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Retrieval of SO_2 height from TROPOMI using a look-up-table Covariance-Based Retrieval Algorithm (COBRA)

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Volcanic plume after the eruption of Raikoke (June 2019) observed from the ISS

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Context

SO_2 layer height information important for:

- Aviation safety.
- Constraining SO_2 vertical columns/mass/fluxes.
- Monitoring volcanic eruptions and understand underlying processes.
- Assessing the impact of volcanic eruptions on the atmosphere (e.g. climate)

⇒ **TROPOMI's high-spatial resolution is particulary well suited and complements existing SO_2 plume height retrievals from IASI**

SO_2 Layer Height and VC retrieval

Optical depth closure equation:

$$y_{meas} = y_{bckg} + y_{SO2}$$

$$y_{meas} = -log\left(\frac{I}{I_0}\right)$$

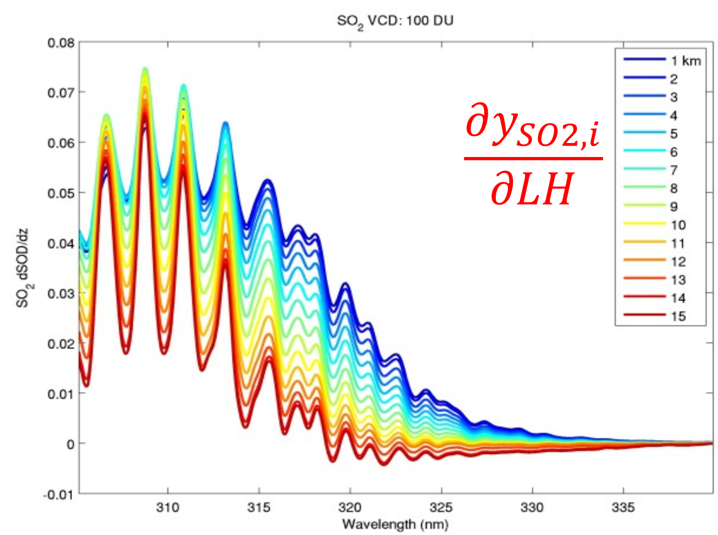
Iterative retrieval (310.5-326 nm)

$$y_{meas} - y_{SO2,i} = y_{bckg} + \alpha \frac{\partial y_{SO2,i}}{\partial VC} + \beta \frac{\partial y_{SO2,i}}{\partial LH}$$

?

SO_2 LUT splined @ {TO_3, geometry, LER} => fct(LH,VC, λ)

$LH_{i+1} = LH_i + \beta$
$VC_{i+1} = VC_i + \alpha$



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SO_2 Layer Height and VC retrieval

TROPOMI

Initial approach: LUT-DOAS

y_{bckg} modelled by DOAS : polynomial, cross-sections (or pseudo) of O_3, Ring + closure terms

disadvantage: many fitting parameters.
For low SO_2 loadings => bias and noise on SO_2 LH and VC.

Improved approach: LUT-COBRA

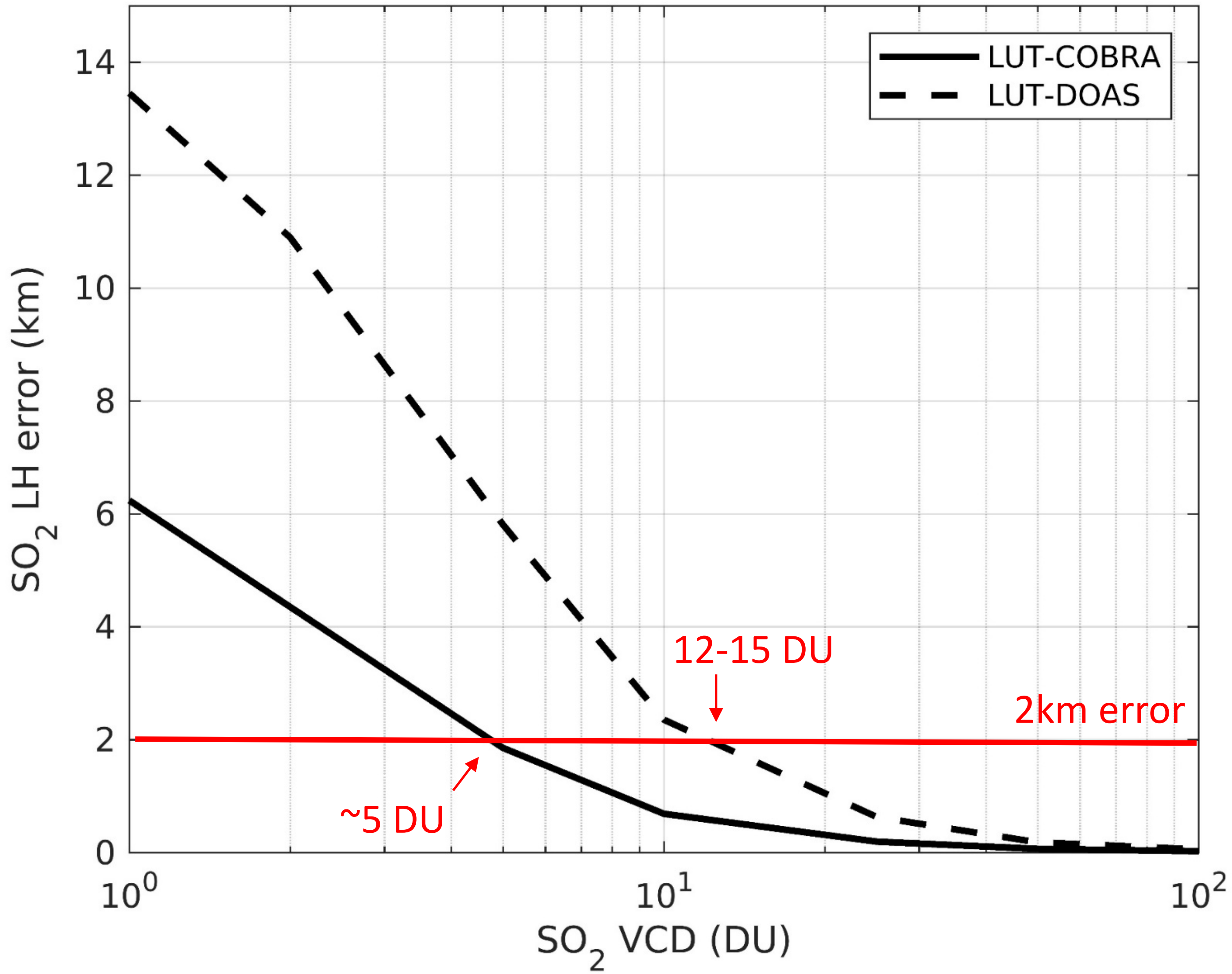
y_{bckg} statistical characterization from a set of SO_2-free spectra by $\bar{y}, S$ (mean spectrum and covariance matrix) see Theys et al., ACP, 2021.

$$\hat{x}_{i+1} = \hat{x}_i + \left(k_i^T S^{-1} k_i\right)^{-1} k_i^T S^{-1} (y_{meas} - y_{SO2,i} - \bar{y})$$

$x = \begin{bmatrix} LH \\ VC \end{bmatrix}$ SO_2 layer height and SO_2 column

$k_i = \begin{bmatrix} \frac{\partial y_{SO2,i}}{\partial LH} & \frac{\partial y_{SO2,i}}{\partial VC} \end{bmatrix}$ SO_2 Jacobeans

Gain in sensitivity



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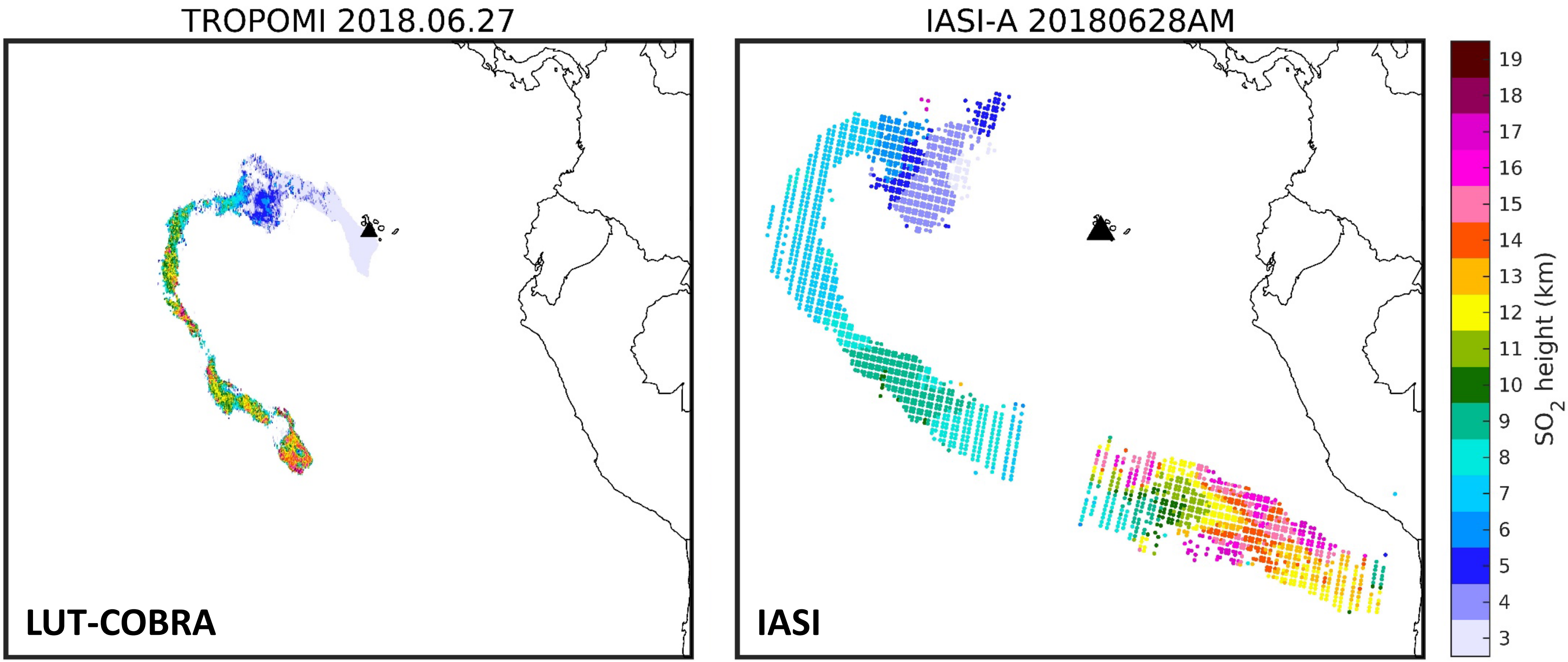
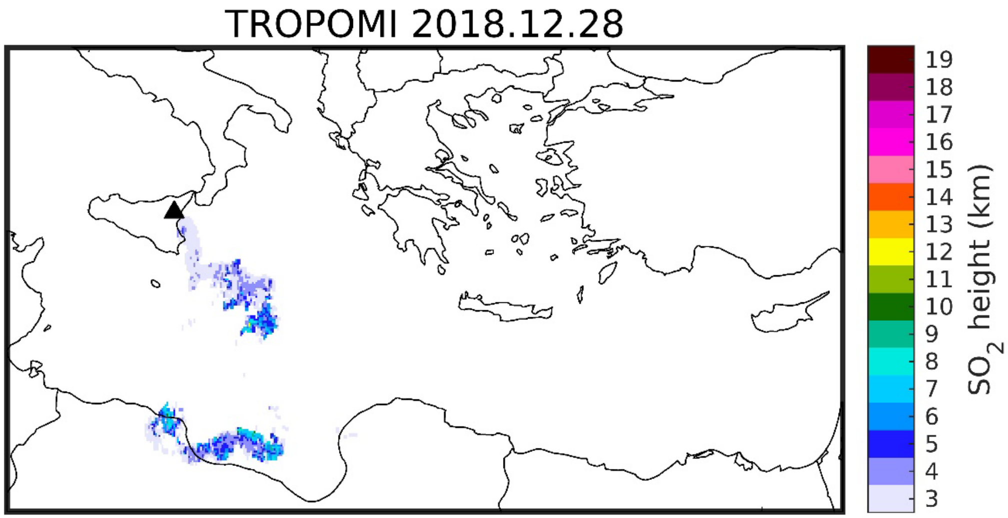
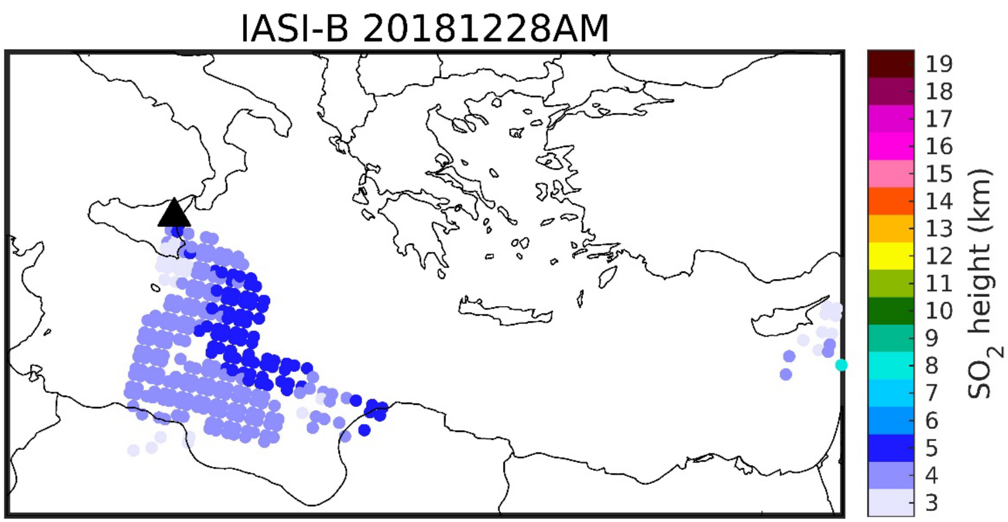
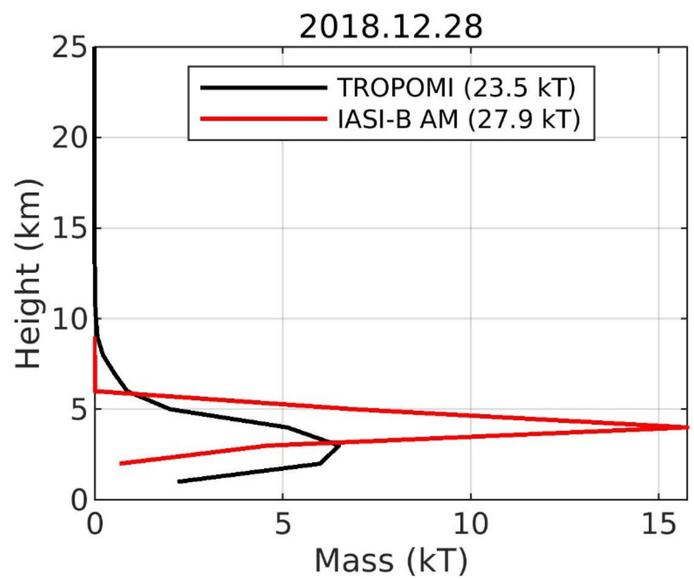
2018 Sierra Negra eruption



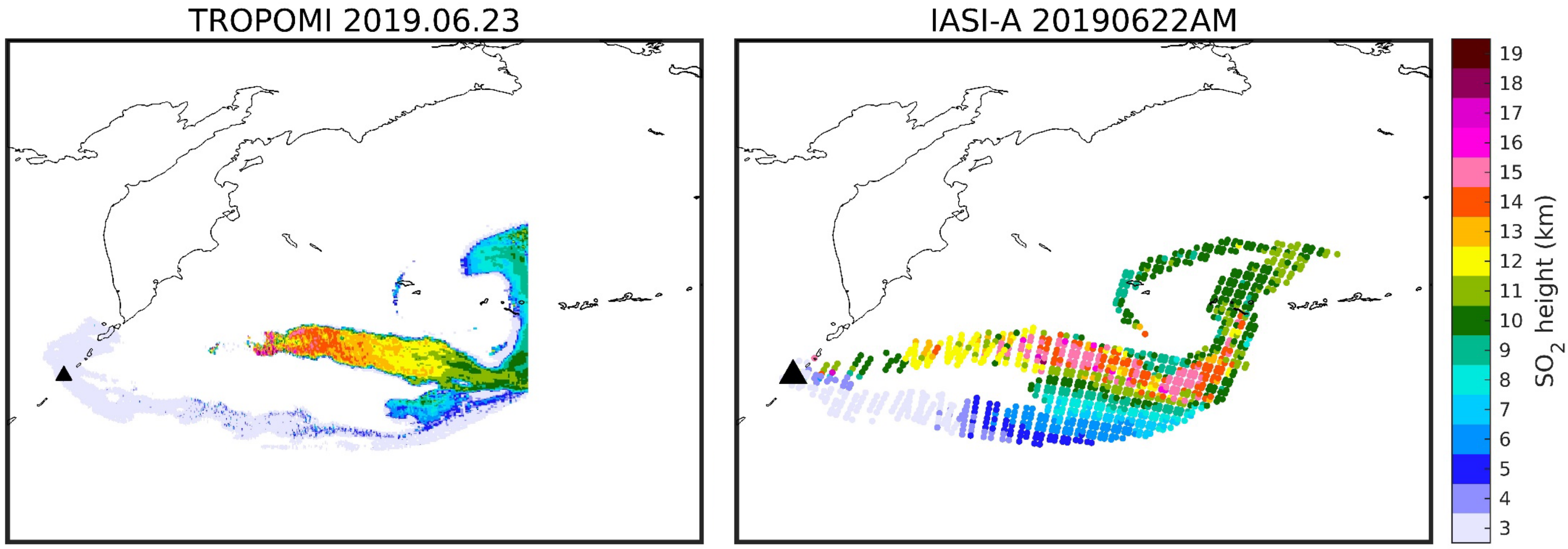
2018 Etna eruption



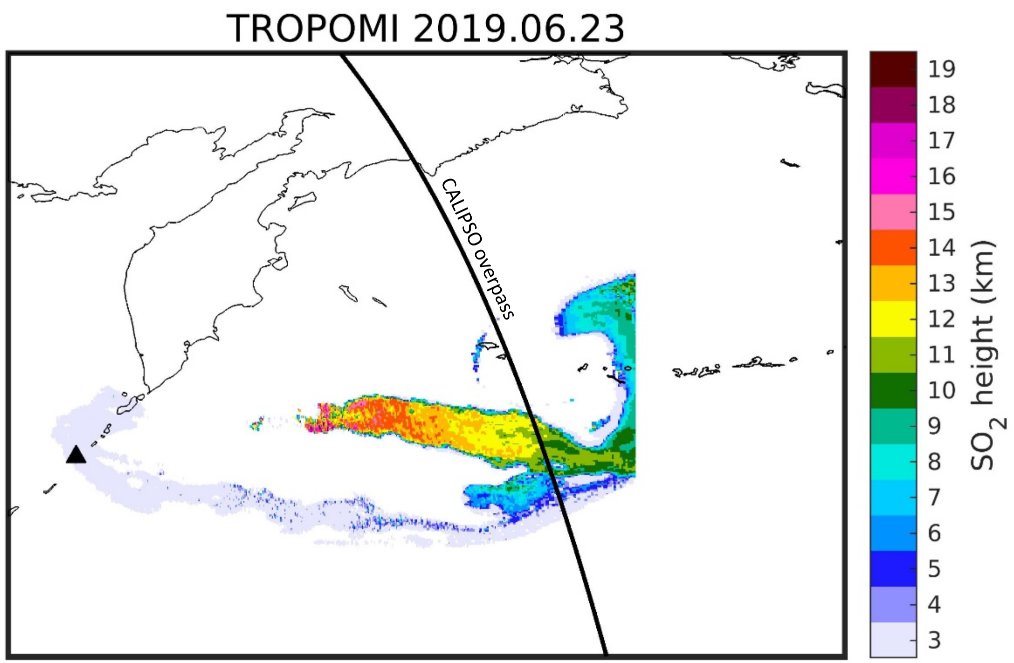


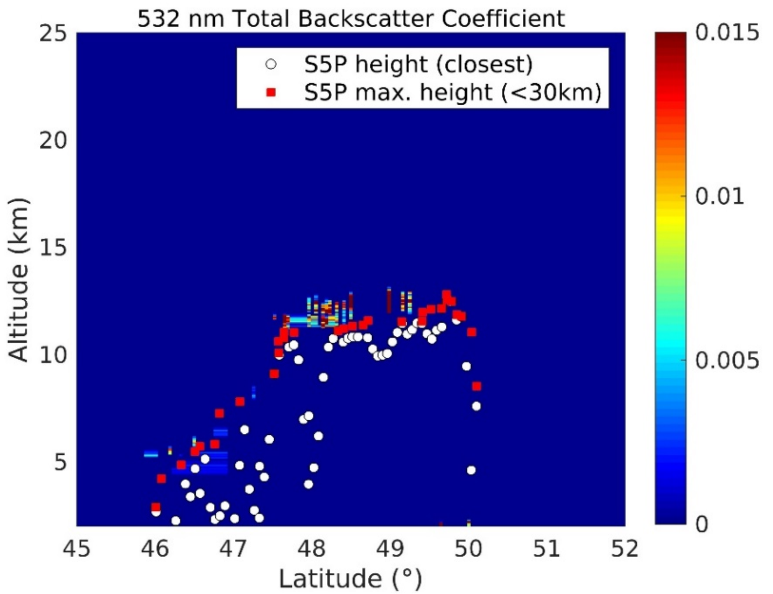


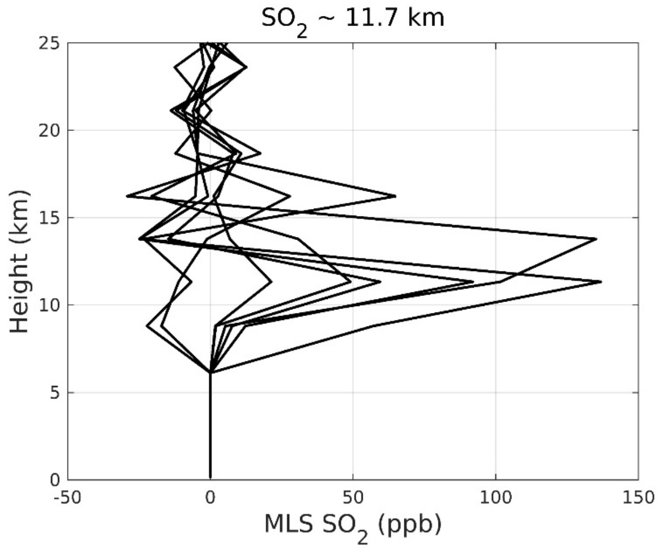
2019 Raikoke eruption



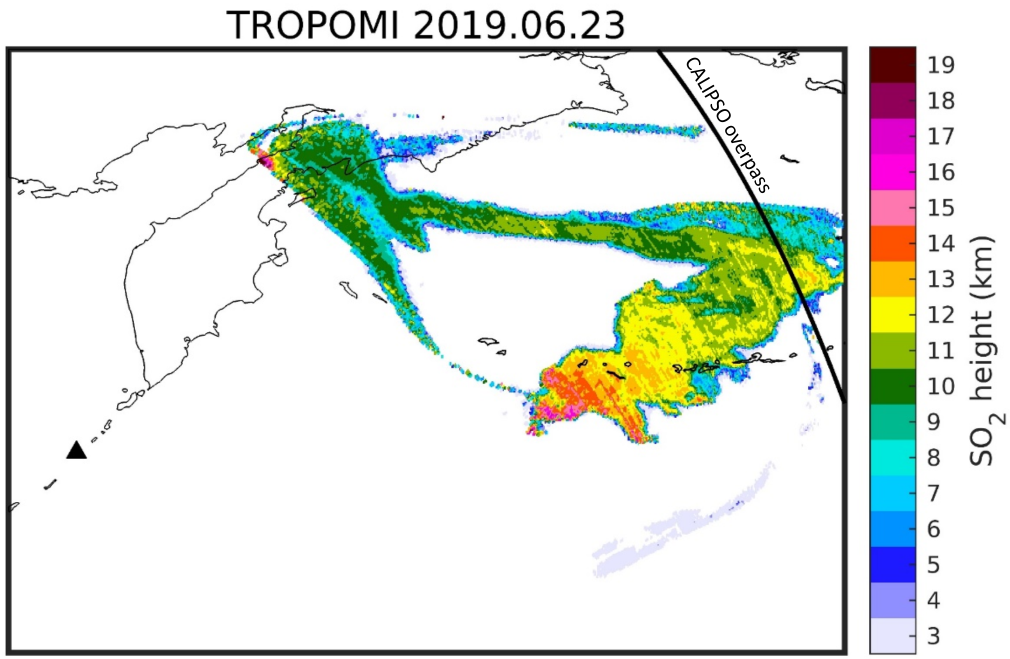
2019 Raikoke eruption

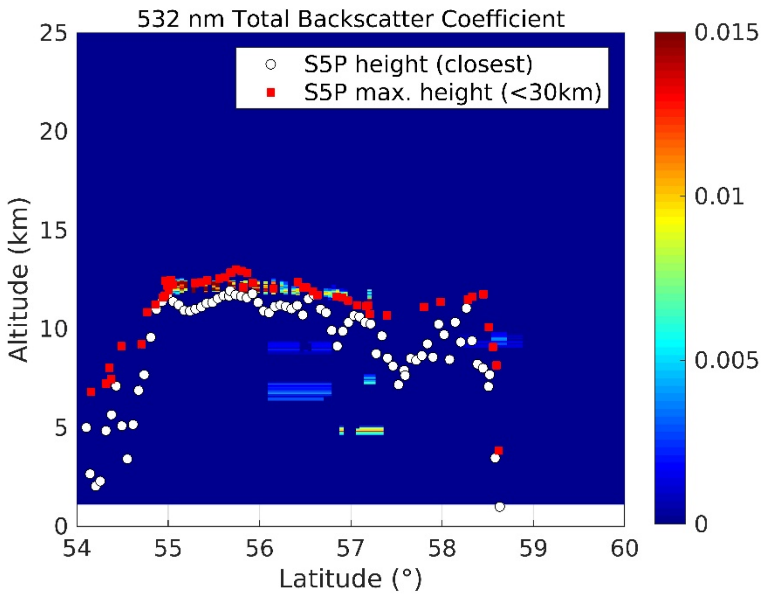


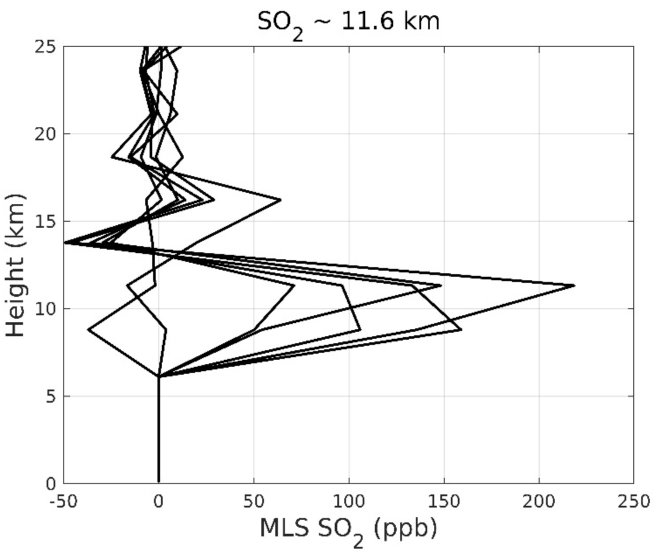




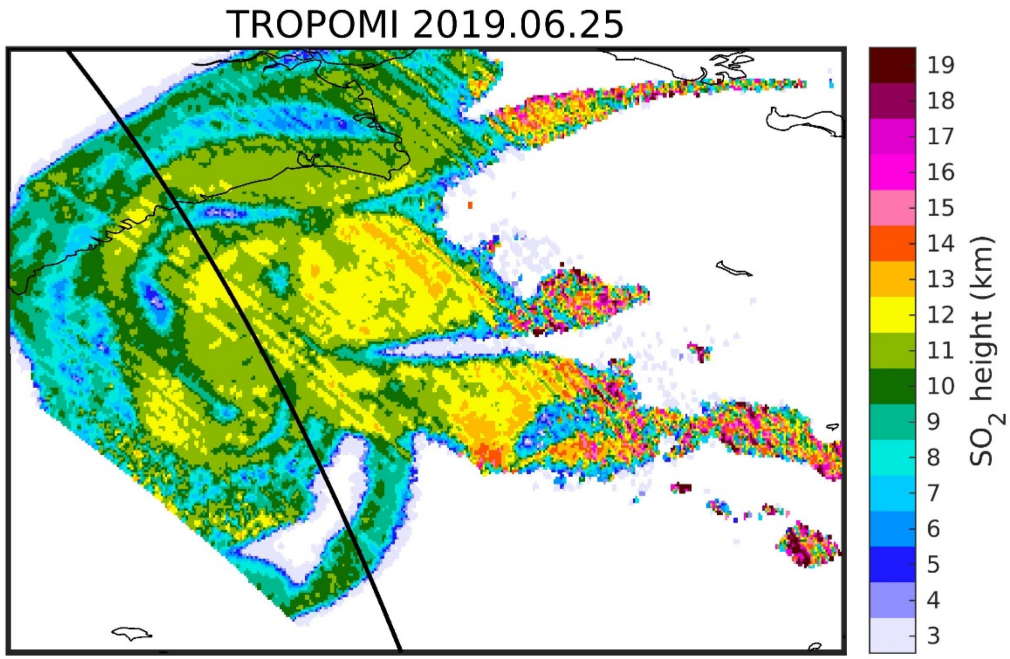
2019 Raikoke eruption

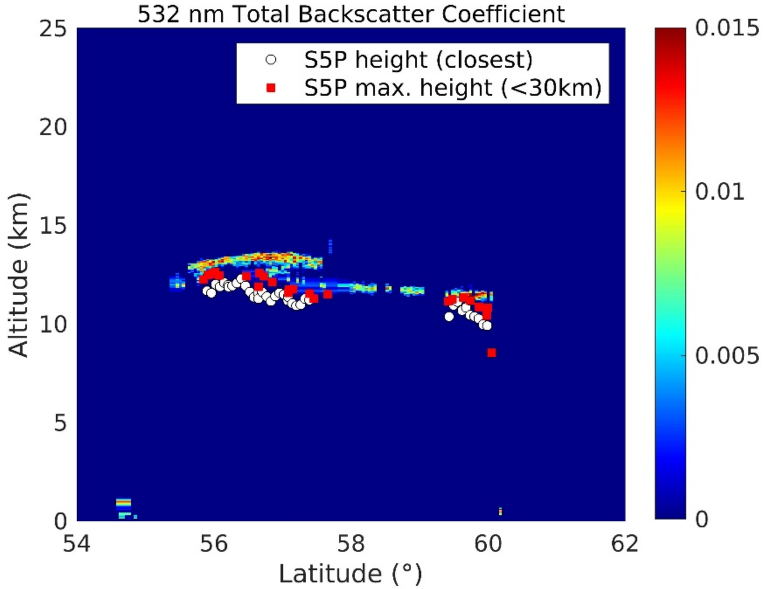


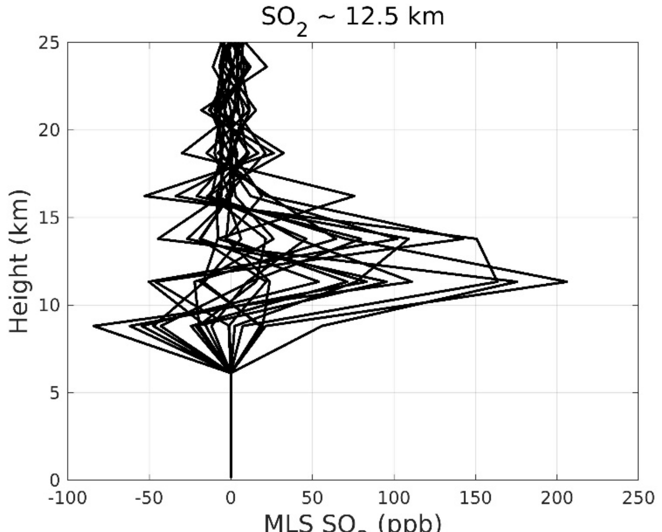




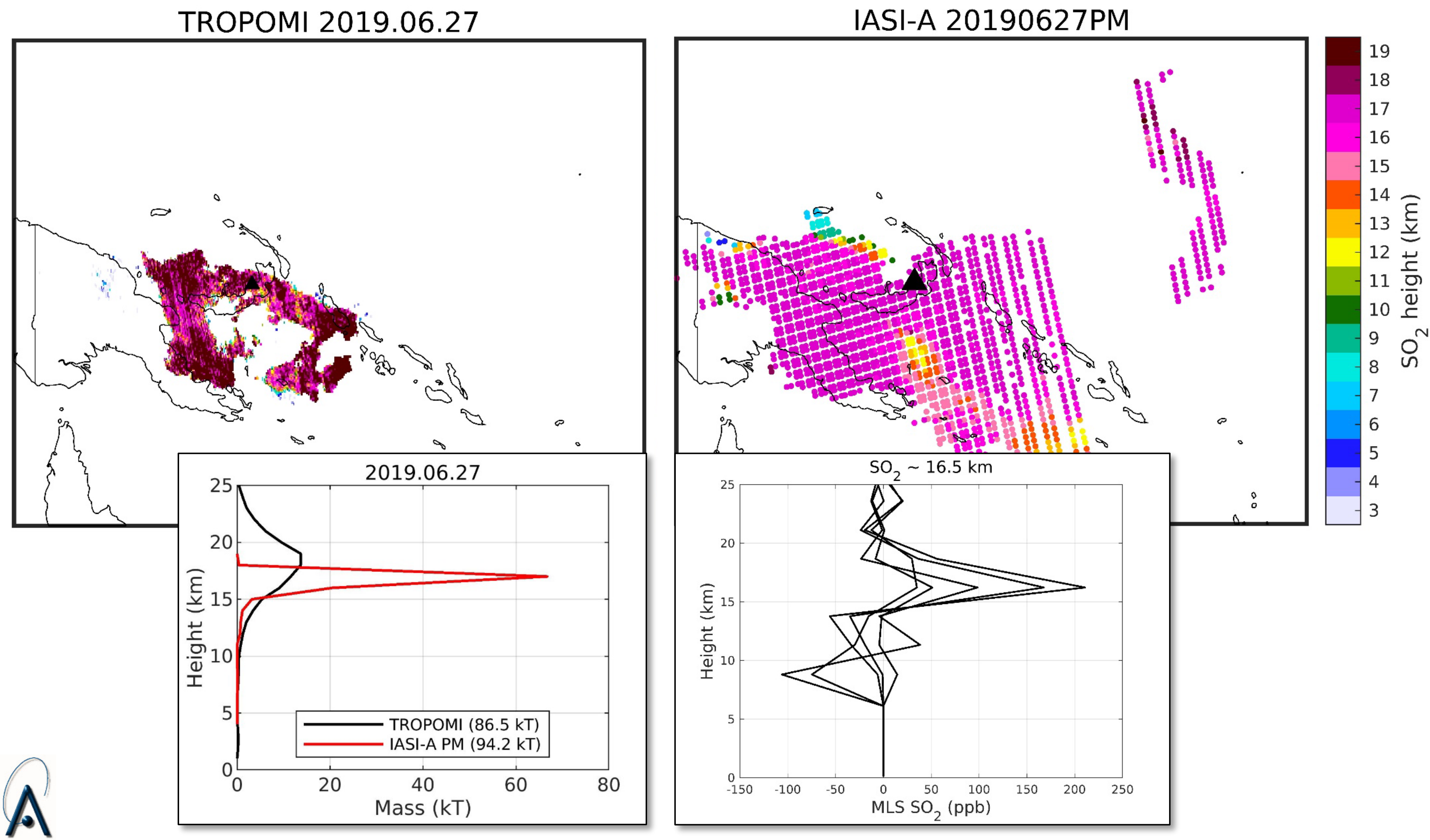
2019 Raikoke eruption



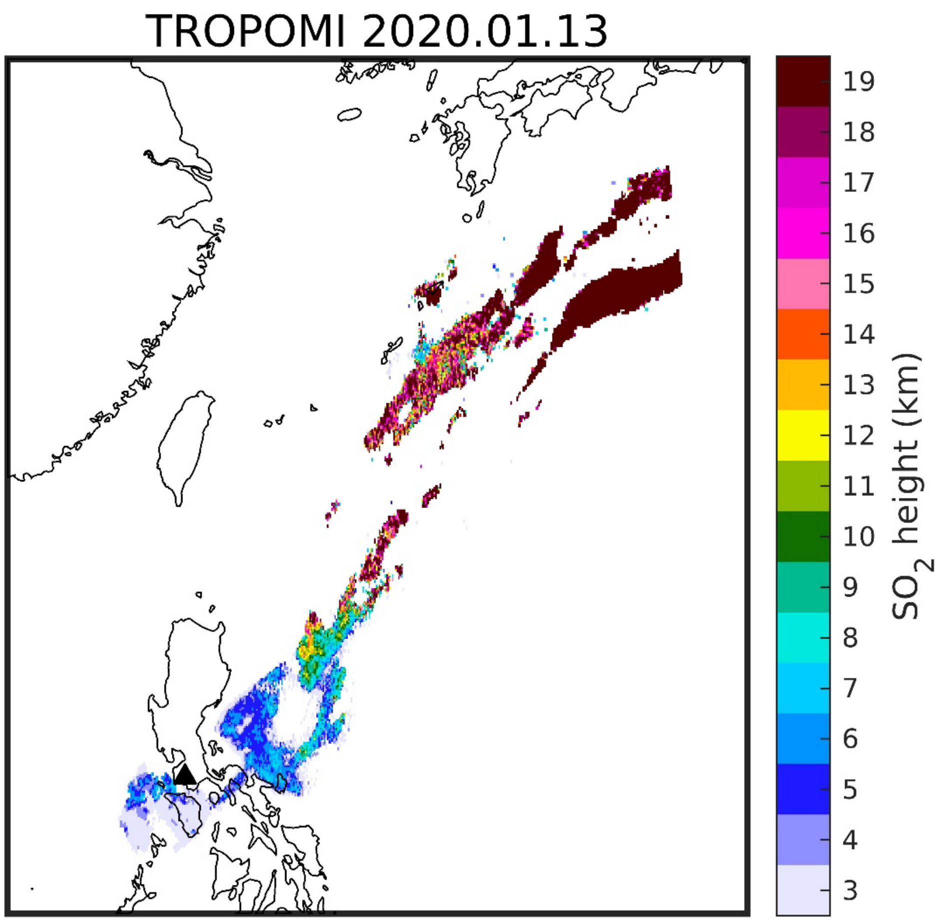


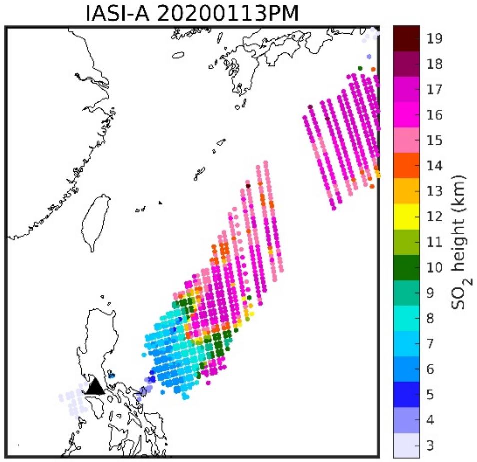


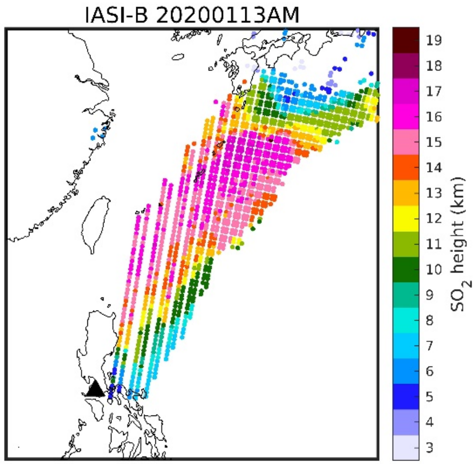
2019 Ulawun eruption



2020 Taal eruption







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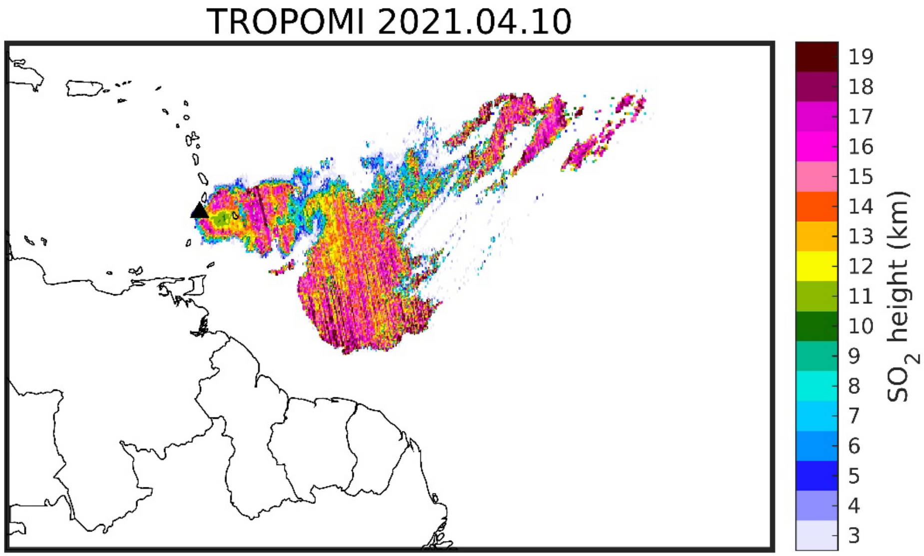
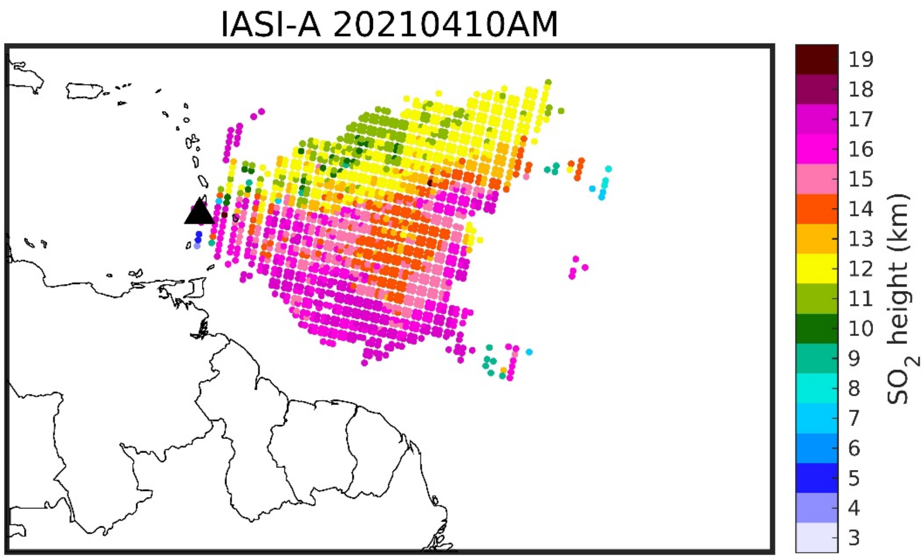
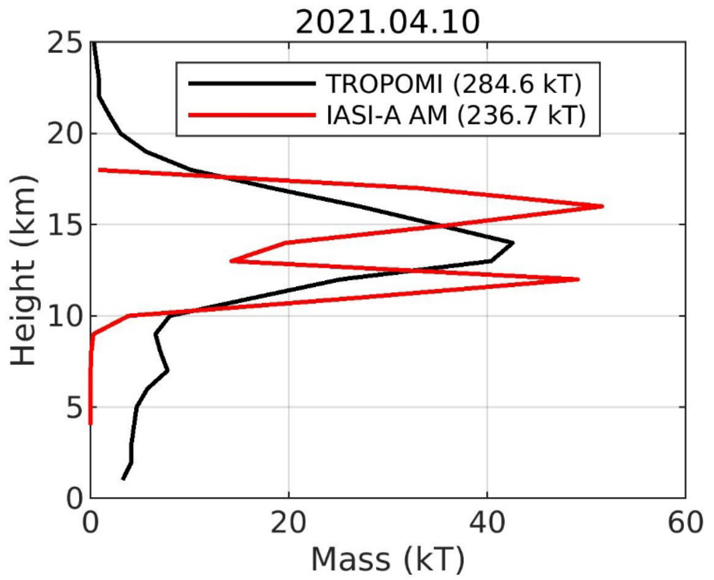
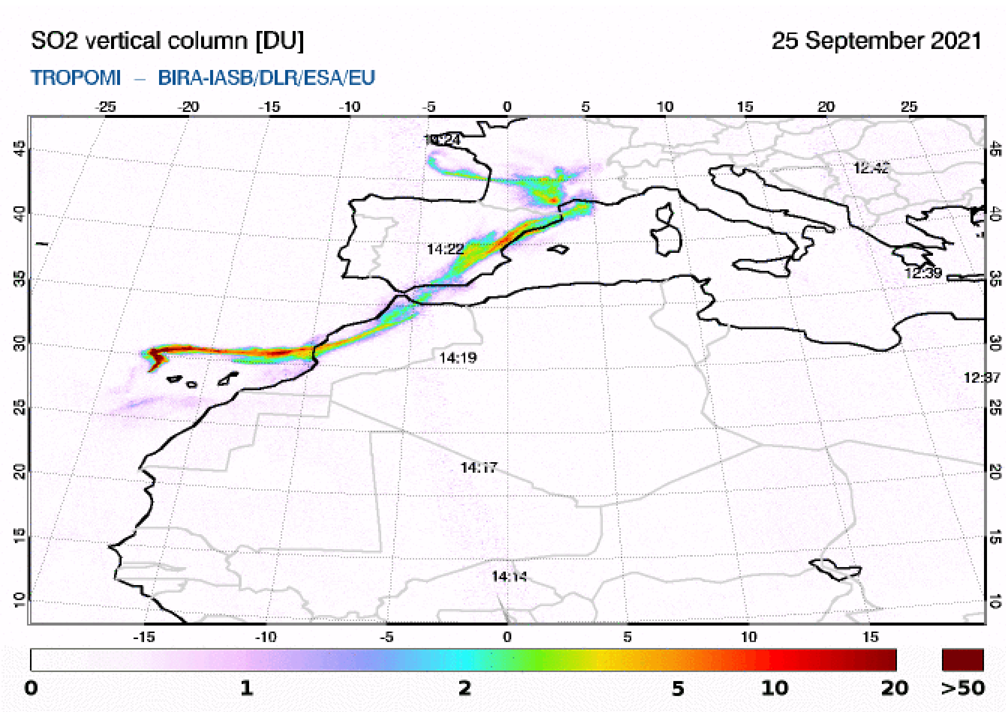
2021 Soufrière eruption

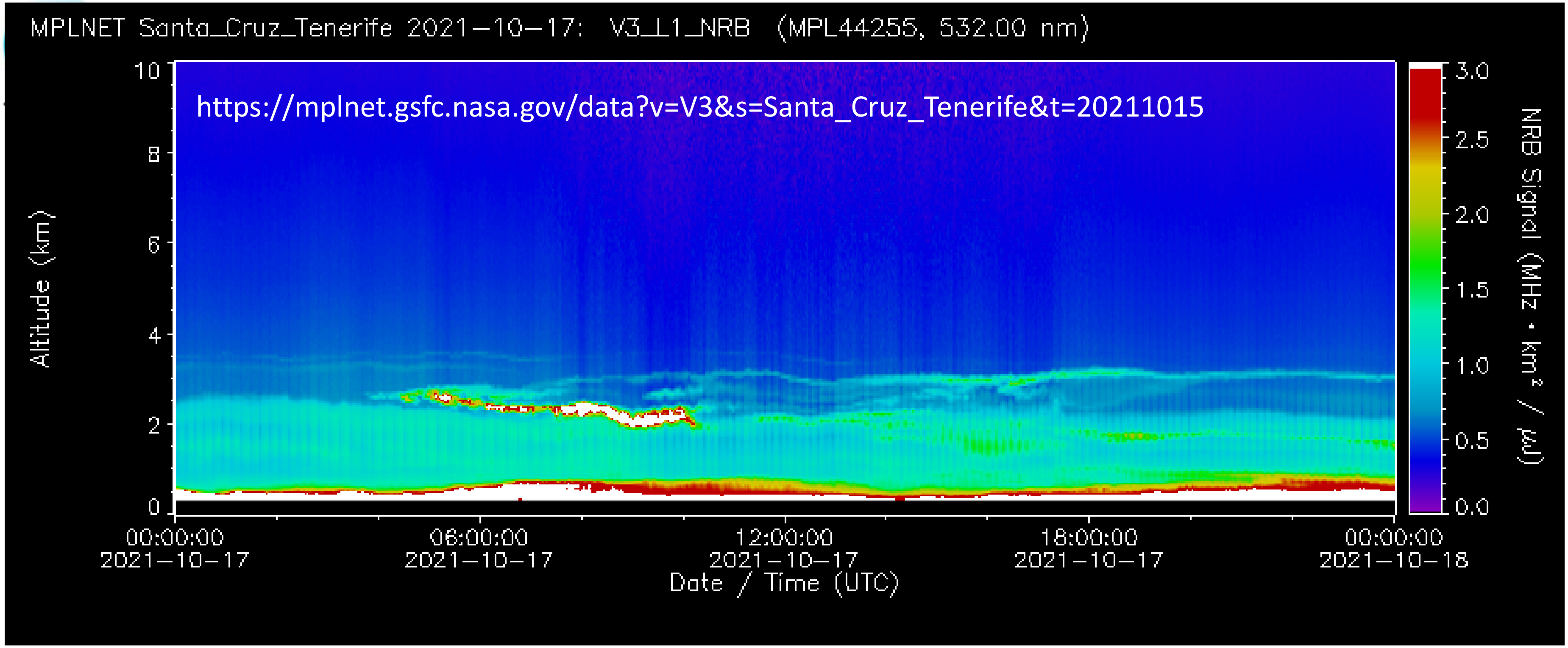




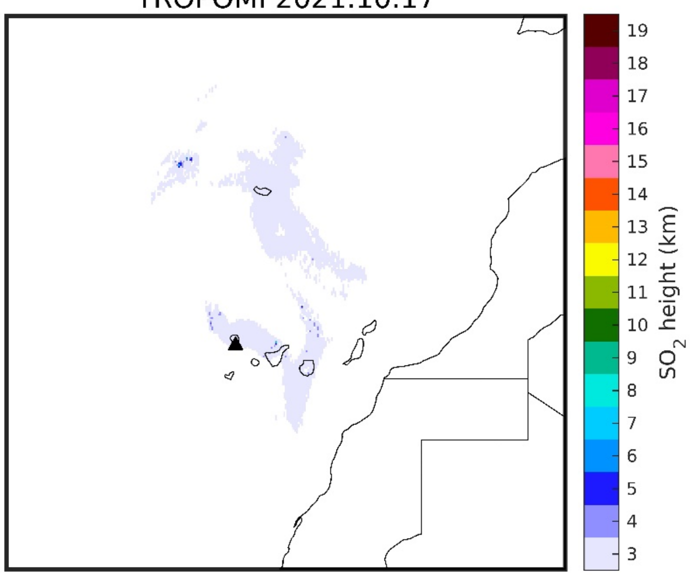


2021 Cumbre Viaje (Palma) eruption





TROPOMI 2021.10.17



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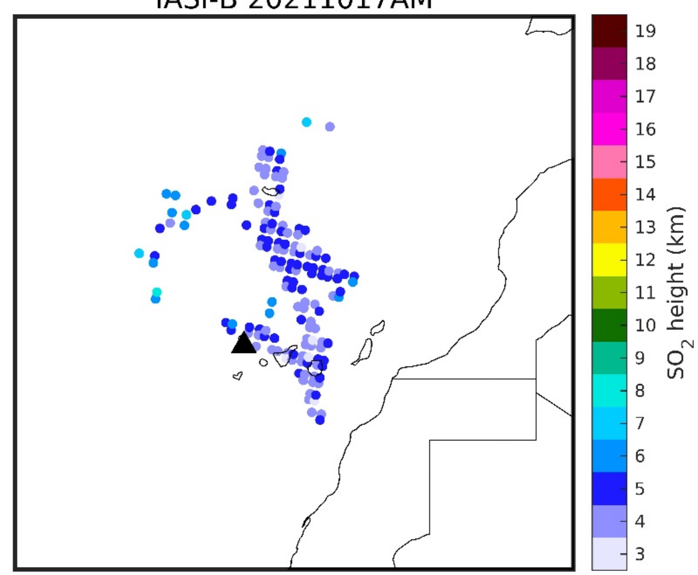
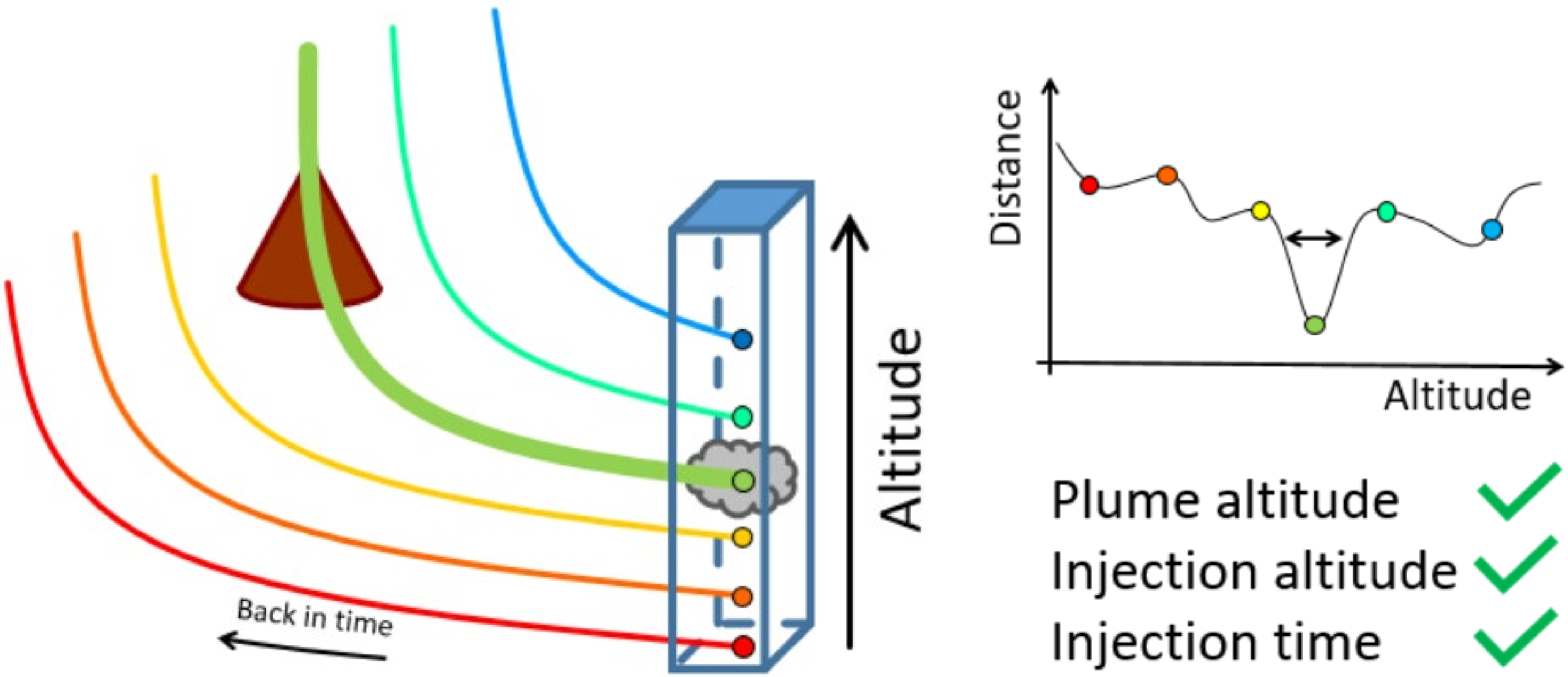


Comparison to back trajectory analysis

Plume_traj tool: Take advantage of high resolution SO_2 measurements and back-trajectories to invert **height-time resolved SO_2 emissions**



Plume altitude ✓
Injection altitude ✓
Injection time ✓

Back trajectories:

- Computed using HYSPLIT
- Uses NOAA GDAS 0.25° 3D wind field

Pardini et al., JVGR, 2018
Queißer et al., Sc. Rep., 2019
Burton et al., Sc. Adv., 2021

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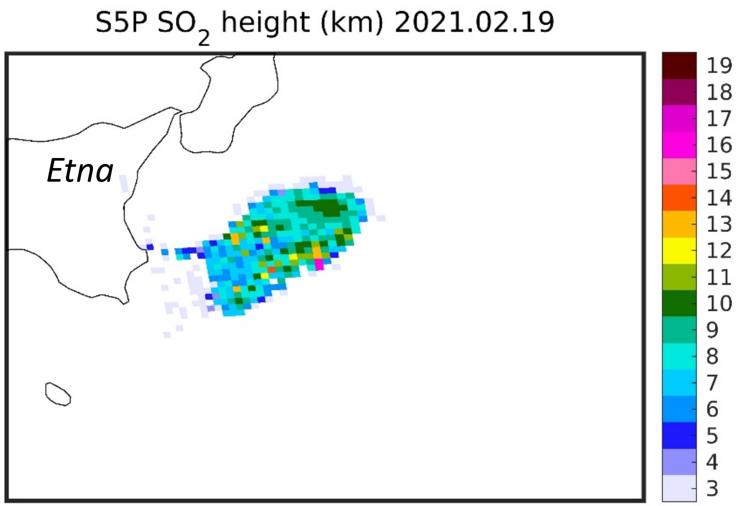
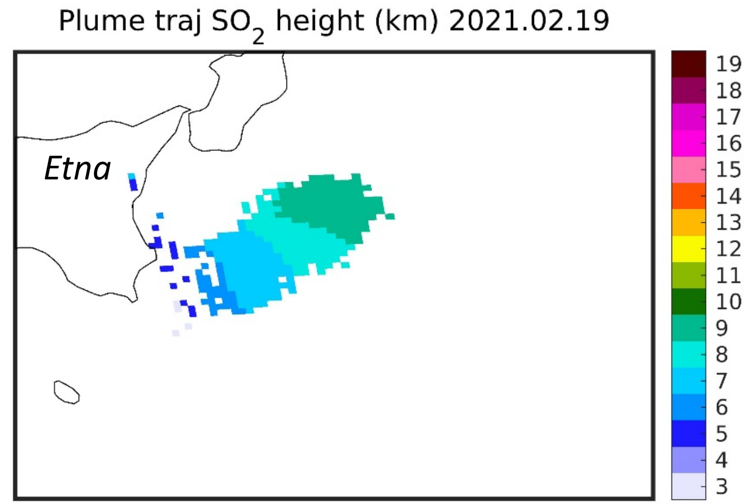
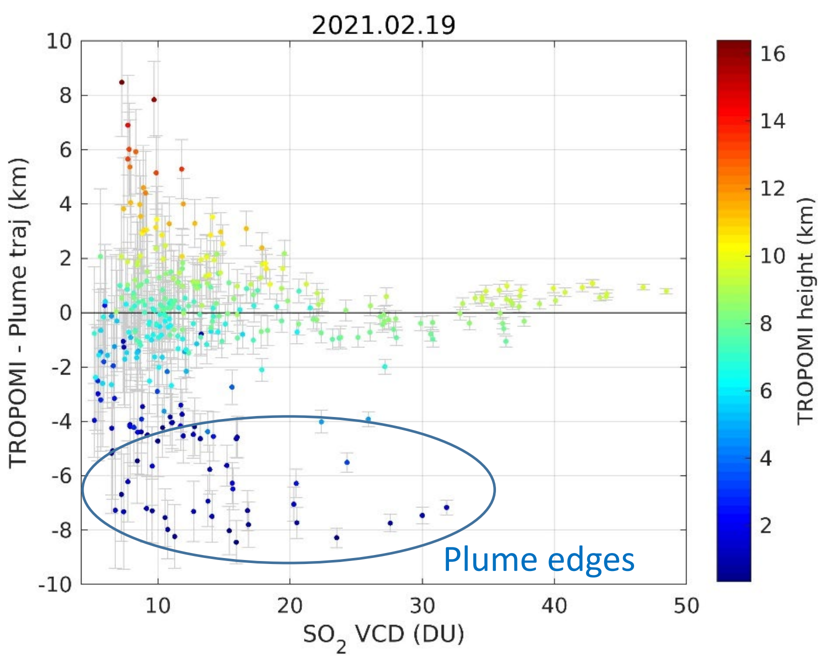
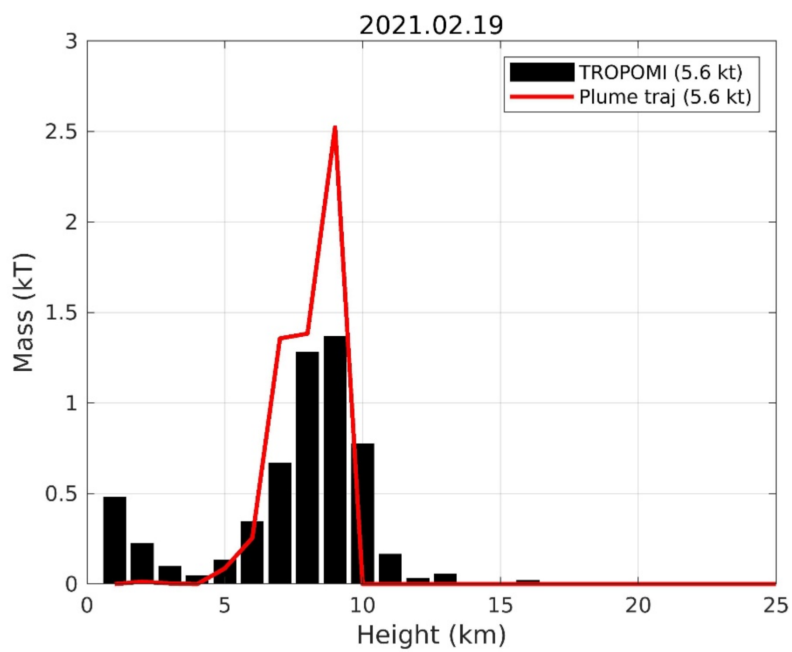
Comparison to back trajectory analysis









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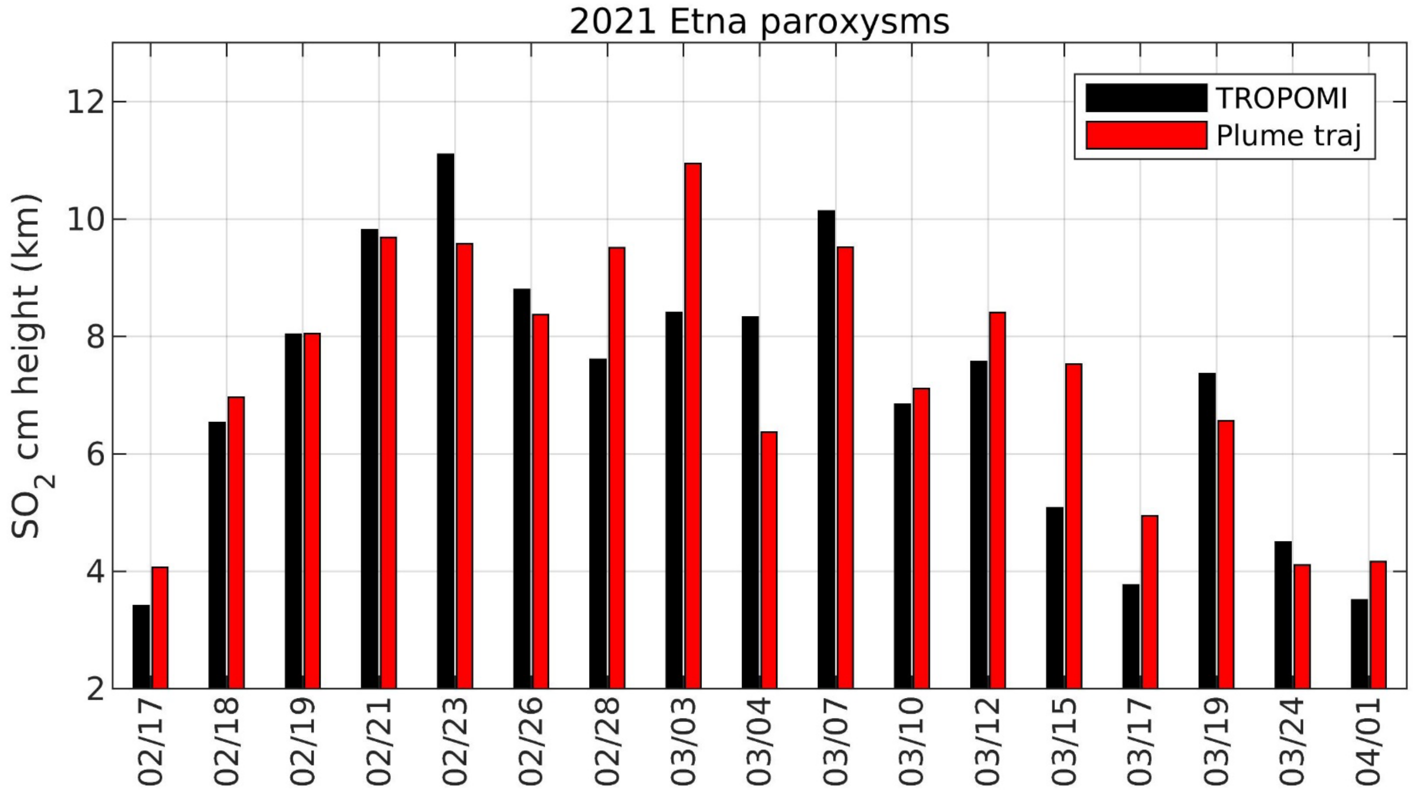

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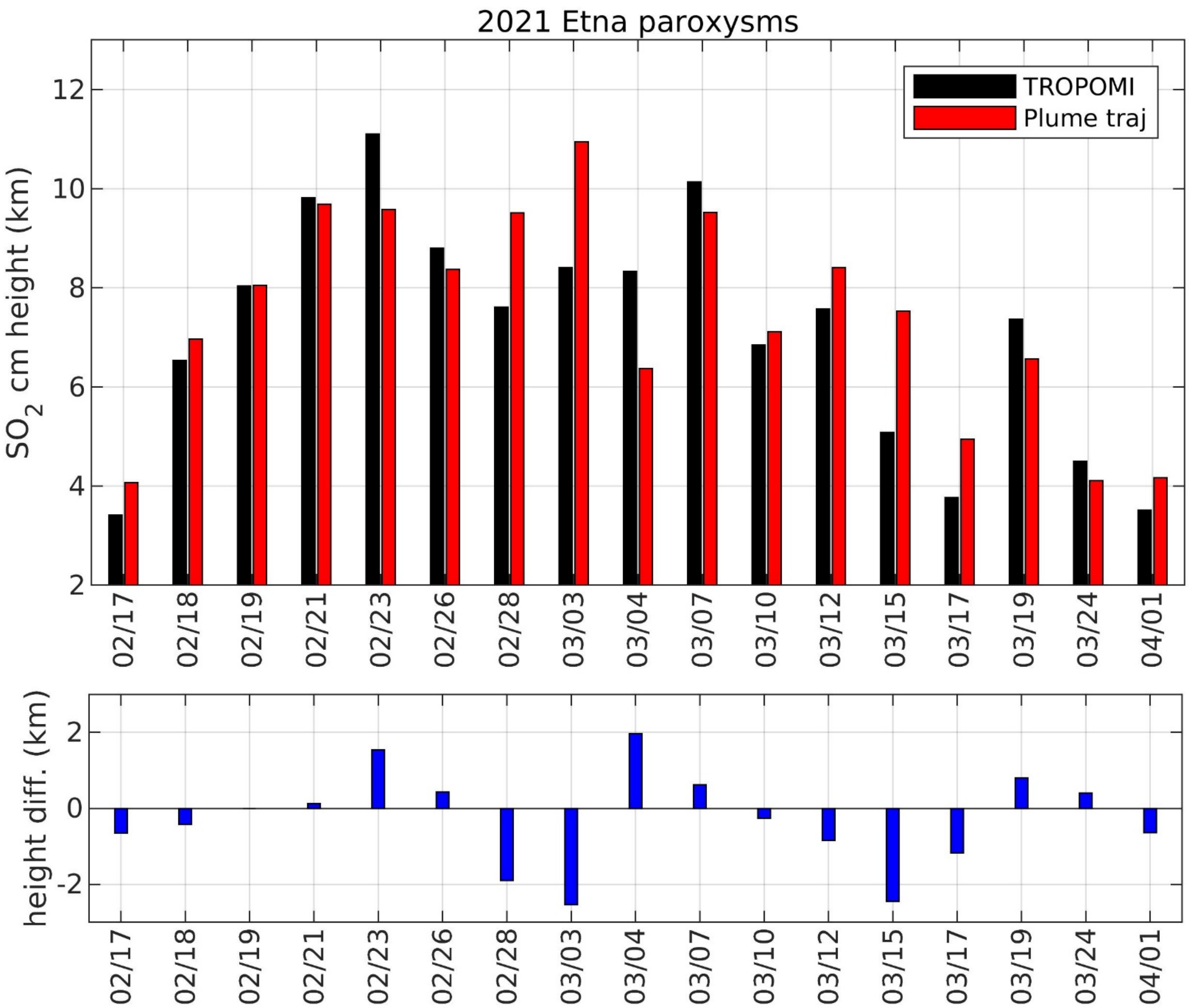
Comparison to back trajectory analysis



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Summary

- A look-up-table Covariance-Based Retrieval Algorithm (LUT-COBRA) enables to retrieve SO_2 height with improved sensitivity (for SO_2 VCD>5DU).
  => clear added-value for dispersed plumes and the study of modest volcanic eruptions.

- Comparison to CALIOP, MLS, IASI, back trajectories: **reasonable results on a number of volcanic events**.

- SO_2 height accuracy: 1-2 km except for young ash laden plumes and at plume edges (effect of pixel underfilling).

- For tropical eruptions with SO_2 injection at tropopause level, retrieved SO_2 heights are generally too high (by several kms).

- For plumes in lower troposphere, TROPOMI is lower than IASI (by 1-2 km).

Thank you for your attention!