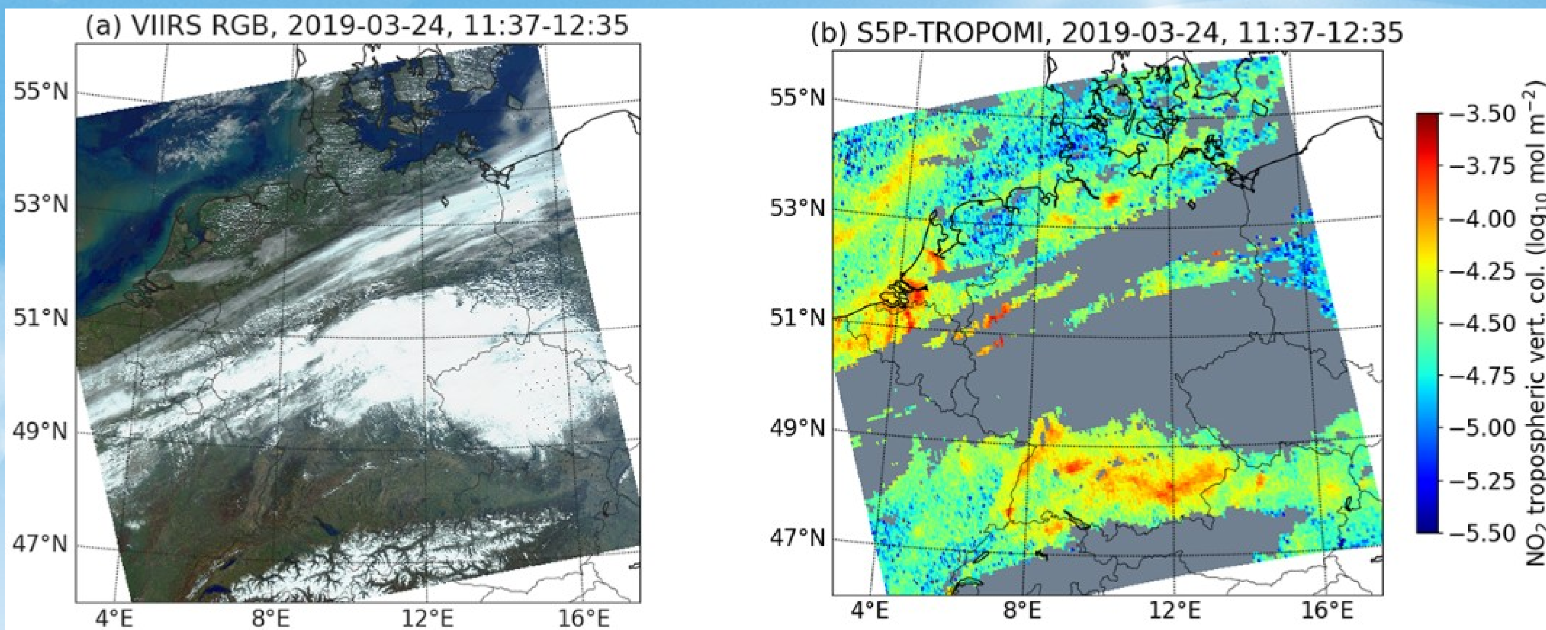
Impact of 3D Cloud Structures on NO_2 trace gas retrievals from UV-VIS Sounders

Arve Kylling, Claudia Emde, Huan Yu, Michel Van Roozendael, Ben Veihelmann, Kerstin Stebel, and Bernhard Mayer



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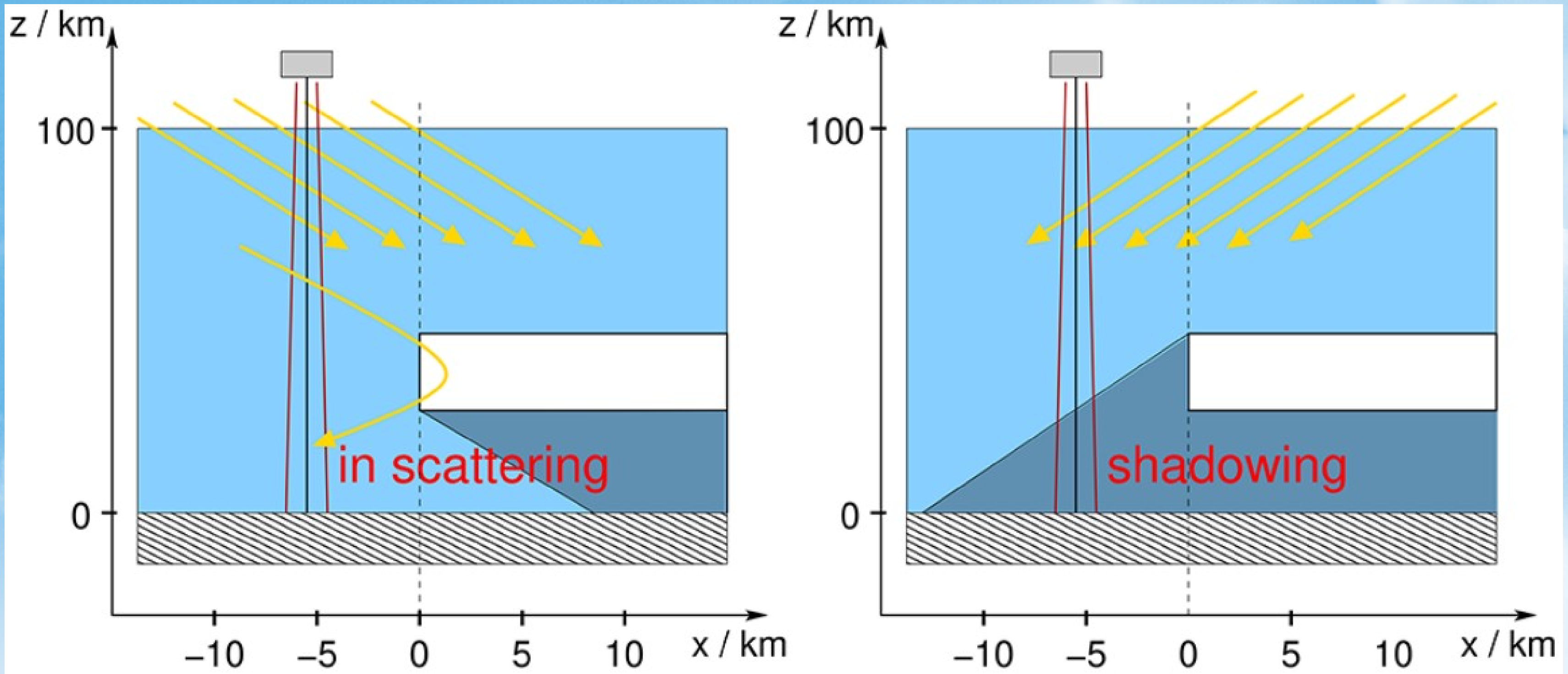
3D cloud effects



Not accounted for in 1D radiative transfer models

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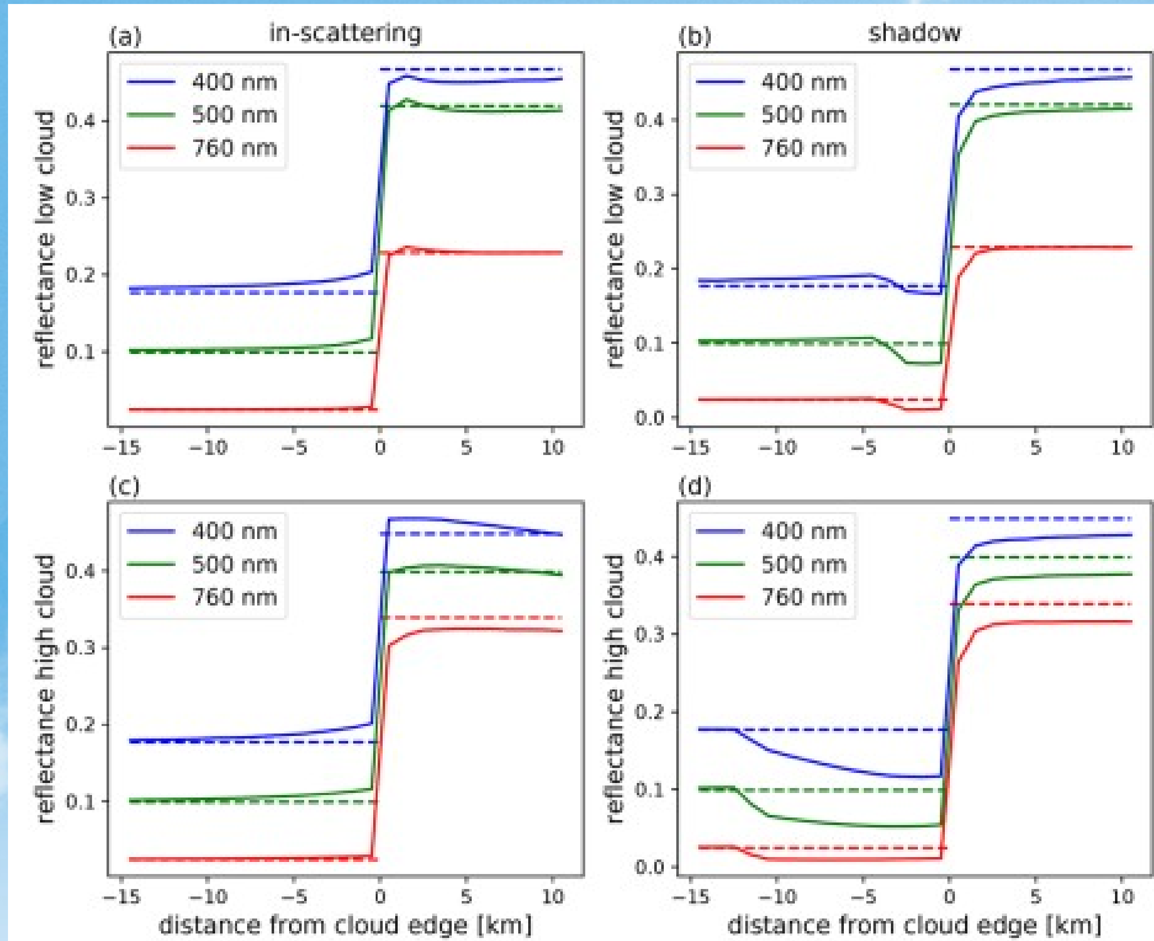
Adopted from Emde et al. (2022).

Nadir reflectance for box cloud



Spectra calculated by the 3D MYSTIC Monte Carlo radiative transfer model in the visible spectral range from 400–500 nm and in the O_2 -A band region from 755–775 nm. SZA=50°, cloud bottom heights 2 and 10 km, cloud thickness 1.0 km. Adopted from Emde et al. (2022).

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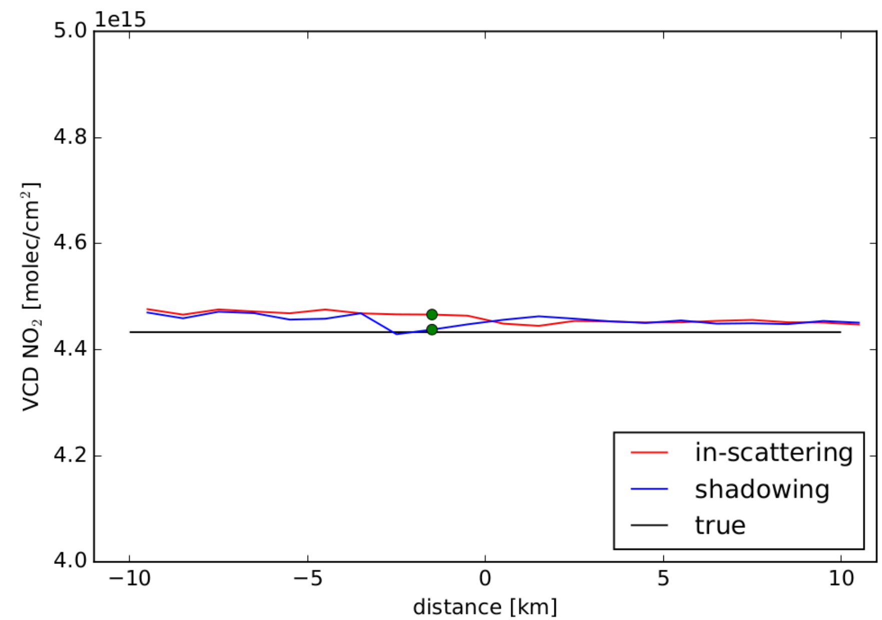
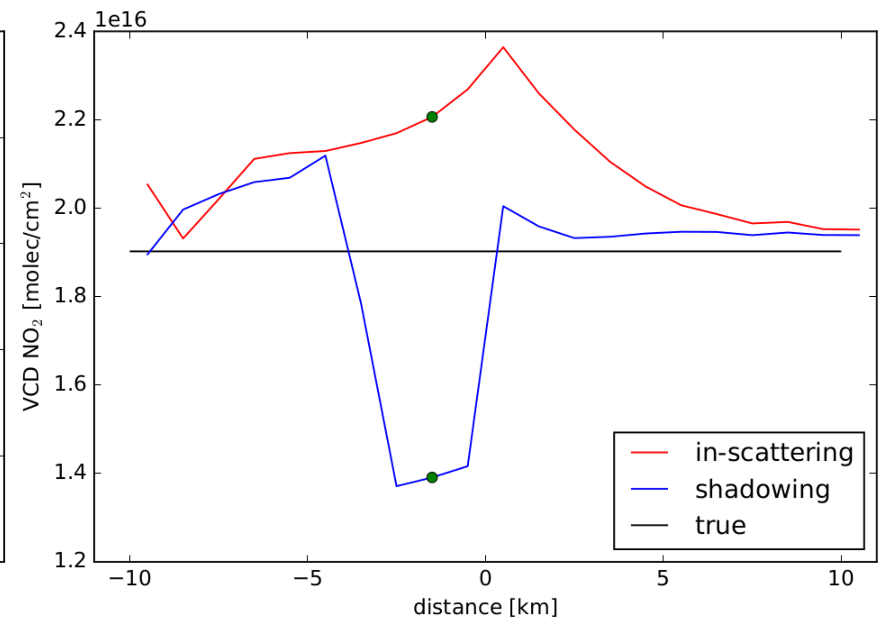
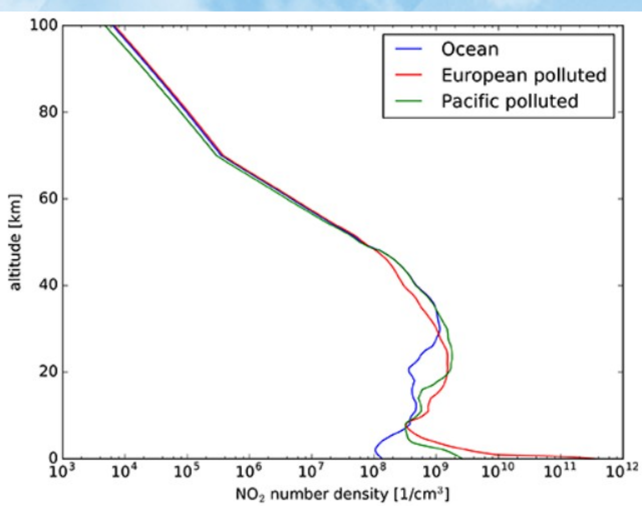
Effect on NO_2 retrieval

Pacific polluted



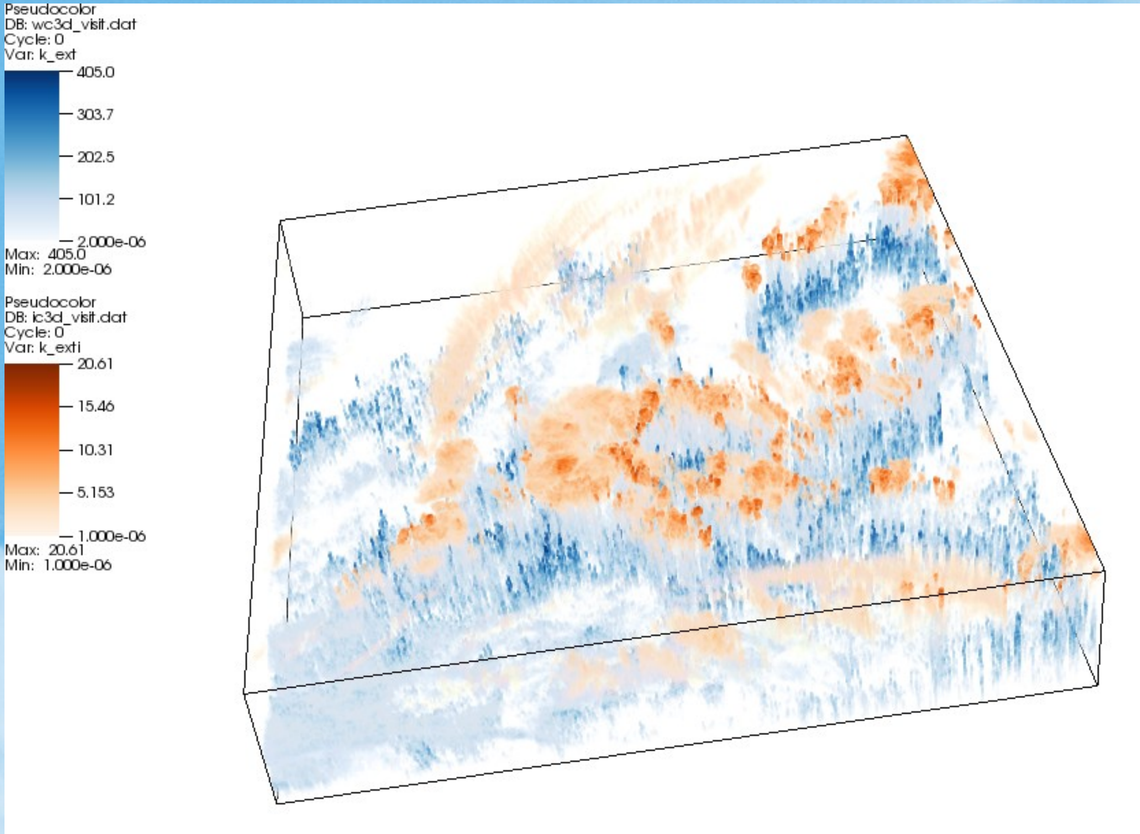
European polluted





DOAS fit with the QDOAS software to get NO_2 slant column densities. The slant column densities converted to vertical column densities (VCD) using layer air mass factors based on the VLIDORT 1D radiative transport model.

Realistic clouds from LES



3D fields of liquid water content (blue) and ice water content (red) from ICON model. Domain covers most of Germany.

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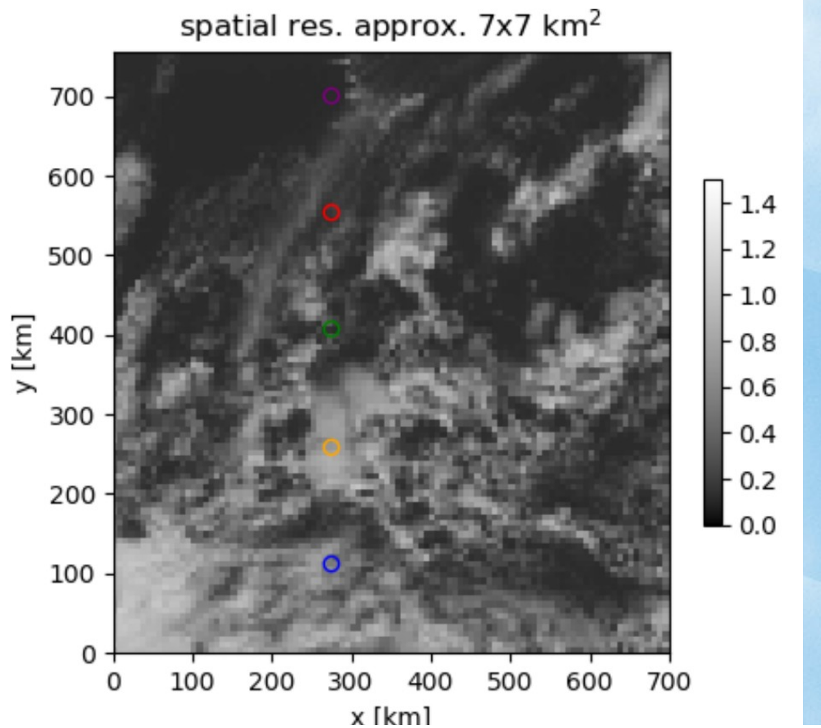
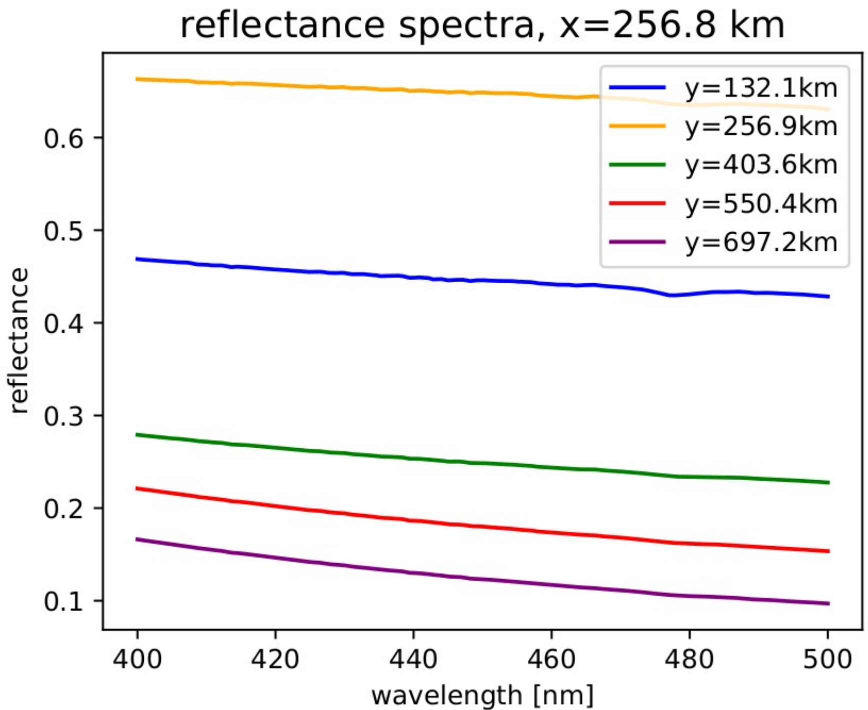
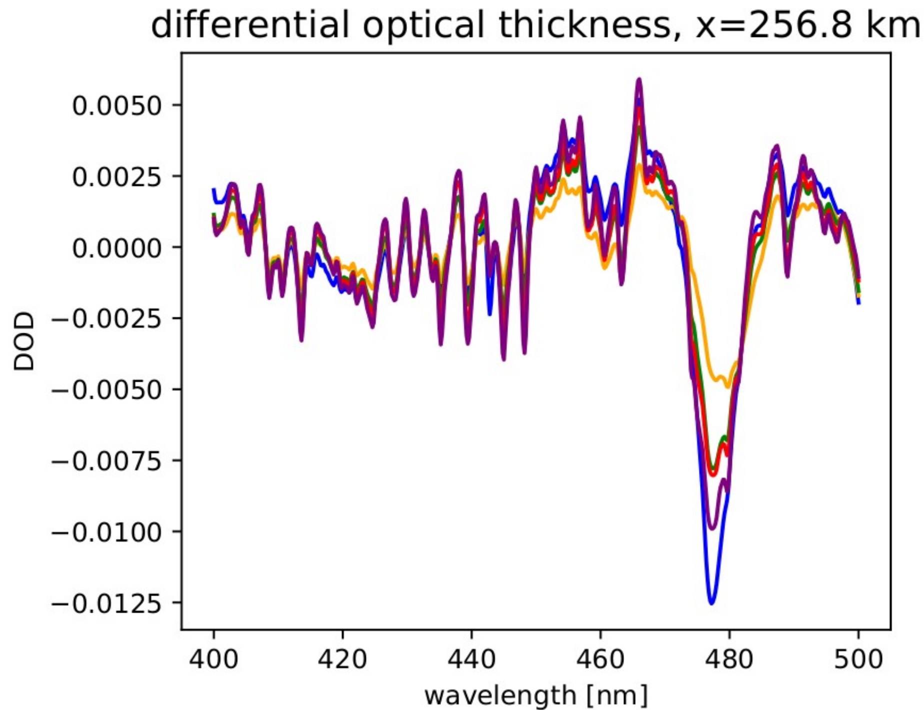
TROPOMI simulation

Purple: clear pixel
Red and green: between clouds
Yellow: large convective cloud
Blue: Stratocumulus cloud

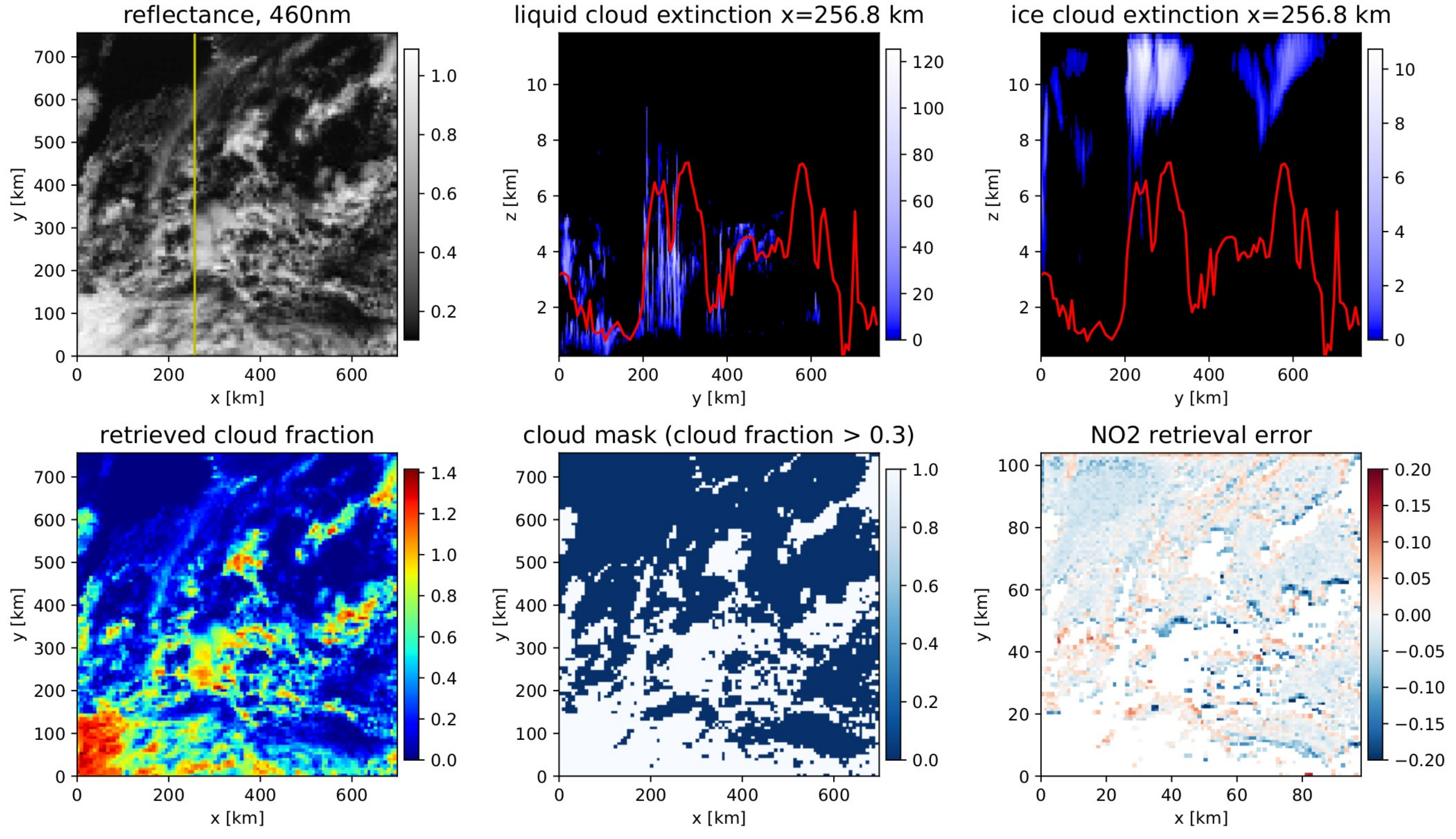
$$DOD = -\ln(E/E_0)$$





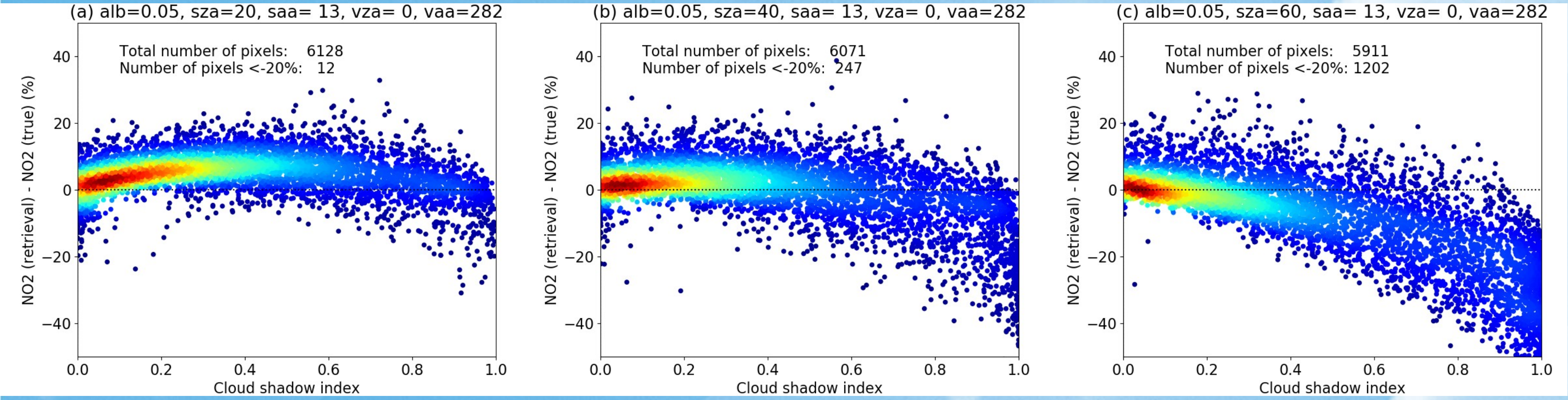


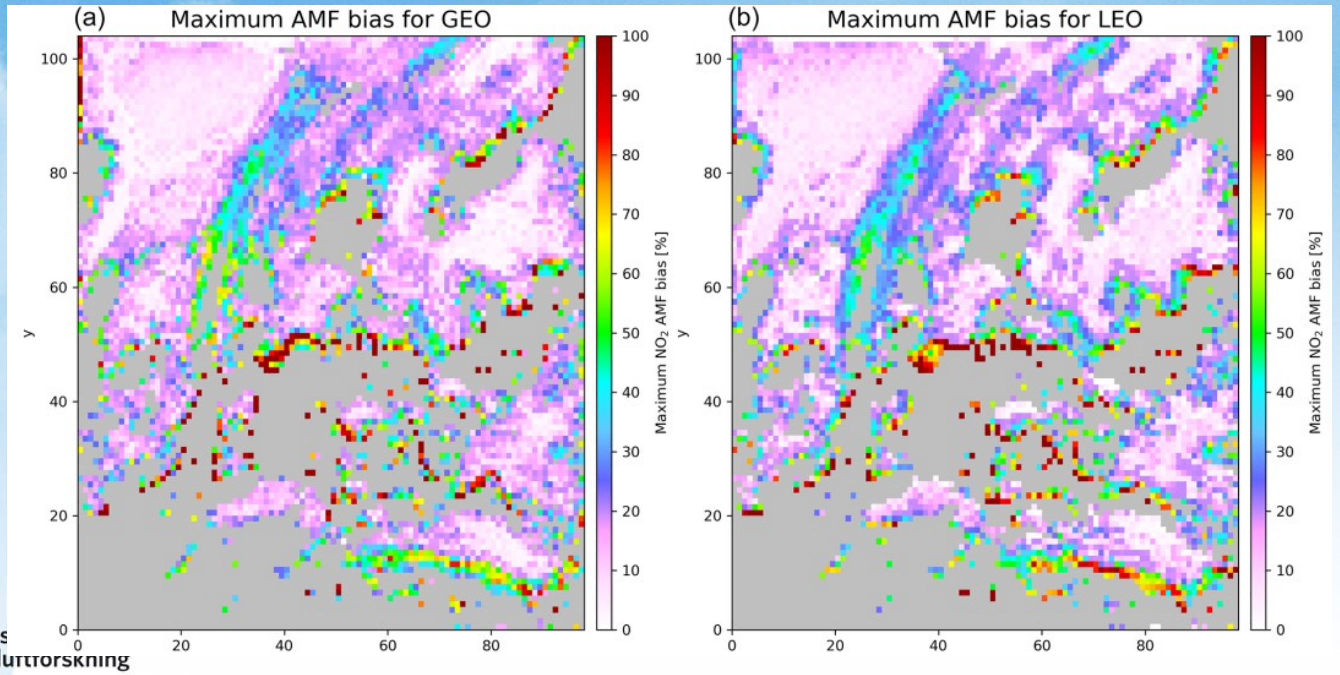
TROPOMI simulation and NO_2 retrieval



Standard 1D retrieval method, true NO_2 constant over scene.

Cloud shadow impacts





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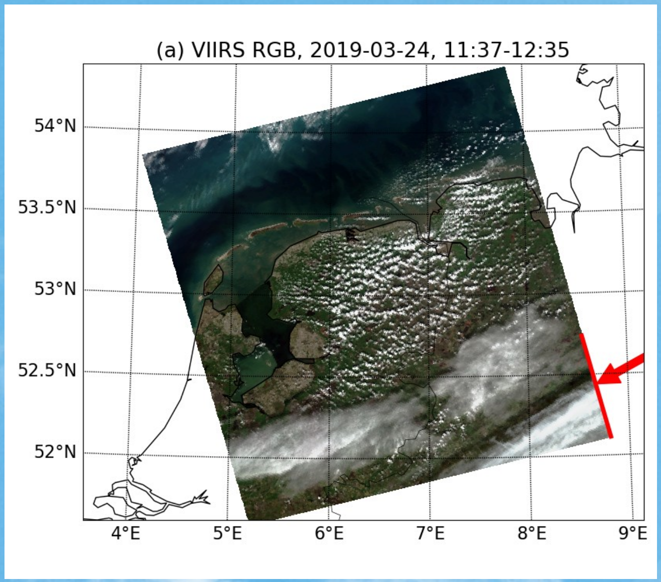
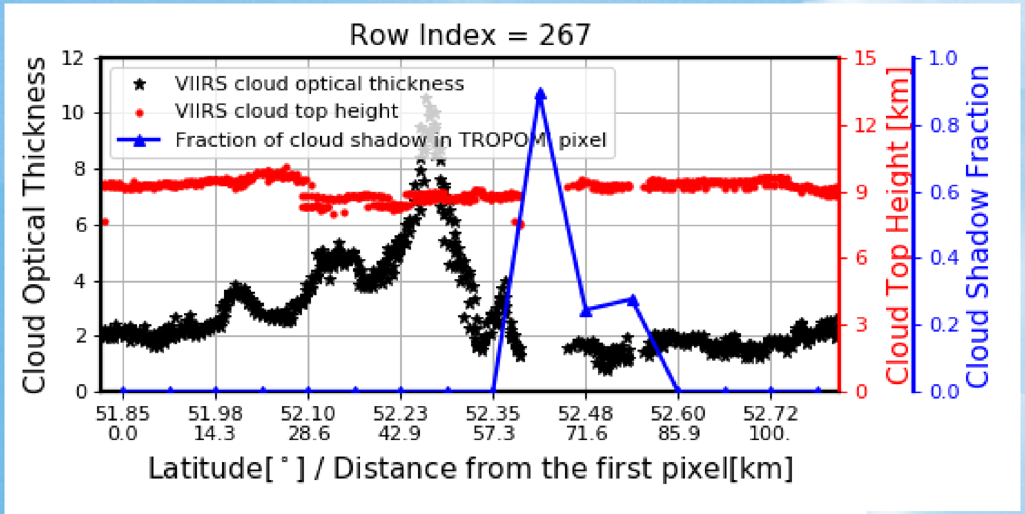
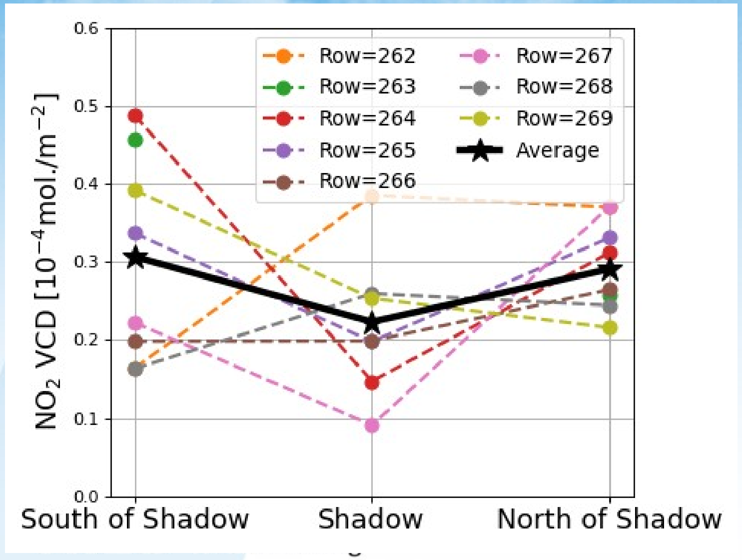
Cloud shadow index: CSI=$E_0 - E_{sza} / \cos(sza)$

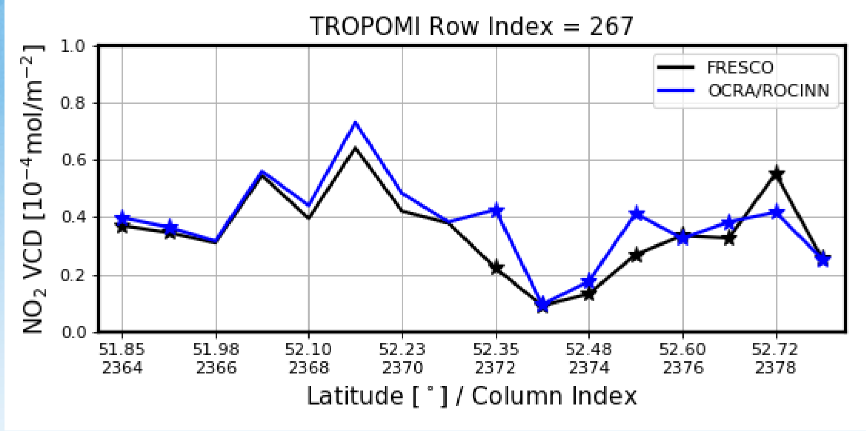
Adopted from Kylling et al. (2022).

Can cloud shadow effects be seen in real data?





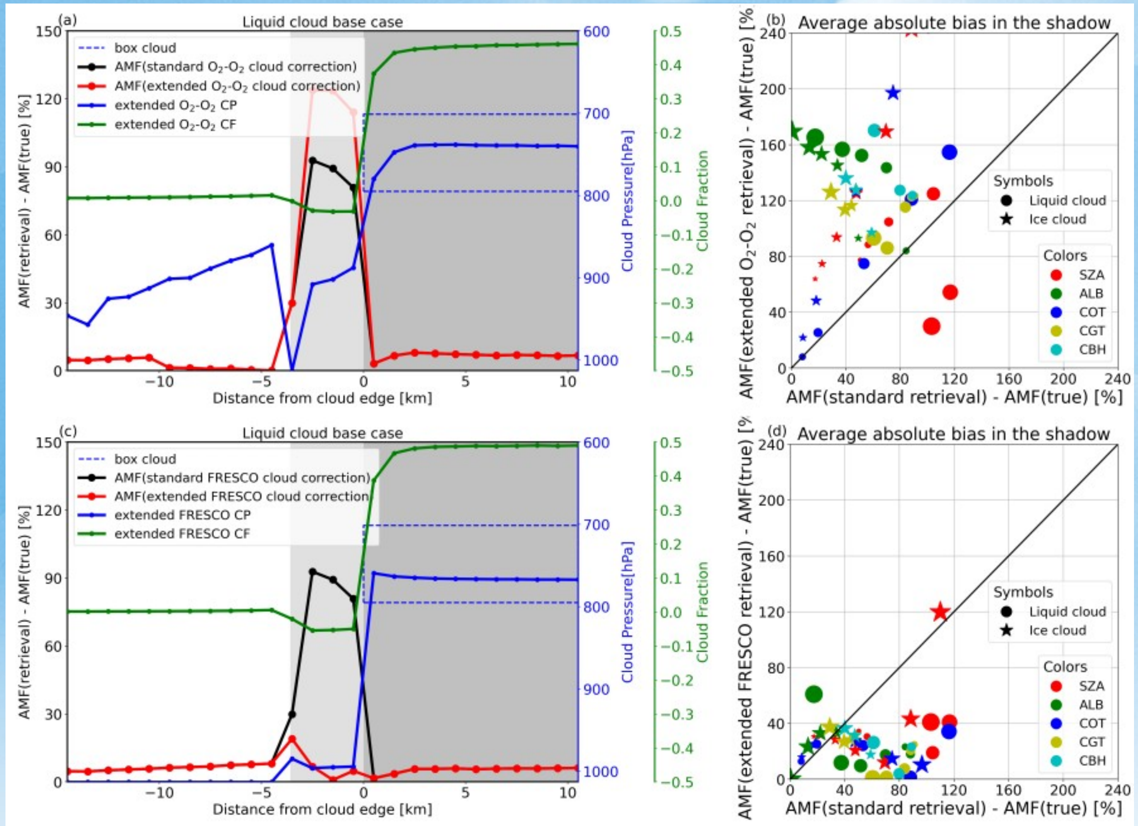




Do not know the true NO_2 TVCD.
Differences in VIIRS and TROPOMI overpass times: shift in cloud and cloud shadow positions.

Mitigation methods

- AMF by using cloud correction based on the extended O_2-O_2/FRESCO (negative cloud fractions) and Cloud as Layer (CAL) retrievals.
- Calculation of the AMF using an effective surface albedo based on the measured radiance.
- Correction of the NO_2 retrieval by using the difference of retrieved O_2-O_2 SCDs and reference calculations for a clear scene for the same geometry.



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Some conclusions

- Realistic synthetic data are suitable for 3D cloud impact studies.
- NO_2 profile shape, cloud shadow fraction, cloud top height, cloud optical depth, solar zenith and viewing angles were the most important metrics in identifying 3D cloud impacts on NO_2 retrievals.
- Analysis of the synthetic data shows that for LEO and GEO geometries, 89% and 93%, respectively, of the retrieved NO_2 TVCDs are within 10% of the actual column for small solar zenith angles. For large solar zenith angles, the numbers decrease to 53% and 61%.
- Lack of knowledge about the “true” NO_2 TVCD in the vicinity of clouds makes it difficult to identify 3D cloud impacts in real data.
- Validation of the mitigation methods is needed. Such validation is non-trivial and possibly requires new experimental approaches for measurements of both cloud shape and trace gas spatial variation.

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Thank you for your attention

Emde, C., Yu, H., Kylling, A., van Roozendael, M., Stebel, K., Veihelmann, B., and Mayer, B.: Impact of 3D cloud structures on the atmospheric trace gas products from UV–Vis sounders – Part 1: Synthetic dataset for validation of trace gas retrieval algorithms, Atmos. Meas. Tech., 15, 1587–1608, https://doi.org/10.5194/amt-15-1587-2022, 2022.

Yu, H., Emde, C., Kylling, A., Veihelmann, B., Mayer, B., Stebel, K., and Van Roozendael, M.: Impact of 3D Cloud Structures on the Atmospheric Trace Gas Products from UV-VIS Sounders – Part II: impact on NO2 retrieval and mitigation strategies, Atmos. Meas. Tech. Discuss. [preprint], https://doi.org/10.5194/amt-2021-338, in review, 2021.

Kylling, A., Emde, C., Yu, H., van Roozendael, M., Stebel, K., Veihelmann, B., and Mayer, B.: Impact of 3D Cloud Structures on the Atmospheric Trace Gas Products from UV-VIS Sounders – Part III: bias estimate using synthetic and observational data, Atmos. Meas. Tech. Discuss. [preprint], https://doi.org/10.5194/amt-2021-331, in review, 2021.

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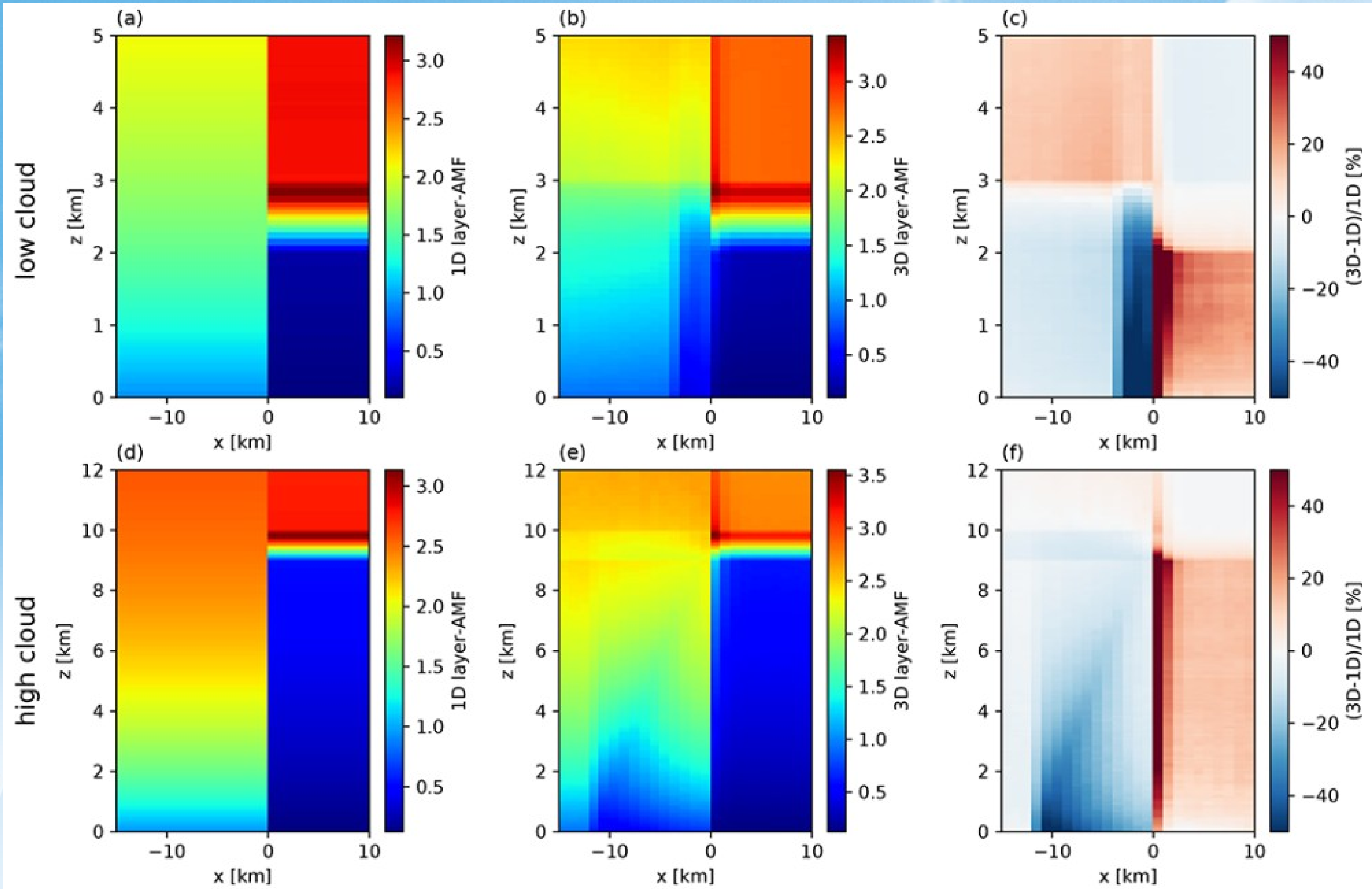
Layer air mass factors



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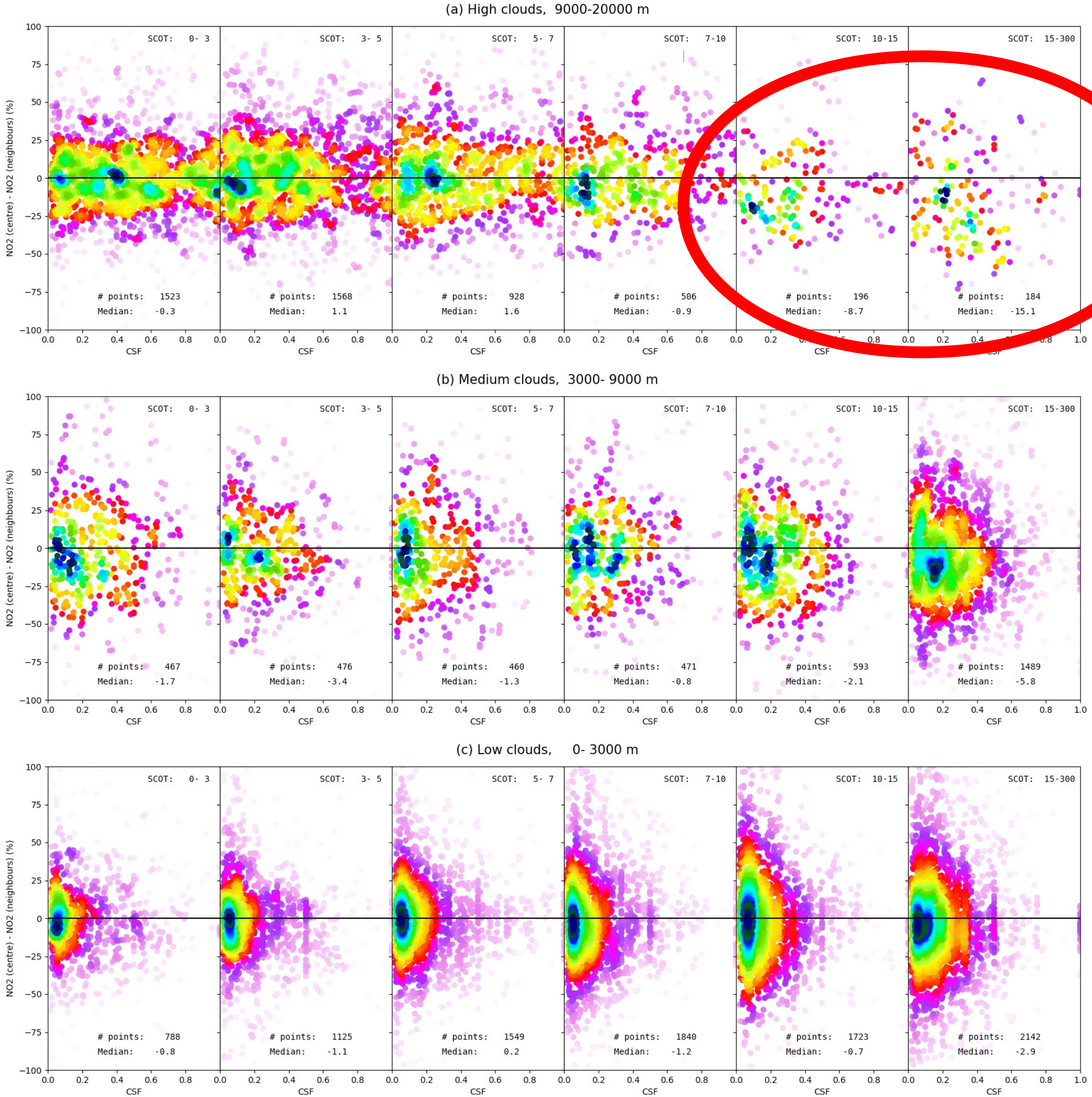
SZA=50°. Adopted from Emde et al. (2022).


(a) High clouds, 9000-20000 m
(b) Medium clouds, 3000- 9000 m
(c) Low clouds, 0- 3000 m
NO2 (centre) - NO2 (neighbours) (%)
CSF
SCOT: 0- 3
SCOT: 3- 5
SCOT: 5- 7
SCOT: 7-10
SCOT: 10-15
SCOT: 15-300
points: 1523
Median: -0.3
points: 1568
Median: 1.1
points: 928
Median: 1.6
points: 506
Median: -0.9
points: 196
Median: -8.7
points: 184
Median: -15.1
points: 467
Median: -1.7
points: 476
Median: -3.4
points: 460
Median: -1.3
points: 471
Median: -0.8
points: 593
Median: -2.1
points: 1489
Median: -5.8
points: 788
Median: -0.8
points: 1125
Median: -1.1
points: 1549
Median: 0.2
points: 1840
Median: -1.2
points: 1723
Median: -0.7
points: 2142
Median: -2.9

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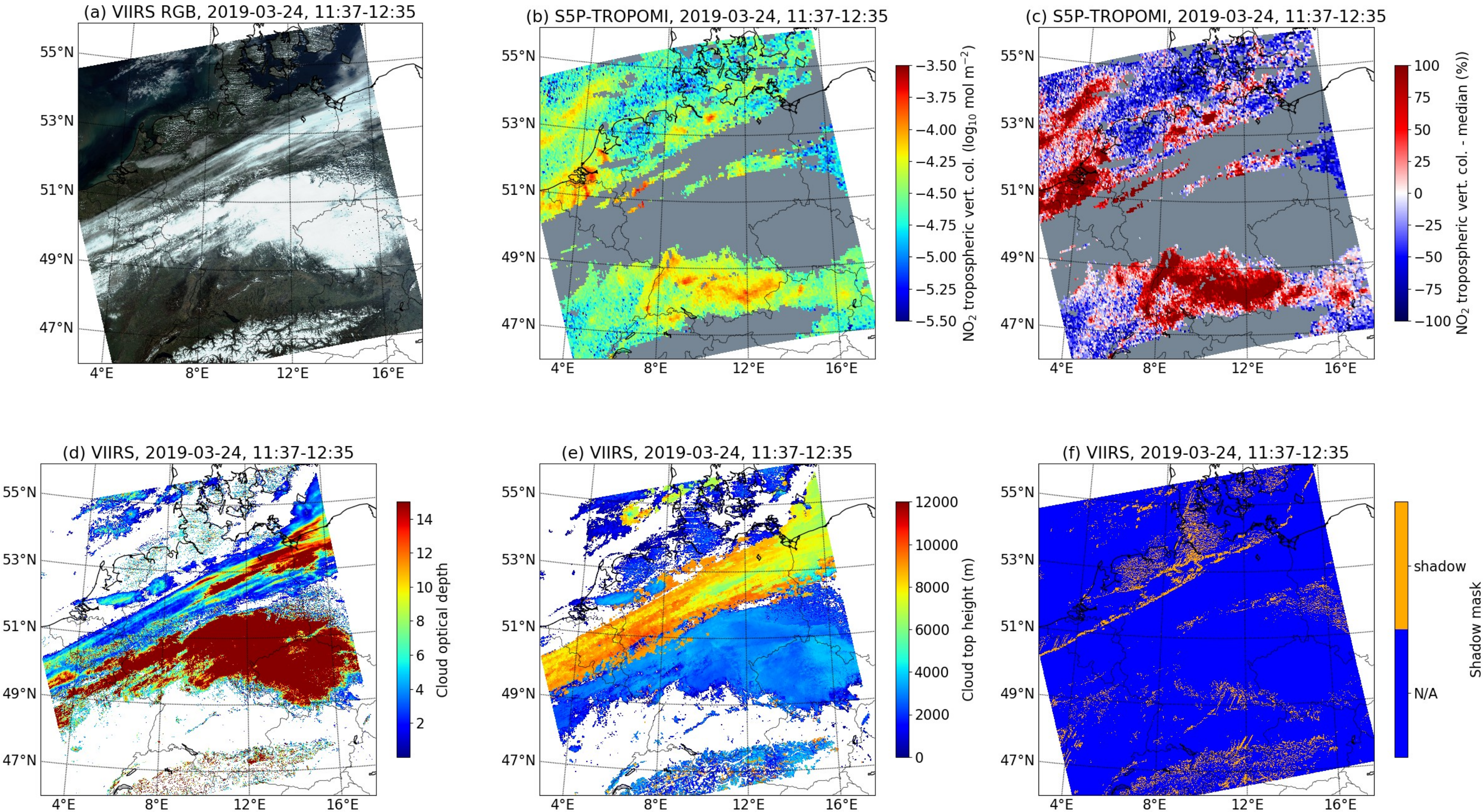
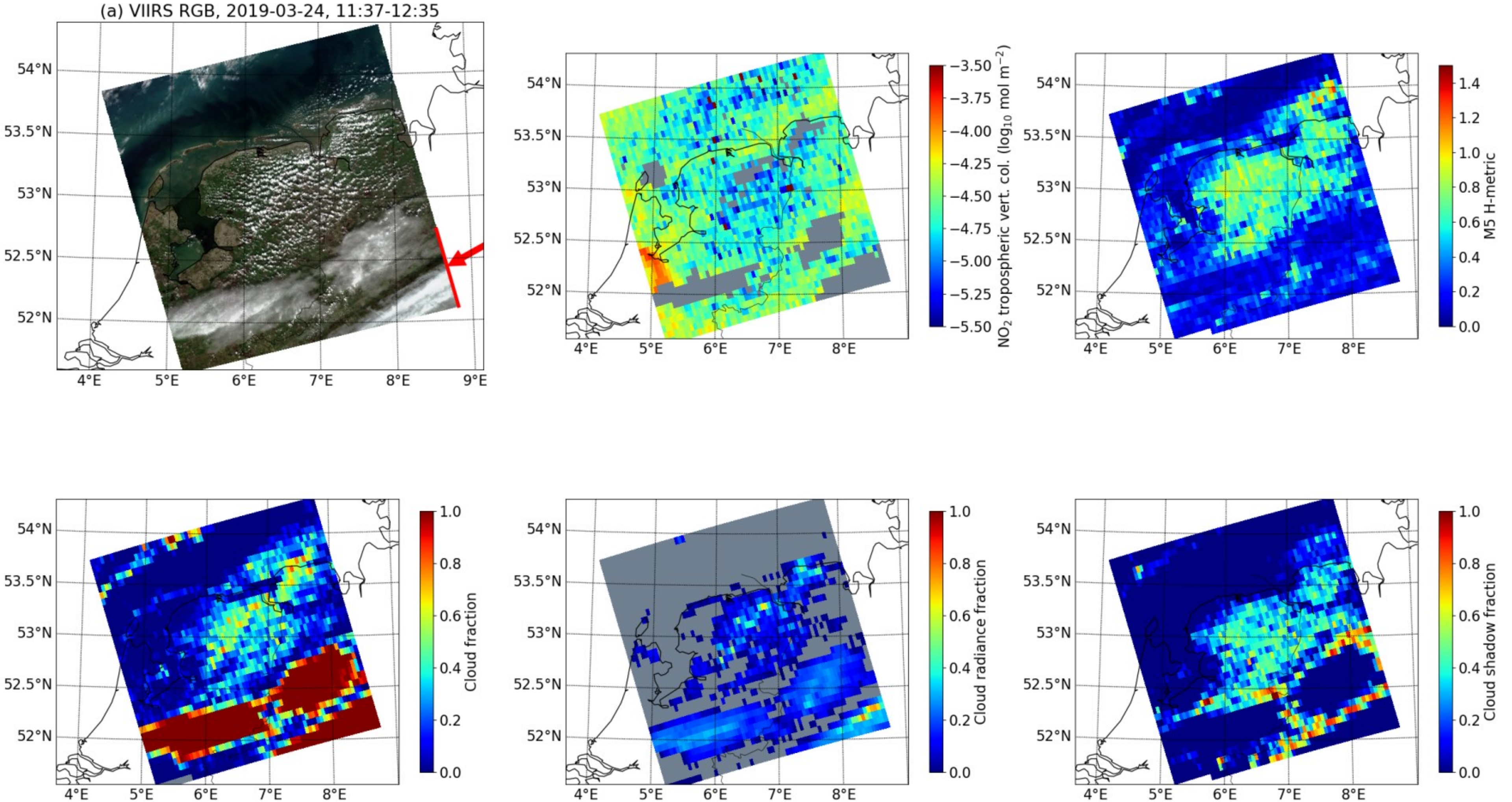

(a) VIIRS RGB, 2019-03-24, 11:37-12:35
(b) S5P-TROPOMI, 2019-03-24, 11:37-12:35
(c) S5P-TROPOMI, 2019-03-24, 11:37-12:35
(d) VIIRS, 2019-03-24, 11:37-12:35
(e) VIIRS, 2019-03-24, 11:37-12:35
(f) VIIRS, 2019-03-24, 11:37-12:35
55°N
53°N
51°N
49°N
47°N
4°E
8°E
12°E
16°E
NO_2 tropospheric vert. col. (log_{10} mol m^{-2})
−3.50 −3.75 −4.00 −4.25 −4.50 −4.75 −5.00 −5.25 −5.50
NO_2 tropospheric vert. col. - median (%)
100 75 50 25 0 −25 −50 −75 −100
Cloud optical depth
14 12 10 8 6 4 2
Cloud top height (m)
12000 10000 8000 6000 4000 2000 0
Shadow mask
shadow
N/A

Zoom in on cloud shadow band



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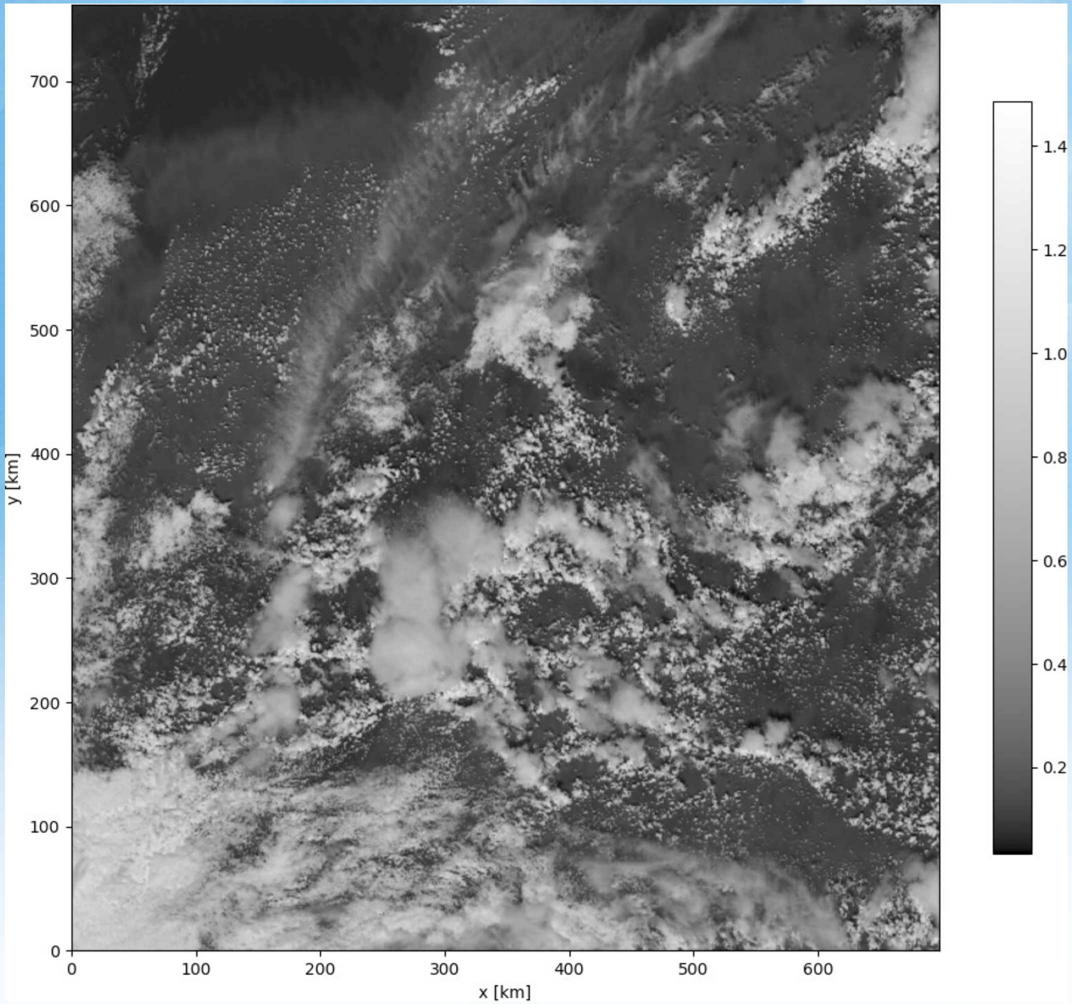
Simulated reflectance for Sentinel-3-SLSTR, band 1 centered at 555 nm

The simulation includes all cloud types that are typical for Europe, i.e. shallow cumulus, cirrus, stratus and convective clouds.

Solar zenith angle: 30°
Solar azimuth angle: 13°



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