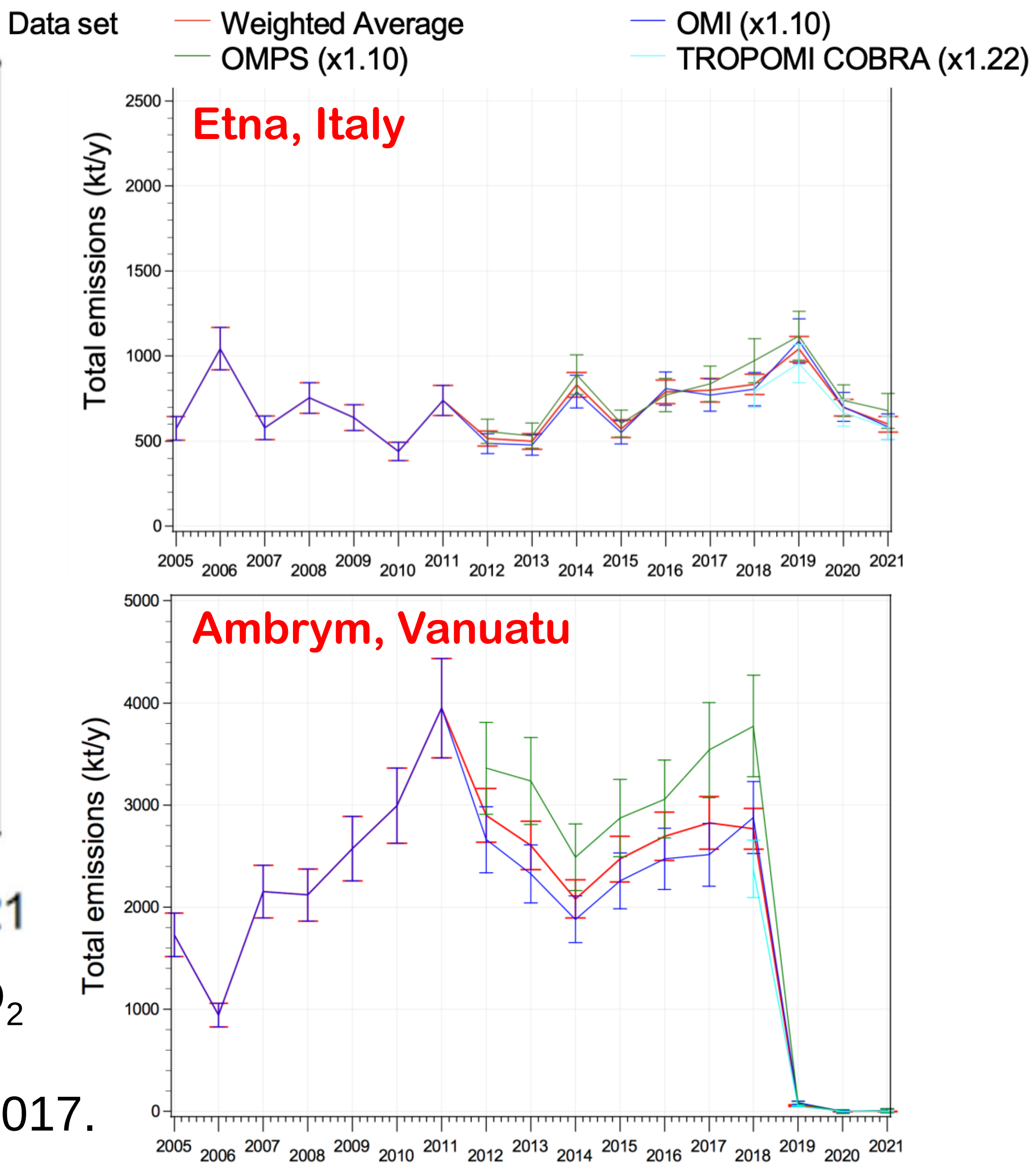


- Robust correlation between annual SO_2 emissions (OMI) and heat flux (MODIS) for some volcanic SO_2 sources.
- Potential OMI-MODIS or TROPOMI-VIIRS synergy to infer style of volcanic activity and magmatic sulfur content.

N. Rodriguez-Sepulveda (MS, MTU)

Extension of SO_2 emissions catalog with TROPOMI





- After minor adjustment, general consistency between SO_2 emissions derived from OMI, OMPS and TROPOMI.
- Notable decline in global volcanic SO_2 emissions since 2017.

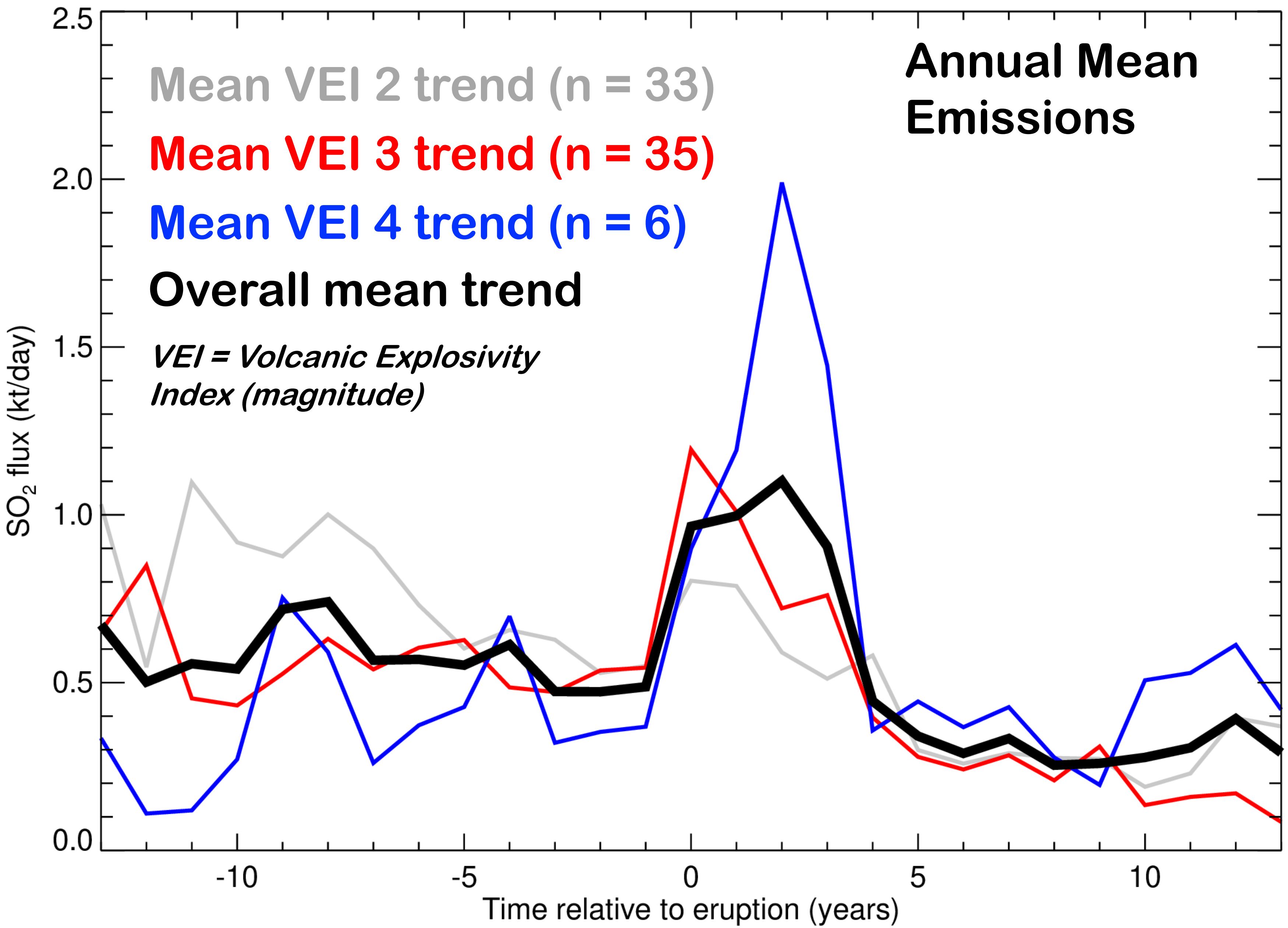
Trends in SO_2 emissions at erupting volcanoes

- **2005-2019 OMI SO_2 data**
- **Annual mean emissions**

- **Superposed Epoch Analysis (SEA) for all VEI 2-4 eruptions**

- Eruption years aligned at zero

- Inverse correlation between pre-eruptive SO_2 flux and VEI -> **Increased degassing inhibits large eruptions?**



Carn et al., in prep.

Summary

• Satellite observations with high spatial *and* temporal resolution are required to detect and measure SO_2 emissions from volcanic eruptions and passive degassing.

• DSCOVR/EPIC observations show the value of high cadence UV imaging of volcanic eruptions. We look forward to the era of geostationary UV imaging from GEMS, TEMPO, and Sentinel-4.

• Continued satellite monitoring of long-term trends in volcanic SO_2 emissions (TROPOMI, JPSS-OMPS) is critical for volcanic hazard assessment.