A tropospheric NO_2 research product from TROPOMI for air quality applications in Europe

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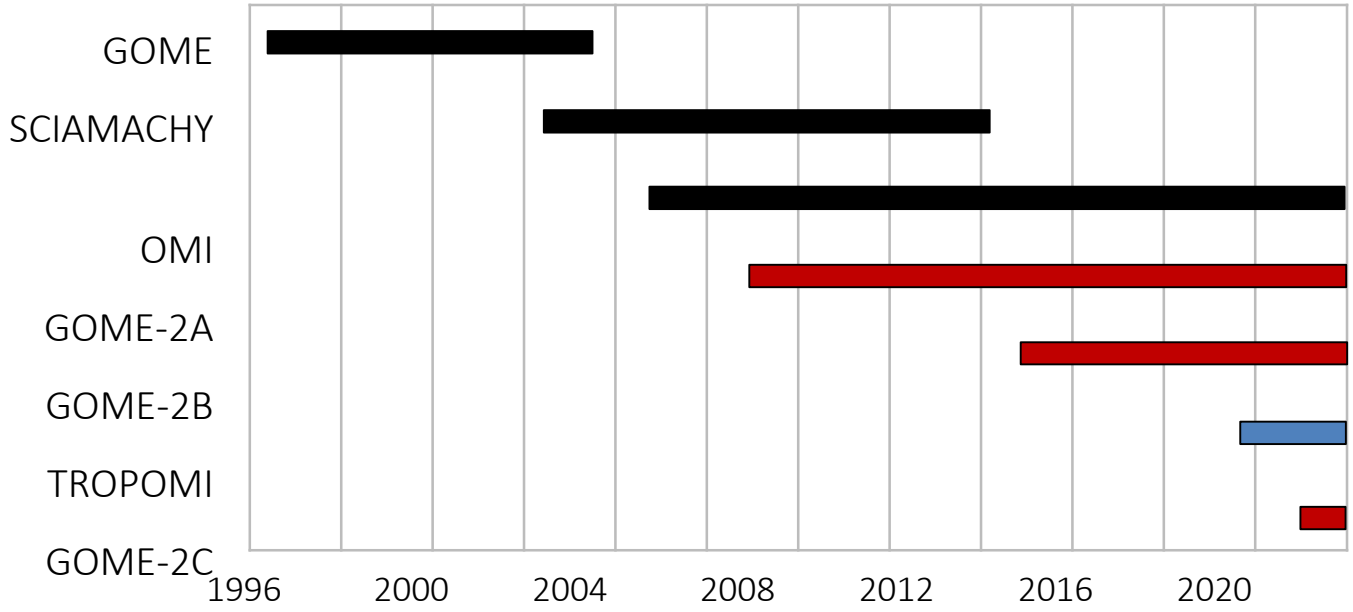
Sentinel-5P Mission: 5 years anniversary
10-14 Oct 2022

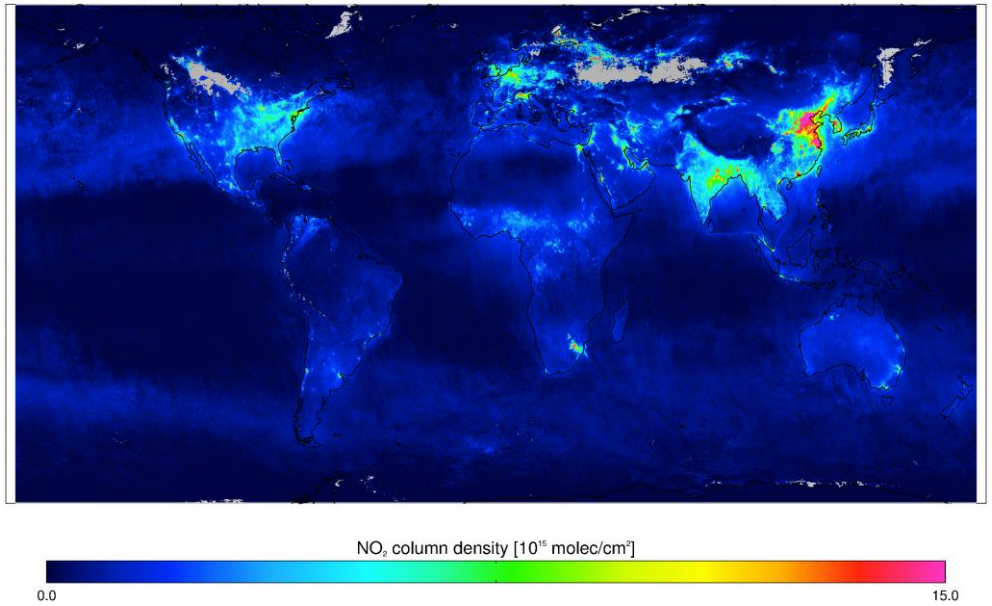
Introduction

Tropospheric NO_2

- an important atmospheric trace gas -> formation of tropospheric ozone, urban haze, and acid deposit
- have been monitored from space for more than a decade on a global scale and daily basis by European satellite instruments
- TROPOMI with high spatial resolution (3.5x5.5 km) and good data quailty
  -> a detailed analysis of local distribution and evolution of NO_2

This study focuses on improvements in tropospheric NO_2 retrieval over Europe from TROPOMI





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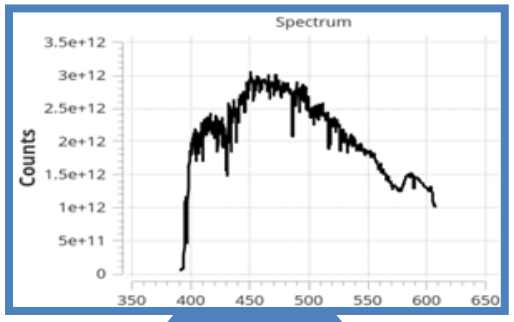
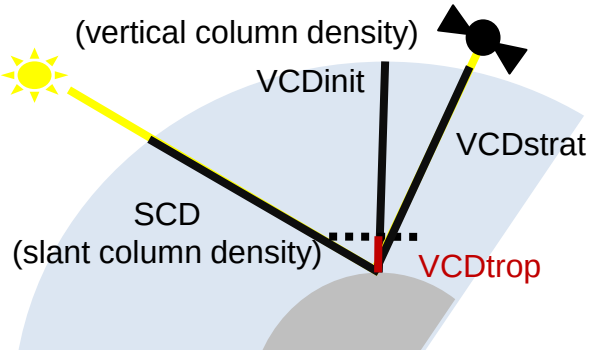
TROPOMI tropospheric NO_2 retrieval

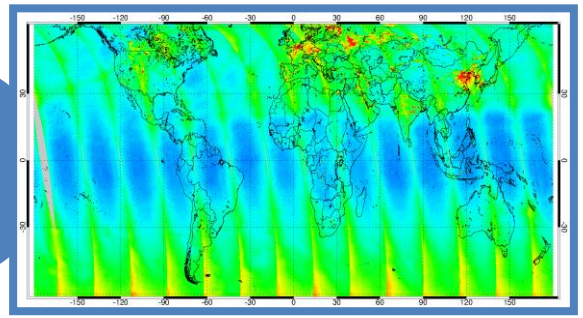




Spectrum

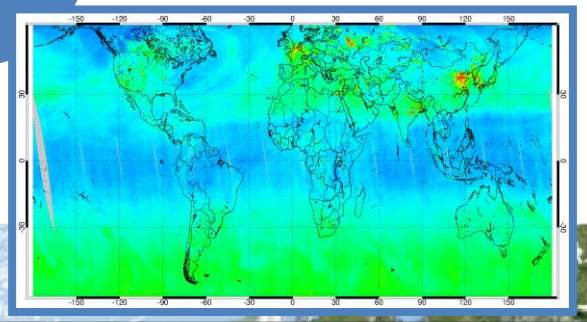
Spectral fitting of slant column (DOAS)

SCD



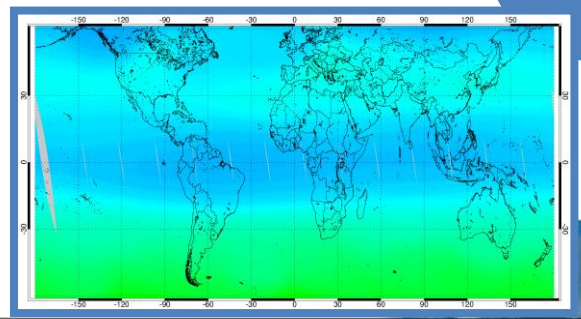
air mass factor (AMF) calculation

VCD init.



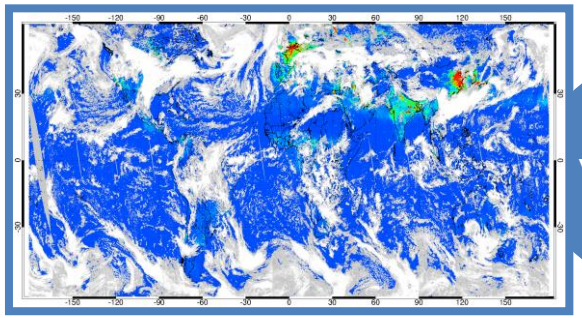
Stratosphere -Troposphere -Separation

VCD strat.



tropospheric AMF calculation

VCD trop.



TROPOMI tropospheric NO_2 retrieval

(1) DOAS NO_2 slant column retrieval

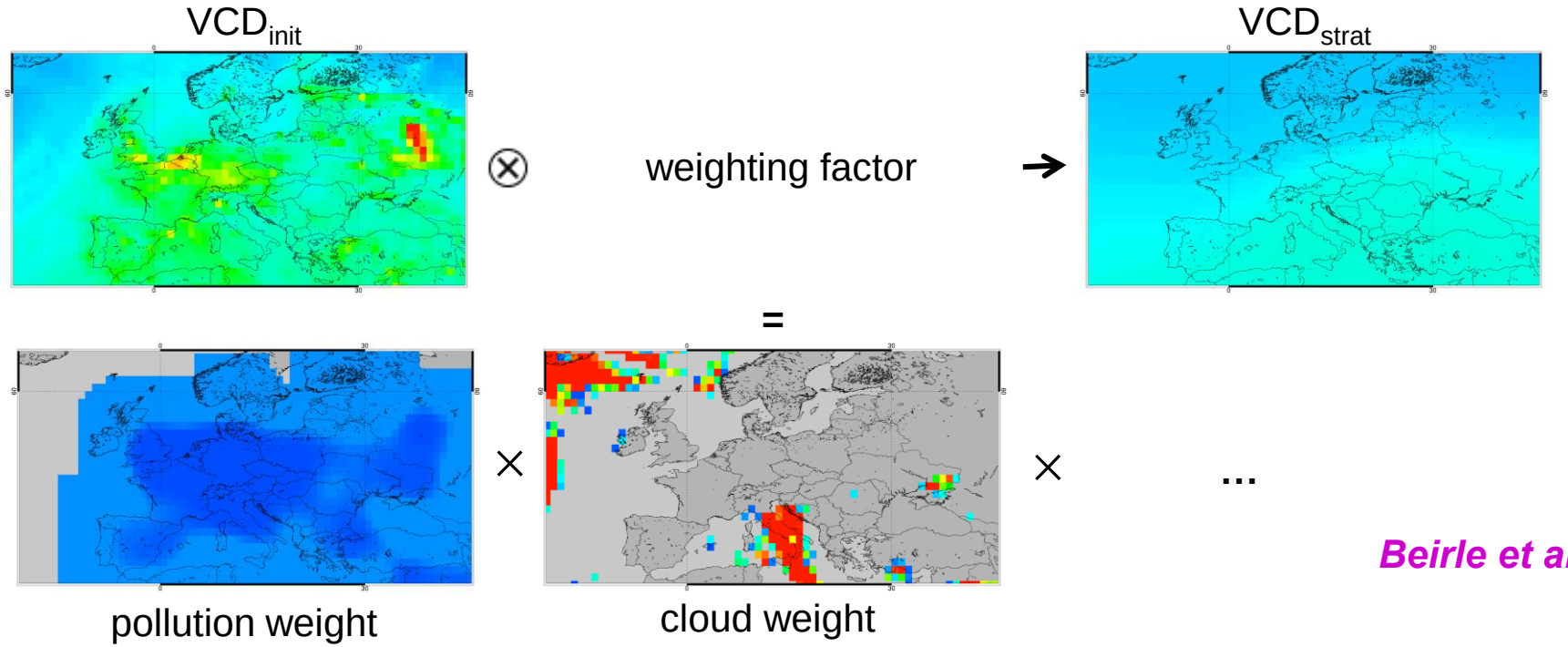
- DOAS settings used for TROPOMI NO_2 slant column retrievals

Fitting window	405 – 465 nm
Cross-sections	NO_2 Vandaele et al. (2002) 220K O_3 Brion et al. (1998) 228K H_2O_{vap} Rothman et al. (2010) 293K, rescaled as in Lampel et al. (2015) O_4 Thalman and Volkamer (2013) H_2O_{liq} Pope and Fry (1997) 297K, smoothed as in Peters et al. (2014)
Ring effect $R(\lambda)$	Ring reference spectrum (pseudo absorber)
Polynomial	5 orders
Offset	Intensity offset correction
Destriping correction	A posteriori box-car averaging method – The daily averaged across-track variability of NO_2 slant columns over clean regions between 20° S and 20° N

TROPOMI tropospheric NO_2 retrieval

(2) Stratosphere-Troposphere Separation (STS)

- Stratospheric NO_2 is esimated using the STRatospheric Estimation Algorithm (STREAM) from Mainz
- STREAM consists basically of two steps
  (1) the definition of weighting factors for each satellite pixel
  (2) the application of weighted convolution
  -> an improved treatment of polluted and cloudy pixels



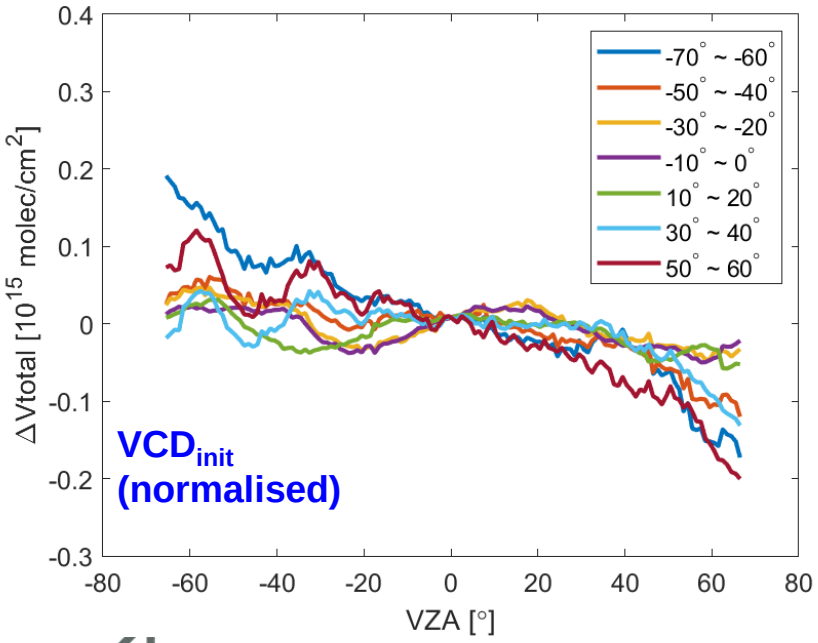
Beirle et al., AMT, 2016

TROPOMI tropospheric NO_2 retrieval

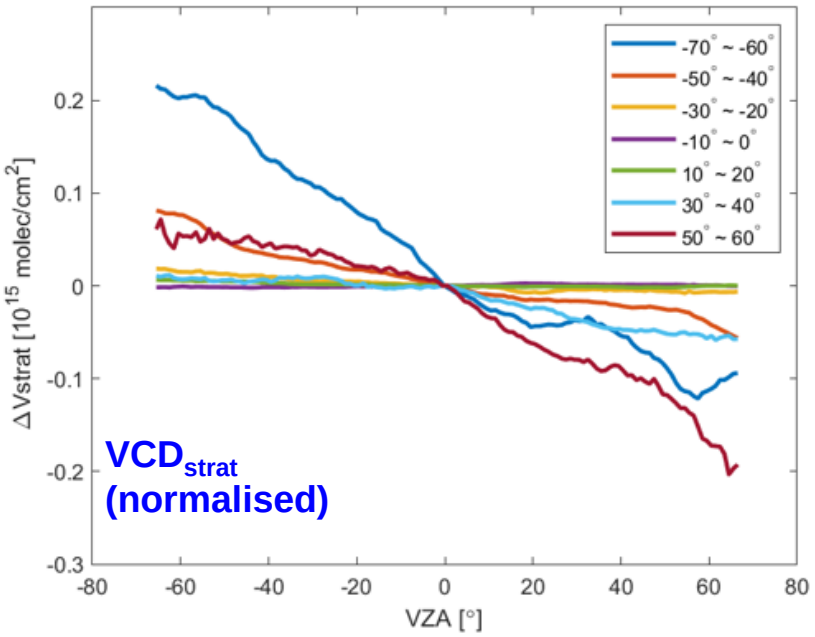
(2) Stratosphere-Troposphere Separation (STS)

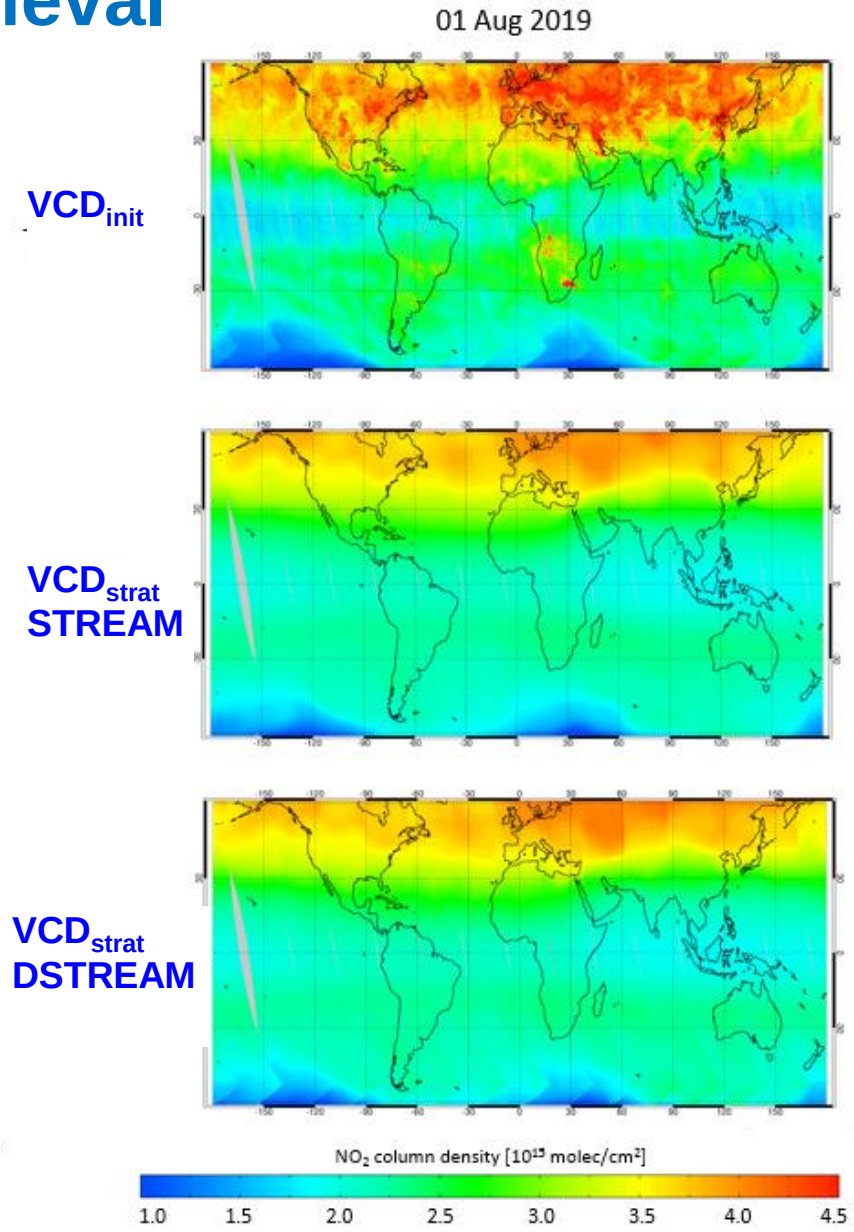
- To correct for the VZA dependency of stratospheric NO_2, a directional-dependent STREAM (DSTREAM) is developed
  - Diurnal variation in stratospheirc NO_2
  - TROPOMI NO_2 columns show dependency on VZA
  - DSTREAM divides the orbit swath into western, central, and eastern segments

Total column



DSTREAM





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TROPOMI tropospheric NO_2 retrieval

(3) Air mass factor calculation

$$VCD = \frac{SCD}{AMF} \qquad AMF = \frac{\sum_l m_l(b) x_l c_l}{\sum_l x_l}$$

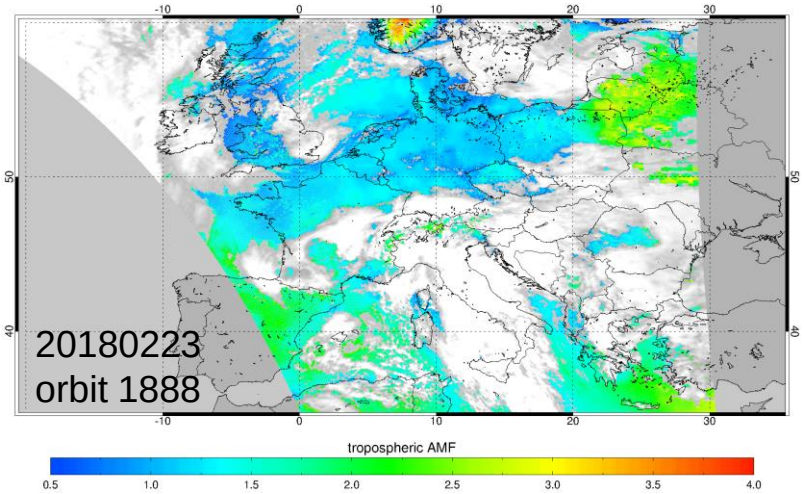
: a box-AMF in layer l, : the partial column from a priori NO_2 profile
: a correction coefficient to correct for the temperature dependency of NO_2 cross section

- The light path in the troposphere is affected by scattering on air molecules as well as cloud and aerosol particles
- The box AMFs are calculated with the linearized vector code VLIDORT version 2.7
- Tropospheric AMF depends on the viewing geometry, surface albedo and pressure, cloud properties, and a priori NO_2 profiles

- Overview of input datasets for DLR NO_2 retrieval algorithm and KNMI operational product

	DLR improved algorithm	KNMI operational product
Surface albedo	TROPOMI GE_LER data	OMI LER climatology
Cloud parameter	OCRA/ROCINN_CAL version 2.1	FRESCO-S
A priori NO_2 profile	LOTOS-EUROS (0.1°x0.1°) POLYPHEMUS/DLR (0.2°x0.3°)	TM5-MP (Global, 1° x 1°)

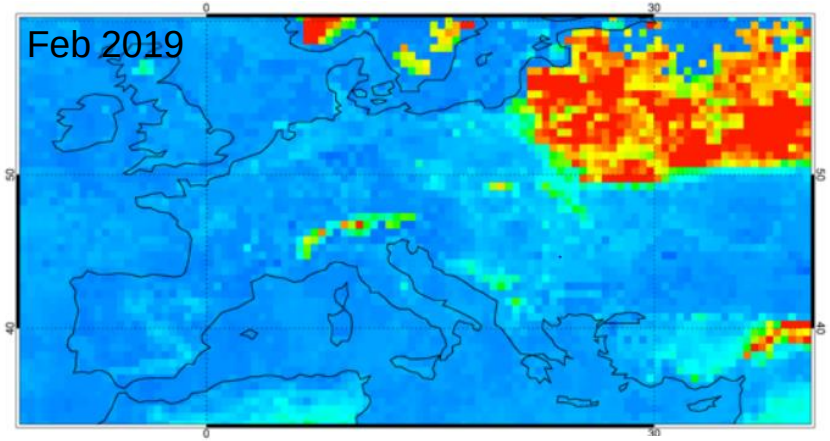
tropospheric AMF



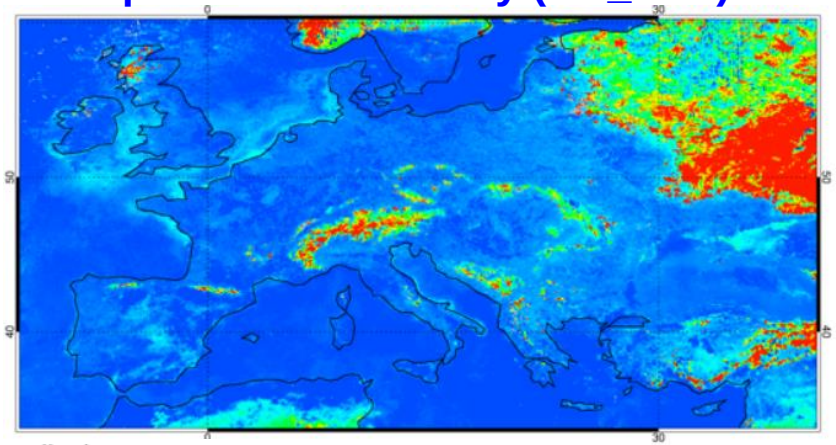
Improvements in AMF calculations

(1) Surface albedo

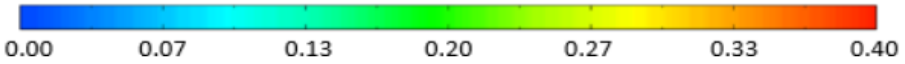
OMI LER climatology



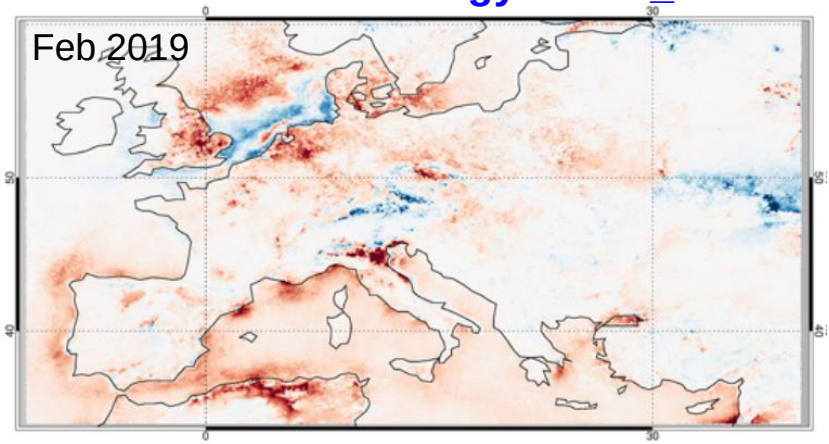
Geometry-dependent Lambertian equivalent reflectivity (GE_LER)



Surface albedo



Trop NO_2 VCD differences OMI LER climatology vs GE_LER



NO_2 column density difference [10^{15} molec/cm^2] (GE_LER – climatological OMI LER)

- Based on 4 years of OMI LER for 440 nm (0.5°x0.5°)

- consistent with NO_2 retrieval
- generated using a trained neural network and DOAS results from TROPOMI spectra (0.1°x0.1°)

Advantages using GE_LER:
Due to consistent measurements from the TROPOMI itself with a higher spatial resolution (0.1° x 0.1°),
better characterize the actual surface conditions especially snow/ice scenes

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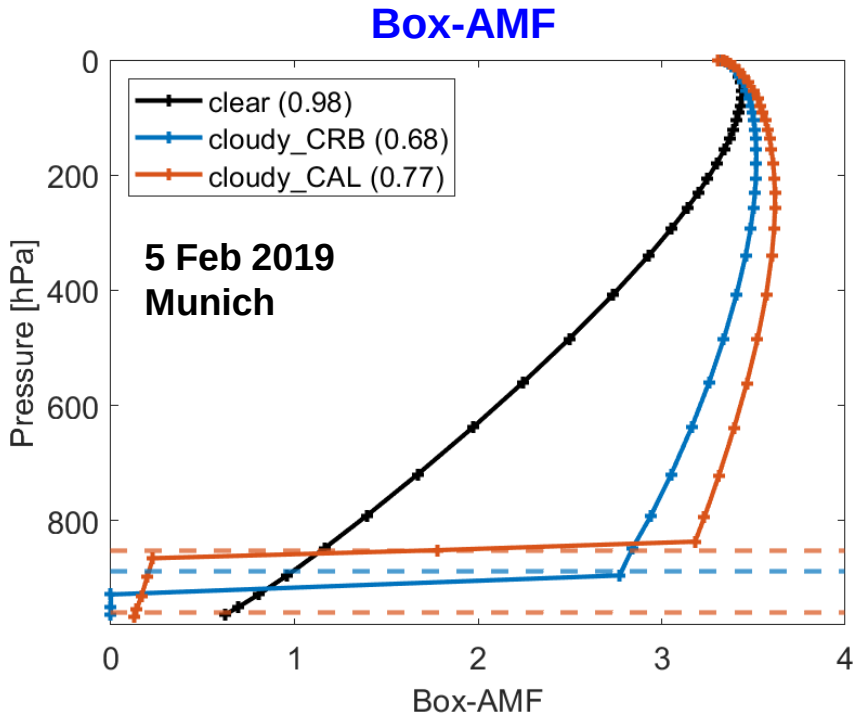
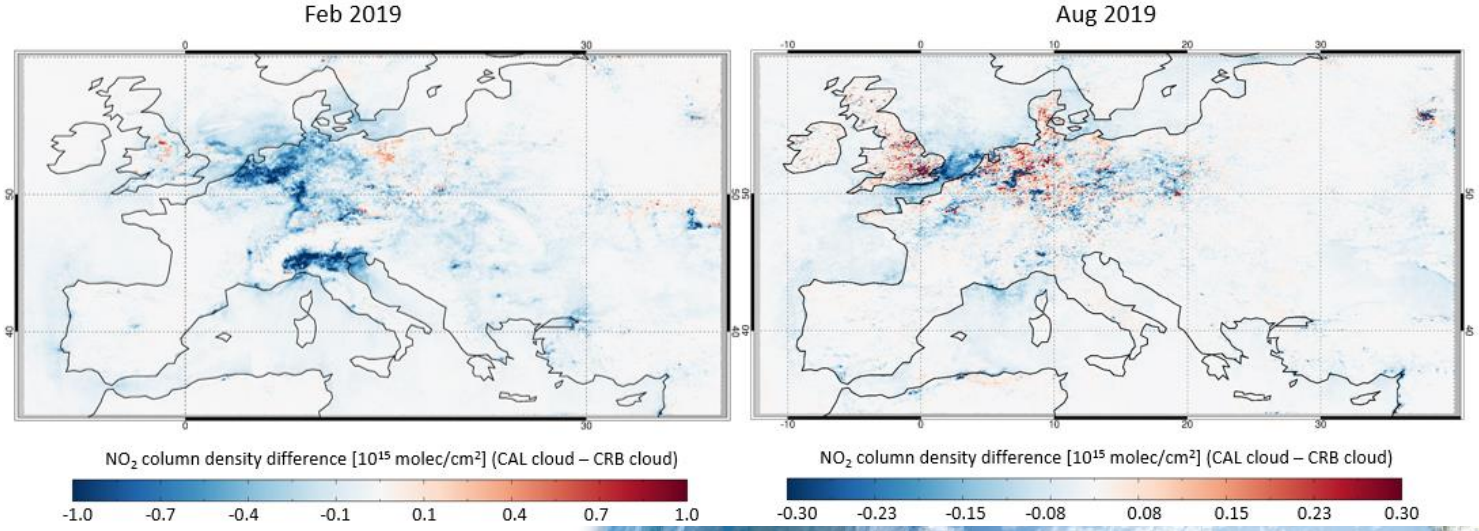
Improvements in AMF calculations

(2) Cloud correction

- Latest OCRA/ROCINN v2 cloud parameters
- Clouds-as-Layers (CAL) model
  - Clouds are treated as uniform layers of scattering water droplets instead of idealised Lambertian reflectors (CRB)
- advantages
  - allows photon penetration
  - accounts for multiple scattering
  - retrieved cloud height closer to the actual cloud height -> more representative of the real situation





Trop. VCD difference CAL vs CRB

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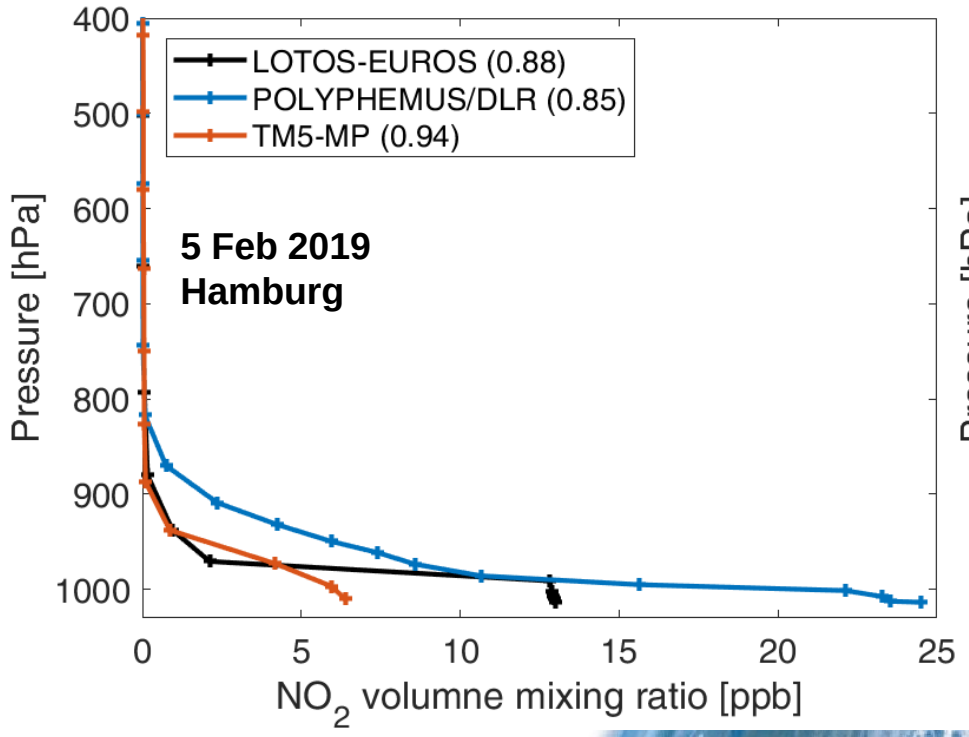
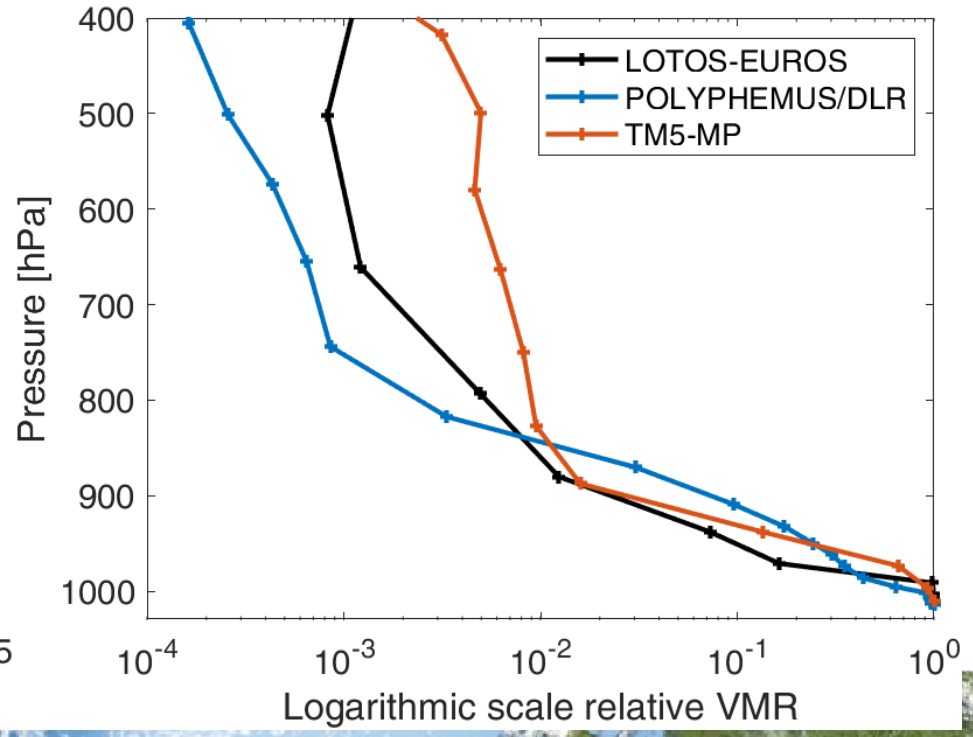
Improvements in AMF calculations

(3) A priori NO_2 profiles

Model	**TM5-MP (Global)**	**POLYPHEMUS/DLR**	**LOTOS-EUROS**
Spatial resolution	1º× 1º	0.2º×0.3º	0.1º×0.1º
Tropospheric Chemistry	Modified CB05	RACM	Modified CBM-IV
Anthropogenic Emissions	MACCity (Granier et al., 2011)	TNO-MACC (Kuenen et al., 2014)	CAMS European emissions (2018)

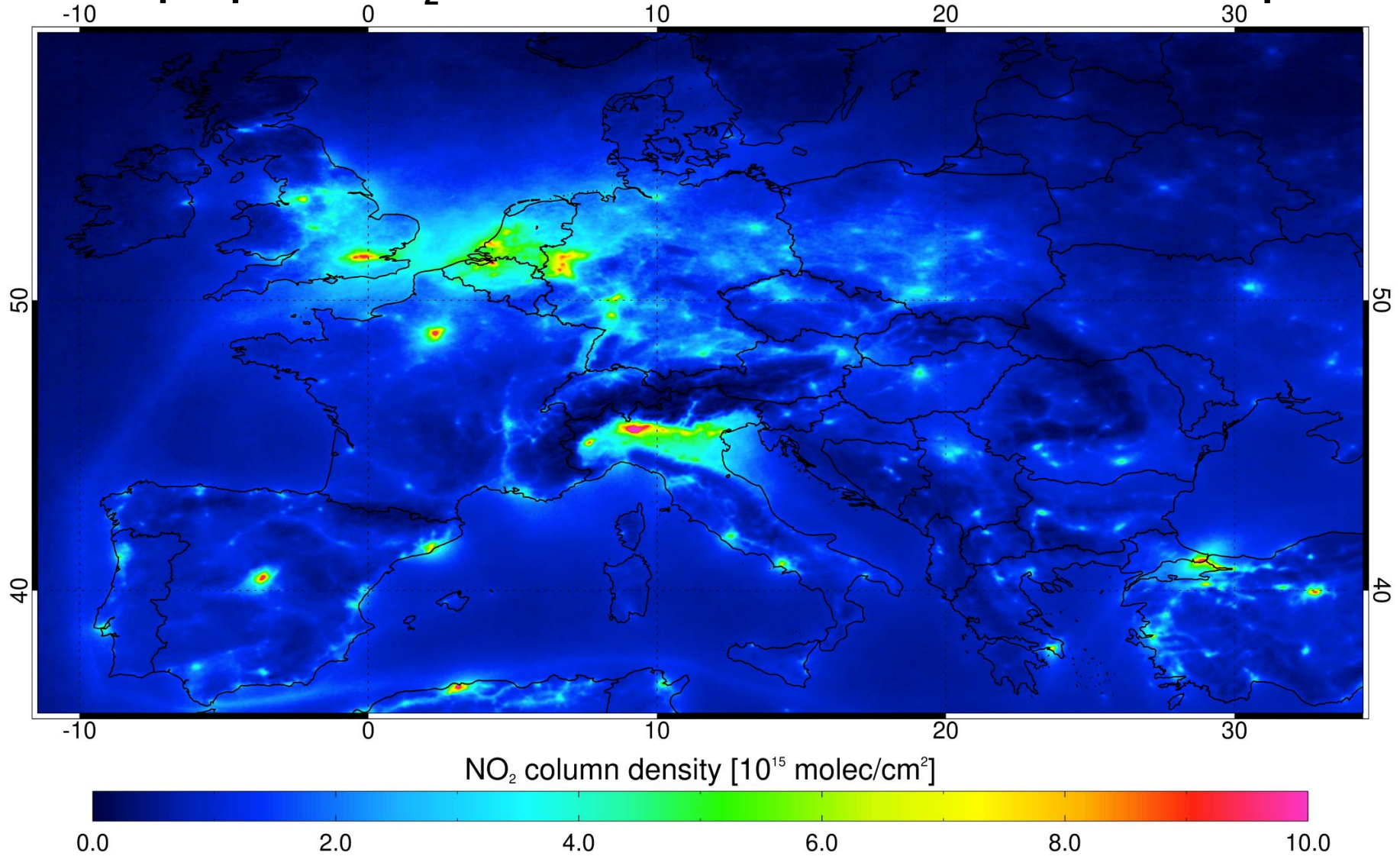




Improvements in AMF calculations

(3) A priori NO_2 profiles

Yearly mean tropospheric NO_2 columns from TROPOMI with the TM5-MP profiles in 2019



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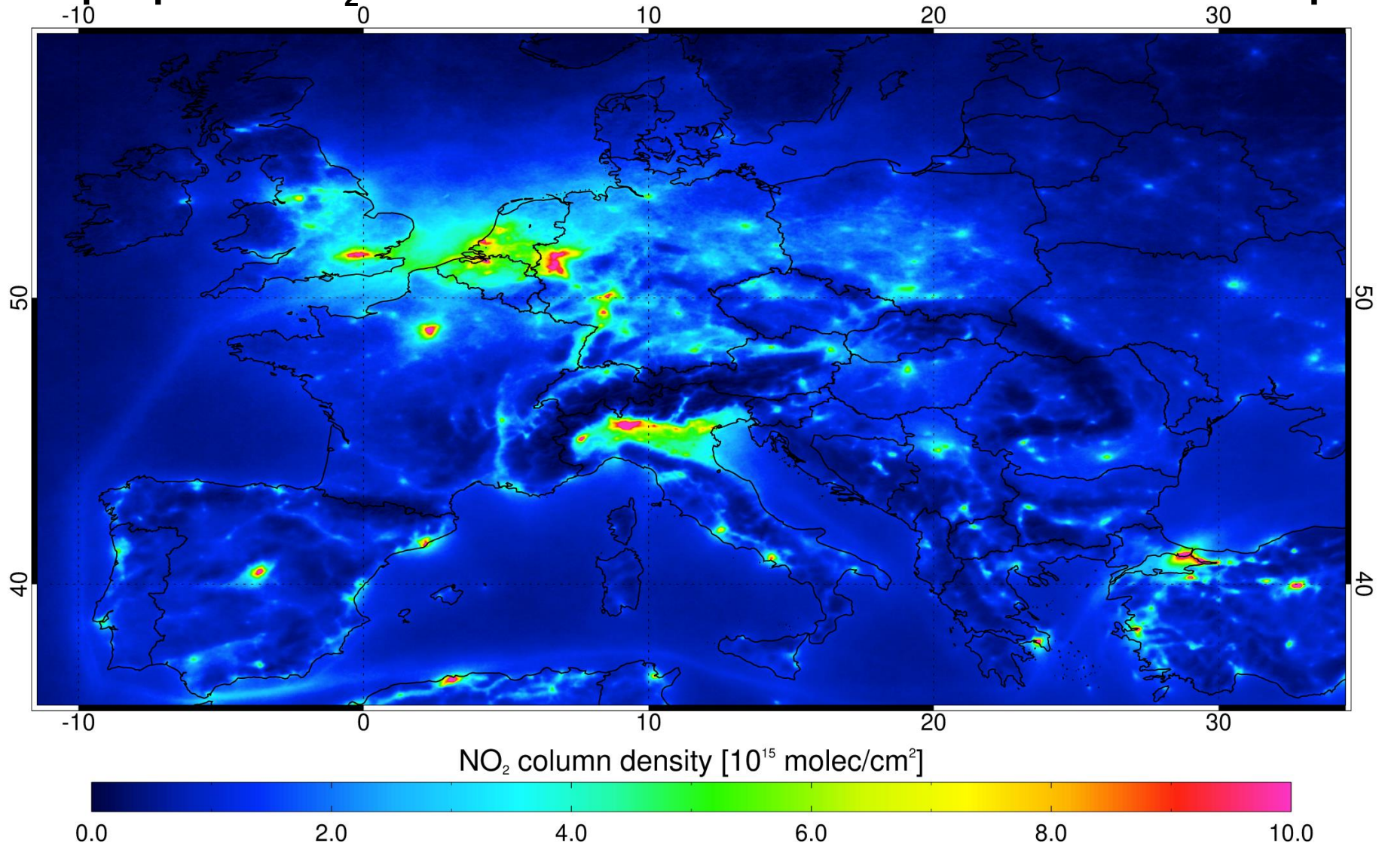
Improvements in AMF calculations

(3) A priori NO_2 profiles

Yearly mean tropospheric NO_2 columns from TROPOMI with the LOTOS-EUROS profiles in 2019



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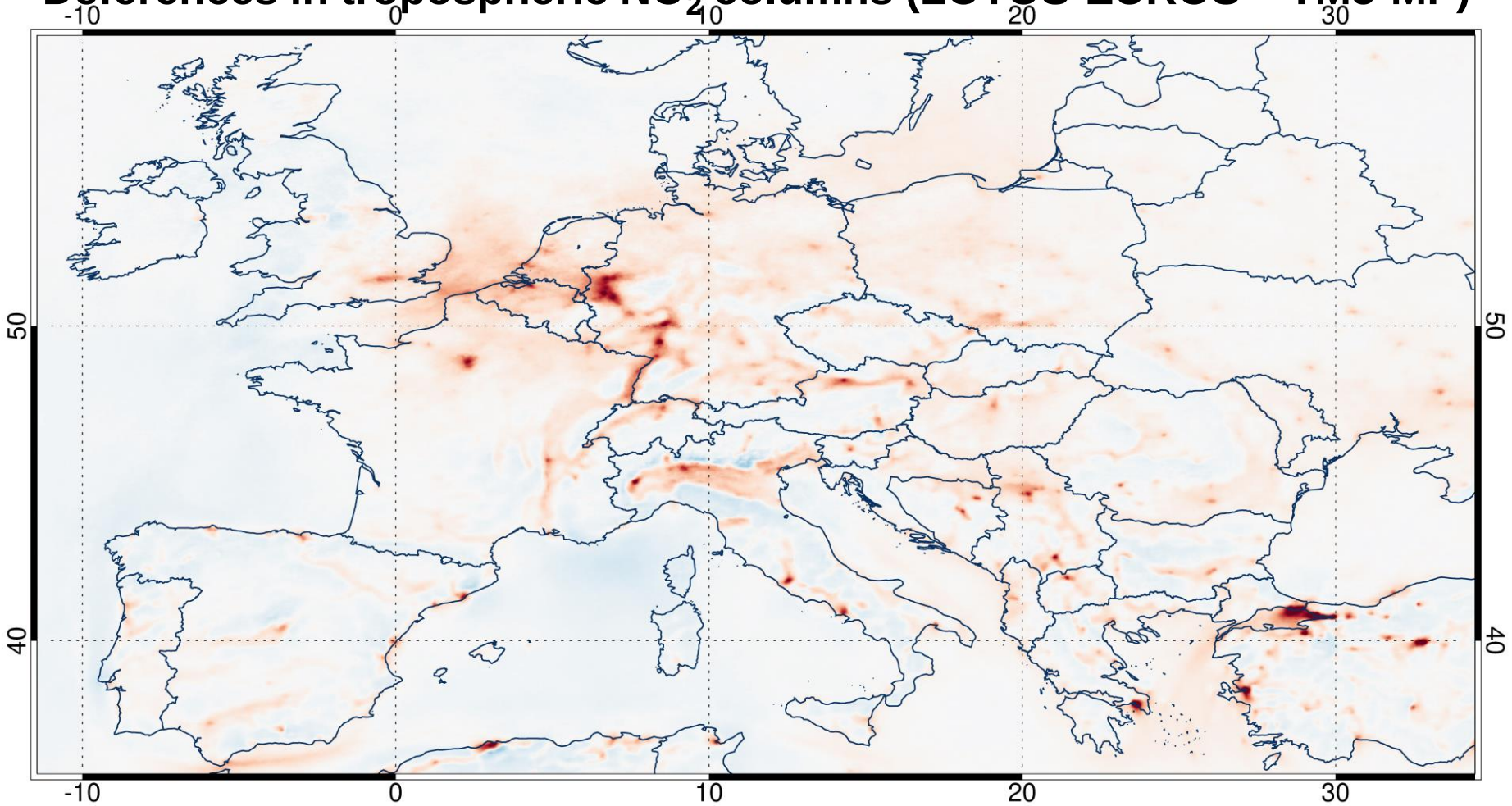
Improvements in AMF calculations

(3) A priori NO_2 profiles

Deferences in tropospheric NO_2 columns (LOTOS-EUROS – TM5-MP)



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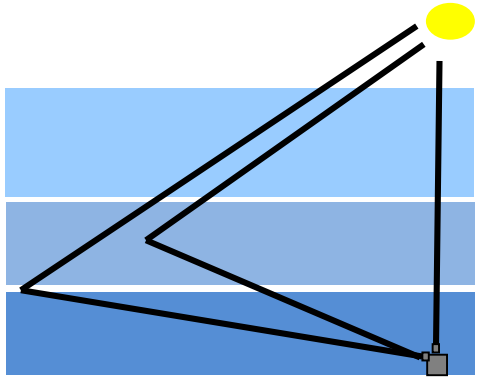
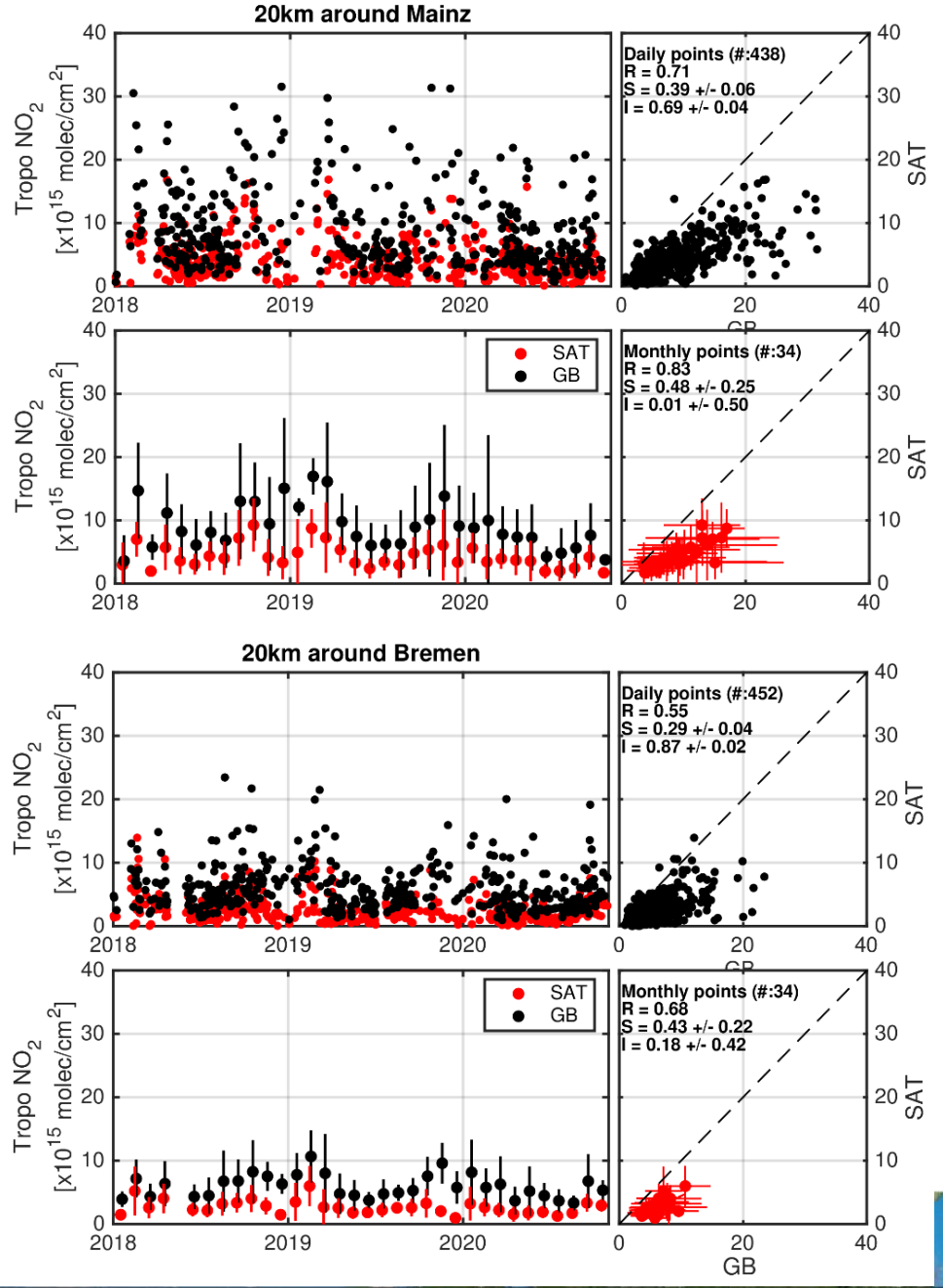
Validation with MAX-DOAS measurements

- Comparisons with nine stations in Europe
  - mostly (sub)urban polluted conditions
- Cloud free satellite pixels within 20 km radius
- Period: Jan 2018 – Dec 2020
- TROPOMI tropospheric NO2 columns are underestimation by ~20 %
  - gradient smoothing effect
  - different sensitivity to NO_2
  - structural uncertainties





Conclusions

- Improved NO_2 retrieval algorithm from TROPOMI measurements over Europe

- DOAS retrieval (405-465 nm) with intensity offset correction
- New stratosphere-troposphere separation using DSTREAM method
- Tropospheric AMF calculation
  - surface albedo from TROPOMI GE_LER data
  - cloud correction based on latest OCRA/ROCINN cloud parameters (CAL)
  - a priori profiles from regional CTM (LOTOS-EUROS and POLYPHEMUS)

- Validation with ground-based MAX-DOAS measurements
  - Good correlations for nine (sub)urban stations in Europe (R=~0.8)
  - underestimation of ~20%

Liu et al., An improved TROPOMI tropospheric NO_2 research product over Europe, Atmos. Meas. Tech., 2021

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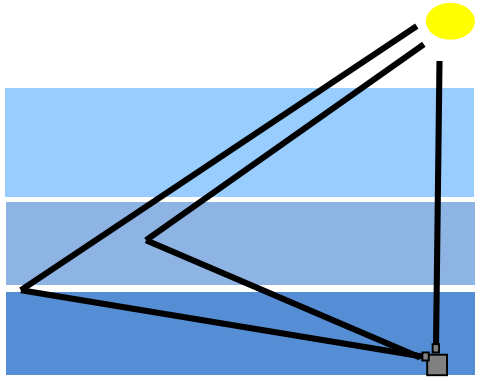

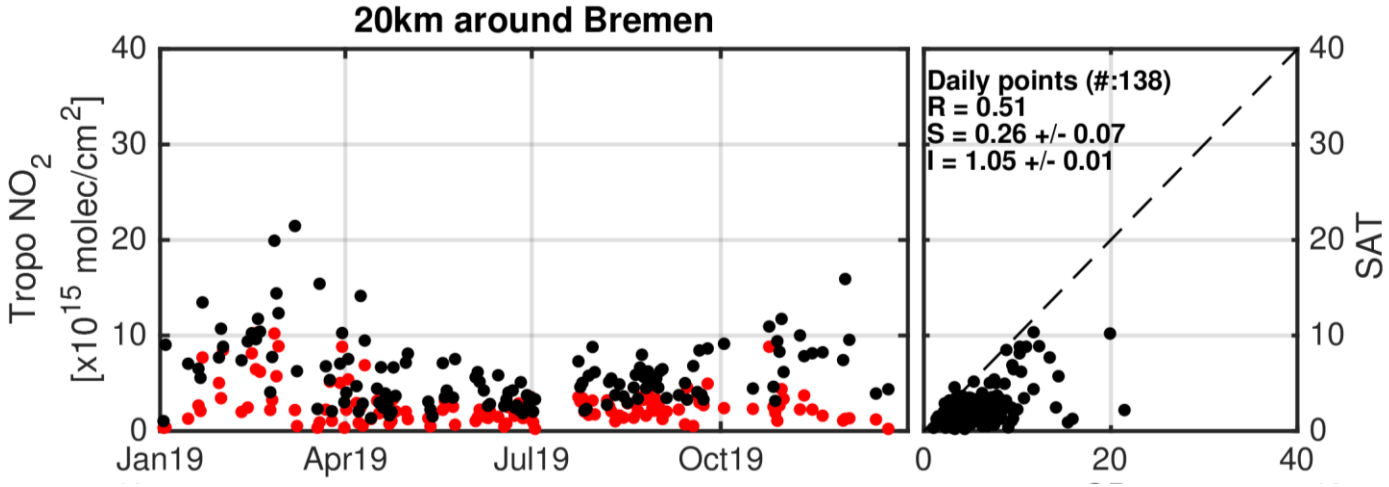

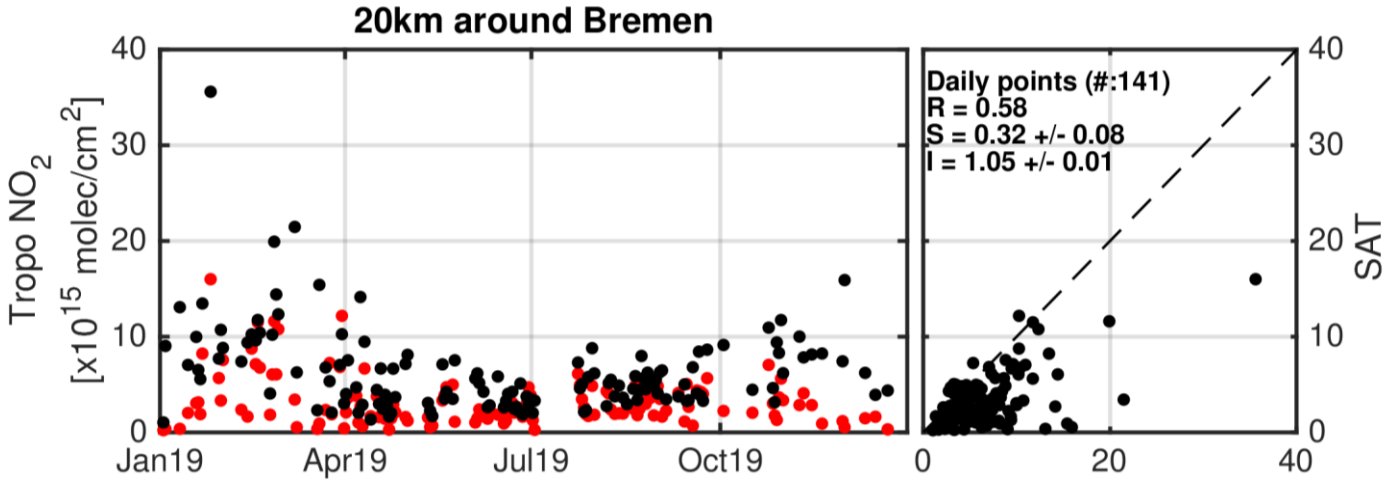

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