Impact of 3D Cloud Structures on the Atmospheric Trace Gas Products from UV-VIS Sounders (3DCATS)

- Quantify the impact of 3D cloud features on tropospheric trace gas products from the atmospheric Sentinels (S4, S5P, S5).
- Explore improved handling of cloudy scenes and the possible mitigation of 3D cloud features using both simulated and measured spectral and imager data.
- 3DCATS - two years project (01.11.2018-12.11.2020). Funded by ESA.
- Partipants:
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  - LMU, Claudia Emde, Bernhard Mayer
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  - Ben Veihelmann (ESA)

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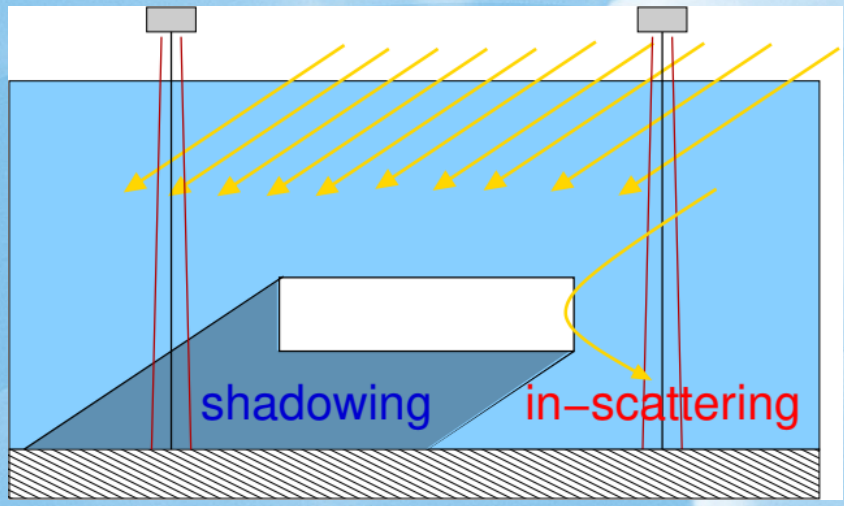
BIRA-IASB

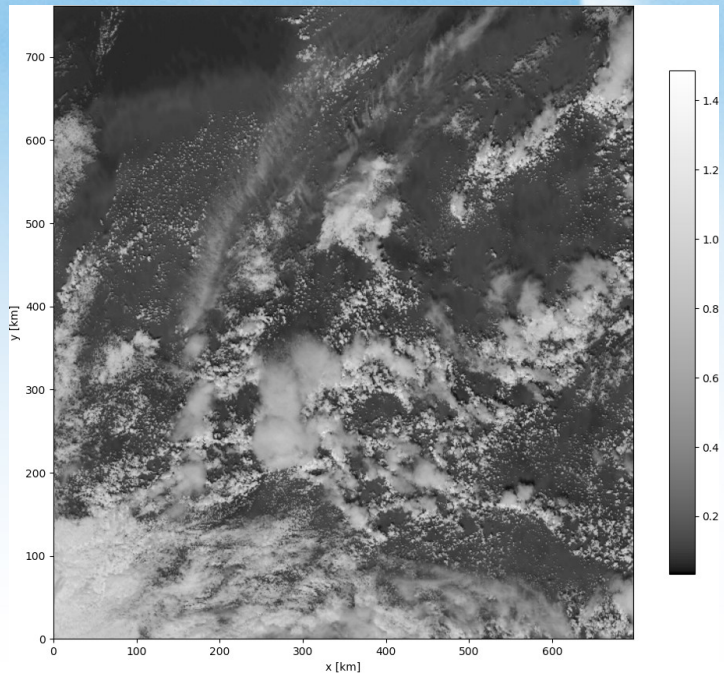
Focus on NO_2: important for air quality, key tropospheric trace gas measured by the amospheric Sentinels

- Use **synthetic data** to identify situations with high likelihood of NO_2 bias due to 3D cloud structures
- Identify the **parameters** that have the largest impact on the NO_2 bias (e.g. cloud shadow, cloud top height, NO_2 profile)
- Look for NO_2 bias in **observations** based on findings from synthetic data exploration
- Explore **mitigation** of 3D cloud effects on NO_2 retrieval



Synthetic data:

- Idealised **box cloud** simulations for process understanding
- **Realistic 3D liquid and ice water clouds** from ICON LES simulation
- **Simulate TROPOMI radiances using 3D radiative transfer** (MYSTIC -Monte Carlo)
- **Standard** 1D NO_2 retrieval (DOAS+AMF)



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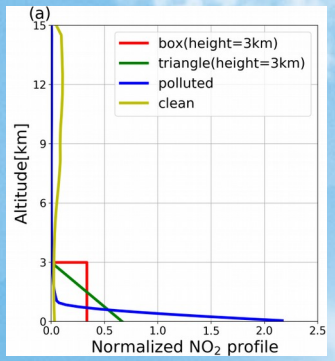
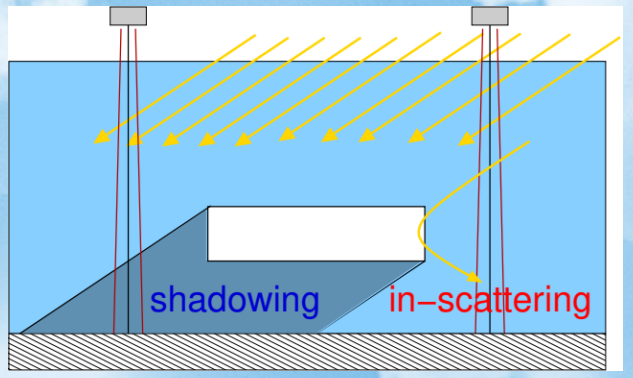
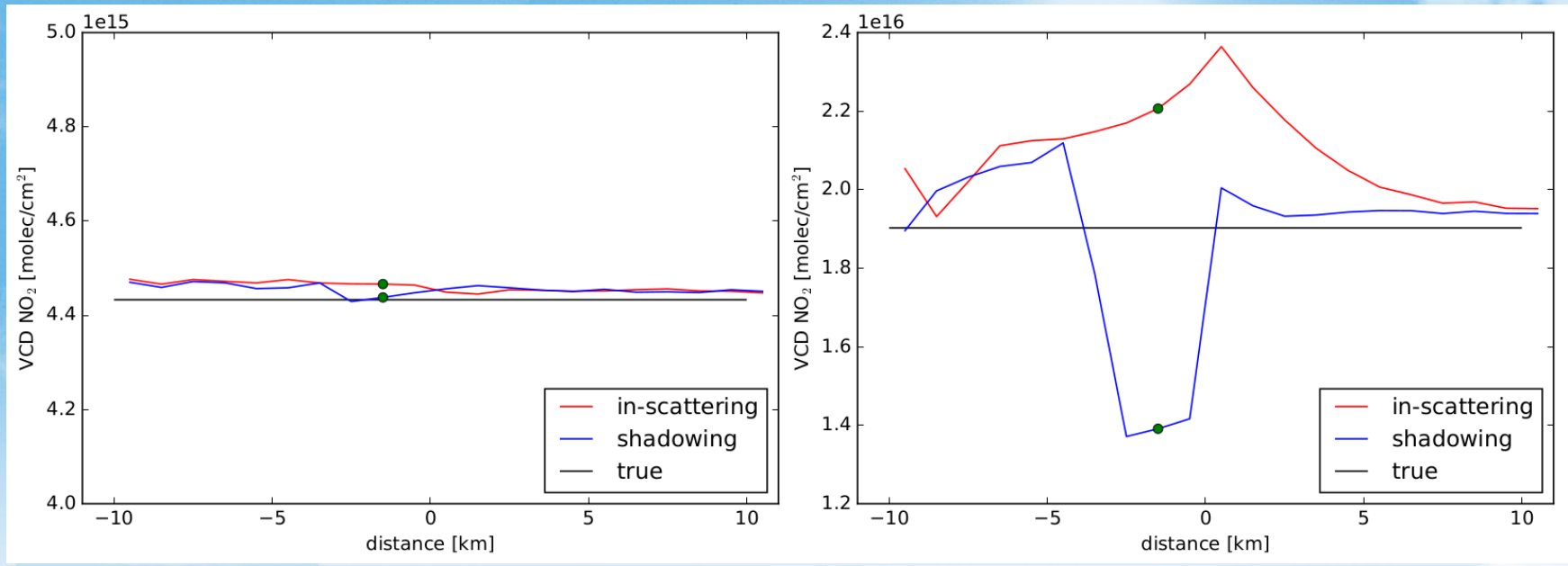
Box cloud results







Clean NO_2 profile

Polluted NO_2 profile

Large NO_2 bias in shadow region for cases with a large amount of NO_2 in the lower troposphere.

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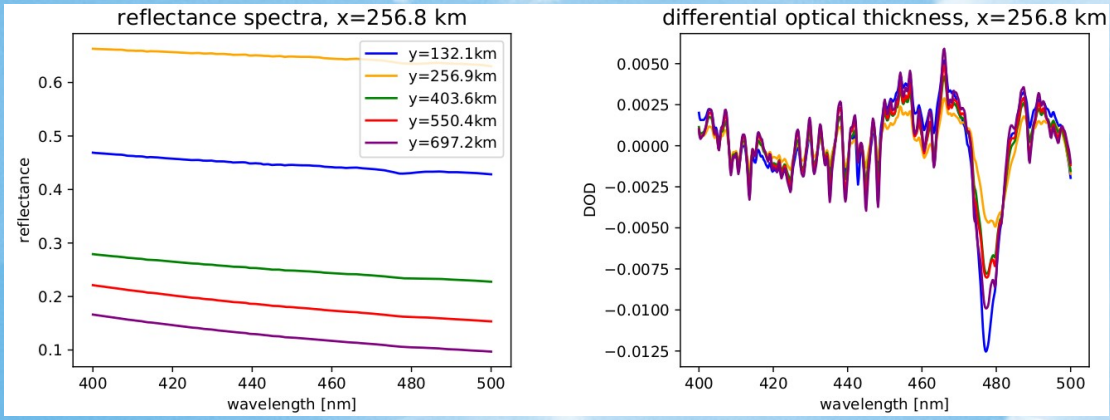
ICON-LES, MYSTIC and NO_2 retrieval

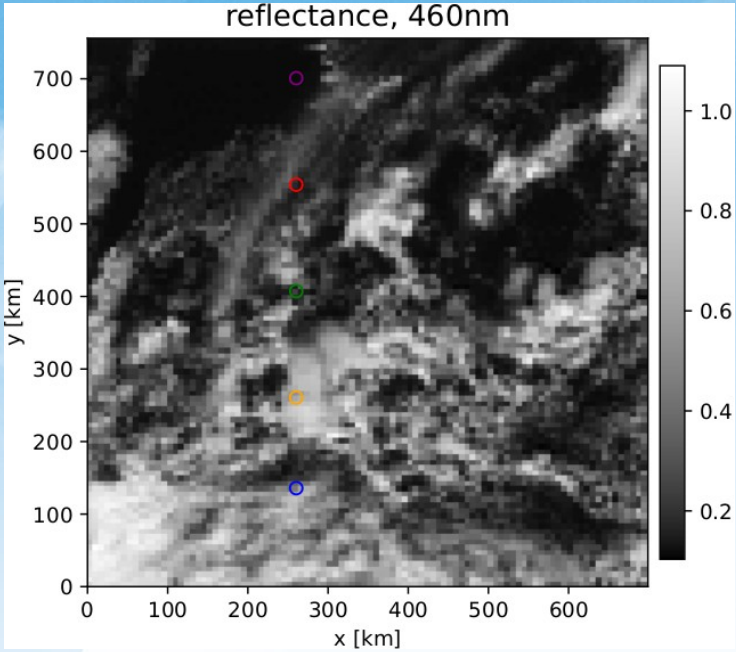
Standard 1D retrieval of NO_2 tropospheric VCD.

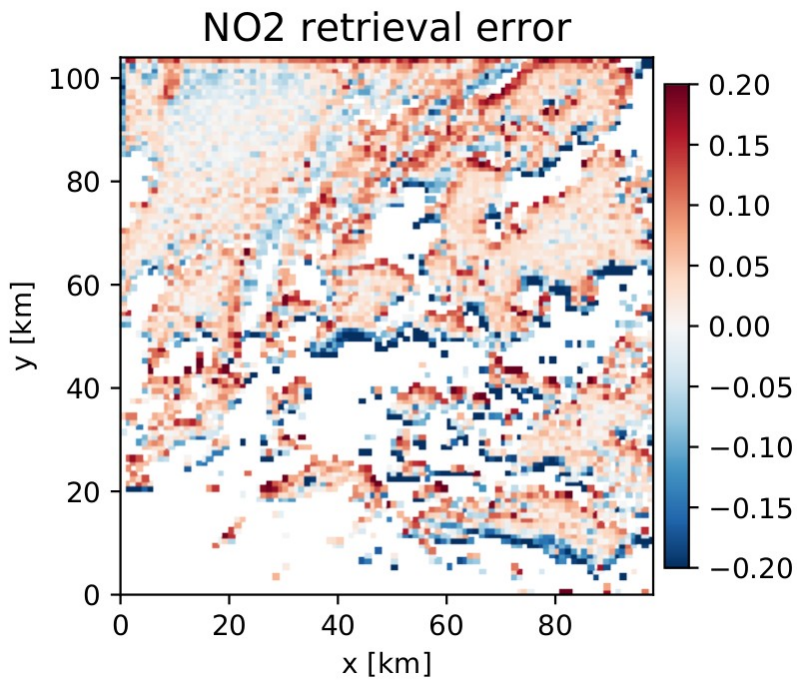
True NO_2 VCD constant.

Polluted NO_2 profile.

NO_2 bias large in cloud shadow







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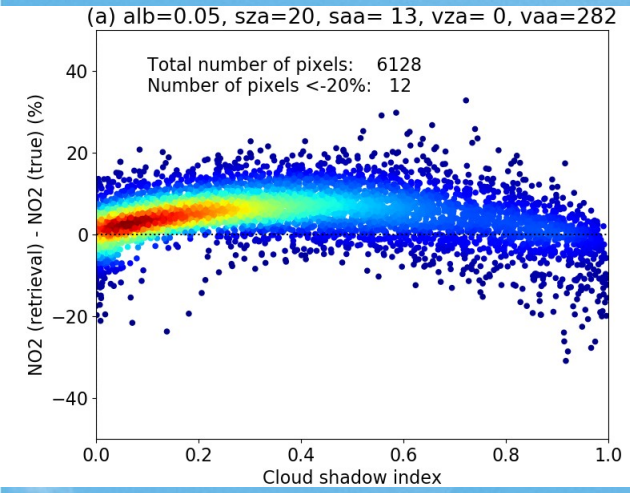
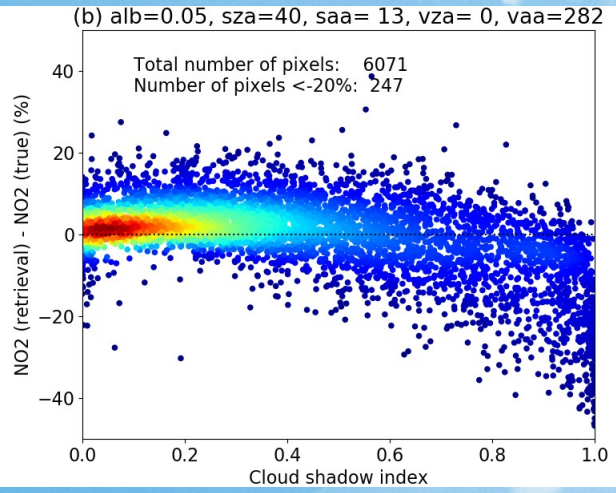
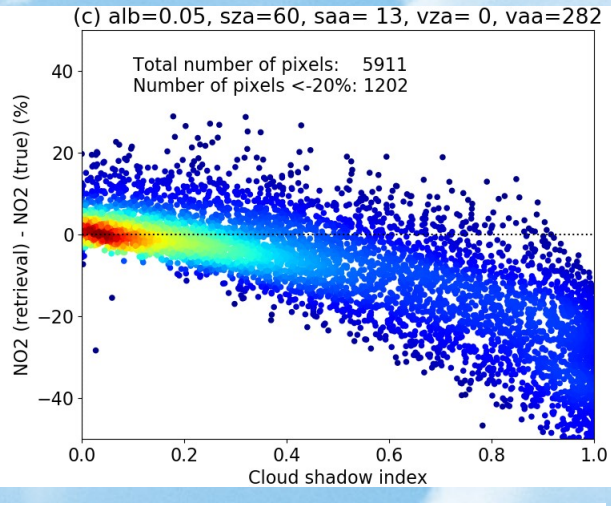
Cloud shadow impacts







LEO geometry (108-scenes)
Viewing zenith angles (VZA): 0° ,20° ,60°
Viewing azimuth angles (VAA): 109.5° ,281.7°
Solar zenith angles (SZA): **20° ,40° ,60°**
Solar azimuth angles (SAA) 13° ,353°
3 Surface albedos

GEO geometry (45 scenes)
Viewing zenith angles (VZA): 58.3°
Viewing azimuth angles (VAA): 196.3°
Solar zenith angles (SZA): 20° ,40° ,60°
Solar azimuth angles (SAA) -90°, -45°, 0°, 45°, 90°
3 Surface albedos

NO_2 bias depends on cloud shadow fraction, cloud top height, cloud optical depth, solar zenith and viewing angles.

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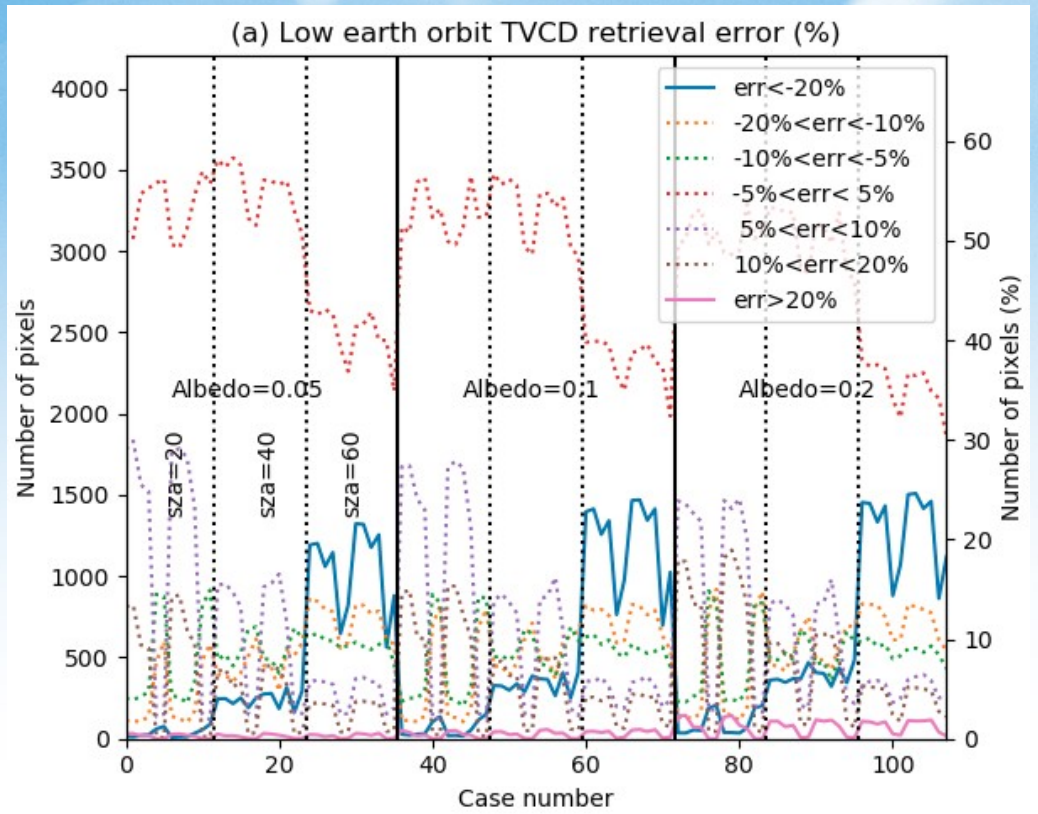

Can NO_2 bias be seen in real data?

NO_2 bias largest in the cloud shadow

Look for NO_2 bias in data with:

1) Large solar zenith angles (Europe spring, fall and winter)
2) High cloud top height

Need cloud top height, cloud shadow, “true” NO_2.

NO_2 from TROPOMI-S5P, imager data from VIIRS/S-NPP.

Look at neighbour pixels in a 3×3 pixel matrix where the pixel of interest is in the centre. The **“true” NO_2** TVCD is taken to be the average of cloudfree neighbours with NO_2 retrieval quality value > 0.95.

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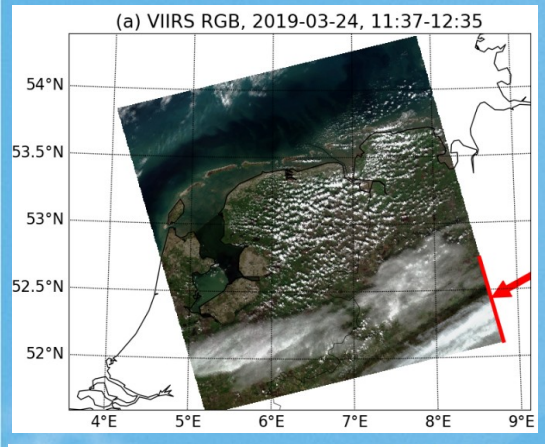
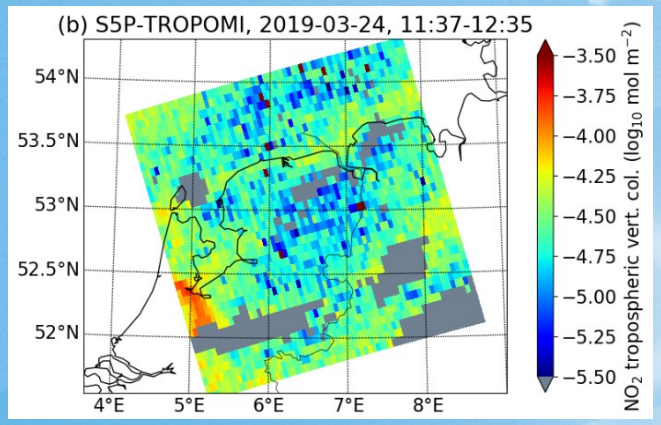
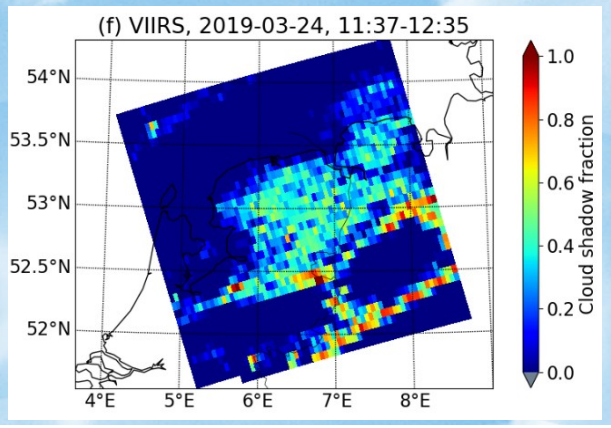
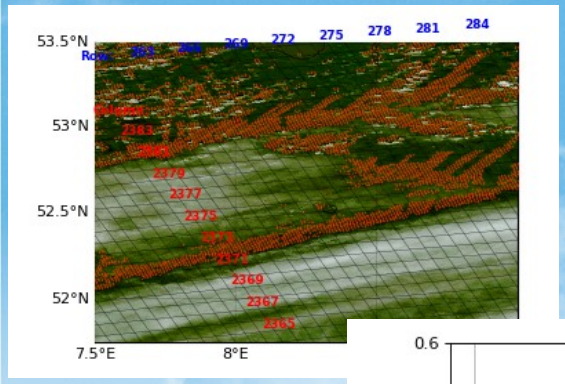
Cloud shadow band

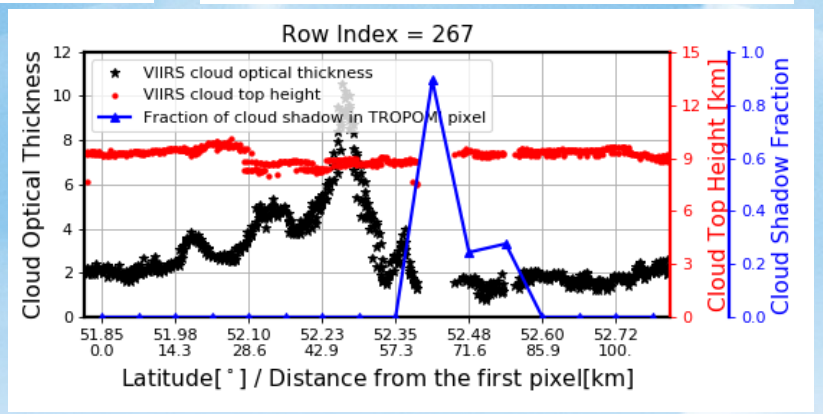




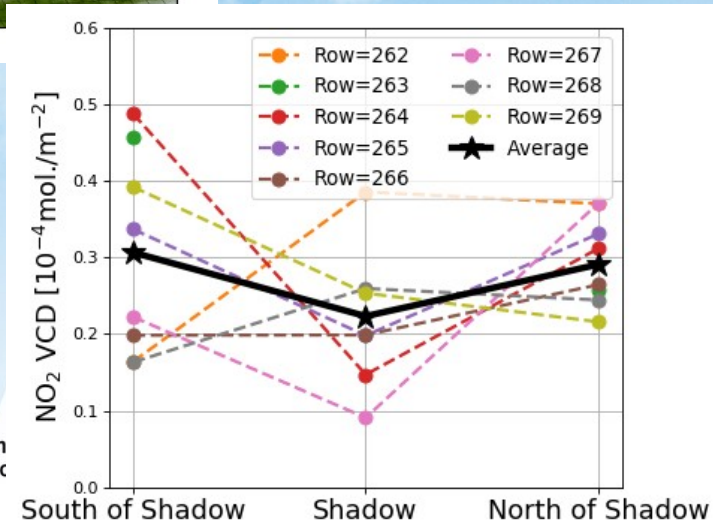


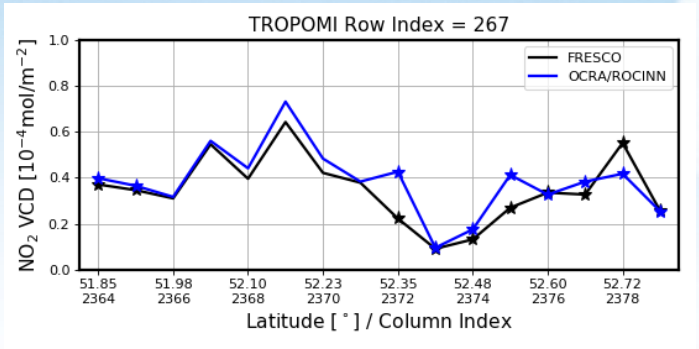


NO_2 25% low in cloud shadow band in agreement with theory



Low NO_2 bias also seen in the general case. However, note assumptions made about “true” NO_2.





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Mitigation of NO_2 bias due to 3D clouds

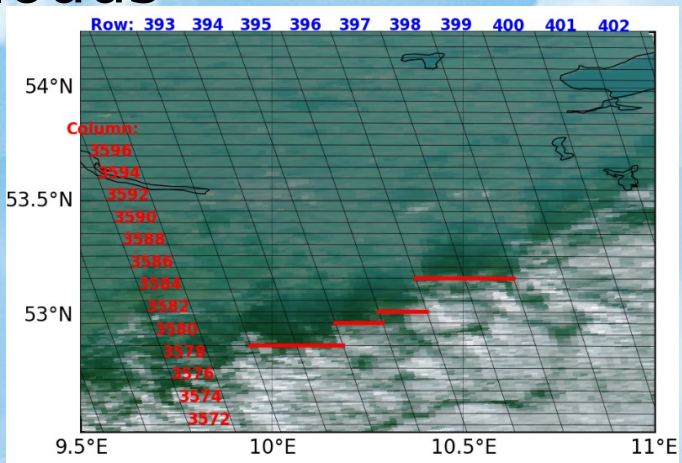
Mitigation approaches

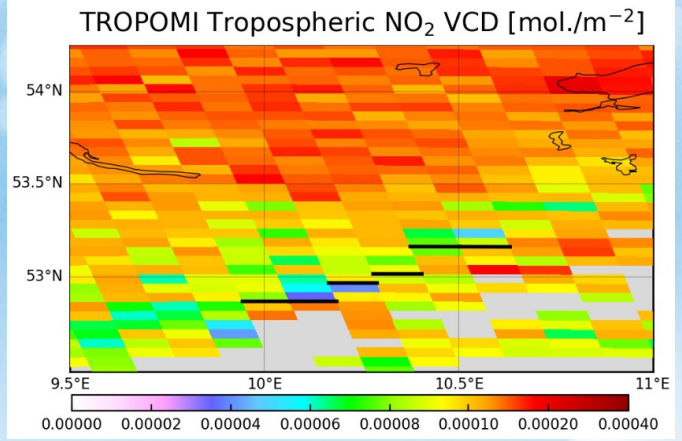
1) Calculate the AMF using a fitted surface albedo
2) Scale O_2-O_2 slant column depth (SCD) using the retrieved O_2-O_2 SCD and the reference SCD.

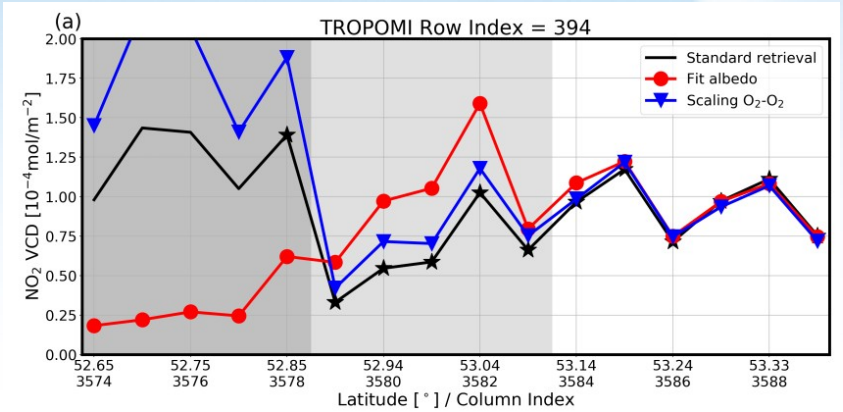
However, these approaches are limited to cloud-free pixels affected by surrounding clouds.

Flagging of 3D affected pixels

Parameterization approach based on relationships derived from the sensitivity study (cloud shadow fraction, slant cloud optical thickness, the NO_2 profile and neighboring cloud top height). Useful for identifying pixels for which the standard NO_2 retrieval produces a significant bias, and therefore provides a way to improve the current data flagging approach.







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Conclusions

- Cloud shadow effects important for “polluted” NO_2 profiles.
- Synthetic study shows that for LEO and GEO geometries and “polluted” NO_2 profiles, 89 and 93%, respectively, of the retrieved NO_2 TVCDs are within 10% of the actual column for low albedo. (High albedo: 53 and 61%)
- Observational data suggest that for SZAs between 50-60°, about 16% of TROPOMI pixels with high quality value NO_2 retrieval, were found to be impacted by cloud effects larger than 20% (NB. “true” NO_2 assumption).
- Three manuscript submitted to AMT.
  - Realistic synthetic data are suitable for 3D cloud impact studies.
  - Approaches for partly correcting and flagging of cloud shadow effects presented.
  - For observational studies independent measurement of the “true” NO_2 TVCD is needed.
  - For 3D cloud impact investigations a cloud shadow product may be warranted.
  - Cloud shadow fraction, cloud top height, cloud optical depth, solar zenith and viewing angles were the most important metrics for identifying 3D cloud impacts on NO_2 retrievals.
  - For SZA < 40° the synthetic data show that the NO_2 TVCD bias is <10%. For larger SZA both synthetic and observational data show NO_2 TVCD bias on the order of tens of %.
  - For SZAs between 50-60°, about 16% of TROPOMI pixels with high quality value NO_2 retrieval, were found to be impacted by cloud effects larger than 20%.
  - Further work in ongoing project: Understand and mitigate impacts of 3D clouds on UV-VIS NO_2 trace gas retrievals by AI exploration of synthetic and real data (MIT3D) – started 12.10.2021.

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