BrO retrievals using TROPOMI on Sentinel-5 Precursor and comparison with independent satellites and ground-based measurements

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e-poster

1 Introduction

- Bromine compounds are present in both stratosphere and troposphere
- They play an important part in atmospheric chemistry and catalytically deplete ozone
- Due to their effect on the oxidizing capacity of the atmosphere, global distributions of bromine monoxide (BrO) have been monitored by satellites
- Sentinel-5 Precursor (S5P) is a low earth orbit polar satellite that was launched in October 2017
- TROPOMI is a spectrometer on board of the S5P which has a wide swath of ~2600 km with a ground pixel area of 3.5x 7 (5.5) km^2
- TROPOMI can detect spatial variations and small-scale BrO explosion events in more detail than other satellite instruments

2 TROPOSPHERIC BrO retrievals

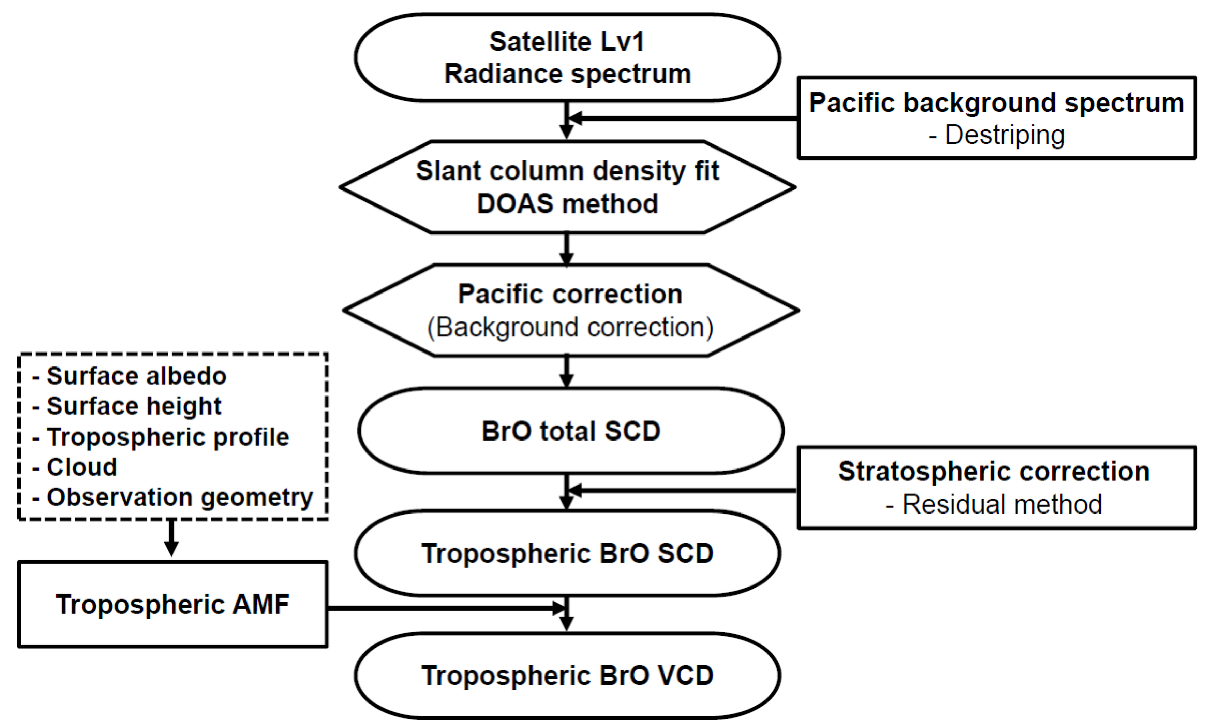

Fig 1. Overview of the tropospheric BrO retrieval algorithm

Step 1. DOAS BrO slant column retrieval

- **DOAS** (Differential Optical Absorption Spectroscopy)
- Based on Beer-Lambert's law: $\mathbf{I(\lambda, s) = I_0 \exp(-\sigma(\lambda)\rho s)}$
- λ: wavelength; σ: absorption cross section; ρ: absorber number density

Table 1. DOAS settings used for the BrO slant column retrievals

Parameter	Description
Fitting window	334.6 - 358 nm
Solar Reference Spectrum	Kurucz solar spectrum
Absorption cross sections	BrO (228K), O_3 (223K, 243K), NO_2 (220K) OCIO (213K), O_4 (298K), HCHO (298K)
Ring effect	Ring cross-section calculated by SCIATRAN
Polynomial degree	5 coeff
Background	Daily Earthshine, Pacific region (30°S-30°N, 150-240°E)
Intensity offset correction	Linear offset

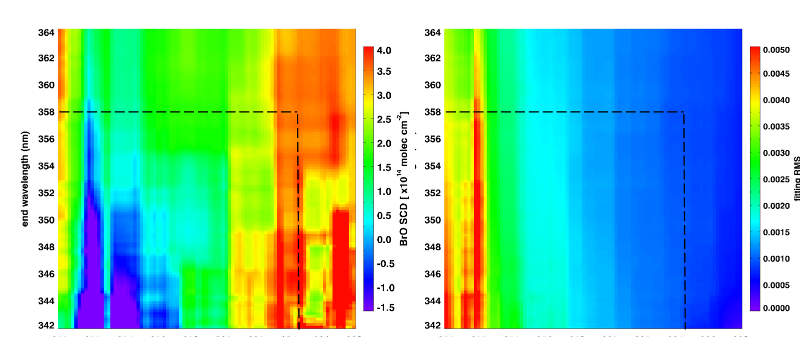

Fig 2. Color-coded means of (a) BrO SCDs and (b) fitting errors retrieved over the Arctic sea ice region from TROPOMI measurements at different wavelength with start limits of 320-338 nm, end limits 342-364 nm

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

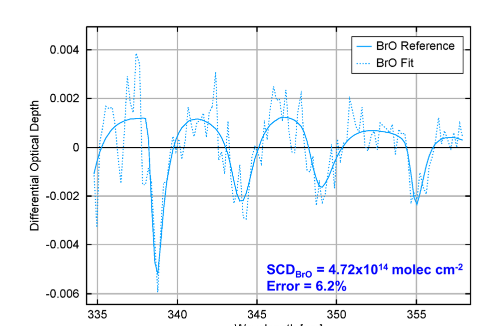

Fig 3. Example of a BrO fit applying the DOAS setting of Table 1

- Selection of the retrieval fitting window is one of the most important things in the DOAS retrieval

Step 2. Stratospheric BrO correction

- **Residual method**

$$VCD_{tropo} = \frac{SCD_{total} - VCD_{strato} \cdot AMF_{strato}}{AMF_{tropo}}$$

- **Stratospheric BrO column (VCD_{strato})**

1. 3D atmospheric chemistry model (cb05-BASCOE model)
2. Empirical multiple linear regression model

$$a_0 + a_{lon} \cdot lon + a_{lat} \cdot lat + a_{sza} \cdot \cos(SZA) + a_{los} \cdot \cos(LOS) + a_{tropoH} \cdot \frac{1}{tropoH}$$

3. Stratospheric BrO VCDs derived from the Theys et al. (2011) BASCOE model climatology (look-up table) using satellite retrievals of O_3 (total) and NO_2 (stratospheric) as input

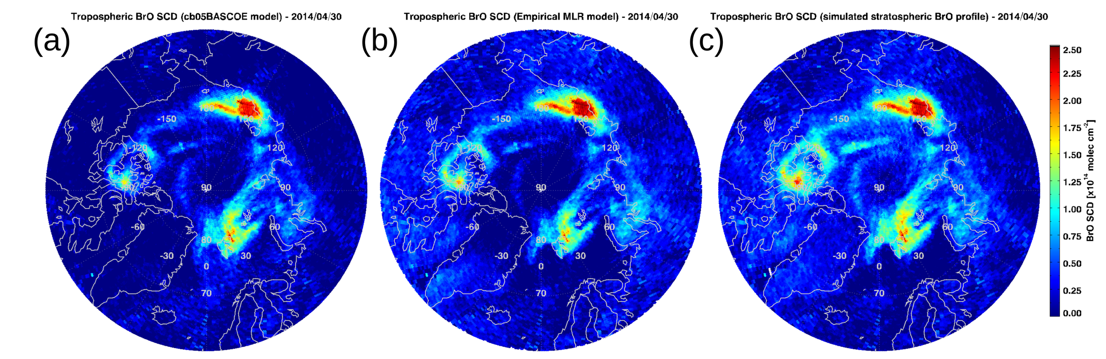

Fig 4. Tropospheric BrO slant columns calculated from GOME-2B applying three different stratospheric correction methods: (a) cb05-BASCOE stratospheric model data, (b) empirical MLR model, and (c) BASCOE climatology stratospheric BrO profile based on Theys et al. (2011)

Step 3. Tropospheric AMF calculation

- Pre-calculated Box AMF LUT from the SCIATRAN model
- f(λ, raa, vza, sza, surface altitude, surface albedo, z)
- Surface albedo from GOME-2 surface MSC LER database
- Surface height from Global 30 Arc-Second Elevation (GTOPO30)
- Homogeneous vertical distribution of BrO within the planetary boundary layer (200 m)
- Linear interpolation for LUT parameters

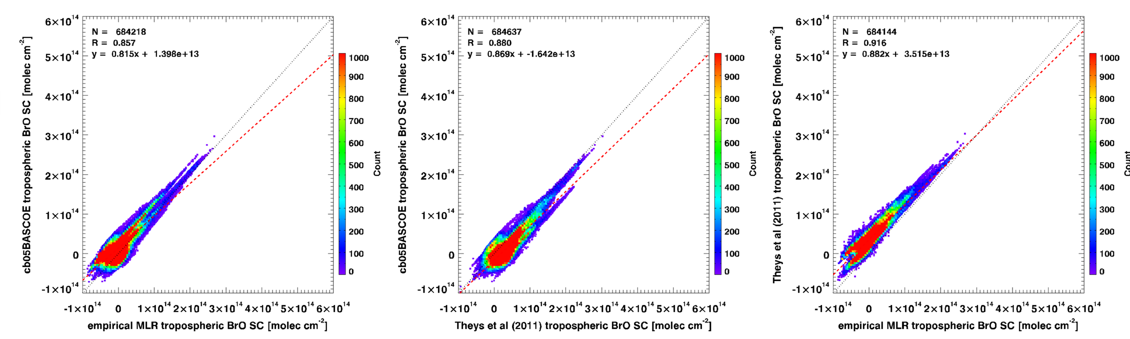

Fig 5. Comparisons of tropospheric BrO SCD calculated from three different stratospheric correction methods for the data shown in Fig. 4

- Results applying three different stratospheric BrO correction methods show generally good agreements (Fig.4 and 5)

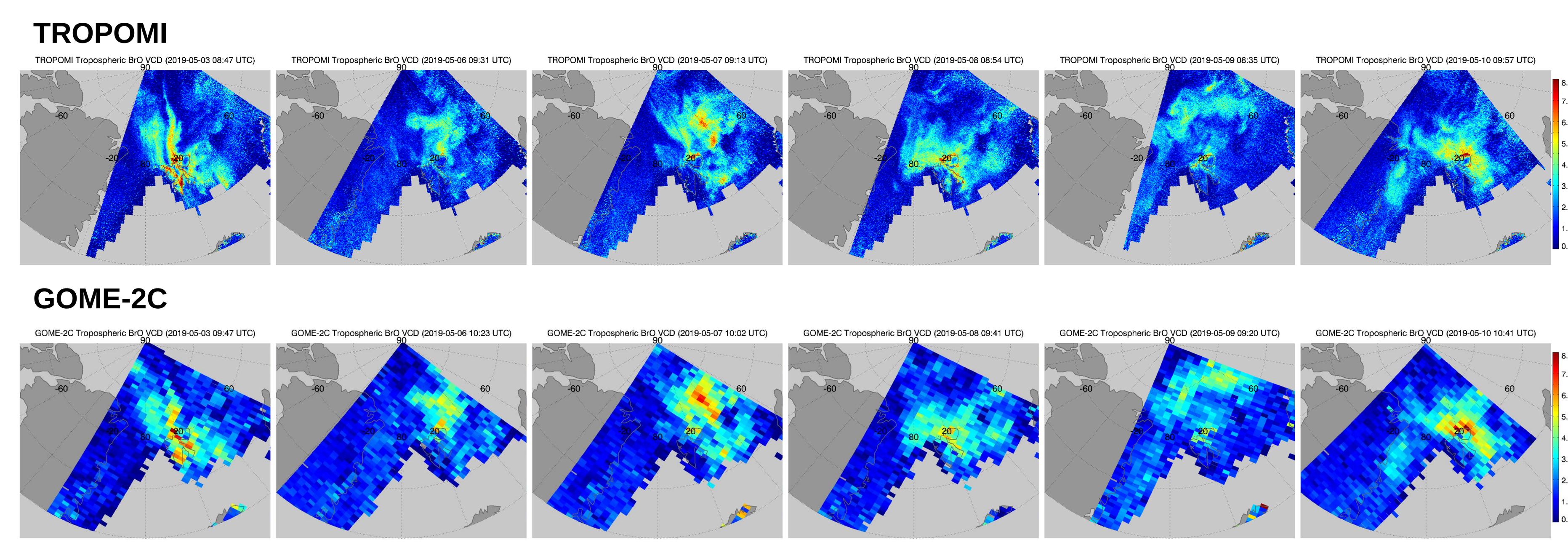

Fig 6. Maps of tropospheric BrO VCD (10^{13} molec cm^{-2}) from TROPOMI (top) and GOME-2C (bottom) over Svalbard from 3 May to 10 May 2019

- Here, the empirical multiple linear regression model was used for the stratospheric BrO correction
- Spatial distributions of tropospheric BrO vertical columns from GOME-2C and TROPOMI are similar
- Details of the spatial distribution and plume shapes are observed by TROPOMI due to the higher spatial resolution

3 Validation of satellite BrO

Location of the MAX-DOAS instrument in Ny-Ålesund

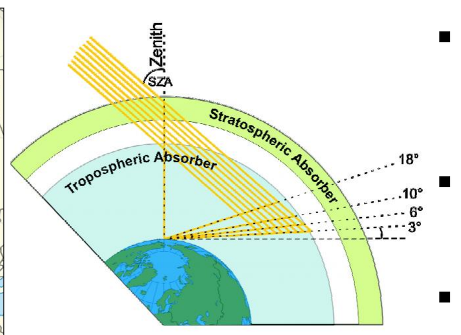

Illustration of the MAX-DOAS geometry (Wittrock et al., 2004)

- MAX-DOAS measurements at the NDSC station in Ny-Ålesund (78˚55' N, 11˚56' E), Svalbard
- Here, a geometrical approximation was used for simplicity (elv = 15°)
- $VC_{geo} = \frac{DSC_{15°}}{DAMF_{15°}} = \frac{DSC_{15°}}{\left(\frac{1}{\sin(15°)}\right) - 1}$

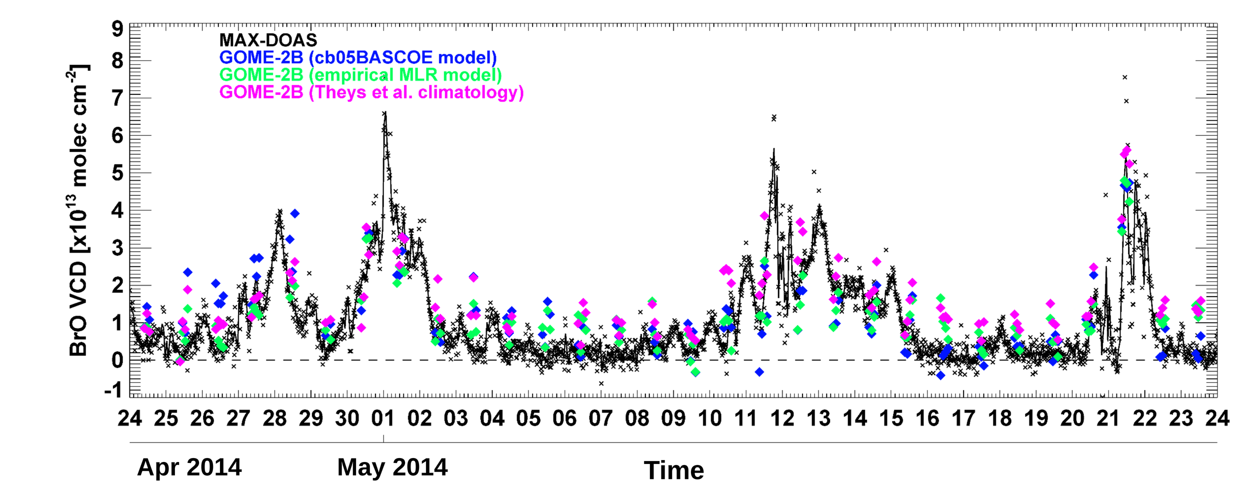

Fig 7. Time-series of retrieved tropospheric BrO VCDs from ground-based MAX-DOAS measurements and GOME-2B measurements in Ny-Ålesund during April and May 2014

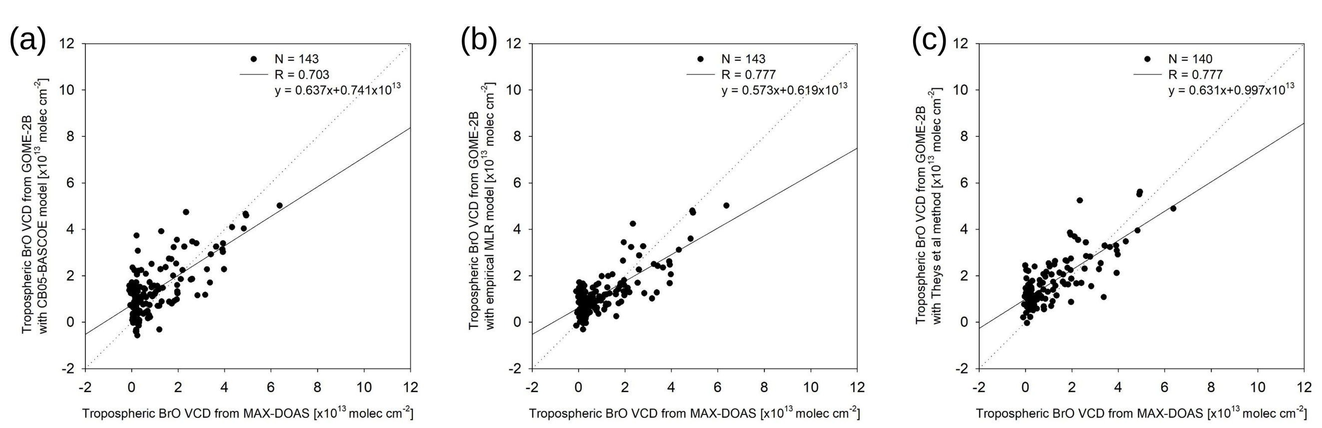

Fig 8. Scatter plots between tropospheric BrO VCD of ground-based MAX-DOAS and GOME-2B tropospheric BrO VCD derived with three different stratospheric correction methods: (a) cb05-BASCOE model, (b) empirical MLR model, and (c) Theys et al. (2011)

- Generally good agreements between the MAX-DOAS and satellite tropospheric BrO vertical columns with correlations of 0.70 and 0.78

4 Conclusions and Outlooks

- We have developed an algorithm to retrieve tropospheric BrO columns from satellite nadir UV/vis radiance measurements including TROPOMI
- Tropospheric BrO columns are derived based on the residual method that combines measured DOAS slant columns and estimated stratospheric columns
- For the stratospheric BrO correction, three different methods were tested: (1) atmospheric chemistry model cb05-BASCOE, (2) empirical multiple linear regression model, and (3) Theys et al. (2011) climatological approach using satellite O_3 and NO_2 observations
- Satellite tropospheric BrO vertical columns were validated with ground-based MAX-DOAS measurements. The comparisons between ground-based and satellite tropospheric BrO show a good agreement.
- Small-scale tropospheric BrO explosion events will be investigated using tropospheric BrO retrievals of TROPOMI with high spatial resolution

5 Selected references & Acknowledgements

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