Bromine monoxide measurements in volcanic plumes from S5-P/Tropomi

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Motivation

Active bromine compounds including bromine monoxide (BrO) affects atmospheric chemistry

Bromine/sulphur ratio is linked to volcanic activity

Tropomi small spatial resolution (3.5x7 km) allows to:
- resolve small plumes
- Better statistic due to more pixels in plume

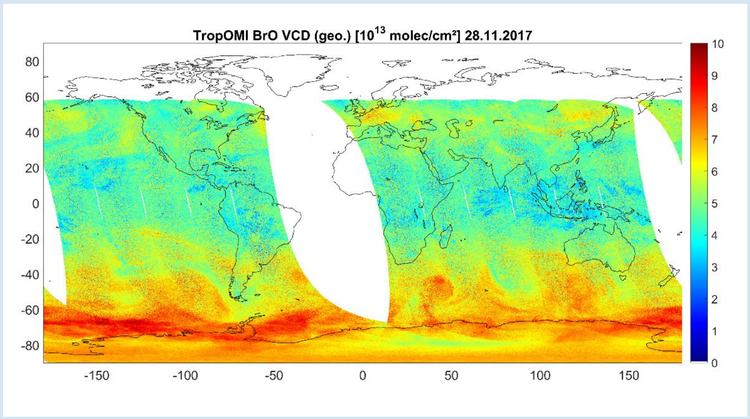
In combination this yields the potential for:
- more precise observation of the BrO/SO_2 ratio of plume
- long term monitoring of BrO & BrO/SO_2 ratio at many volcano due to the more frequent detection of BrO

Algorithm retrieval

Tropomi fit:
- linearized DOAS Fit (Beirle, 2013)
- Fast (30-60 min for one day of data on a standard computer)
- Includes pseudo-absorber for ISRF change over orbit
- DOAS fit settings (Hörmann, 2016):

Species	Fit Range	Absorption cross sections
SO_2	312.1 - 324nm	O_3 (213K & 233K), O3 x λ^4 (Pukite, 2010), Ring Spectrum (Wagner et al, 2009), SO_2 (Bogumil et al., 273K)
BrO	336 - 360nm	See above + BrO (Wilmouth et al, 1999, 228K), O_4 (203K) NO_2 (220K), OClO (293K)

Volcanic Bromine retrieval:
- Retrieve BrO & SO_2
- SO_2 VCD used as tracer of the volcanic plume
- Stratospheric background correction outside of volcanic plume
- Define plume area: rough area, where SO_2 is elevated
- Calculate BrO/SO_2 molar ratio in plume area using a linear fit (Cantrell, 2008)



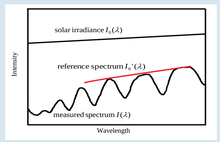
Differential Optical Absorption Spectroscopy (DOAS)

Beer-Lambert-law:
- Solar irradiance is attenuated in the atmosphere:

$$I(\lambda) = I_0'(\lambda) \cdot \exp\left(\sum_i \sigma_{i,diff} \cdot \underbrace{c_i \cdot L}_{S_i}\right)$$

DOAS:
- Calculate optical thickness τ by comparing reference and measurement spectrum

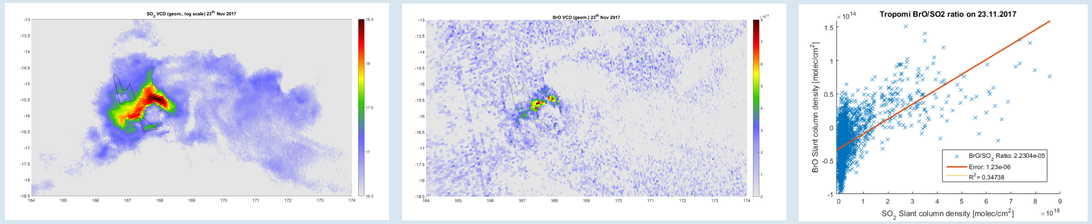
$$\tau_i = \ln\left(\frac{I_0'(\lambda)}{I(\lambda)}\right) = S_i \cdot \sigma_i$$



S: slant column density,
σ: absorption cross section, τ: optical density

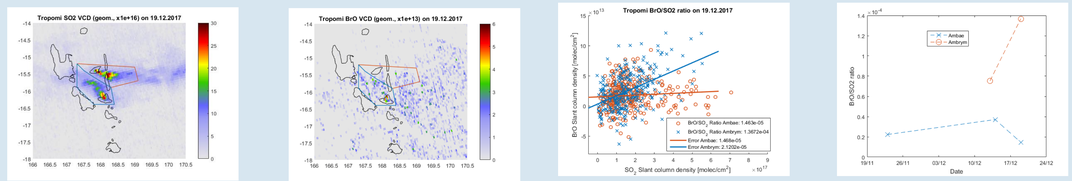
Ambea & Ambrym, Vanuatu

Ambae volcano:

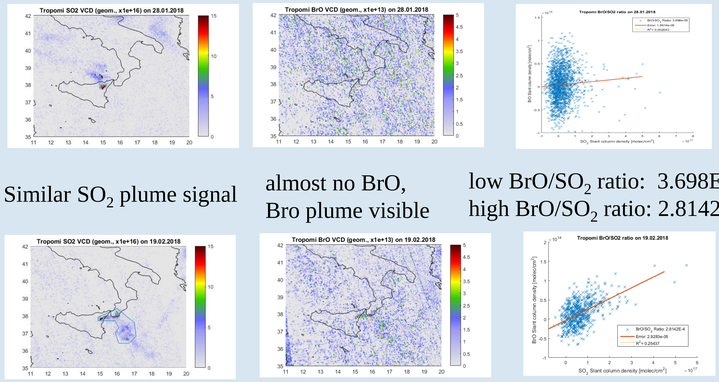


Ambae: Low BrO/SO_2 ratio
23.11.: BrO clearly detectable from Ambae volcano
14. & 19.12: BrO below detection limit.
BrO/SO_2 ratio agree between 1-3x10^{-5}.
Ambrym: BrO rich plume
13. &19.12: BrO clearly detectable BrO/SO_2 ratio on 19.12 comparable to Hörmann, 2013 (3.44x10^{-4})
19.12: clear SO_2 signal from both volcanoes, BrO only detectable over Ambrym

Both volcanoes:



Mt. Etna, Italy



Similar SO_2 plume signal

almost no BrO, Bro plume visible

low BrO/SO_2 ratio: 3.698E-5
high BrO/SO_2 ratio: 2.8142E-4

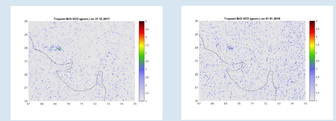
Same SO_2 plume strength - different plume compositions
Ratio agrees with ground based measurements

Date	Tropomi	Ground based
28.01	3.698 x10^{-5}	3.2x10^{-5}
19.02	2.8142 x10^{-4}	(morning) 1 x10^{-4}

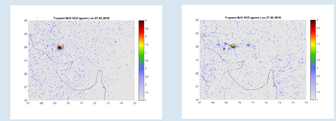
Rann of Kutch

Salt march with seasonal BrO release (Hörmann, 2016)

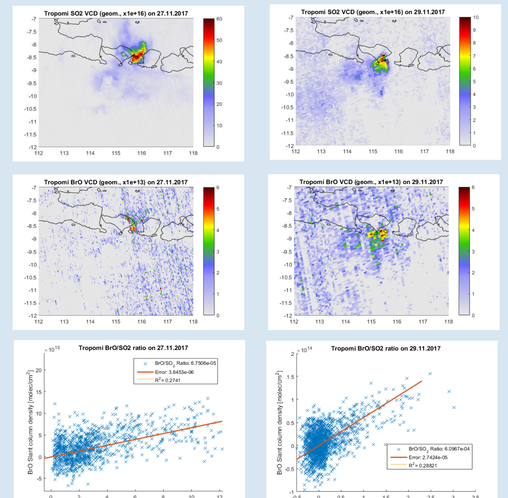
January: no monsoon, but low BrO emissions similar to Hörmann, 2016



February: no monsoon, increased BrO emission



Mt. Agung, Indonesia



Strong increase in BrO/SO_2 ratio between 27 & 29.11

Conclusion

The high spatial resolution of Tropomi allows for Bromine monoxide detection:
- Over weak volcanic plumes
- To seperate Bromine signals from closely adjacent volcanoes (e. g. Ambrym & Ambae)
- Monitor changes in BrO/SO2 ratio over course of volcanic eruptions (e. g. Mt. Agung)
- Monitor BrO/SO_2 ratio of constant degassing volcanoes (e. g. Etna), ratio similar to ground based data
- Detection of single day events over salt marsh Rann of Kutch

Disclaimer: The presented work has been performed in the frame of the Sentinel-5 Precursor Validation Team (S5PVT) or Level 1/Level 2 Product Working Group activities. Results are based on preliminary (not fully calibrated/validated) Sentinel-5 Precursor data that will still change.

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