Observing 3D Cloud Shadow Effects in the S5P NO_2 Product

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Introduction:

As the spatial resolution of satellite spectrometer instruments is moving towards sub-kilometer scale, 3D cloud effects become more prominent in the retrieval of atmospheric trace gases. Currently in the Sentinel-5P (S5P) NO_2 product (5.6x3.6 km^2 at nadir) the FRESCO algorithm is used to retrieve a 1D horizontal homogeneous Lambertian cloud layer for cloud correction. However, clouds are 3D objects, they are not spatially homogeneous and can also have effects on neighboring clear-sky pixels by casting shadows on the ground surface or by scattering light into the scene.

In the S5P NO_2 algorithm the retrieved slant column density is translated to vertical column density (VCD) by correcting for the light path using pre-calculated air-mass factors (AMF) from a radiative transfer model, using surface and cloud parameters as input. When a cloud shadow is cast over a clear-sky pixel the downward light intensity is reduced, altering the average observed light path. This lowers the sensitivity of the measurement for the lower atmospheric layers and thus changes the AMF. As this effect is not accounted for in the current 1D AMF calculation, the AMF used in the retrieval is different from the true AMF, causing a bias in the calculated VCD. When located above a polluted region, the cloud shadow affected pixels should show a different VCD than neighboring pixels.

S5P NO_2 (zoom) data

We searched for cloud shadows over polluted scenes in winter (high SZA, larger shadows) in China using a unique high spatial resolution (2.4x1.8 km^2 at nadir) S5P zoom data-set, in combination with VIIRS data (in constellation with S5P). We then extended our search in the S5P PAL data-set (nominal resolution), to include more scenes.

Cloud shadow effects

Two of the found cases are shown here. In both Figure 1 and 2 the cloud shadow is visible in the VIIRS image and the retrieved scene albedo. The used surface albedo database is modified due to the cloud shadow, which propagates into the AMF. Due to low NO_2 columns at the cloud shadow pixels, the effect is not visible in the VCD for Figure 1. For Figure 2 there is a slight increase visible in the VCD of the cloud pixels.

Albedo correction

In Figure 2 we also compare the S5P PAL product (algorithm v1.5.0) against the S5P OFFL product (algorithm v1.3.0). As of v1.4.0 the surface albedo is adjusted downwards to prevent negative cloud fractions, whilst keeping radiation closure. This also occurs in the cloud shadow pixels, lowering the AMF and thereby artificially increasing the NO_2 VCD. After reprocessing the PAL data without the albedo correction, the effect seen in the NO_2 VCD disappeared. The observed effect was thus caused by the algorithm and not by the cloud shadow.

Conclusion & Outlook

The expected NO_2 bias in the cloud shadow could not be found for the considered cases, apart from the algorithm induced enhancement. Further research including AMF simulations are required to gain more insights in the effect of cloud shadows on NO_2 retrievals.

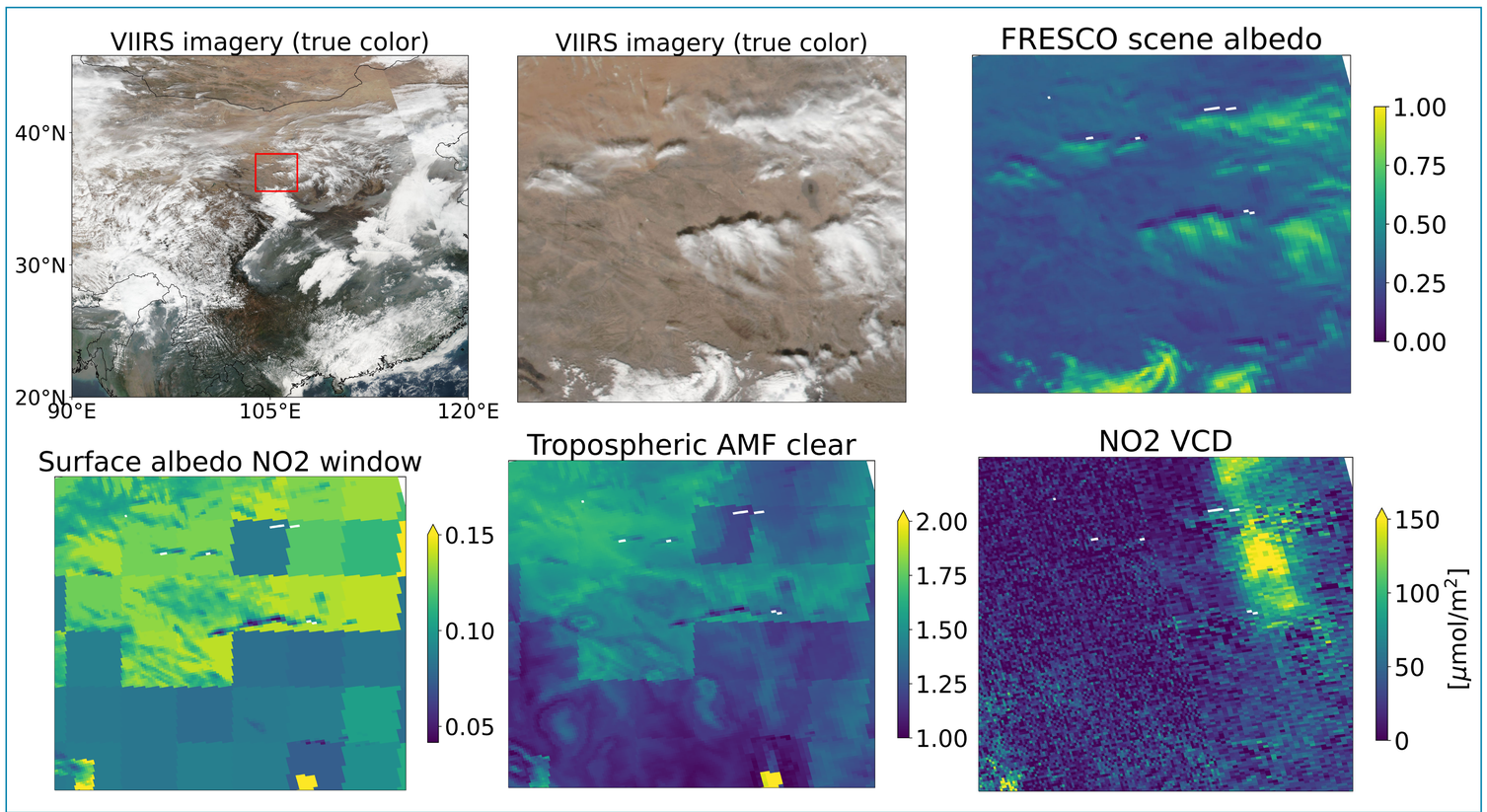

Figure 1: Cloud shadow in Gansu province on 03-03-2018 in the S5P NO_2 zoom data-set. The pixel size is 2.4x1.8 km^2, increasing here towards the East-side of the orbit due to the alternative binning scheme.

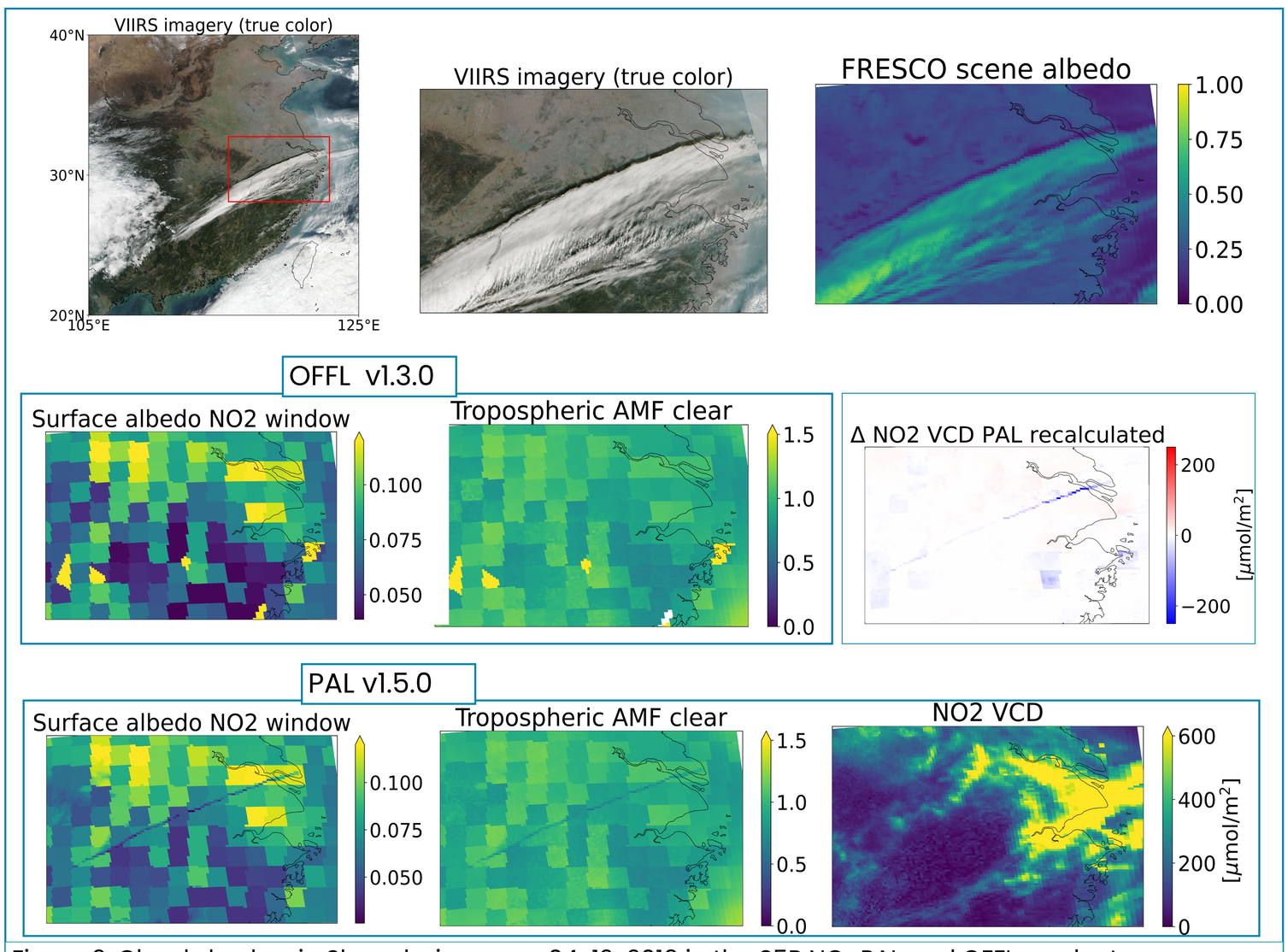

Figure 2: Cloud shadow in Shanghai area on 04-12-2019 in the S5P NO_2 PAL and OFFL products. The pixel size is 5.6x3.6 km^2.

References

- S5P L2 NO2 product: http://www.tropomi.eu/data-products/nitrogen-dioxide
- S5P L2 NO2 product Product Readme File: https://sentinel.esa.int/documents/247904/3541451/Sentinel-5P-Nitrogen-Dioxide-Level-2-Product-Readme-File
- S5P-PAL product: https://data-portal.s5p-pal.com/products/no2.html
- SUOMI-NPP VIIRS data