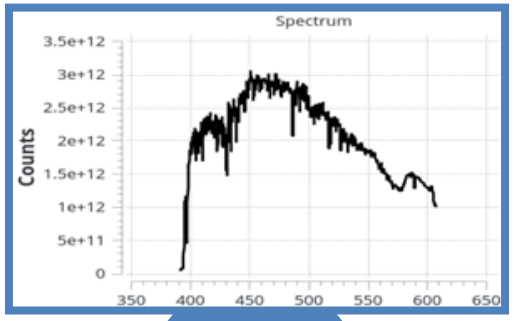
An improved TROPOMI tropospheric NO_2 research product over Europe

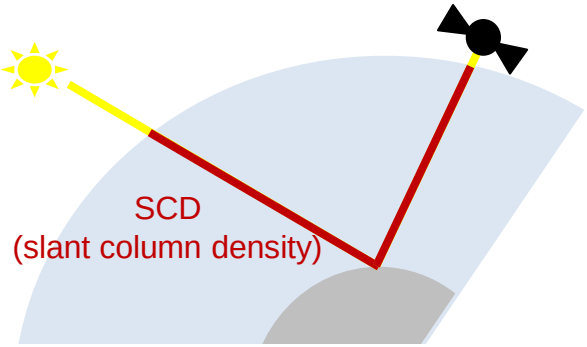
*Song Liu[1,4], **Pieter Valks[1]**, Sora Seo[1], Gaia Pinardi[2,] Jian Xu[1], Ka Lok Chan[1], R. Lutz[1], A. Argyrouli[1], Ehsan Khorsandi[1], Frank Baier[1], Steffen Beirle[3], M .Van Roozendael[2] and D. Loyola[1]*

1. German Aerospace Center (DLR), Wessling, Germany
2. Belgian Institute for Space Aeronomy (BIRA-IASB), Brussels, Belgium
3. Max-Planck-Institut für Chemie (MPIC), Mainz, Germany
4. Southern University of Science and Technology, Shenzhen, China

ESA ATMOS-2021 Conference,
22-26 Nov. 2021 | Virtual Event

Trop. NO_2 retrieval

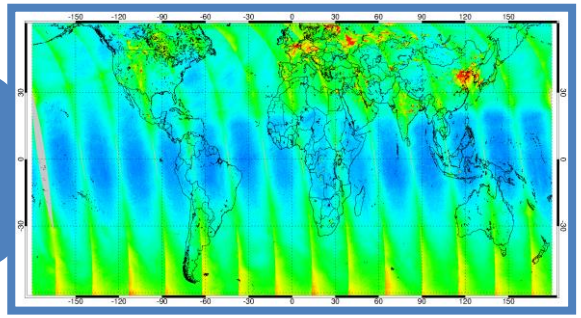




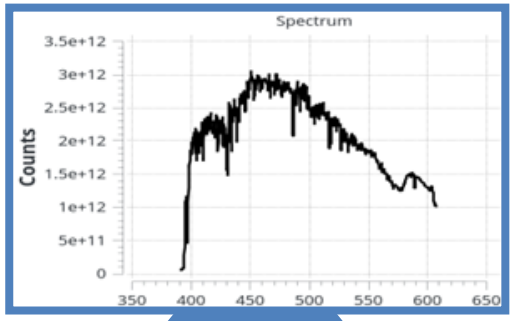
Spectrum

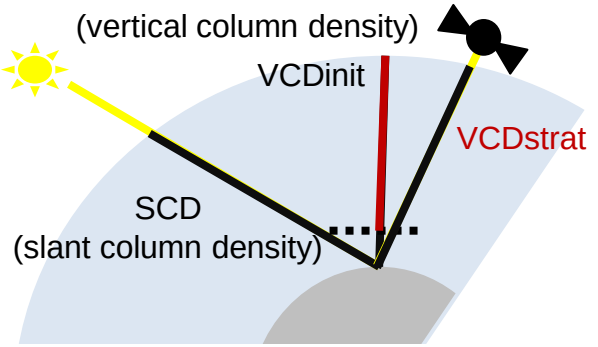
spectral fitting

SCD



Trop. NO_2 retrieval

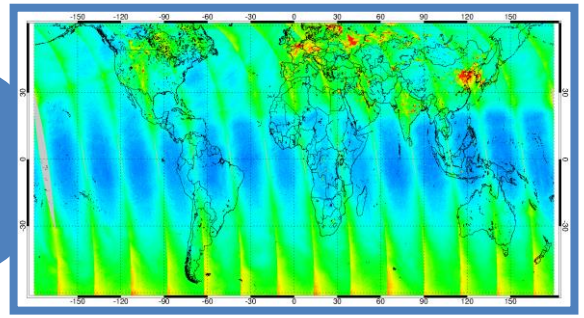




Spectrum

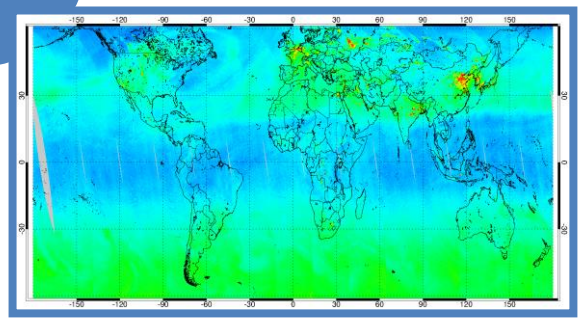
spectral fitting

SCD



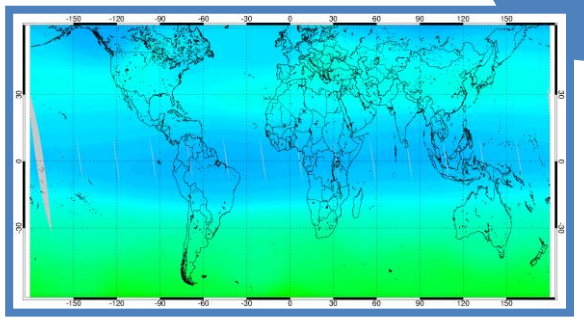
air mass factor (AMF) calculation

VCD init.

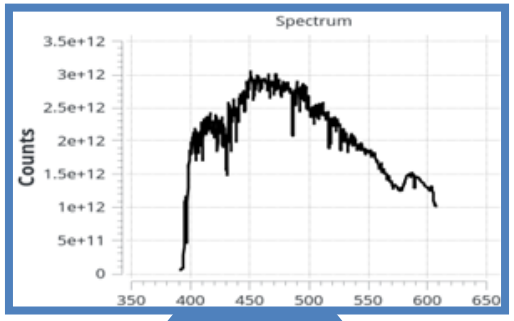


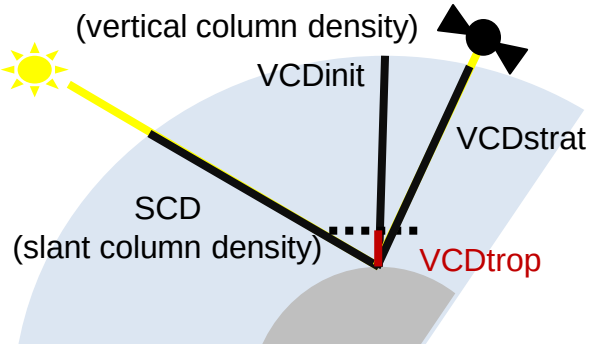
Stratosphere
-Troposphere
-Separation

VCD strat.



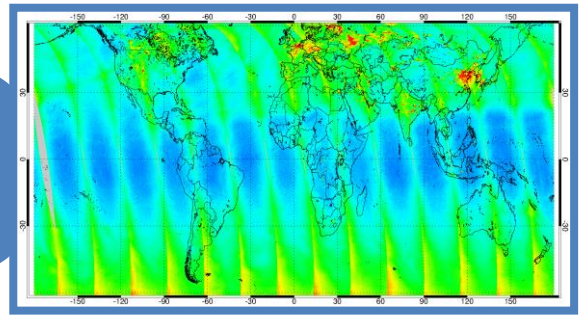
Trop. NO_2 retrieval





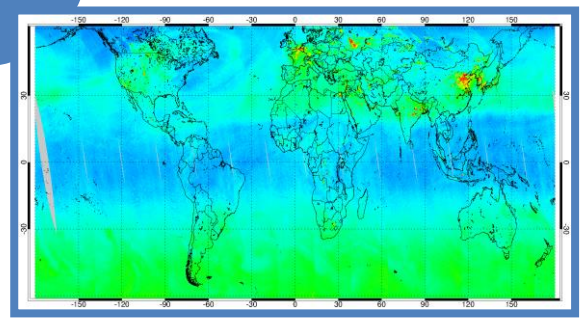
Spectrum

spectral fitting



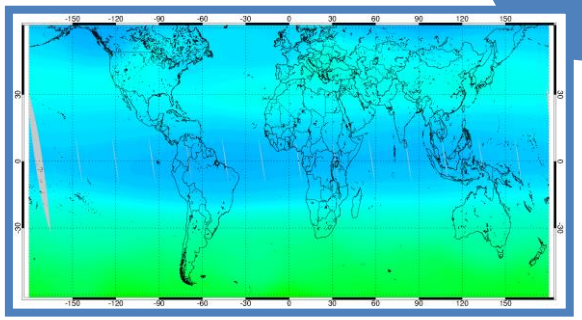
SCD

air mass factor (AMF) calculation



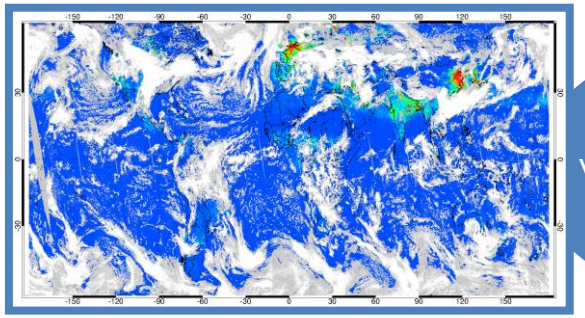
VCD init.

Stratosphere
-Troposphere
-Separation



VCD strat.

tropospheric AMF calculation

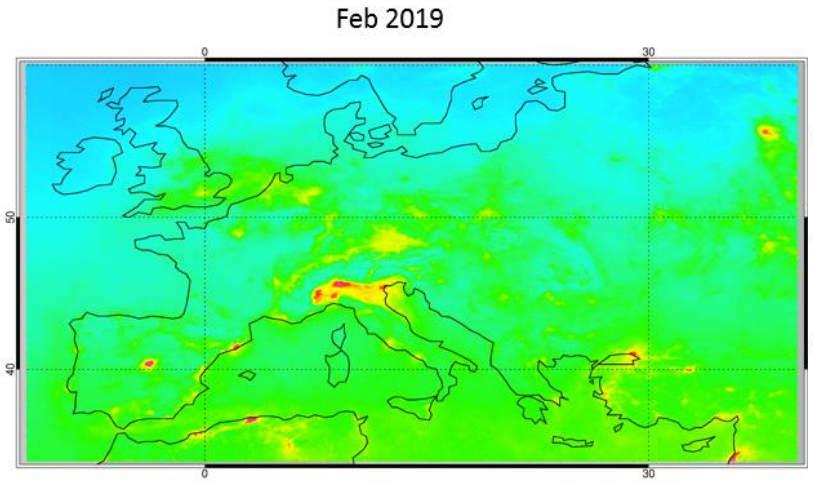


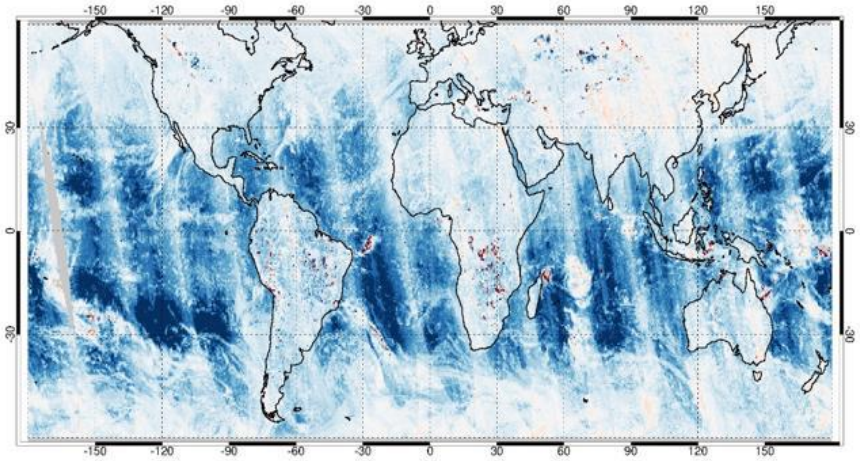
VCD trop.

DOAS slant column retrieval

$$ln\left[\frac{I(\lambda)+offset}{I^0(\lambda)}\right] = -\sum_g S_g\sigma_g(\lambda) - \alpha_R R(\lambda) - P(\lambda)$$

fitting window λ	**405-465 nm**
cross-sections $\sigma_g(\lambda)$	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 $P(\lambda)$	5 orders
offset	Intensity offset correction
de-striping correction	a posteriori box-car averaging method





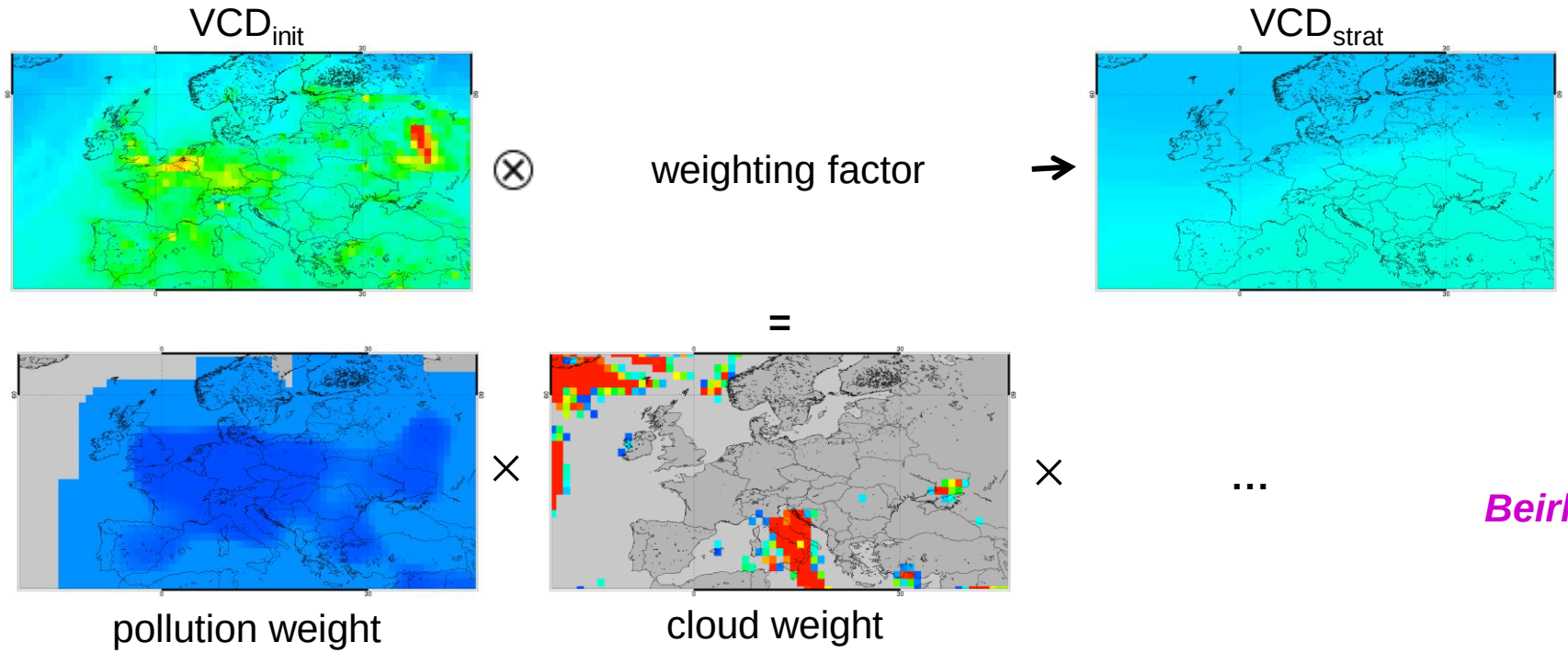
SCD difference 5 Feb. 2019

SCD (scaled by AMF_{geo})

Stratosphere-Troposphere Separation (STS)

- Modified reference sector method
  - use TROPOMI measurements over clean areas and clouded scenes
  - improved treatment of polluted and cloudy pixels by weighting factors

STRatospheric Estimation Algorithm from MPI Mainz (STREAM)

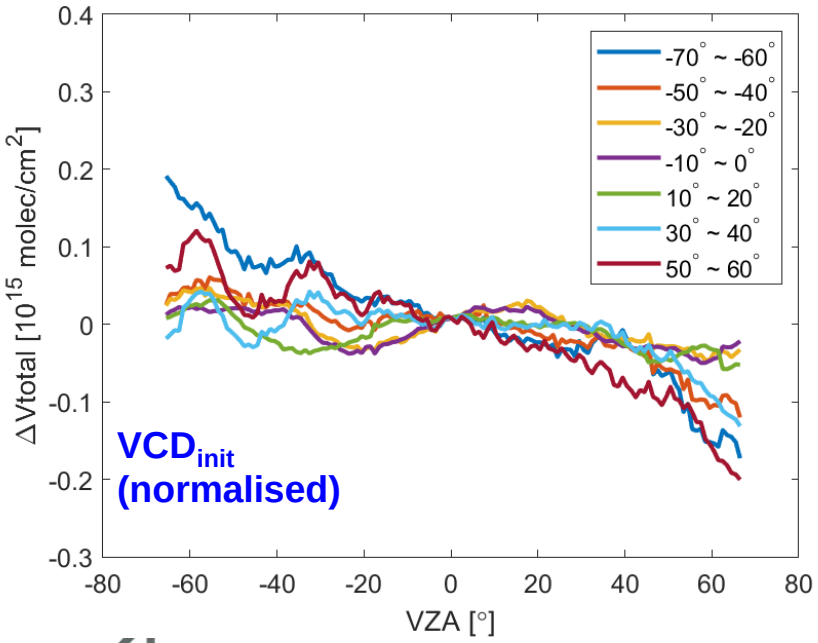


Beirle et al., AMT, 2016

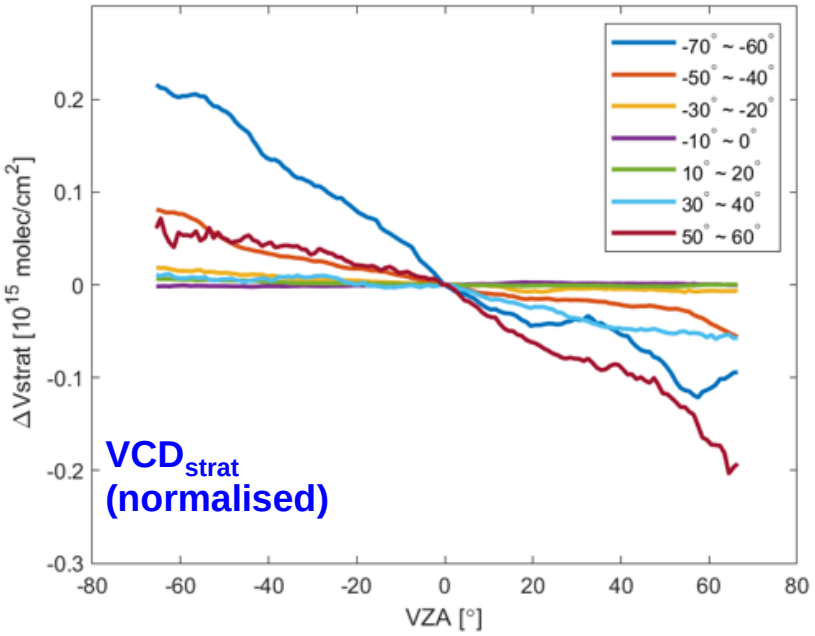
Directional-dependent STREAM

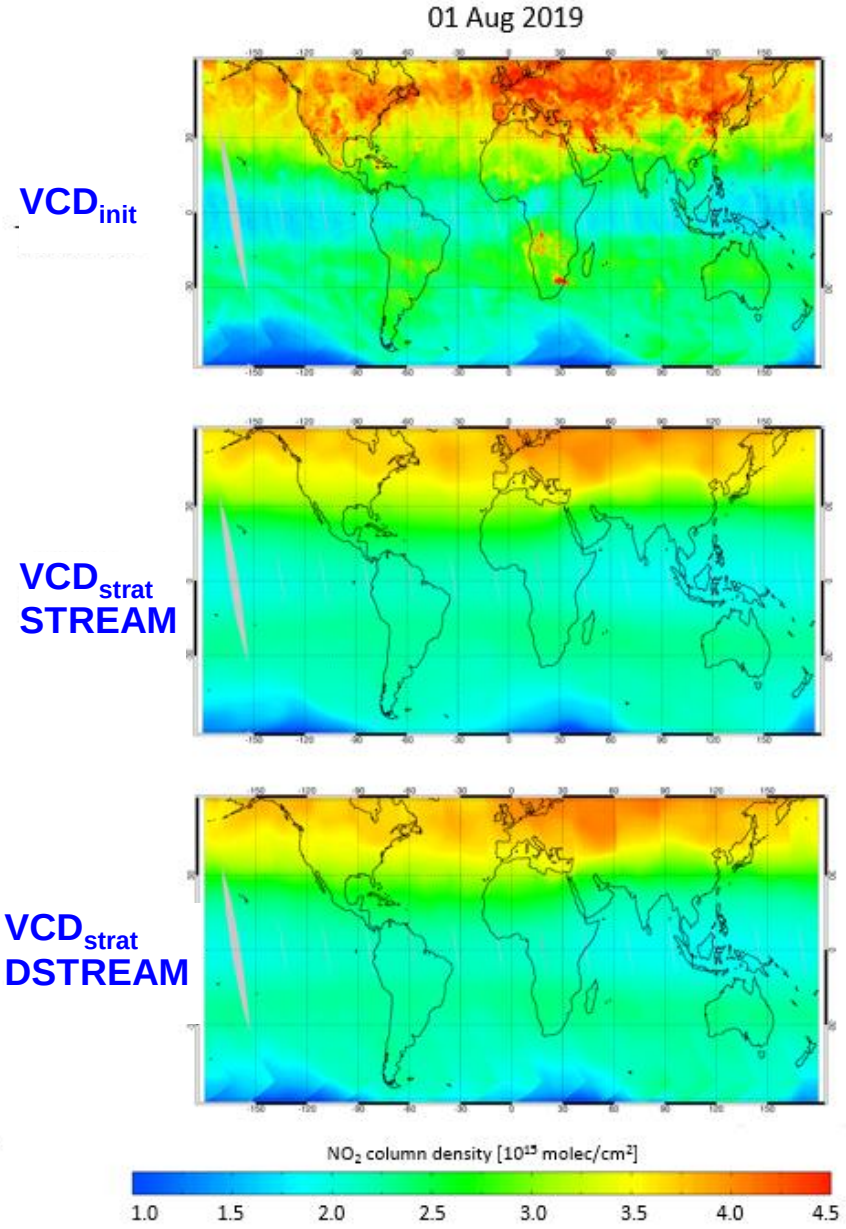
- Directional-dependent STREAM
  - diurnal variation in stratospheric NO_2
  - TROPOMI NO_2 columns show dependency on VZA
  - DSTREAM divides the orbit swath into western, central, eastern segments

Total column



DSTREAM





Tropospheric AMF calculation

$$VCD_{trop} = \frac{SCD_{trop}}{AMF_{trop}}$$

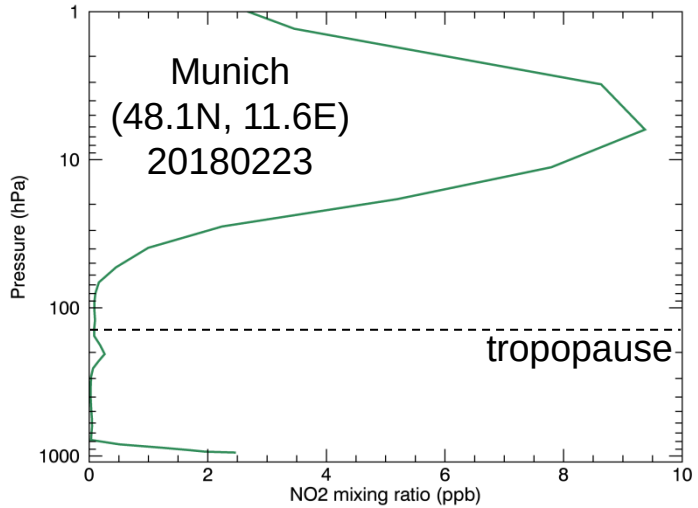
vertical distribution of NO_2 (tropospheric *a priori* profiles)

model parameters (wavelength, geometry, surface albedo, clouds…)

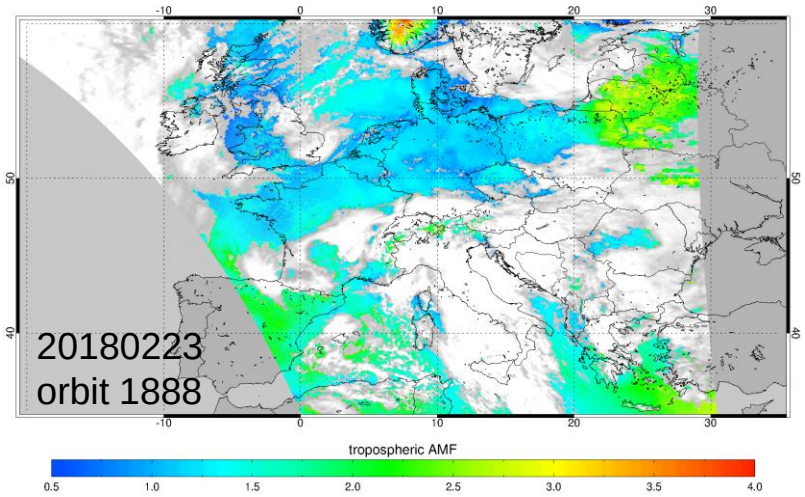
- depends strongly on surface albedo, clouds, a priori profiles……
- describes the sensitivity to NO_2

Liu et al., AMT, 2019

daily TM5 *a priori* profiles (1° ×1°)



tropospheric AMF



AMF calculation – Surface Albedo

OMI LER climatology

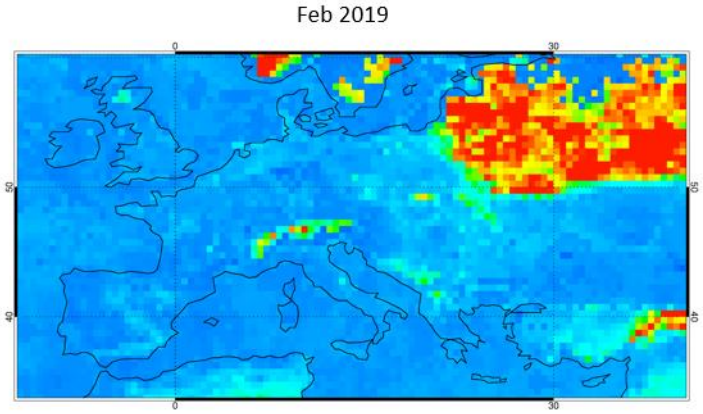
- based on 4 years of OMI LER (2004-2007) for 440 nm
- Resolution: 0.5º×0.5º

Geometry-dependent Lambertian equivalent reflectivity (GE_LER)

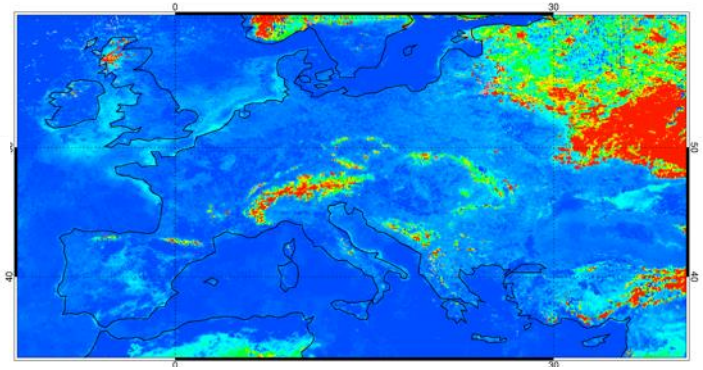
- consistent with NO_2 retrieval
- generated using a trained neural network and DOAS results from TROPOMI spectra (FP_ILM algorithm)
- advantages
  - high resolution: 0.1º× 0.1º
  - actual surface conditions especially snow/ice scenarios
  - consistent application to trace gas, cloud, and aerosol retrievals

Loyola et al., AMT, 2020

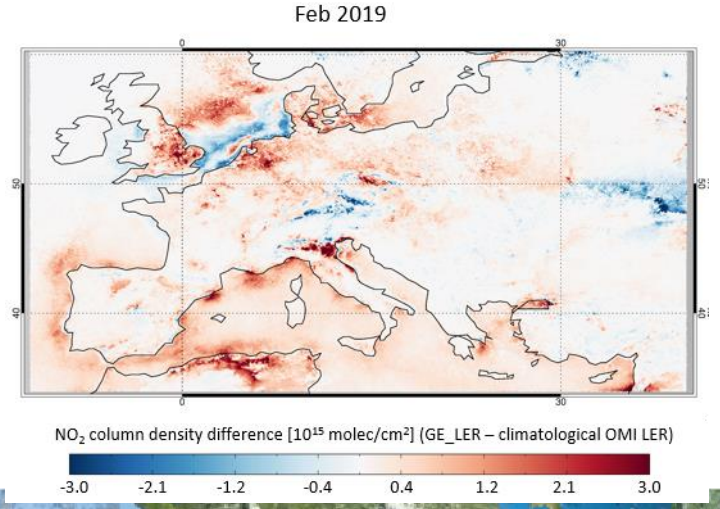
OMI LER clim.



GE_LER



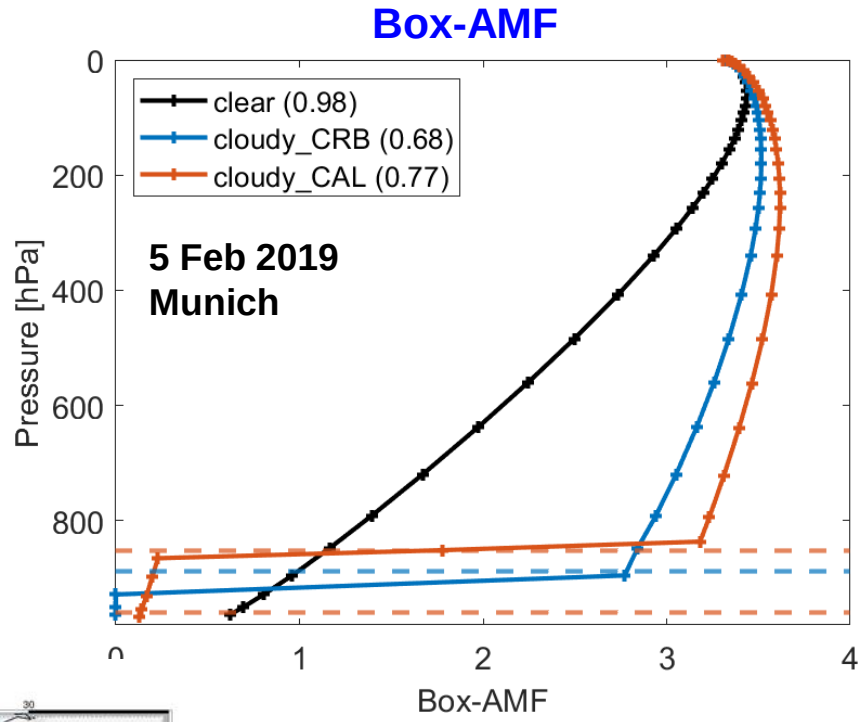
Trop. VCD difference

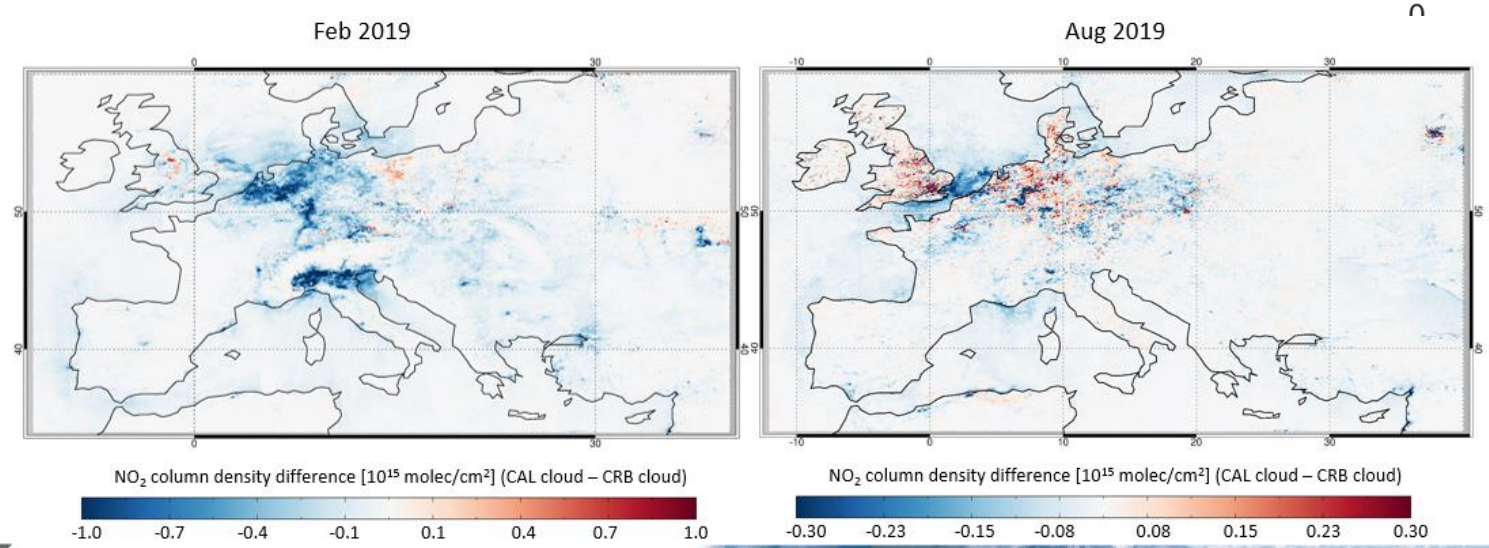


DLR

AMF calculation – Cloud Correction

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





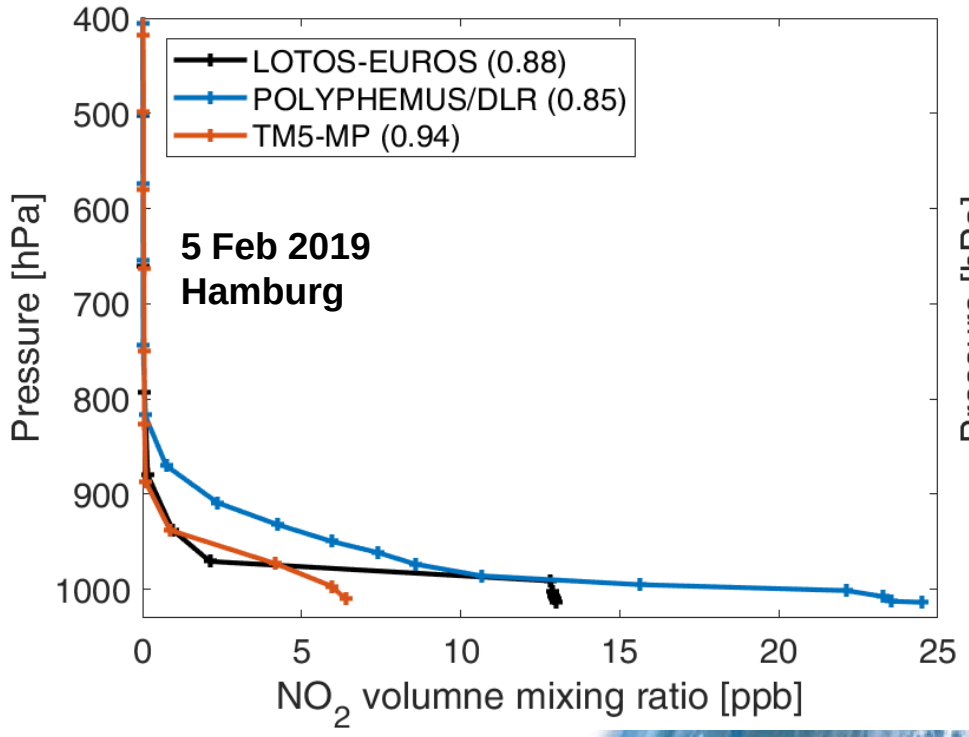
Trop. VCD difference CAL vs CRB

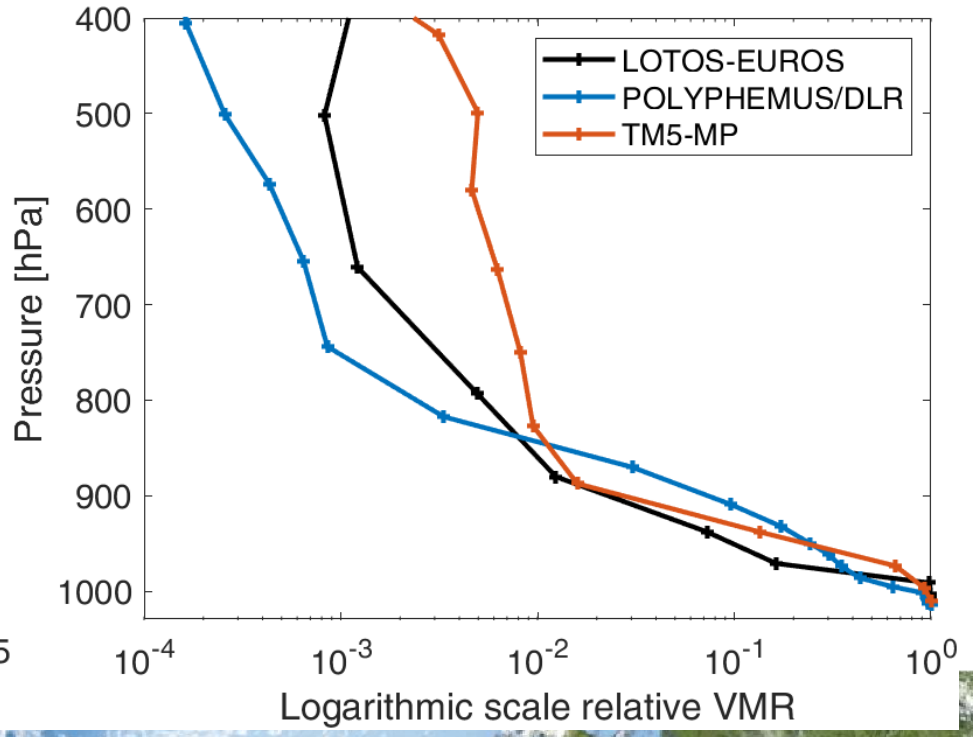
R. Lutz (Session 5.1)

DLR

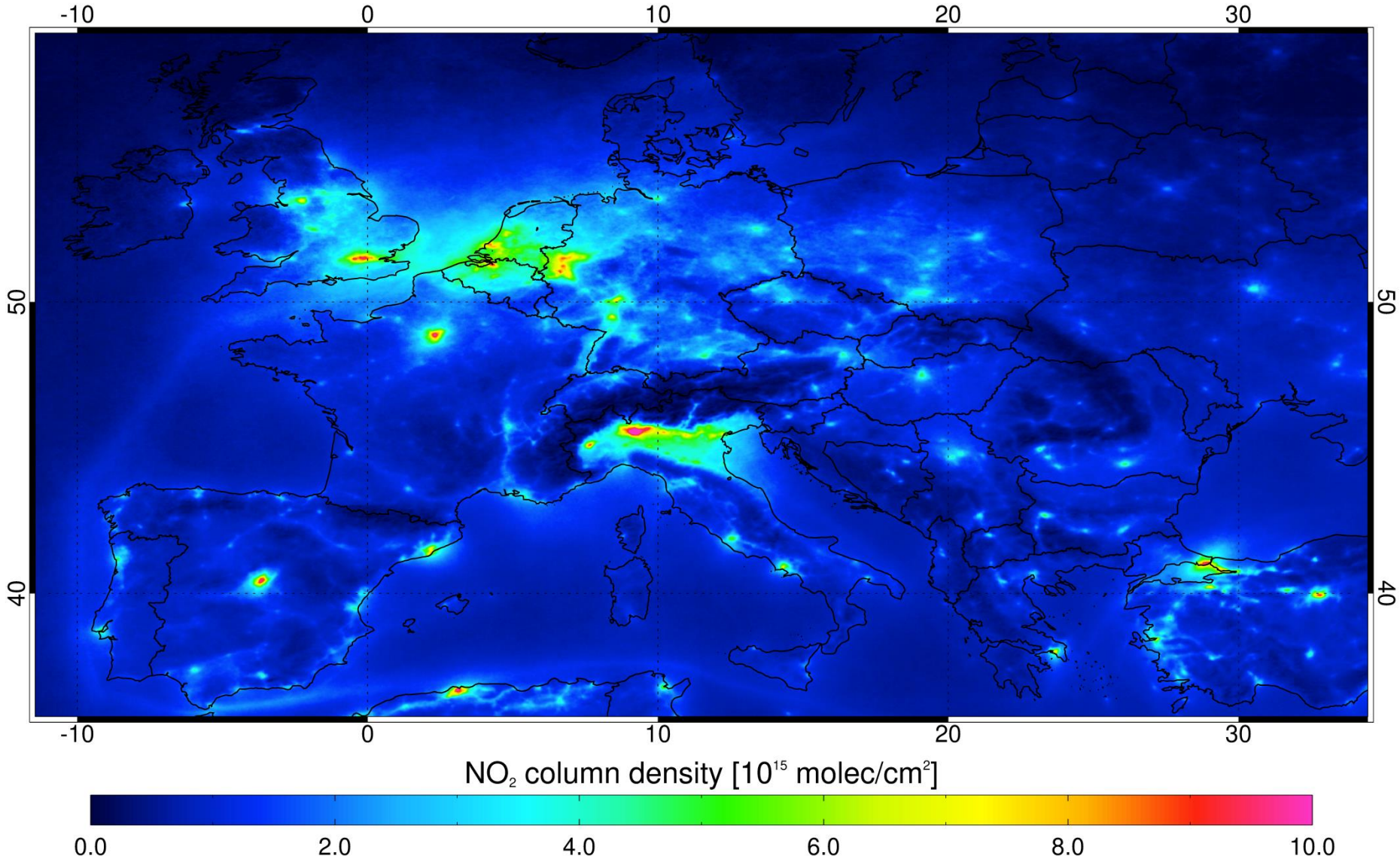
AMF calculation – *a priori* NO_2 profiles from regional CTM

Model	**TM5-MP**	**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)





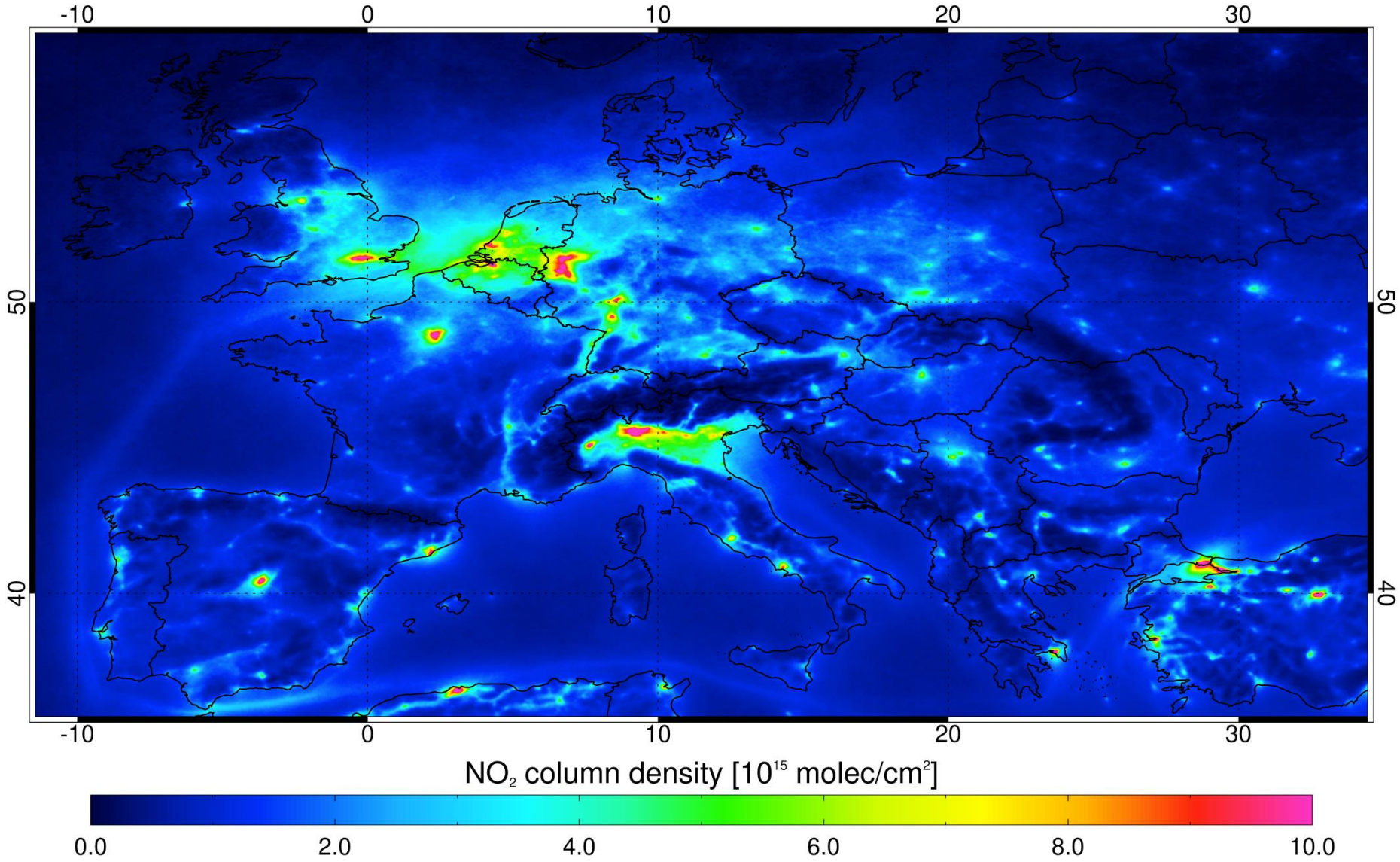
Tropospheric NO_2 – *a priori* NO_2 profiles from TM5-MP



2019

DLR

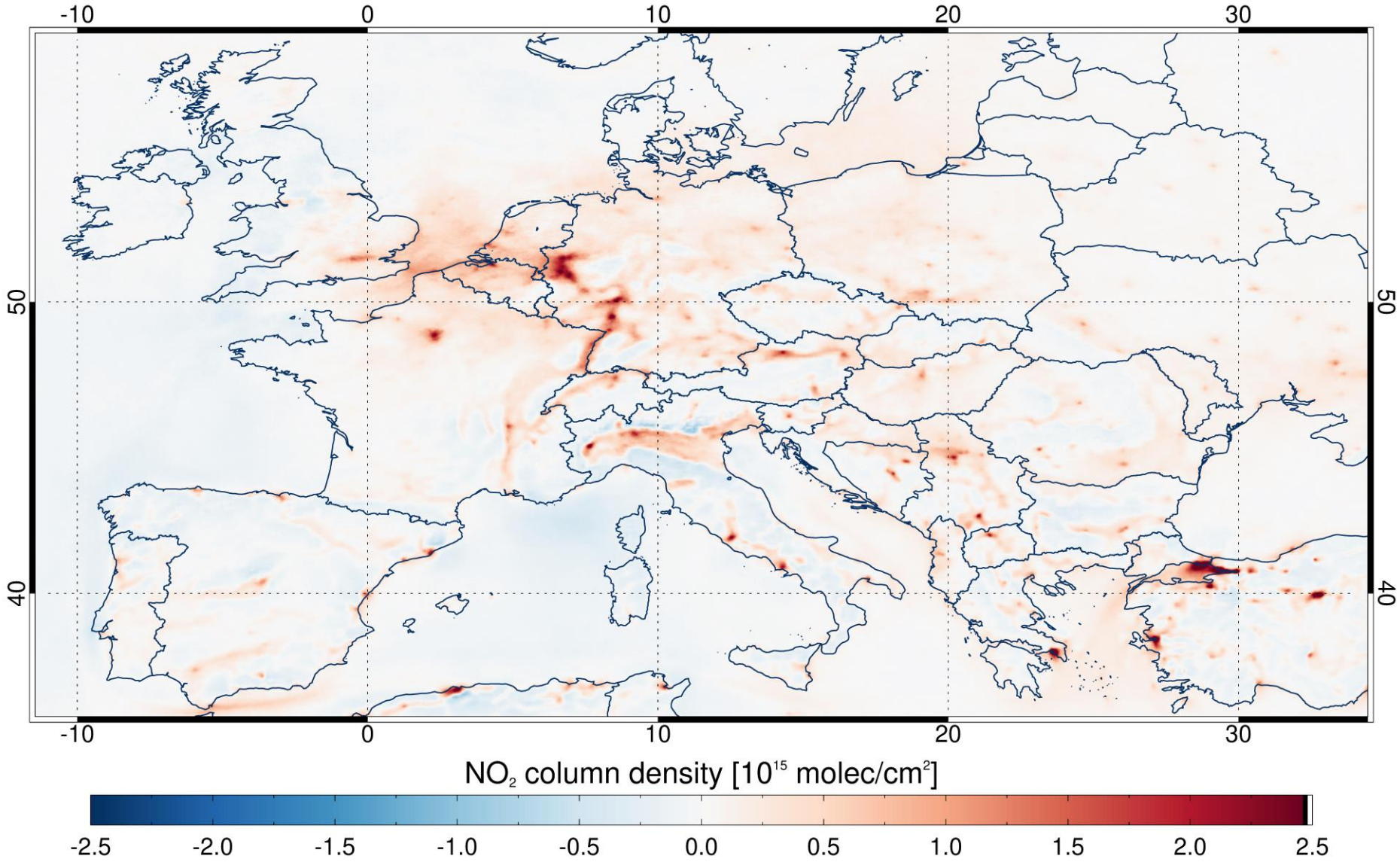
Tropospheric NO_2 – *a priori* NO_2 profiles from LOTOS-EUROS



2019

DLR

Tropospheric NO_2 – *a priori* NO_2 profiles from LOTOS-EUROS

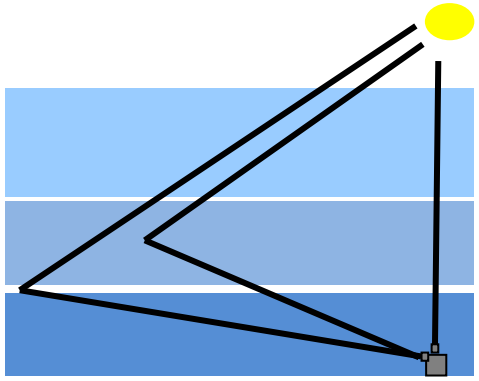


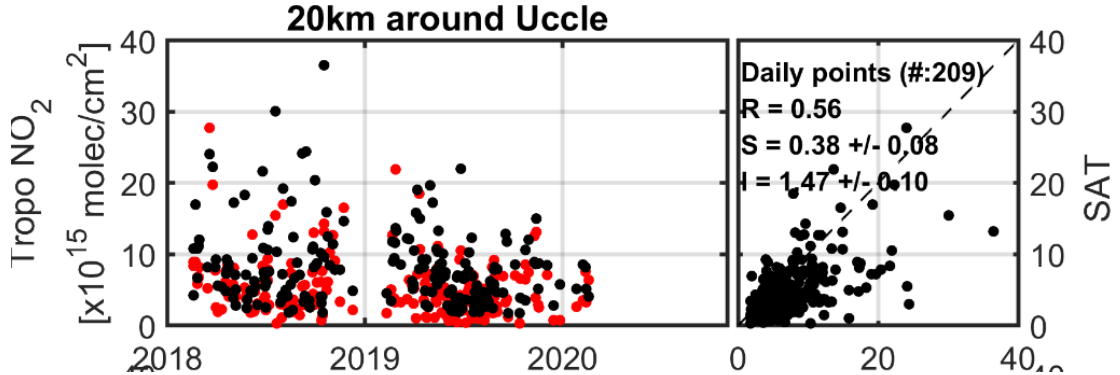
2019

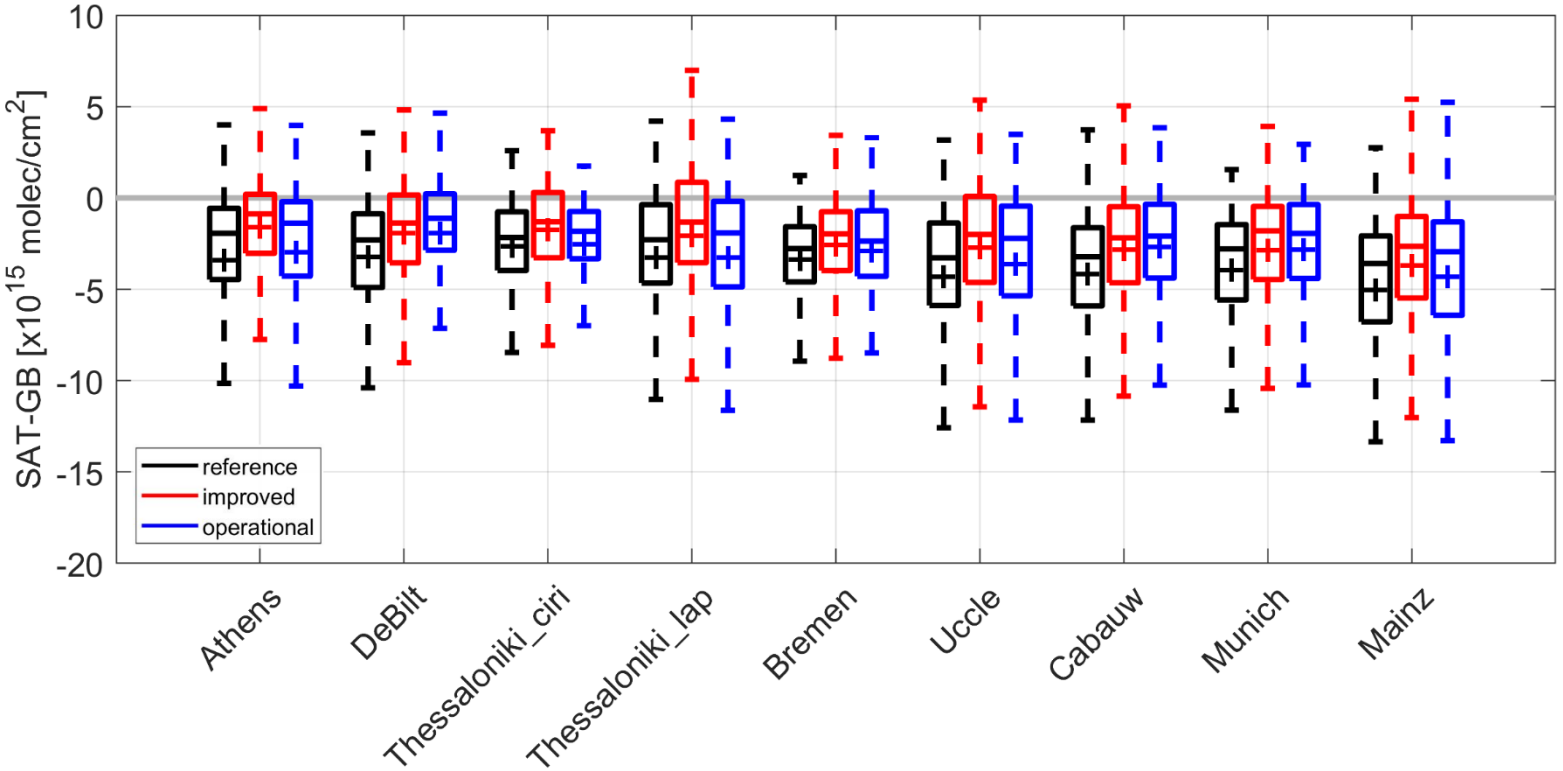
DLR

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 – June 2020
- Underestimation at urban stations:
  - 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