# First high resolution BrO retrievals and small-scale enhancement analysis from TROPOMI onboard Sentinel-5 Precursor

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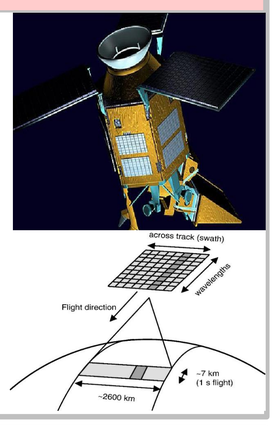
## 1. Introduction

■ Bromine monoxide (BrO) plays an important role in atmospheric chemistry as a catalytic element in ozone depletion processes.
■ Satellite observations from instruments such as GOME, SCIAMACHY, GOME-2 and OMI have been used for monitoring of BrO distributions on regional to global scales for more than two decades.
■ To continue and improve daily global trace gas observations with an unprecedented spatial resolution, the TROPOspheric Monitoring Instrument (TROPOMI) was launched onboard the Copernicus Sentinel-5 Precursor platform in October 2017 (Veefkind et al., 2012).
■ In this study, we performed sensitivity tests to find an optimal TROPOMI DOAS setting of BrO under various measurement conditions.
■ As a consistency test, TROPOMI BrO columns were compared with OMI and GOME-2 BrO columns on both global and regional scale.

## 2. Sentinel-5 Precursor (S-5P)/TROPOMI

■ Low earth orbit polar satellite that was launched in October 2017
■ Daily global information on columns of trace gases and aerosols
■ TROPOspheric Monitoring Instrument (TROPOMI) is a spectrometer on board of the S-5P satellite platform with spectral bands in the UV, VIS, NIR and SWIR. This wavelength range can measure key atmospheric constituents including $O_3$, $NO_2$, $SO_2$, CO, $CH_4$, HCHO, BrO and aerosol properties.
■ Large swath of 2600 km with high spatial resolution of currently 3.5x7 $km^2$ at nadir
■ Compared to previous satellites, TROPOMI has prominent advantages in extended spectral band range and higher spatial resolution.




## 3. BrO retrieval from TROPOMI

### ▪ DOAS retrieval

The retrieval algorithm for BrO uses the **Differential Optical Absorption Spectroscopy (DOAS)** technique. The absorber concentration integrated along the light path, the slant column density (SCD), is determined assuming the Beer-Lambert's law is applicable.

$$I(\lambda, s) = I_0 exp(-\sigma(\lambda)\rho s)$$

(the initial intensity: $I_0$, the length of light path: s, the absorption cross-section: σ, the absorber number density: ρ)

### ▪ Sensitivity test of retrieval fitting intervals

- **Selection of the retrieval fitting window** is one of the most important things in the DOAS retrieval process
- Sensitivity tests of the wavelength interval on DOAS BrO retrievals were performed by evaluating the BrO SCDs and fitting RMS values in many different wavelength
- Start (End) limits of retrieval wavelength : 320–338 nm (342–364 nm)
- Wavelength interval step : 0.2 nm - Polynomial of order 4
- BrO, $O_3$, $NO_2$, HCHO, OClO, $O_4$ and Ring cross sections

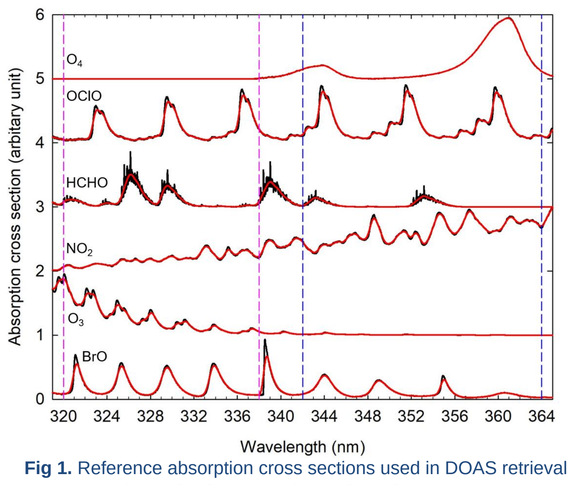



**Fig 1.** Reference absorption cross sections used in DOAS retrieval

▪ **BrO retrievals over the polar sea ice region**

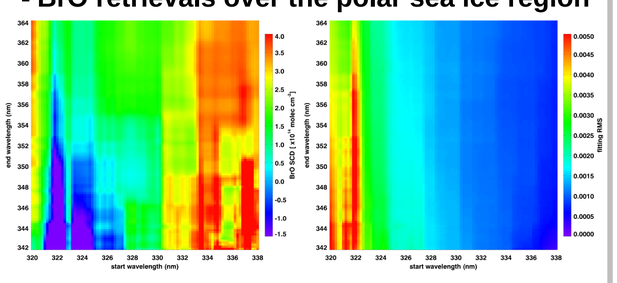



**Fig 2.** Colour coded means of BrO SCDs (left) and fitting RMS values (right) retrieved over the selected Arctic sea ice region for a BrO explosion event using TROPOMI measurements at different wavelength intervals

▪ Negative BrO SCDs with relatively high fitting RMS values at shorter wavelength < 327 nm -> $O_3$ interference

▪ **BrO retrievals in a volcanic plume**

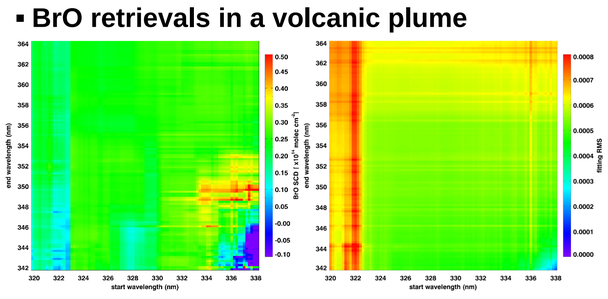



**Fig 3.** As Fig. 2 but for the selected volcanic plume case

▪ Negative BrO SCDs with high fitting RMS values at shorter wavelength < 327 nm -> $SO_2$ interference
▪ Relatively high fitting RMS values at wavelengths >358 nm due to the Ring effect from high aerosol loads or clouds

▪ **BrO retrievals over a salt marsh**

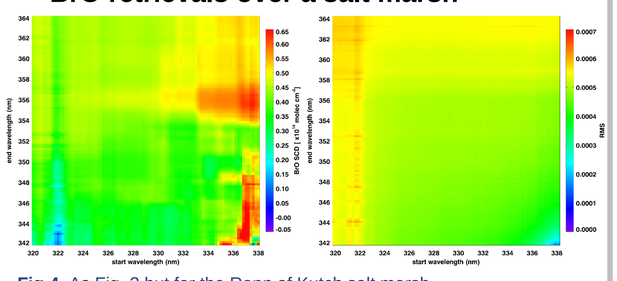



**Fig 4.** As Fig. 2 but for the Rann of Kutch salt marsh

▪ Relatively high fitting RMS values at wavelength <322 nm
▪ High BrO SCDs with low fitting errors
: wavelength range at start limits of 333-338 nm and end limits of 354-364 nm

### ▪ DOAS settings used for the BrO retrievals

| Parameter | Description |
|---|---|
| Fitting window | 333.5 – 357 nm |
| Solar Reference Spectrum | Kurucz solar spectrum (Fraunhofer calibration) |
| Trace gases cross sections | BrO (Wilmouth et al., 1999; 228K)<br>$O_3$ (Serdyuchenko et al., 2013; 223K, 243K)<br>$NO_2$ (Vandaele et al., 1998; 220K)<br>OClO (Kromminga et al., 2003; 213K)<br>$O_4$ (Hermans et al., 298K)<br>HCHO (MellerMoortgat et al., 2000 ;298K) |
| Ring cross sections | Ring cross section calculated by SCIATRAN model |
| Polynomial | 5 coeff |
| Background | For TROPOMI and OMI one spectrum per row, daily averaged earthshine spectrum in selected Pacific region |
| Offset correction | Linear offset (2 parameters) |

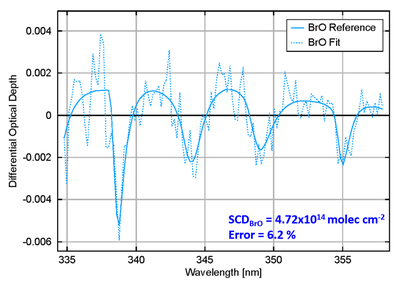
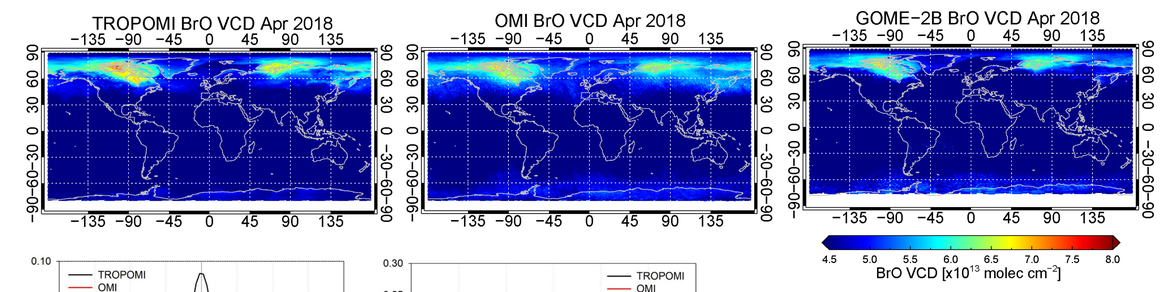



**Figure 5.** Example of a BrO fit result for the Arctic BrO measurement

## 4. Comparison with OMI and GOME-2 retrievals



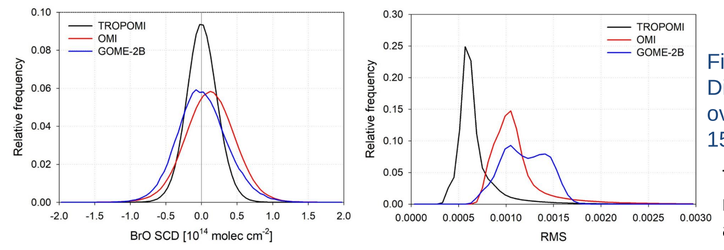




Fig 6. Global distribution of monthly mean BrO VCD. Distribution of BrO SCDs and fitting RMS values over a clean equatorial Pacific region (10°S-10°N, 150-260°E) for April 2018

TROPOMI shows the best performance with narrow SC distribution close to the detection limit and the smallest mode of fitting RMS distributions

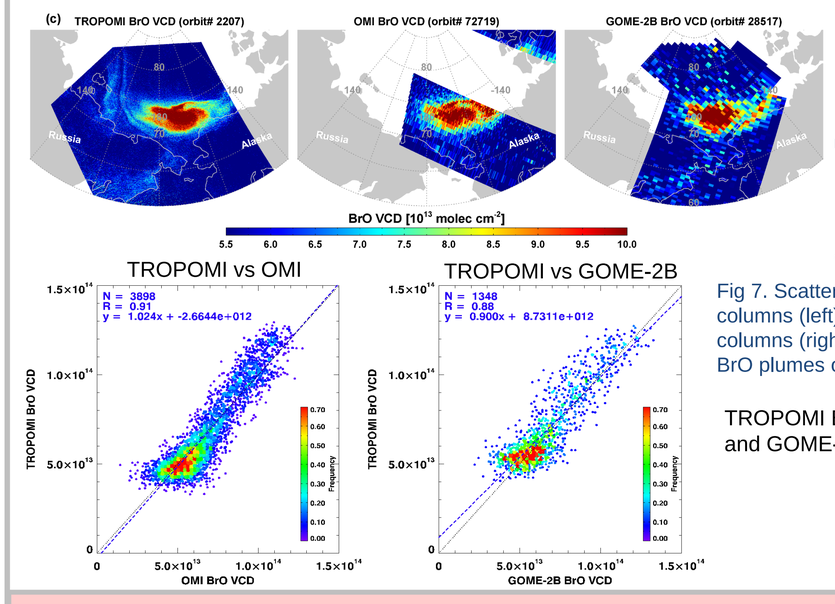
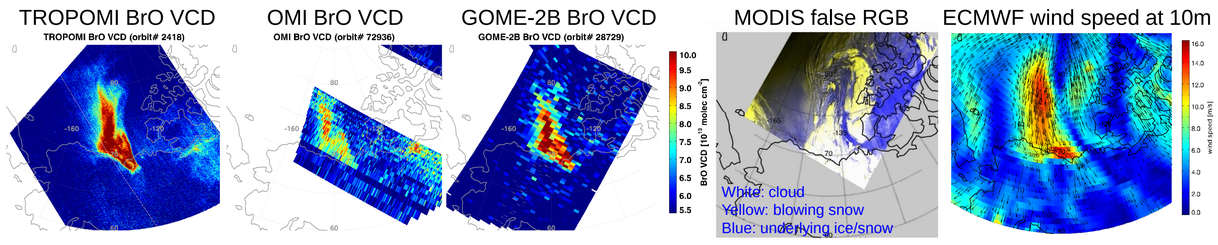



Fig 7. Scatter plots of TROPOMI and OMI BrO vertical columns (left), TROPOMI and GOME-2B BrO vertical columns (right) in the selected region of enhanced BrO plumes on March 17, 2018 (top)

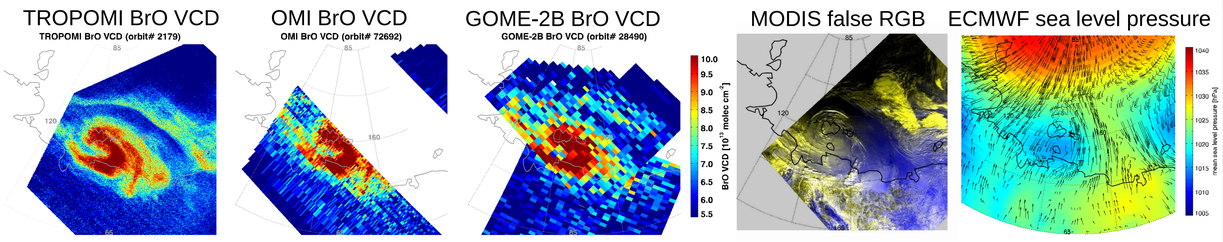
TROPOMI BrO shows good agreements with OMI and GOME-2B with correlations of 0.84 and 0.84

## 5. BrO observations in various source regions

### ▪ BrO plumes over Arctic sea ice

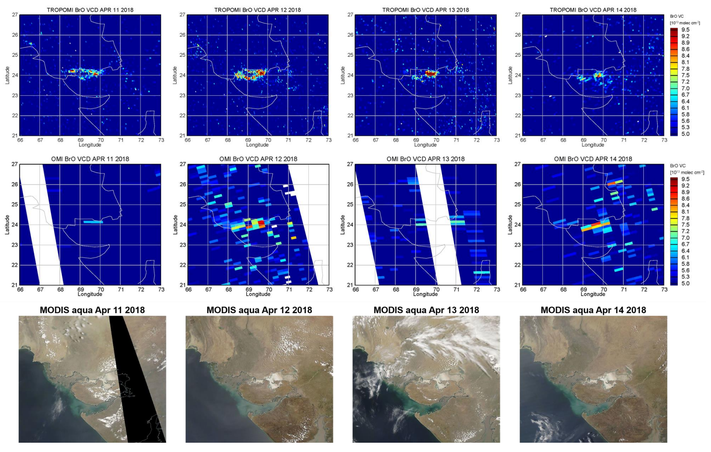



▪ BrO explosion event occurred in conjunction with **wind-driven blowing snow events** (high surface wind speeds)



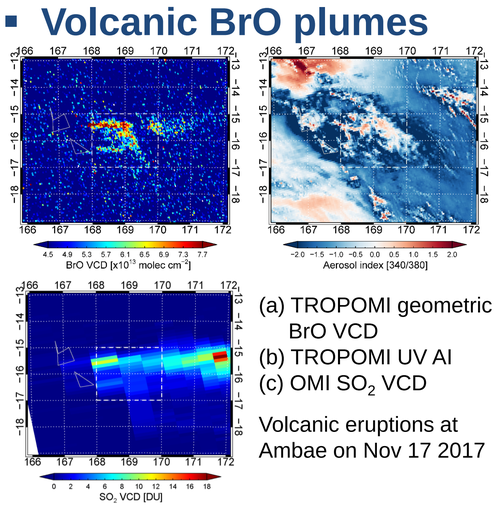

▪ Elevated BrO columns are associated with **polar low pressure system**

### ▪ BrO plumes over a salt marsh




Top: TROPOMI geometric BrO VCD over the Rann of Kutch salt marsh
Middle: OMI geometric BrO VCD Bottom: MODIS true color image

### ▪ Volcanic BrO plumes




(a) TROPOMI geometric BrO VCD
(b) TROPOMI UV AI
(c) OMI $SO_2$ VCD

Volcanic eruptions at Ambae on Nov 17 2017

## 6. Conclusions / Outlook

### Conclusion

- In this study, we present retrievals of BrO column amounts from TROPOMI observations using an optimized and adapted DOAS retrieval algorithm.
- TROPOMI shows excellent performances with much smaller fitting RMS values and lower random scatter of BrO columns than OMI and GOME-2B.
- TROPOMI BrO retrievals show good agreements with OMI and GOME-2B BrO columns.
- More small-scale hotspots can be identified in greater detail by TROPOMI with its improved signal-to-noise ratio and the excellent spatial resolution of 3.5x7 $km^2$.

### Outlook

- Stratospheric correction schemes and more sophisticated air mass factor calculations accounting for factors such as presence of clouds, varying surface albedo, and surface altitude are needed to obtain accurate tropospheric BrO columns.
- Validation with ground-based measurements should be performed for more detailed assessment of the quality of TROPOMI BrO columns.

## Selected references & Acknowledgements

• Seo, S., Richter, A., Blechschmidt, A. M., Bougoudis, I., & Burrows, J. P. (2018). First high resolution BrO column retrievals from TROPOMI. *Atmos Meas Tech Discuss*, *2018*, 1-26.
• Copernicus S5P Lv1 data were used for the BrO retrievals ・ Copernicus S5P UV Aerosol Index data were used
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