A global perspective on BrO/SO_2 ratios from S-5P/TROPOMI

MAX PLANCK INSTITUTE FOR CHEMISTRY

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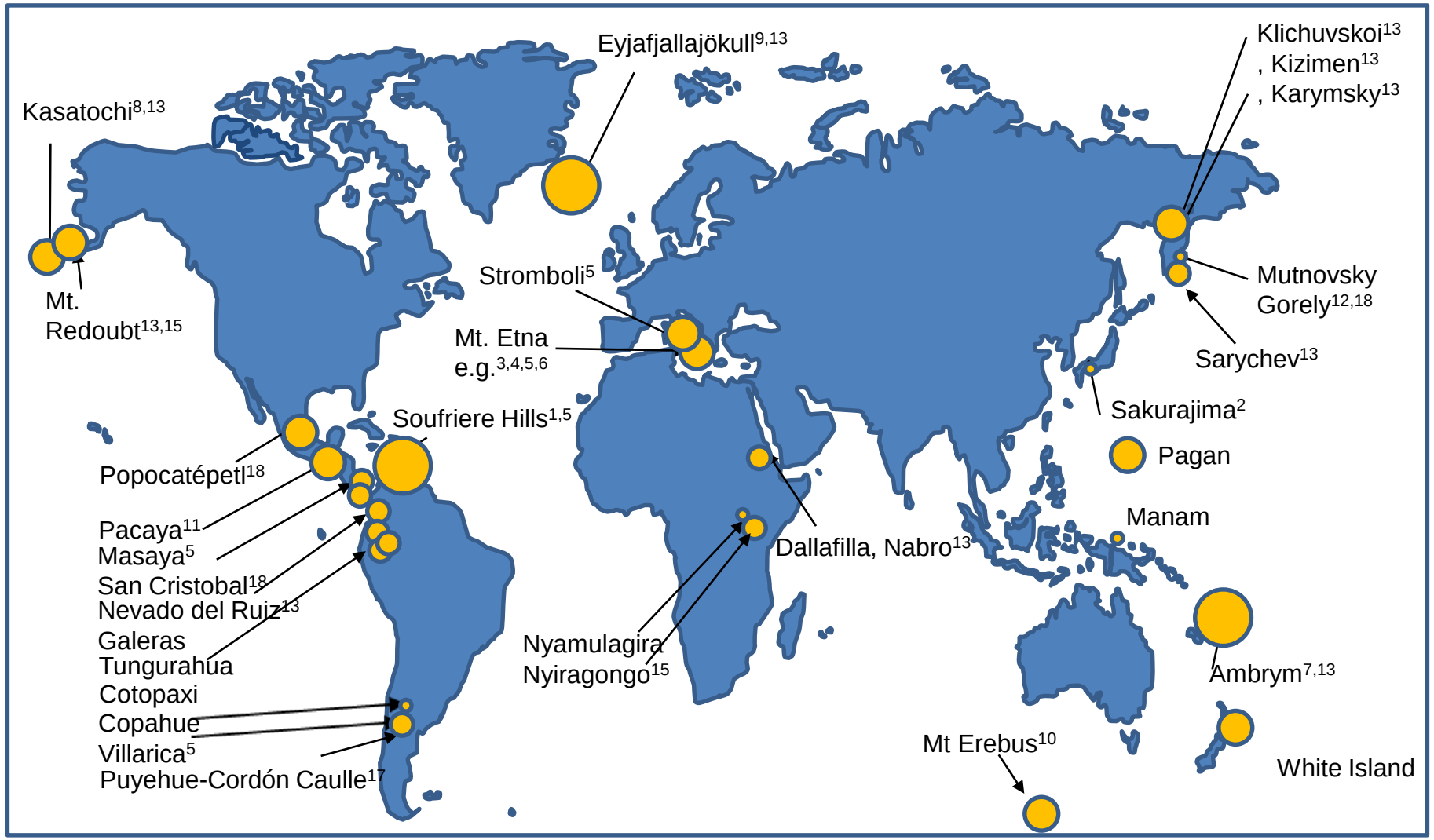
Motivation



[map: Pers. comm. Nicole Bobrowski]

BrO/SO_2 ratio:
10^{-3} – 10^{-6}

Varies as a function of:

1. **Volcanic property**
2. **Volcanic activity**

BrO detected at >25 volcanoes

- >5E-4
- >1E-4
- >0.5E-4
- <0.5E-4

DOAS retrieval

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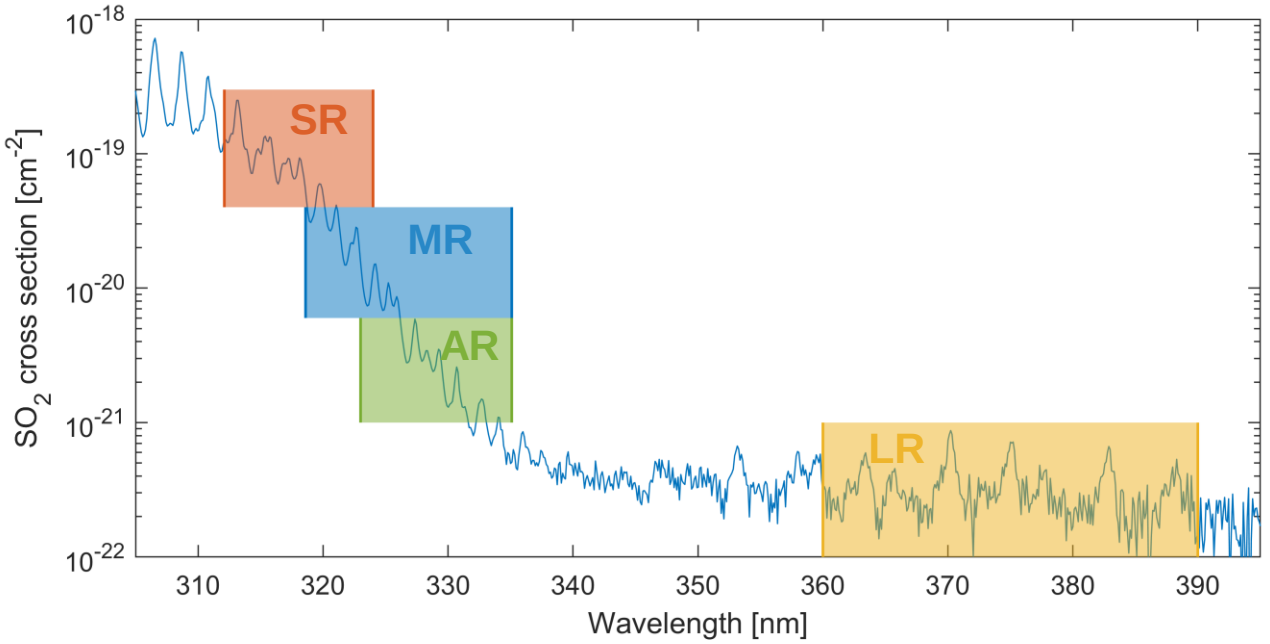
Linearised DOAS fit (Borger et al., 2020)

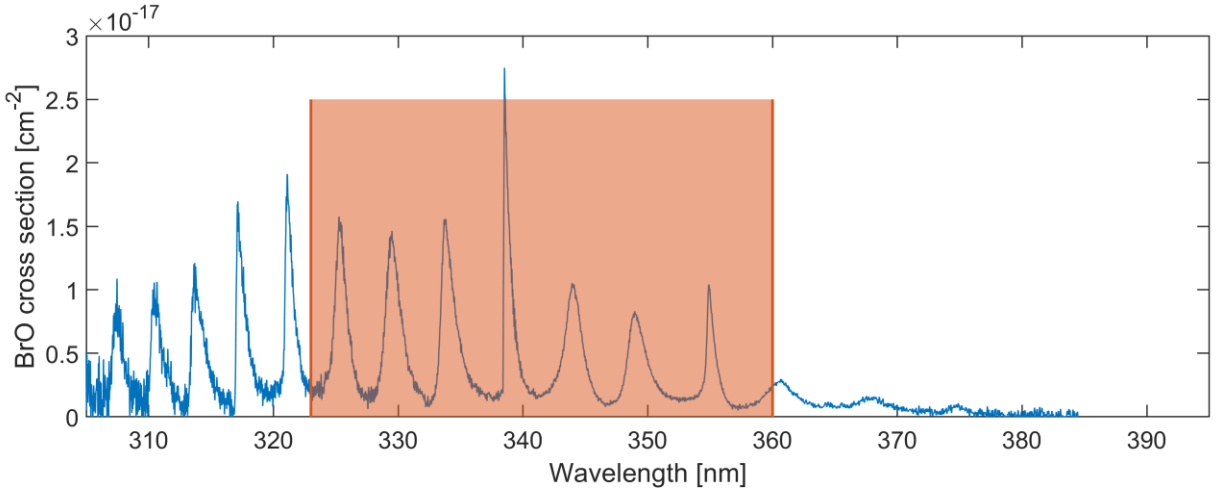
SO_2 DOAS fit:

- S5-P/TROPOMI, S4 & S5 verification algorithm
- Standard (SR): 312.1nm – 324nm
- For higher SO_2 loads:
  - Medium (MR): 318.6nm – 335.1nm
  - Alternative (AR): 323nm – 335.1nm
  - Large (LR): 360nm – 390nm (only for two eruptions)
- Selection based on SO_2 SCD

BrO DOAS fit:

- Standard: 323nm – 360nm





BrO retrieval

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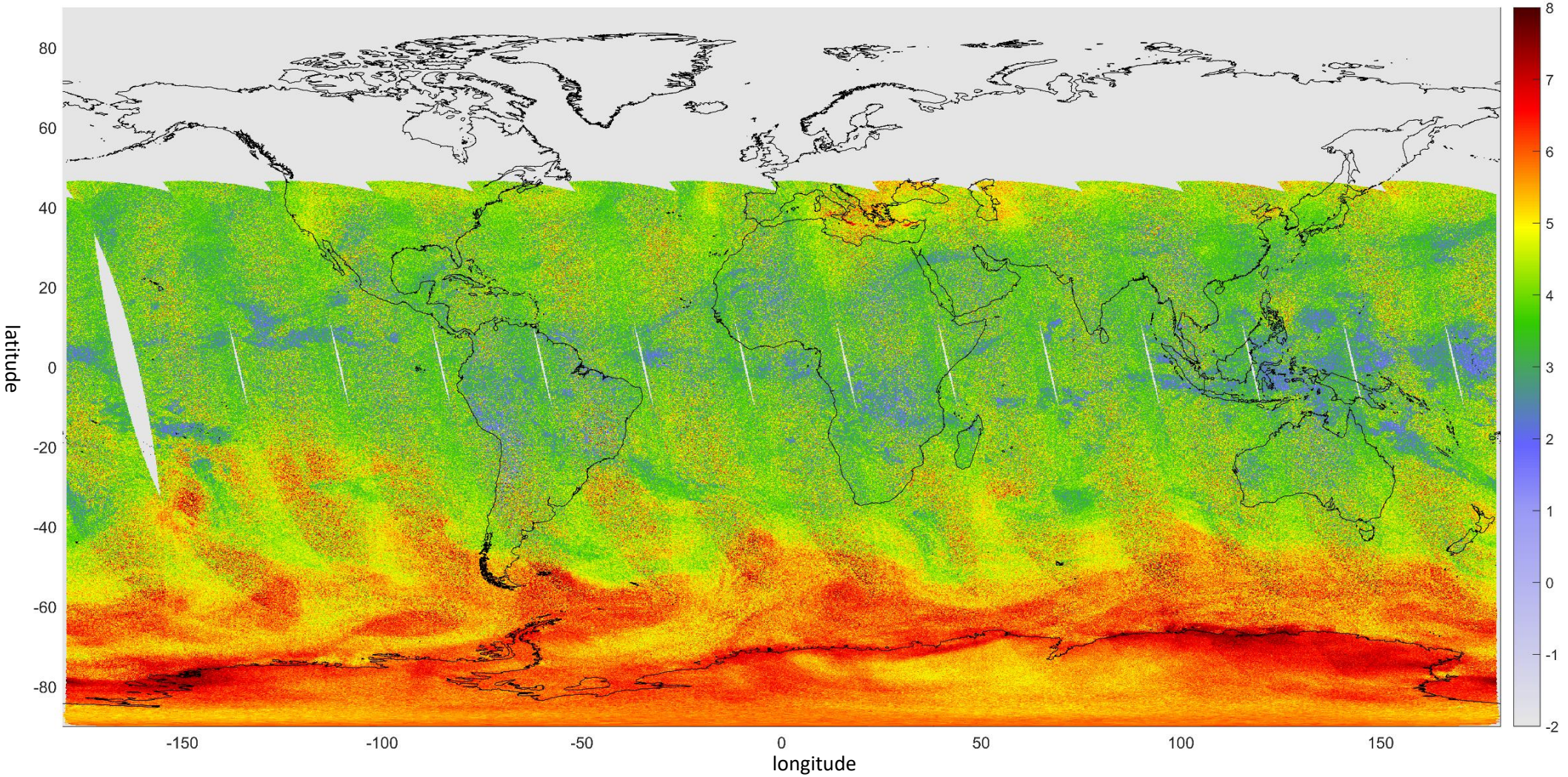
BrO VCD (geom.) on 25 December 2018



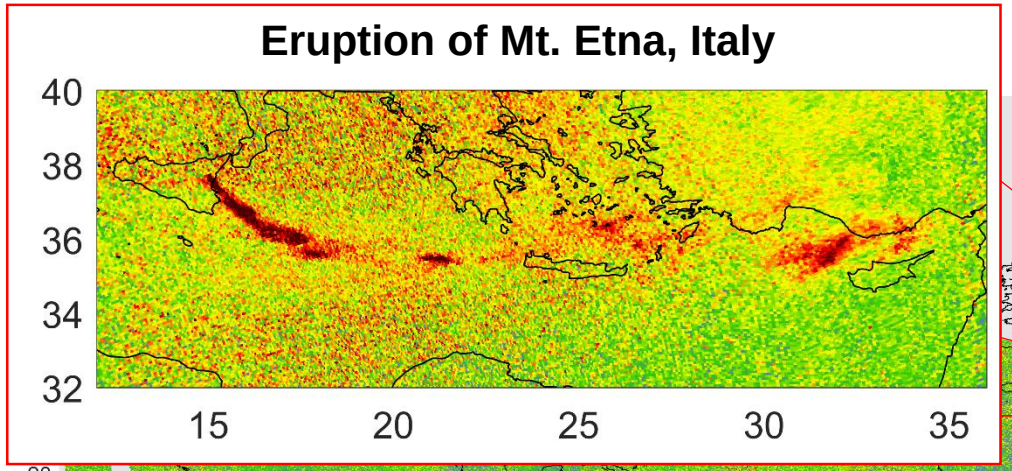
Large scale structure:

- Stratospheric BrO

Volcanic signal:

- Small scale (local) source
- Coincident with SO_2 signal

BrO retrieval



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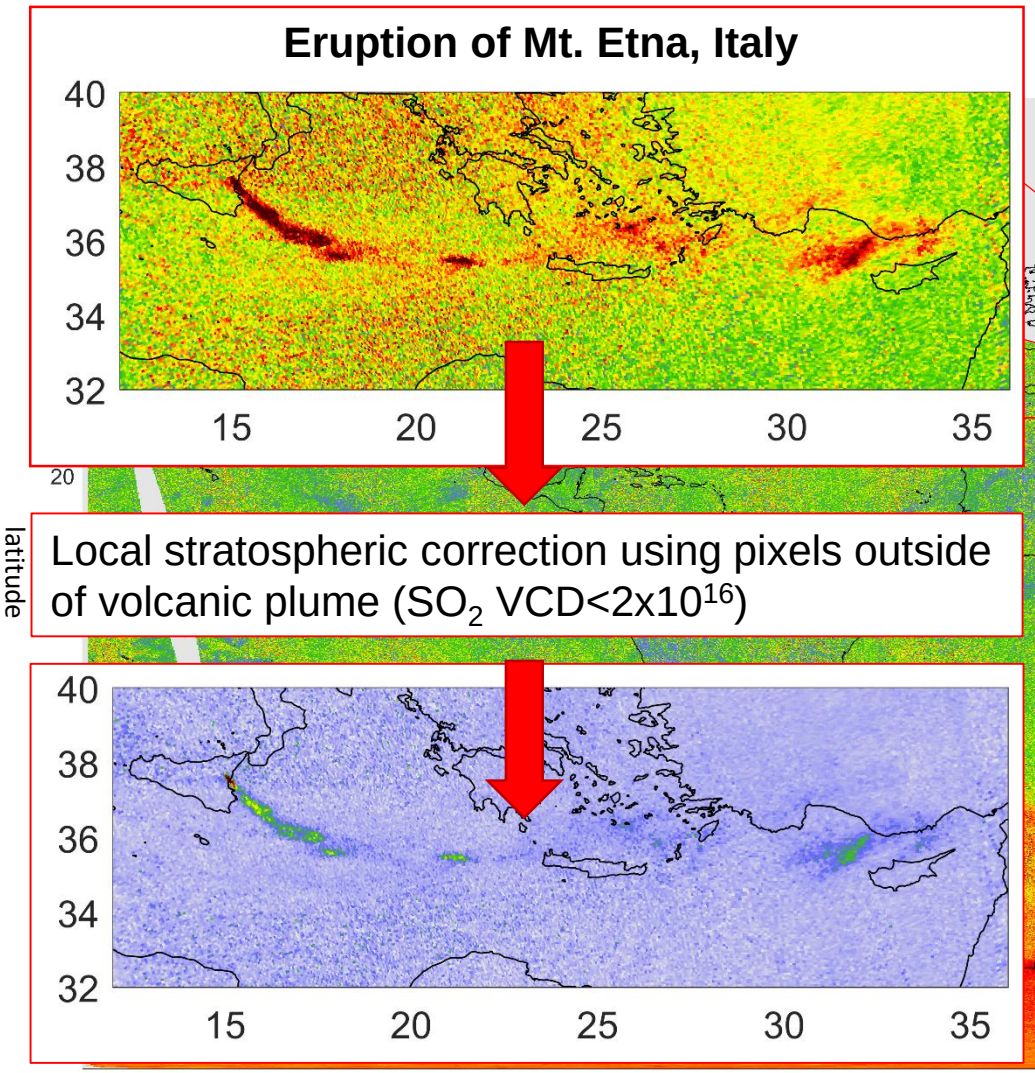

Large scale structure:

- Stratospheric BrO

Volcanic signal:

- Small scale (local) source
- Coincident with SO_2 signal

Automated plume detection

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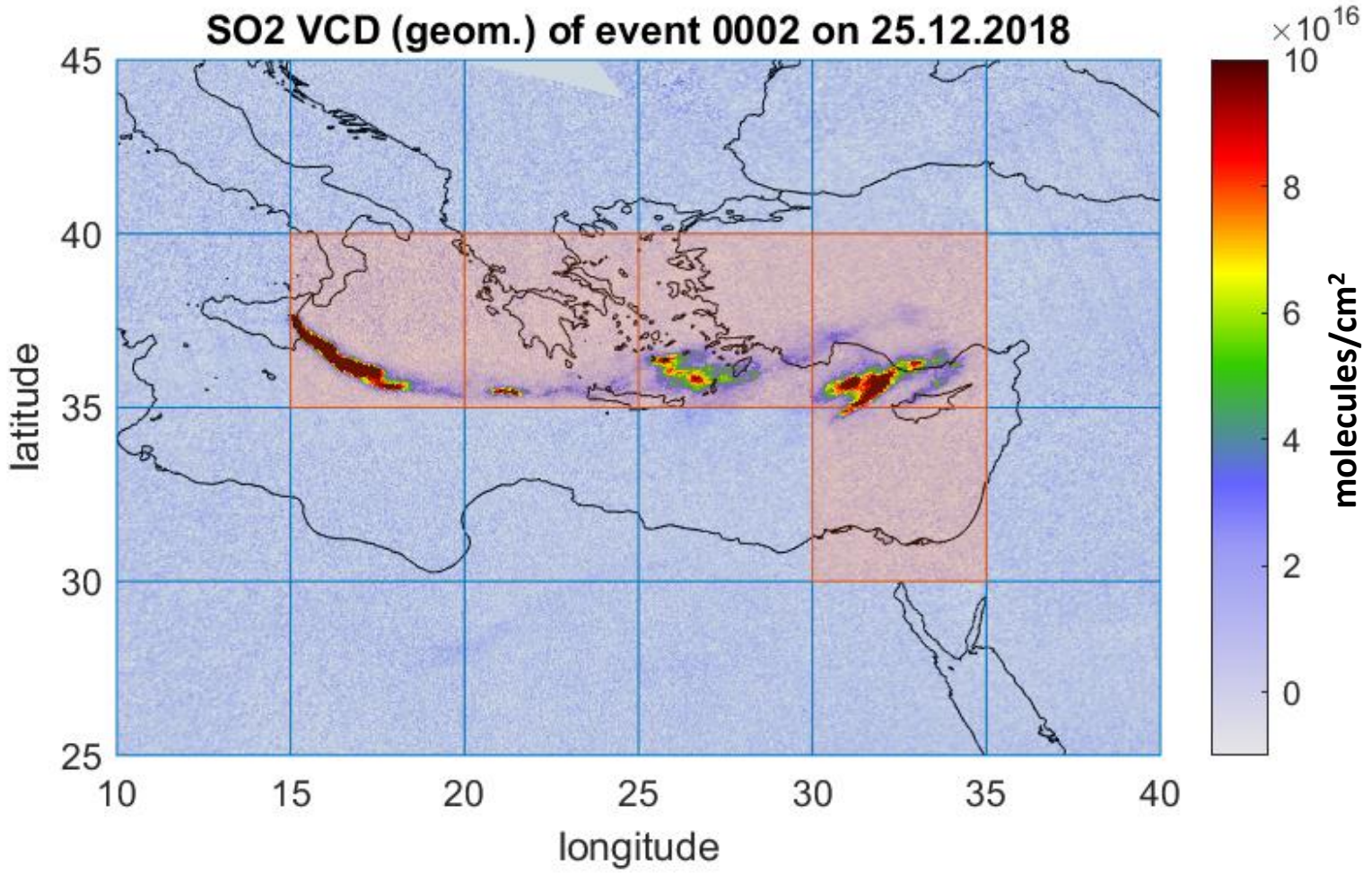
Automated algorithm:

- Based on SO_2 map
- On 5°x5° grid
- Adjacent grid boxes with SO_2>5x10^{16} molecules cm^{-2}

Event processing:

- BrO-SO_2 scatter plot
- BrO/SO_2 ratio calculated from slope



Example: medium size eruption

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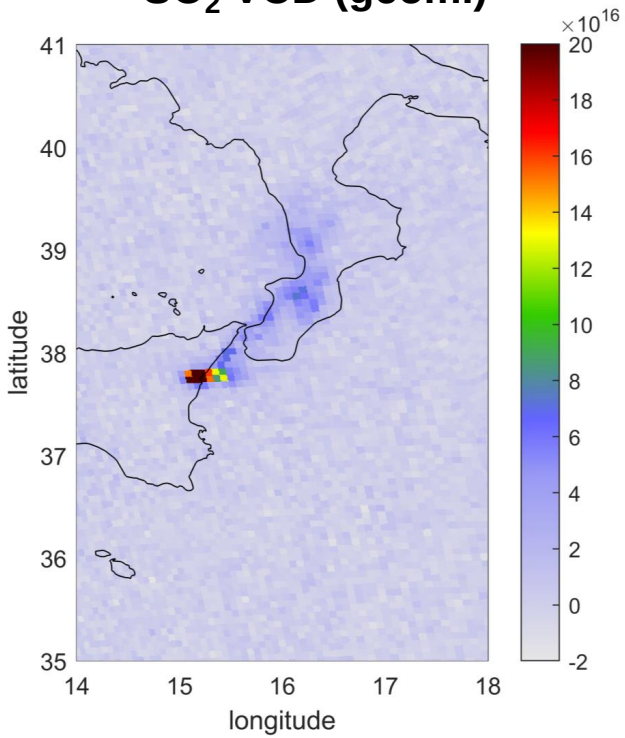
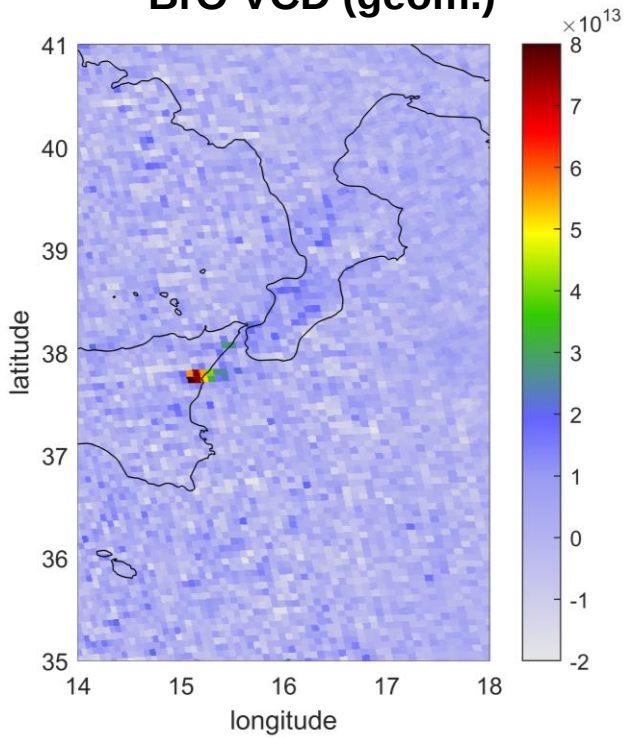
Mt. Etna, 29 January 2019:

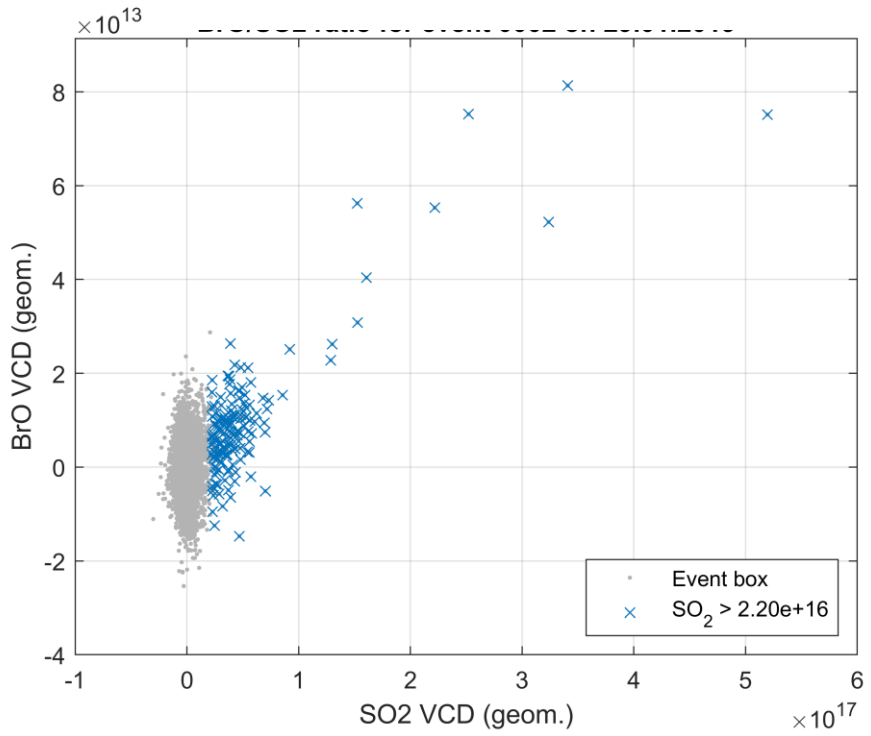
- Localized plume, large SO_2
- Clear linear correlation between BrO and SO_2

SO_2 VCD (geom.)



BrO VCD (geom.)





Example: medium size eruption

MAX-PLANCK-INSTITUT FÜR CHEMIE

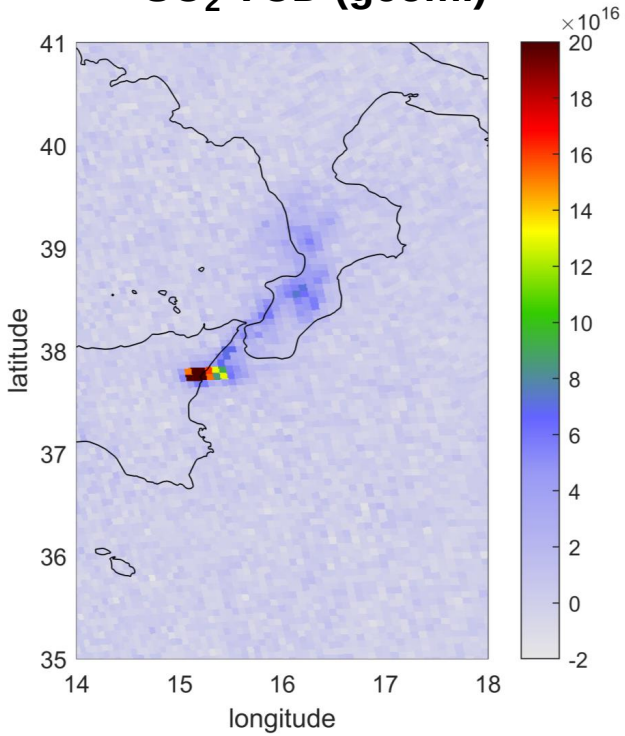
Mt. Etna, 29 January 2019:

- Localized plume, large SO_2
- Clear linear correlation between BrO and SO_2

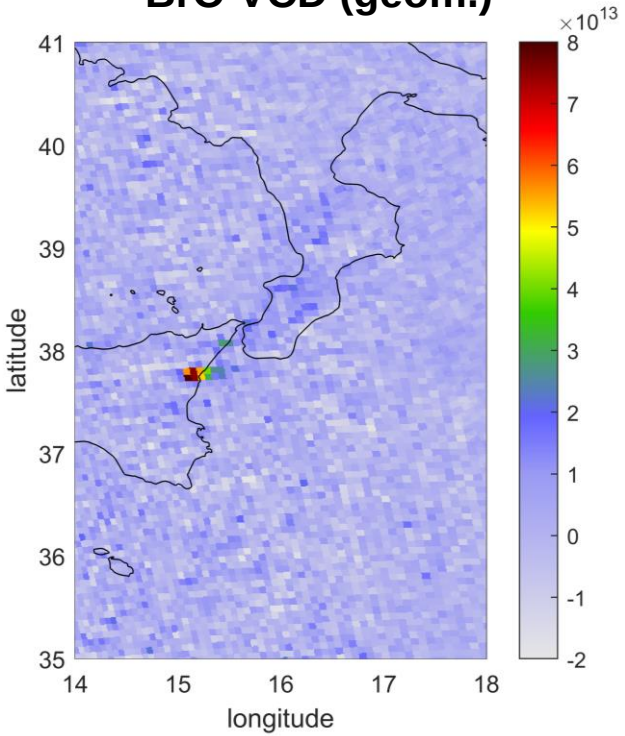
BrO/SO_2 ratio:

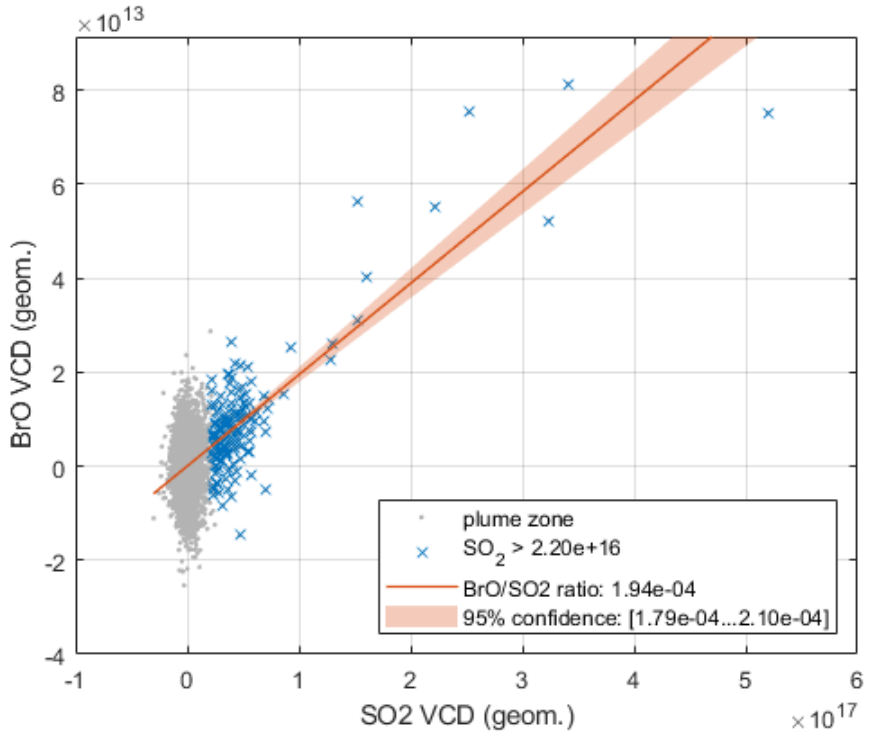
- Slope of BrO-SO_2 scatter plot
- Calculated from pixels above SO_2 detection limit:
  - $SO_2 > 4*\sigma_{SO2}$ (typically 2-3x10^{16})

SO_2 VCD (geom.)



BrO VCD (geom.)





BrO/SO_2 Catalogue

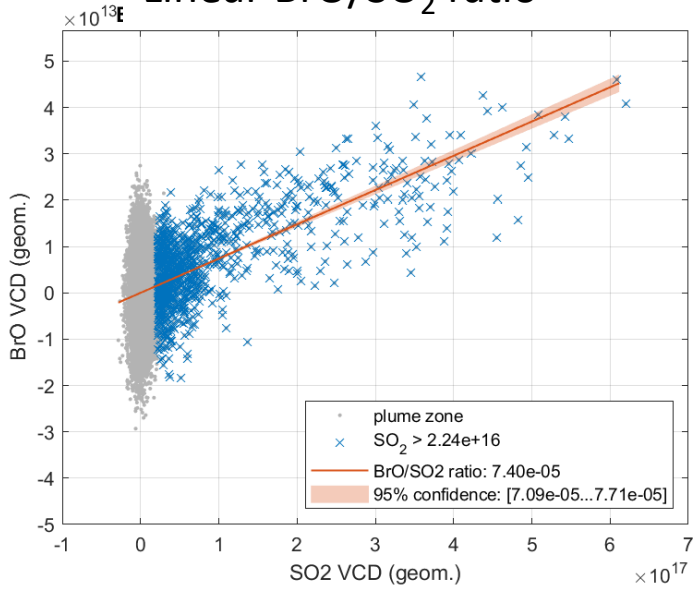
MAX-PLANCK-INSTITUT FÜR CHEMIE

Four years of S-5P/TROPOMI data (2018-2021)

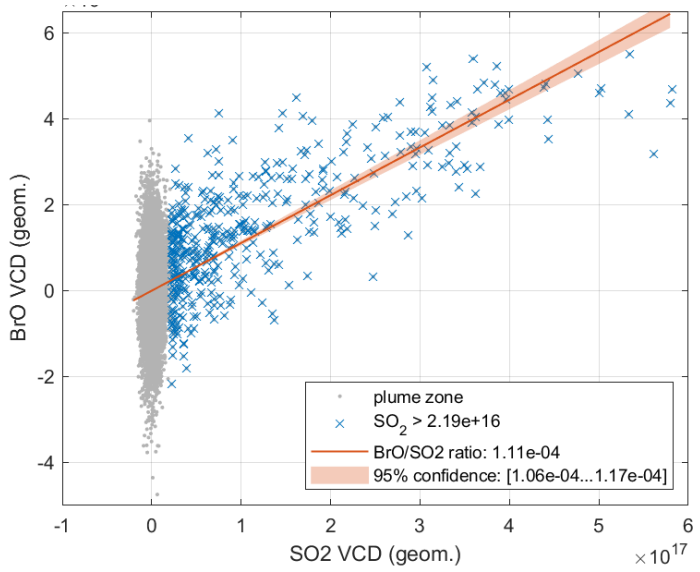
- 3979 plumes detected
- 1414 detections of BrO
- Mostly linear BrO/SO_2 ratios

Classification	# of Events	Significant BrO
All data	3979	1414
… linear	3375	996
… weakly non-linear	410	246
… highly non-linear	194	172

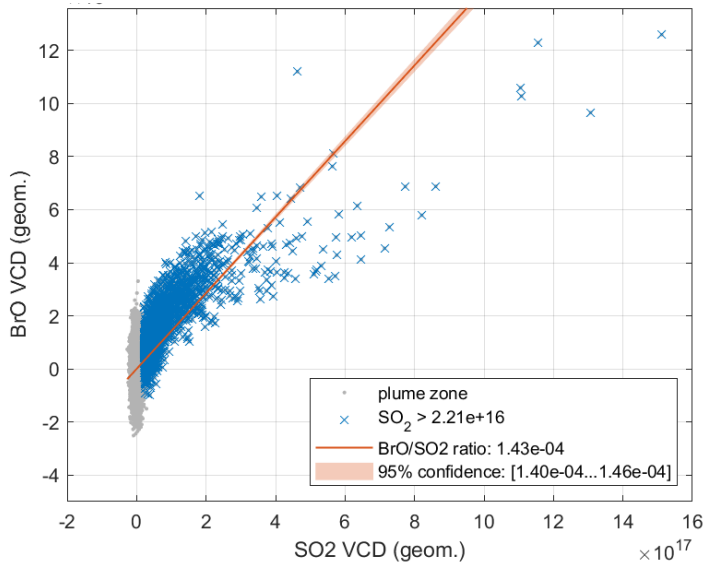
Linear BrO/SO_2 ratio



Weakly non-linear BrO/SO_2 ratio



Highly non-linear BrO/SO_2 ratio



BrO/SO_2 Catalogue

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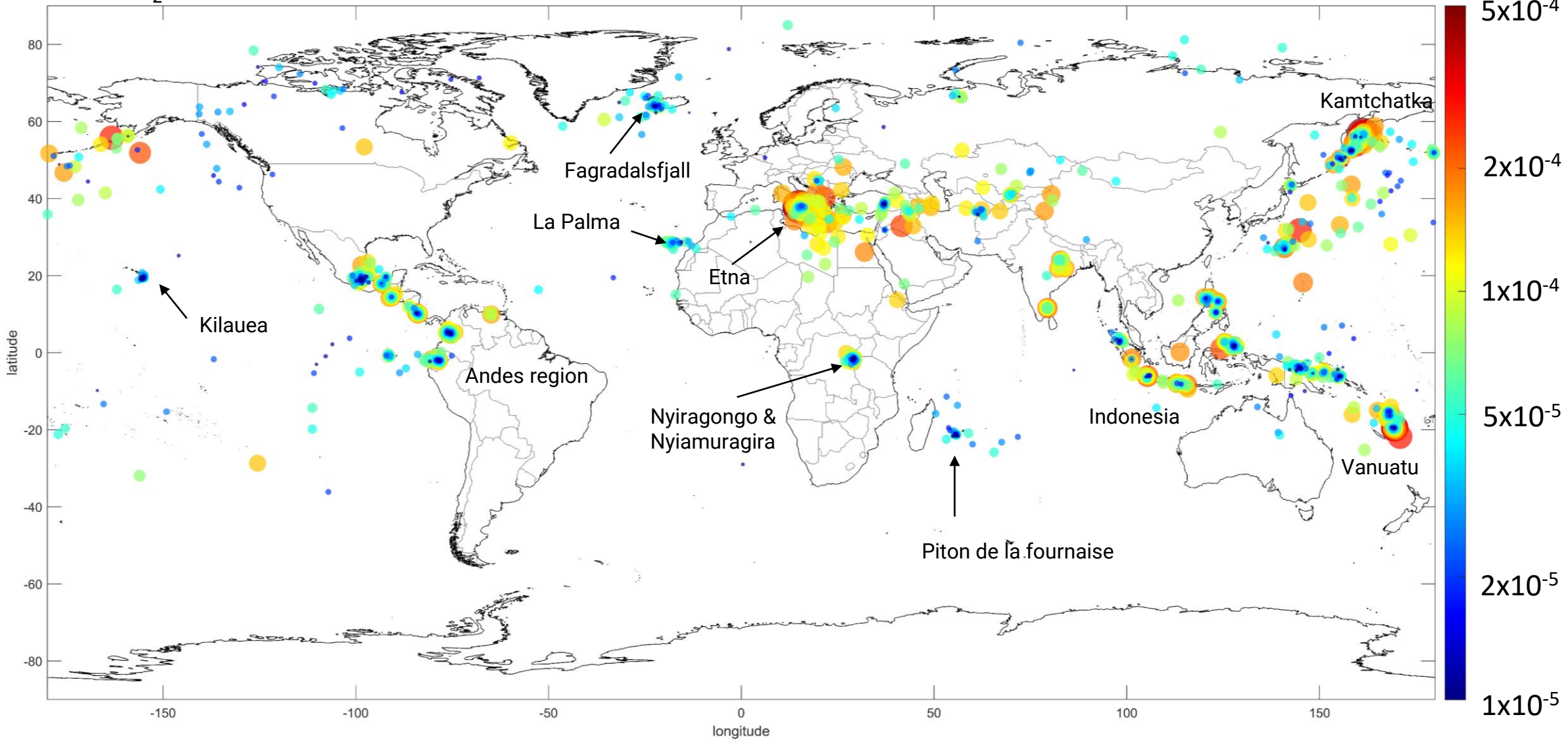
Linear BrO/SO_2 ratios



BrO/SO_2 Catalogue

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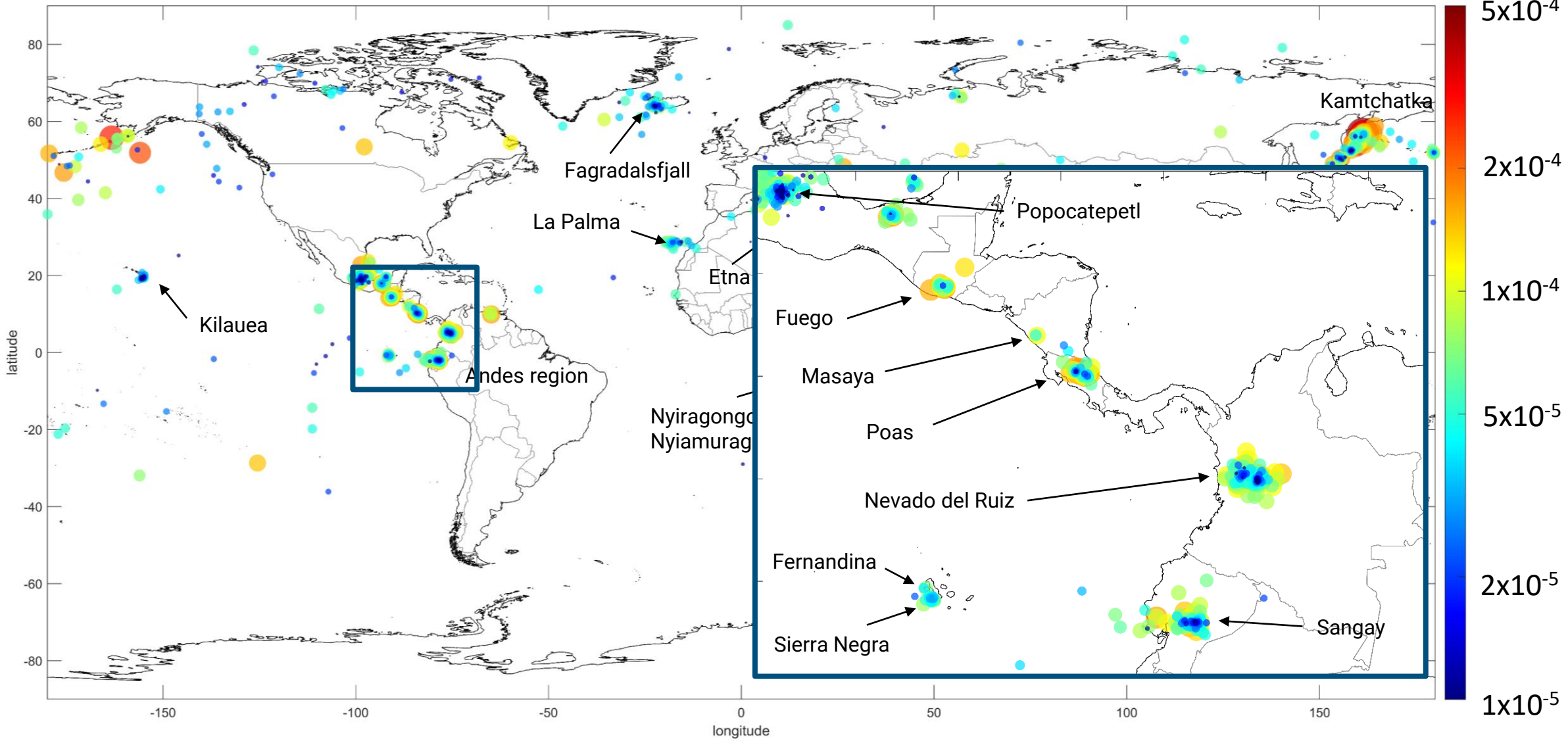
Linear BrO/SO2 ratios



BrO/SO_2 Catalogue

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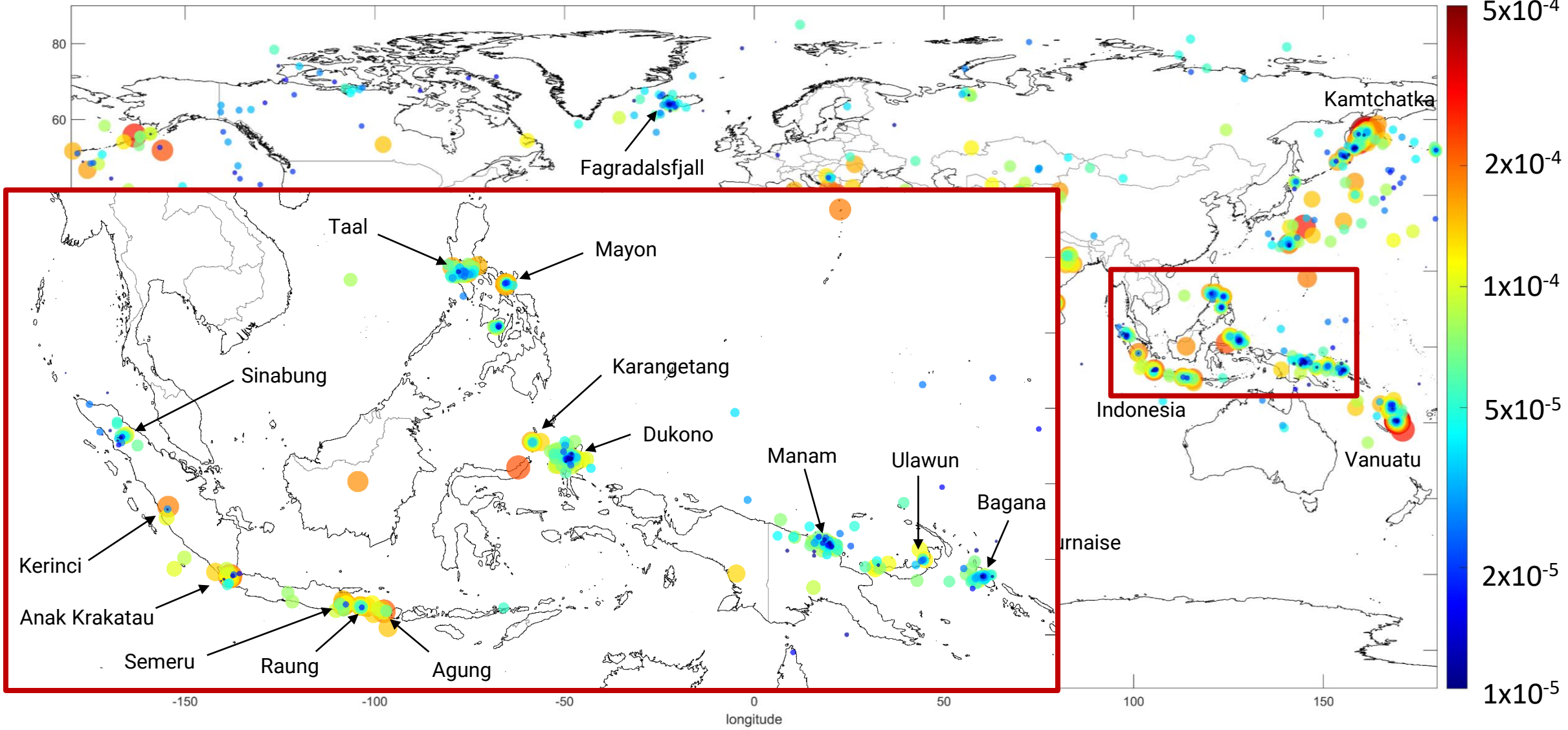
Linear BrO/SO2 ratios



BrO/SO_2 Catalogue

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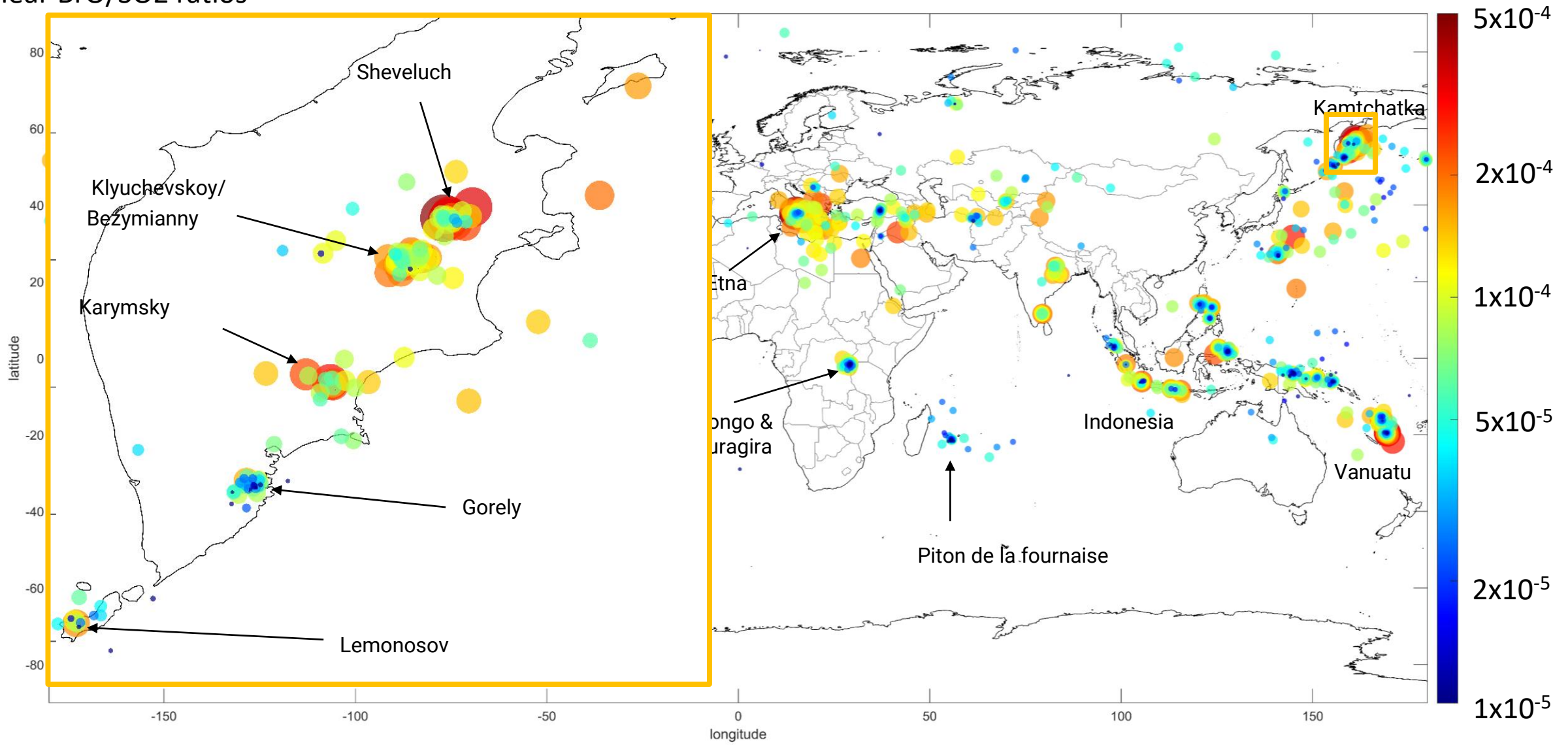
Linear BrO/SO2 ratios



BrO/SO_2 Catalogue

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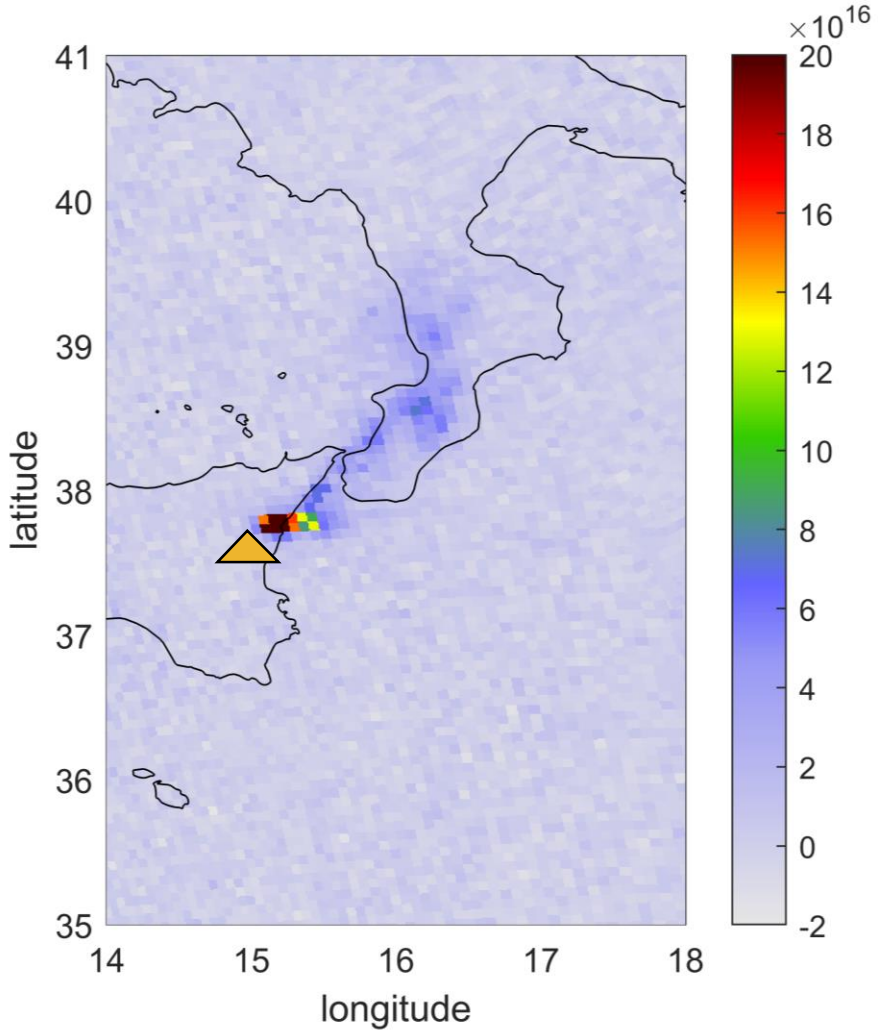
Identify volcanoes:

- One SO_2 plume on map from volcano
- Activity reported by Global volcanism Program [volcano.si.edu/]
- 43 volcanoes

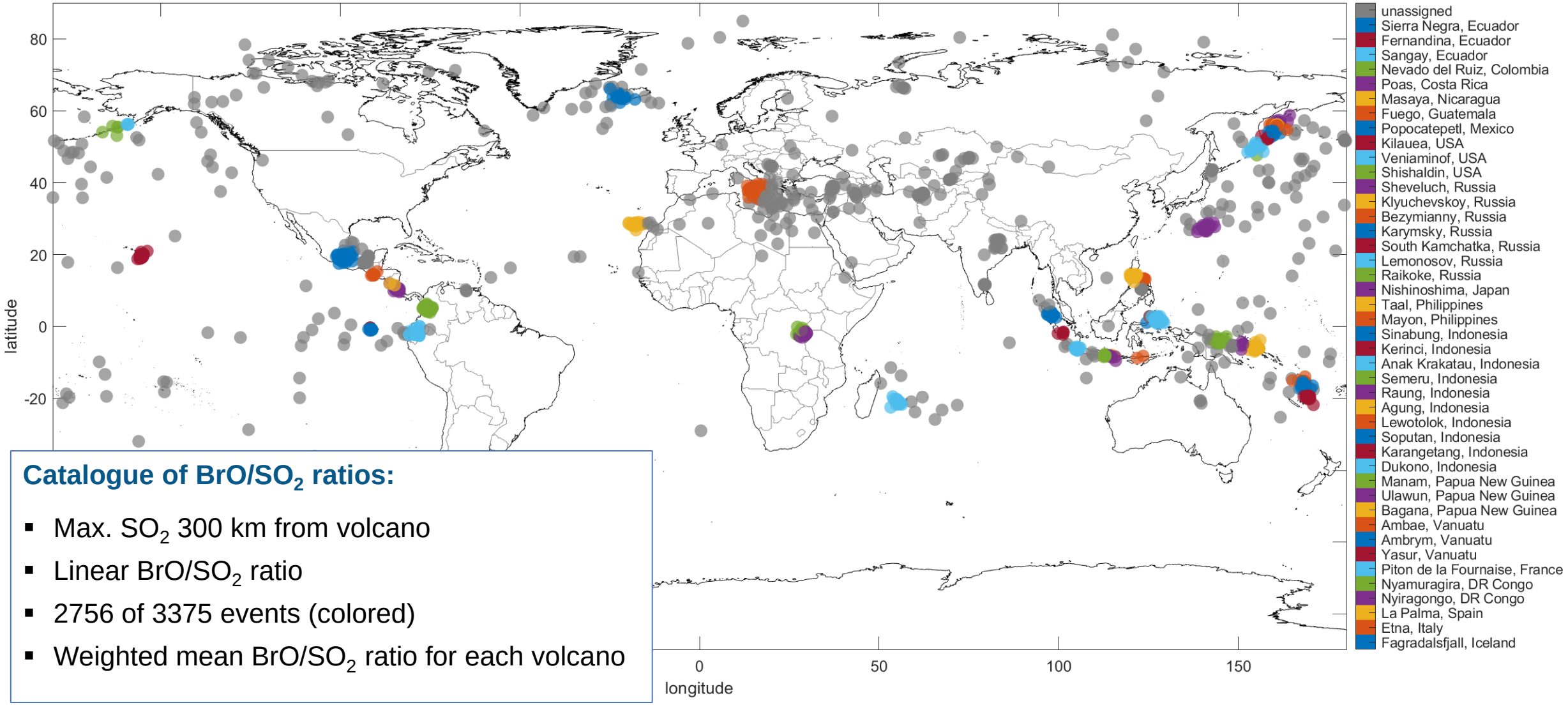
Catalogue of BrO/SO_2 ratios:

- 300 km from volcano
- Linear BrO/SO_2 ratio
- 2756 of 3375 events
- Weighted mean BrO/SO_2 ratio for each volcano



BrO/SO_2 Catalogue

MAX-PLANCK-INSTITUT FÜR CHEMIE

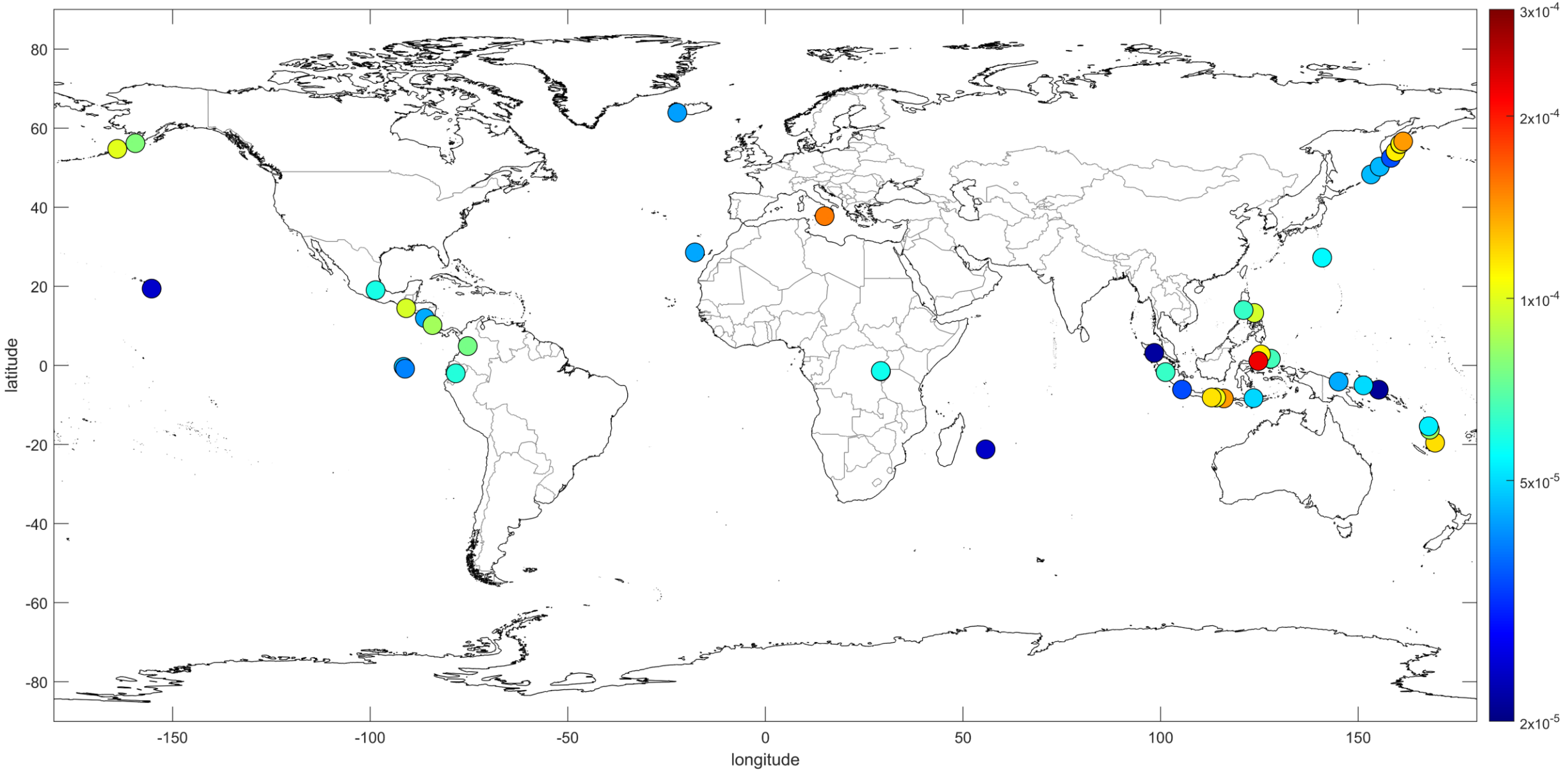


Catalogue of BrO/SO_2 ratios:

- Max. SO_2 300 km from volcano
- Linear BrO/SO_2 ratio
- 2756 of 3375 events (colored)
- Weighted mean BrO/SO_2 ratio for each volcano

BrO/SO_2 Catalogue

MAX-PLANCK-INSTITUT FÜR CHEMIE



BrO/SO_2 Catalogue

Hot spot

Etna

Subduction zone

Rift

Hot spot volcanoes:

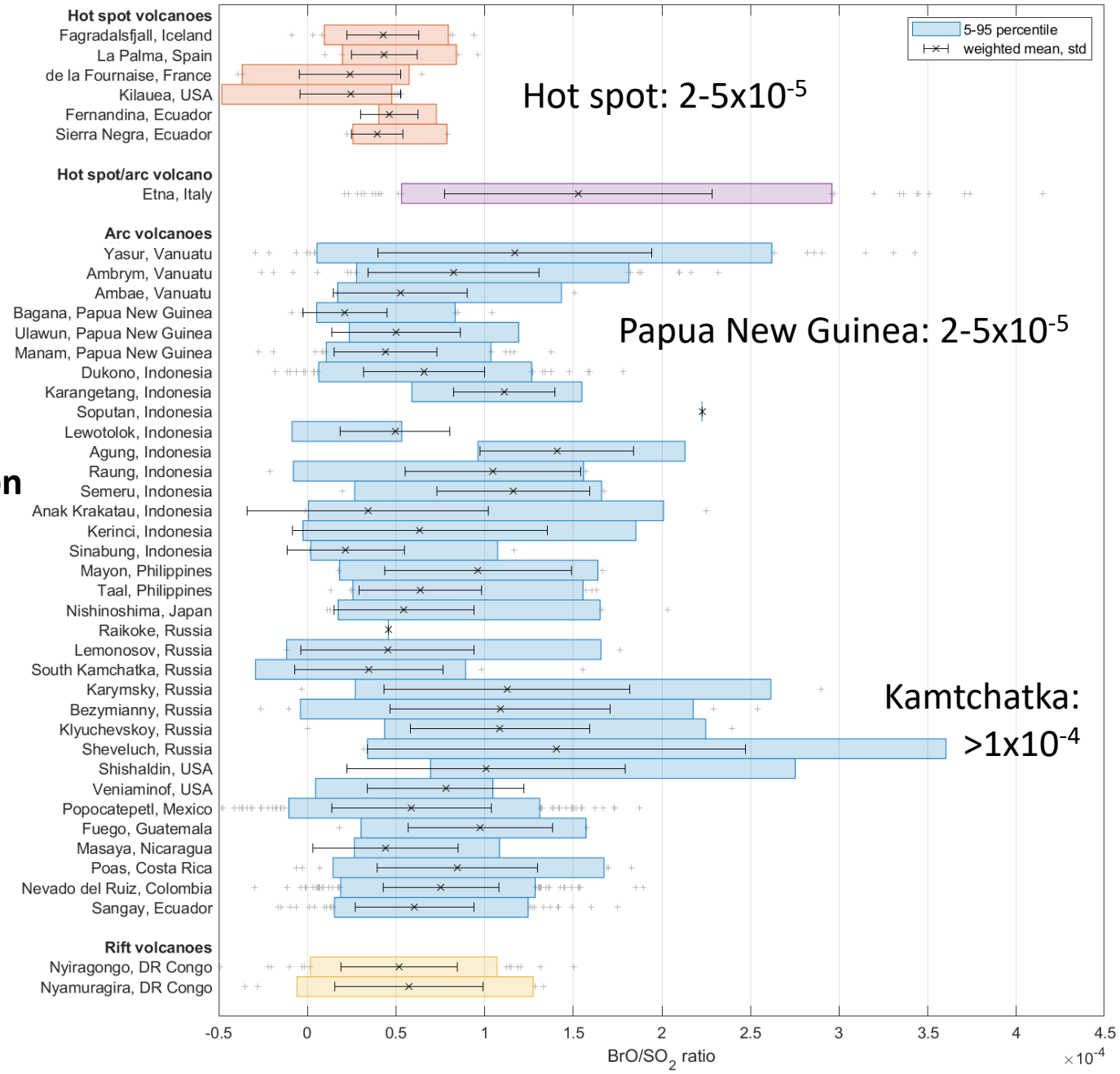
- First BrO/SO_2 detections
- All single BrO/SO_2 $<1x10^{-4}$
- Low mean BrO/SO_2: 2…5 $x10^{-5}$

Subduction zone (Arc) volcanoes:

- Mean BrO/SO_2: 2…14$x10^{-5}$
- Volcano specific differences

➢ **First detection of BrO/SO_2 ratio for 30 volcanoes**

➢ **Doubles number of volcanoes (from 30 to 60)**



Comparison volcano type

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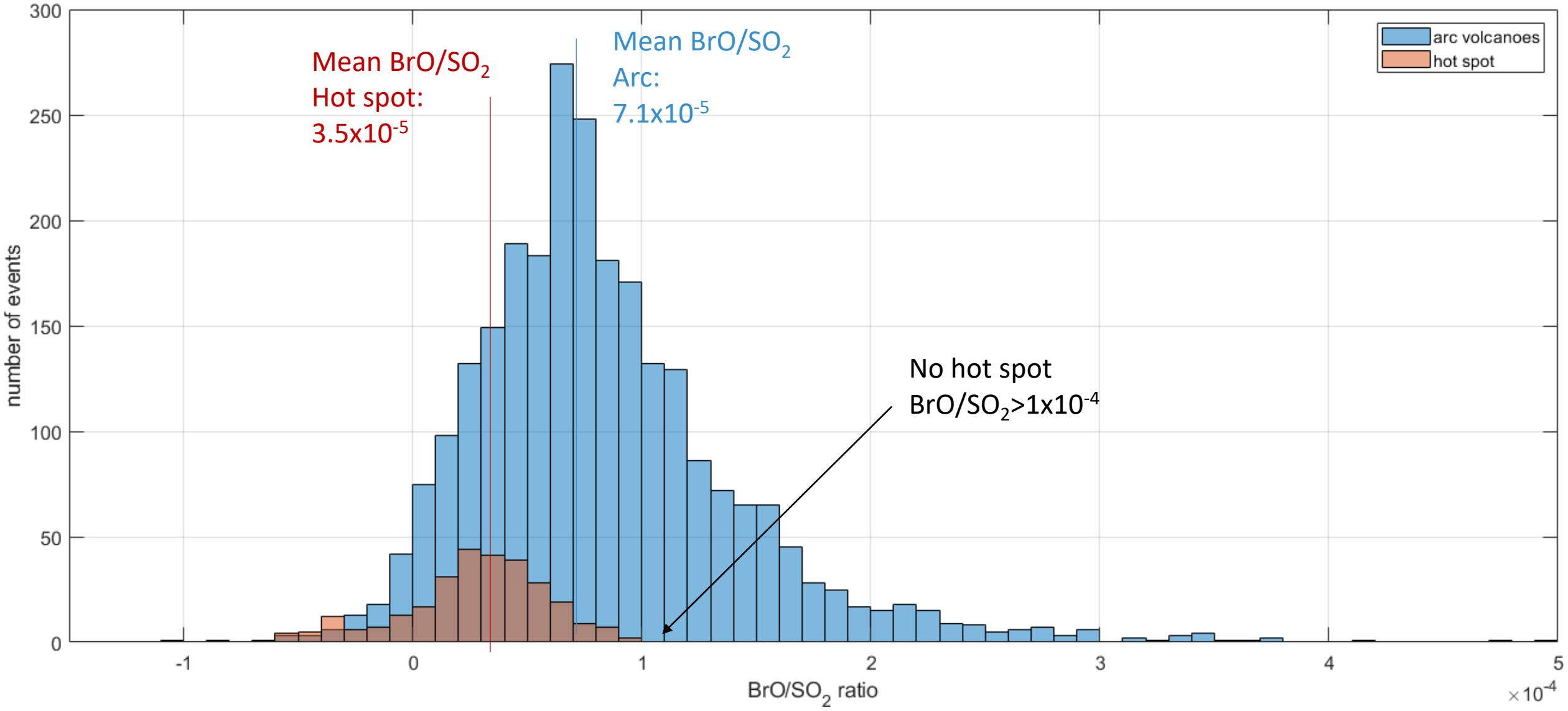

Comparison to Ground-based

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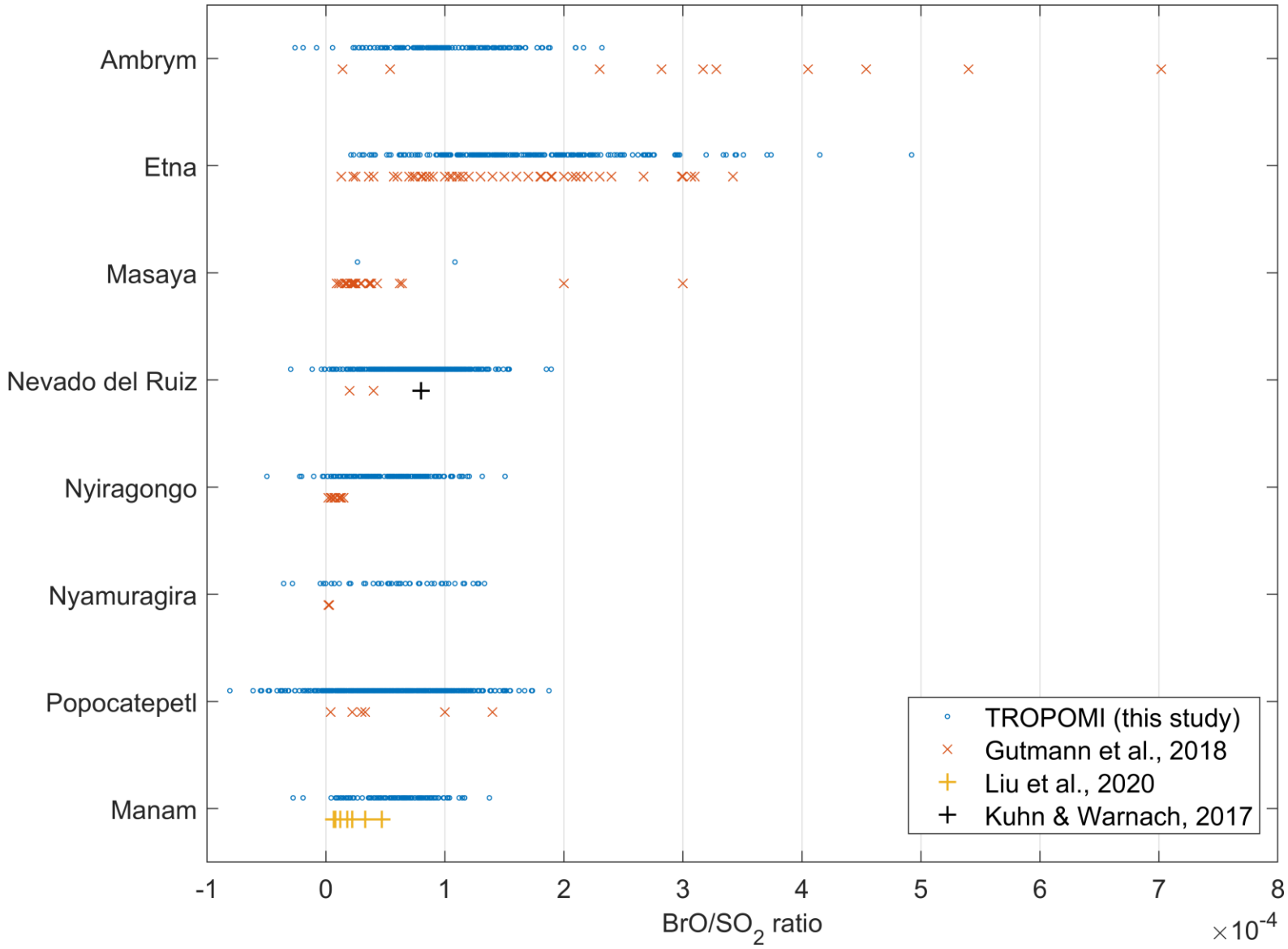
Ground-based data:

- Gutmann et al., 2018 Front. Earth Sci.
- From 2003-2015 -> no overlap
- Generally good agreement

Manam, Papua New Guinea:

- Liu et al., 2020, Sci. Adv.
- Measurements in May 2019

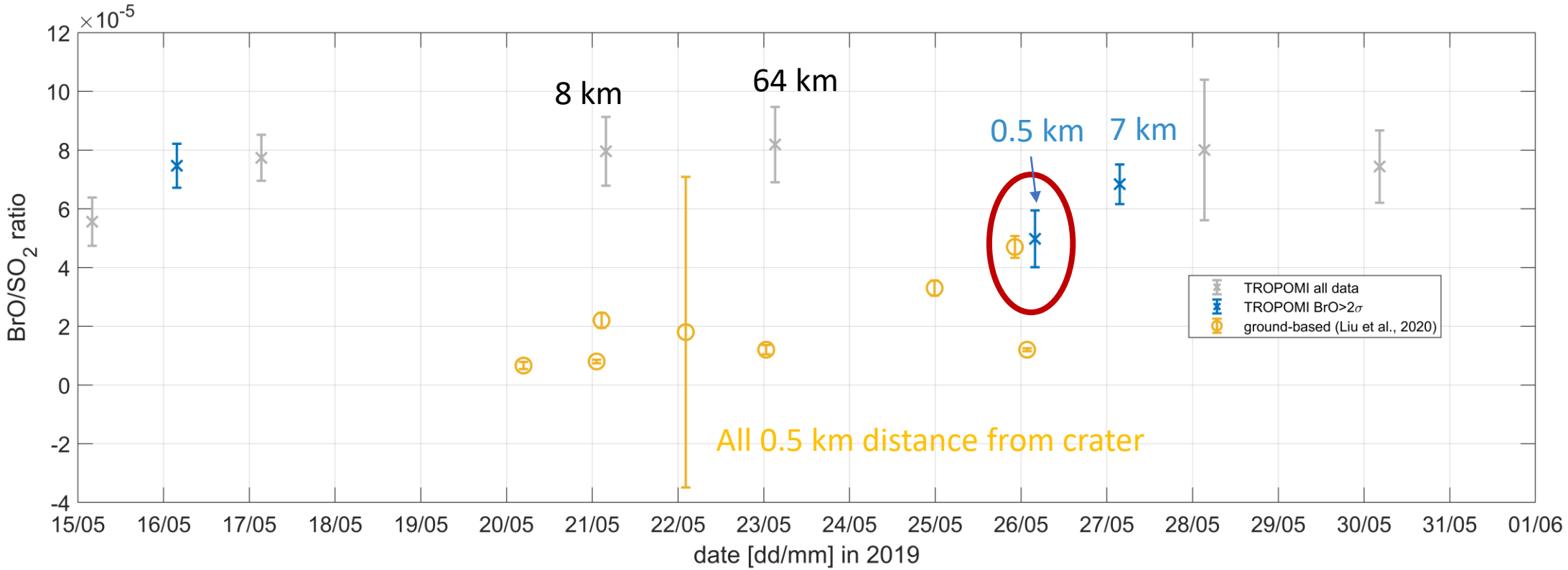


Comparison to Ground-based

MAX-PLANCK-INSTITUT FÜR CHEMIE

Manam, Papua New Guinea:

- Liu et al., 2020, Sci. Adv.
- Measurements in May 2019
- 26 May plume directly above instrument & agreement



BrO recycling

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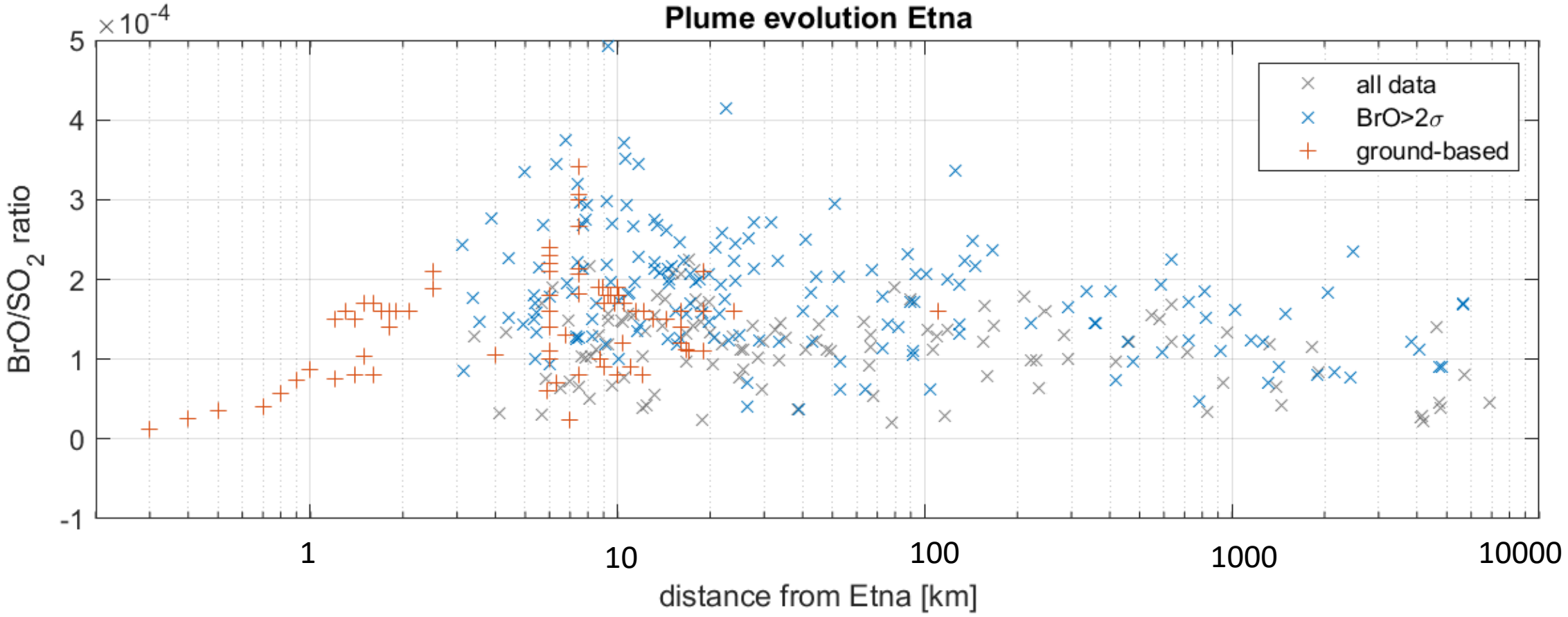
BrO detectable in 1000km distance

- Sign of BrO recycling
- Statistical decrease infers information about lifetime of reactive bromine



Conclusions

Automatic plume algorithm applied to almost four years of S-5P/TROPOMI data

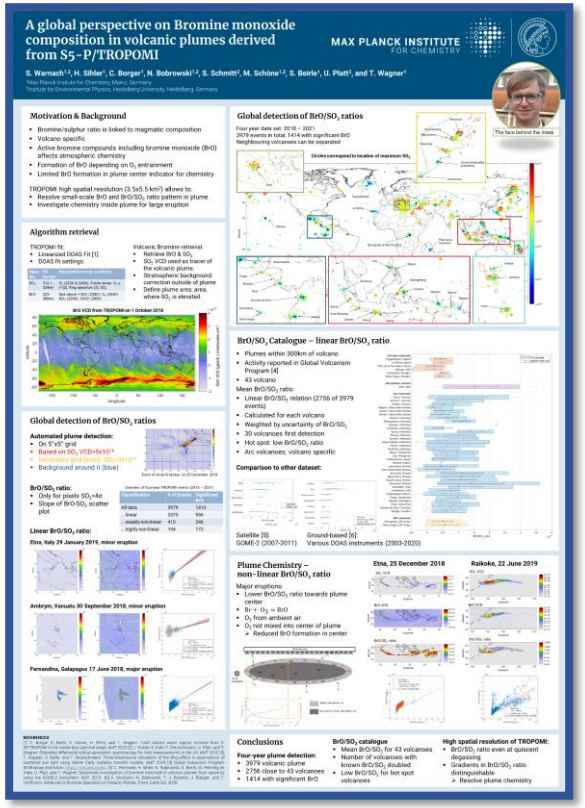
- In total 3979 SO_2 events detected worldwide
- 1414 events with enhanced BrO
- Neighbouring volcanoes distinguishable

BrO/SO_2 Catalogue

- Mean BrO/SO_2 for 43 volcanoes
- 30 first detections of BrO/SO_2 ratio
- Hot spot volcanoes: low BrO/SO_2 ratio
- Agreement with ground-based data

➢ Detection at small, localized plumes and major eruption plume

➢ Detection at global volcanoes!



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➢ Plume chemistry

Acknowledgement: Financial support from DLR under funding number 50EE1811B

Questions?