Evaluation of TROPOMI cloud products for NO_2 retrievals

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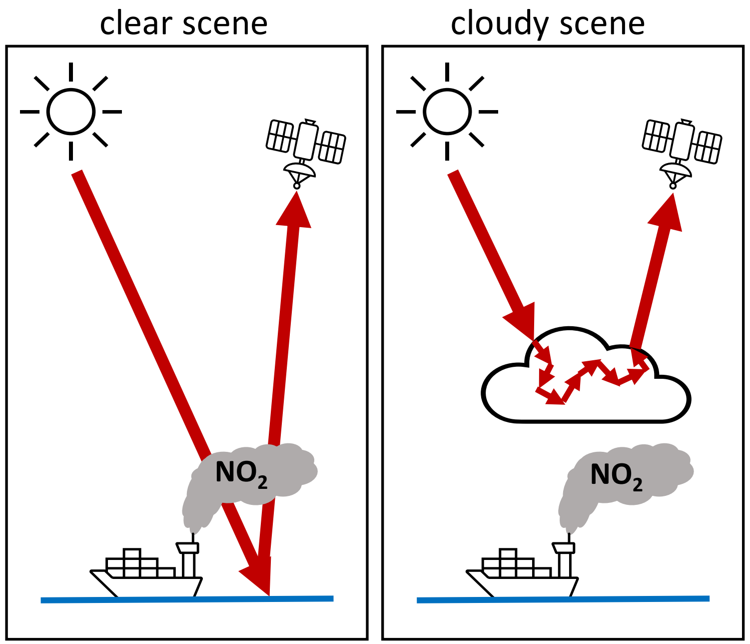
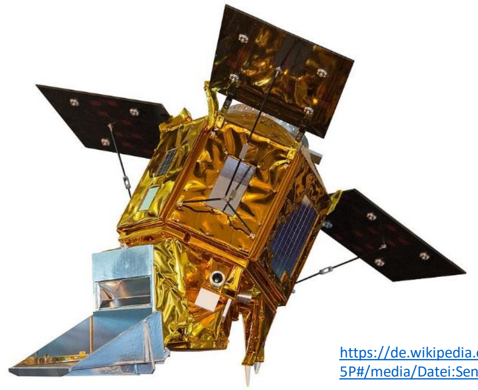
Introduction

- NO_2 is an important trace gas in the atmosphere and affects the human health, the ozone formation, and the climate
- clouds have an impact on satellite measurements of trace gases in the atmosphere such as NO_2
  - shielding of trace gas below and within the cloud from satellite's view
  - light path enhancement due to multiple scattering in the cloud
  - enhancement of visibility of trace gases above the clouds (albedo effect)
- the effects of clouds on the satellite observations depends on cloud fraction, cloud height, surface reflectivity, and aerosol loading and need to be taken into account for trace gas retrievals
- this study (started in April 2020) includes the comparison of different cloud retrieval algorithms for S5P/TROPOMI data to evaluate where and why the cloud products show differences
- the aim of this study is not to decide which product is the best, but to better understand the cloud products



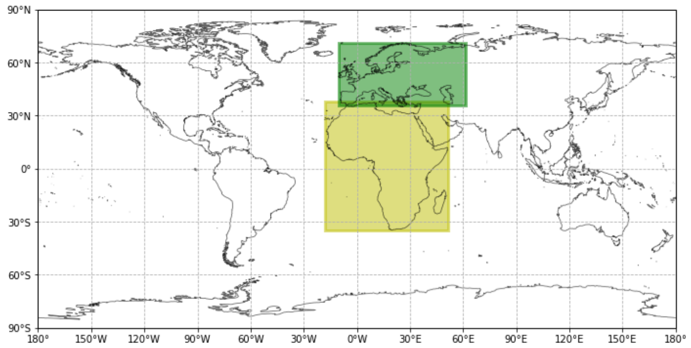
Instrument and Data

- TROPOMI on Sentinel-5 Precursor (S5P)
- launched in October 2017 into a sun-synchronous orbit in 825 km altitude
- daily global coverage with the ascending node at 13:30 LT
- high resolution data with 3.5 x 5.5 km² pixel size at nadir



https://de.wikipedia.org/wiki/Sentinel-5P#/media/Datei:Sentinel_5P_model.jpg

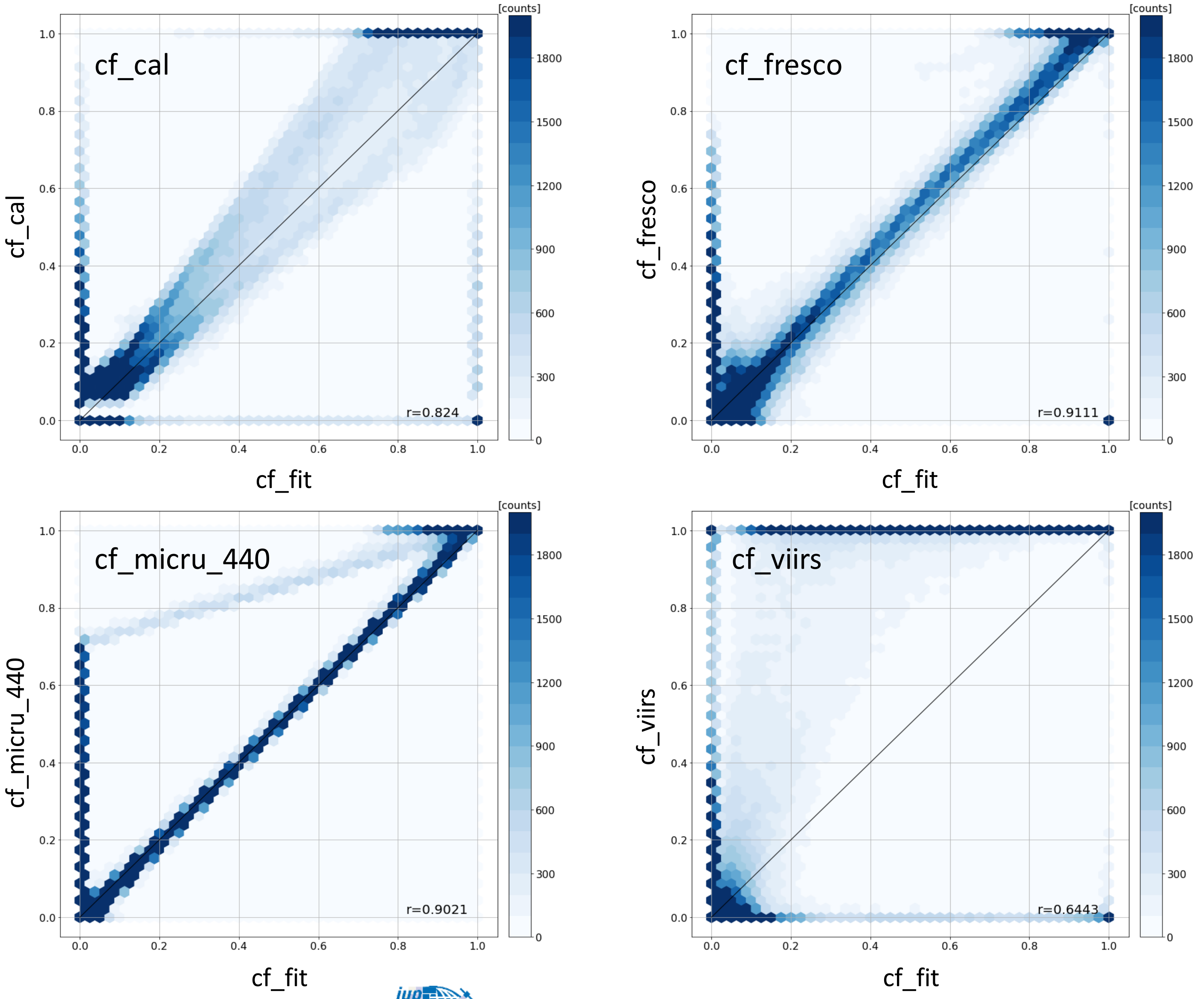
- different cloud products based on S5P/TROPOMI level 1 data (Version 1 - later when available Version 2) are used for the comparison (only results of the cloud fractions are shown):
  - OCRA/ROCINN (CAL and CRB), FRESCO (IR), cloud fraction from the NO_2 fitting window (UV/VIS), MICRU, and VIIRS (see the table on the next slide for more details)
- pixels with a quality assurance flag value (qa) of less than 0.5 are filtered and not used
  - the qa value is a continuous quality descriptor, varying between 0 (no data) and 1 (full quality data), and changes based on observation conditions and retrieval flags
- different regions of the Earth are selected to compare the cloud products (here only results for Europe and Africa are shown)



Overview of the included cloud products

Cloud product00	OCRA – CAL/CRB	ROCINN – CAL/CRB	FRESCO (IR)	cloud fraction from the NO2 fitting window (UV/VIS)	MICRU	VIIRS (ECM)
Developer	DLR		KNMI	KNMI	MPIC	RAL
Input	UV/VIS TROPOMI measurements	OCRA cloud fraction	NIR TROPOMI measurements	UV/VIS TROPOMI measurements	UV/VIS/NIR TROPOMI	VIIRS visible and infrared imagery and radiometric measurements
Output	cloud fraction	cloud top and base height/cloud pressure, cloud optical thickness/cloud albedo	effective cloud fraction, cloud pressure	effective cloud fraction, cloud radiance fraction	effective cloud fraction at different spectral bands	4-level cloud mask with a cloud probability for VIIRS pixels within a S5P scene
Approach	color (whiteness) (350-495nm)	O_2 absorption (760nm)	brightness and O_2 absorption (760nm)	brightness (440nm)	brightness (375-757nm)	brightness (VIS/IR/SWI/TIR)
Features	CAL: Clouds As Layers CRB: Clouds as Reflecting Boundaries setting the lowest 5% to 0		fixed cloud albedo of 0.8	developed due to the misalignment between ground pixel view of the VIS and NIR bands	empirical background; differentiation of land/ ocean; optimized for low cloud fraction (<20%) [for more details see poster 44 - Sihler et al.]	geometric cloud fraction = ratio of sum of pixels in the class(es) of interest and the total number of all pixels
Abbr. in the plots	**cf_cal**		**cf_fresco**	**cf_fit**	**cf_micru**	**cf_viirs**

Results for Europe – Frequency plots of the cloud fraction from the NO_2 fitting window (**cf_fit**) and the OCRA/ROCINN CAL, FRESCO, MICRU, and VIIRS product 05.04.2019, qa=0.5 (~97%)



- the OCRA/ROCINN products CAL and CRB look very similar (only CAL is shown): symmetrical over- and underestimation compared to the cloud fraction from the NO_2 fitting window (**cf_fit**)
- FRESCO shows mainly larger cloud fractions than cf_fit
- MICRU fits well on the 1:1-line, but there is also a second overestimated line compared to cf_fit
- VIIRS has many values of 1, resulting from the strict definition of cloudy pixels
- all cloud products show many values when cf_fit is zero
- for OCRA/ROCINN, FRESCO and VIIRS, a dot is found at the point where cf_fit is 1 and the other products are zero

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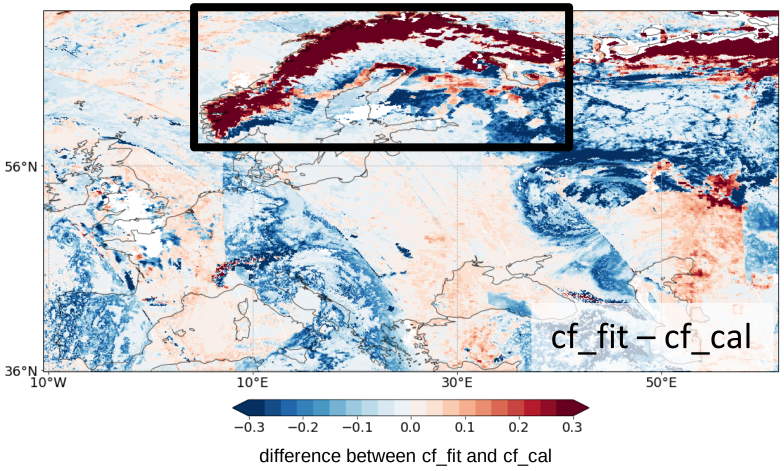
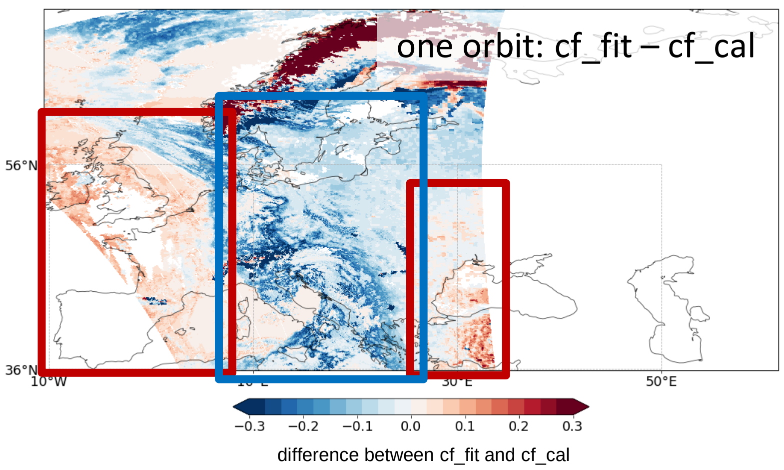
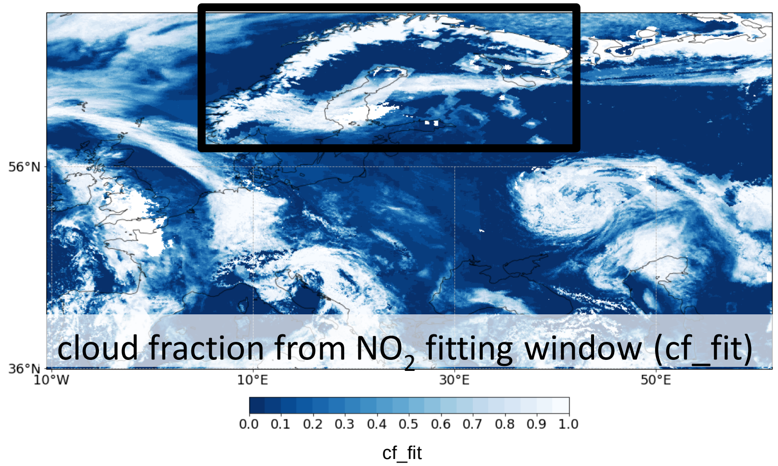
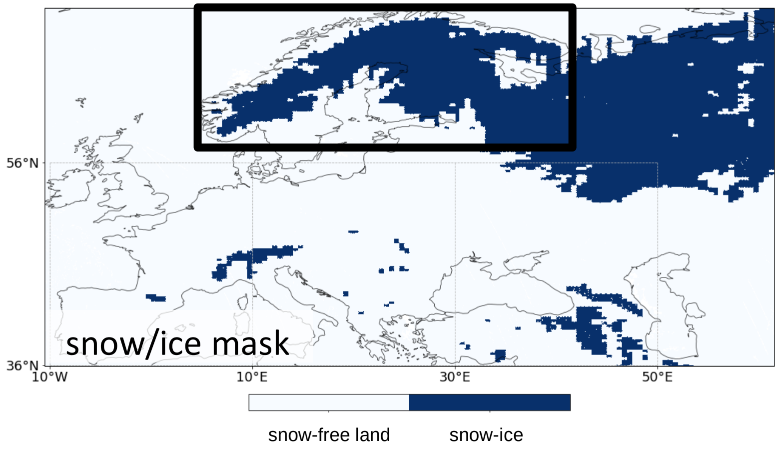
Results for Europe – Difference map of the cloud fraction from the NO_2 fitting window (**cf_fit**) and the OCRA/ROCINN CAL product 05.04.2019, qa=0.5 (~97%), 0.03°x0.03° grid









- the OCRA/ROCINN products (again only CAL) show a pronounced orbit structure in the difference map (**cf_fit – cf_cal**) due to a gradient in the orbits, which can be seen considering only one orbit
  - Positive values on the western and eastern side of the orbits
  - Negative values in the middle of the orbits
- cf_fit detects clouds over Norway, in contrast to OCRA/ROCINN
- the snow/ice mask shows no snow/ice coverage over Norway → different treatment of snow in the products leads to differences of the cloud fractions

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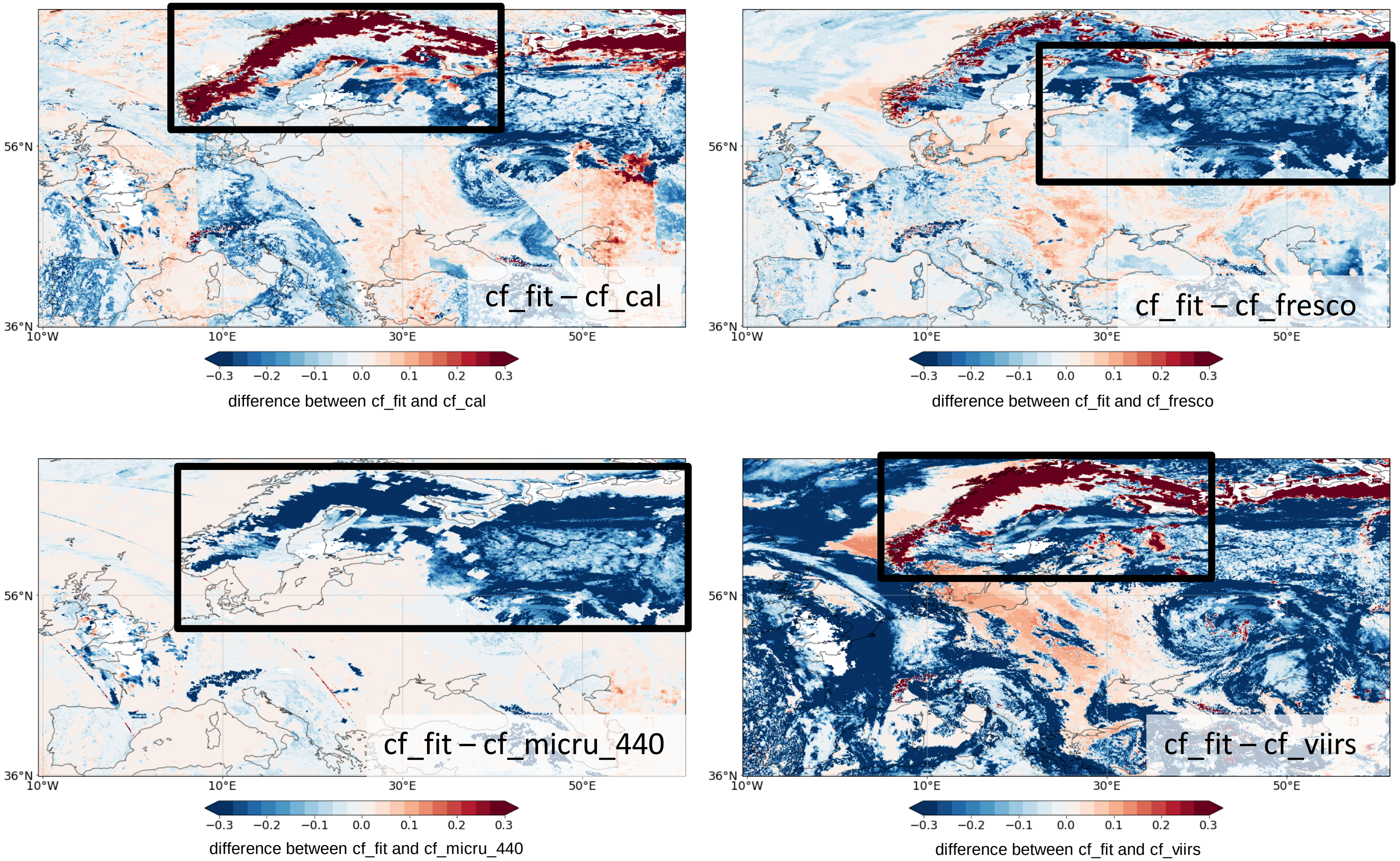
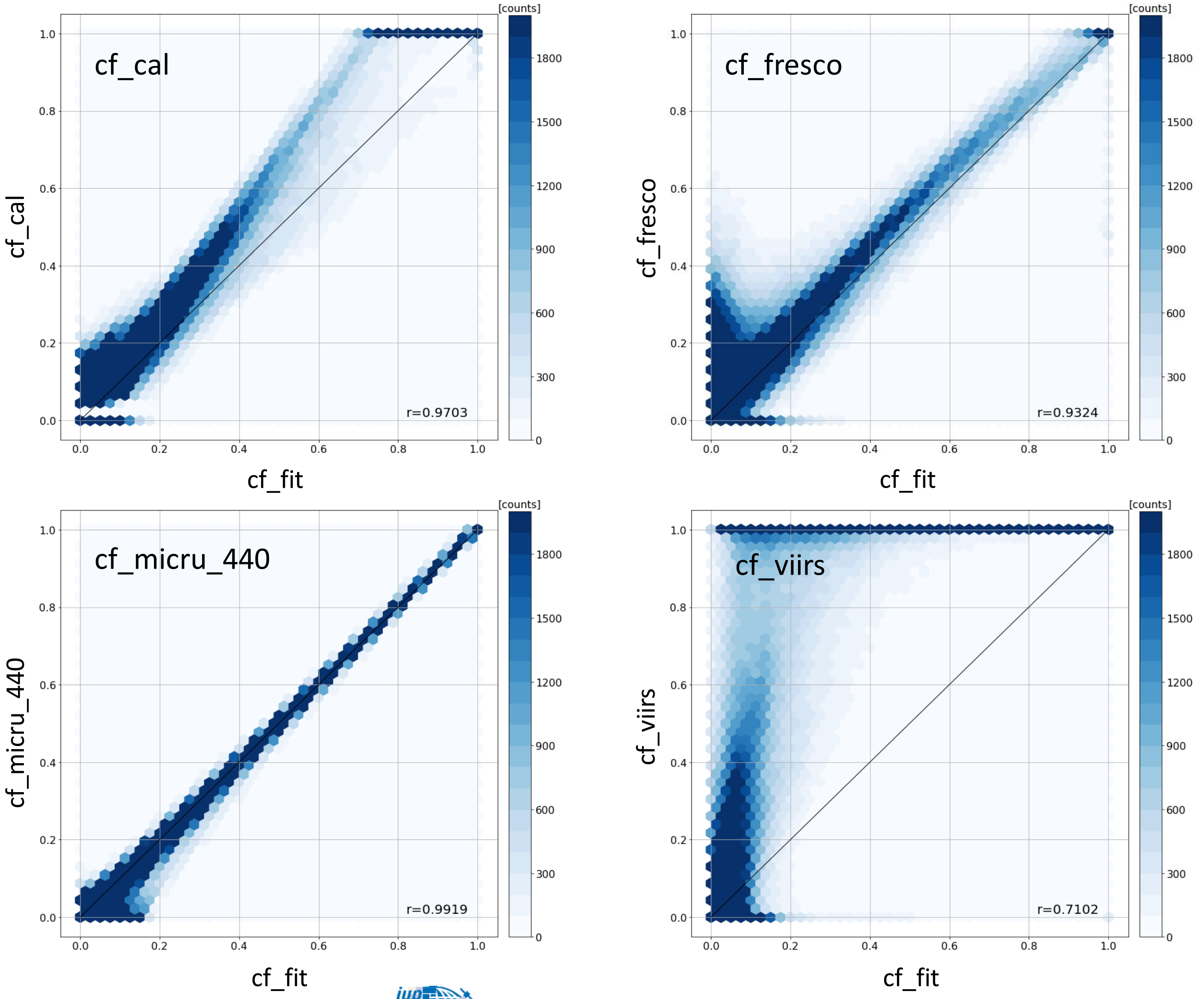
Results for Europe – Difference map of cf_fit and the OCRA/ROCINN CAL, FRESCO, MICRU, and VIIRS product 05.04.2019, qa=0.5 (~97%), 0.03°x0.03° grid



- the differences between cf_fit and the OCRA/ROCINN cloud fraction could be due to the different treatment of snow cover (especially over Norway)
- in the difference map of cf_fit and FRESCO, pronounced coastlines and a land-water-contrast are found; this results from the fact that FRESCO measures in the IR, where land is recognized as bright surfaces in contrast to dark water
- FRESCO and MICRU show larger cloud fractions over snow-covered regions compared to cf_fit (negative differences)
- these differences might be the reason for the many zero values for all products and for the line above the 1:1-line in the frequency plot for MICRU (as seen before on slide 5)
- the VIIRS difference map, like OCRA/ROCINN, shows positive differences over Norway; on the other hand, there are many negative values that probably correspond with the 1-values in the frequency plot

Results for Africa – Frequency plots of cf_fit and the OCRA/ROCINN CAL, FRESCO, MICRU, and VIIRS product 25.12.2018, qa=0.5 (~98%)



- the OCRA/ROCINN products (here CAL) show an overestimation compared to the cloud fraction from the NO_2 fitting window (**cf_fit**)
- FRESCO overestimates the cloud fraction in the form of a hook
- MICRU and cf_fit agree well for larger cloud fraction values; in the lower 20% the cloud fraction is mainly smaller than that from the cf_fit (the lowest 20% of cloud fractions are most relevant for trace gas retrievals)
- VIIRS shows an overestimation and many 1-values where cf_fit is smaller

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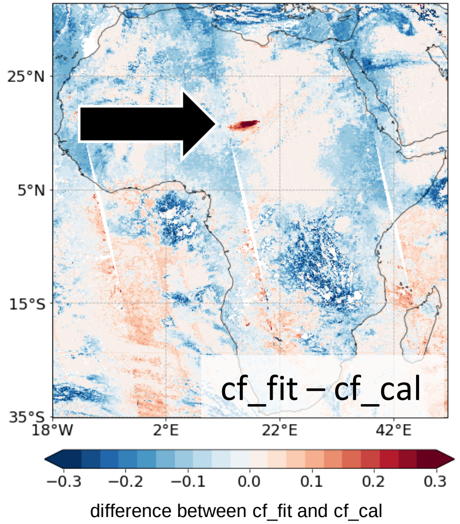
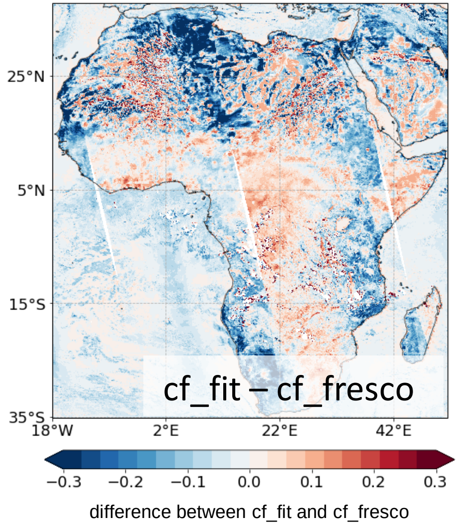
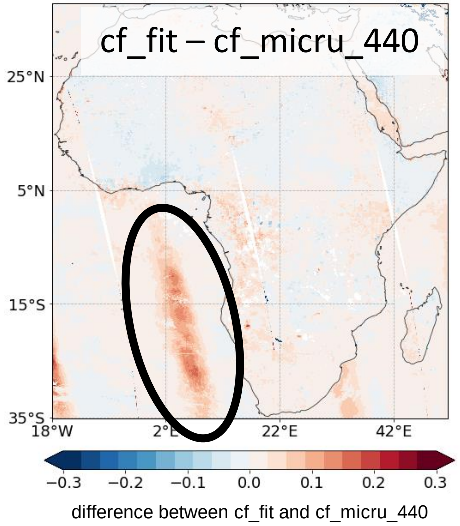
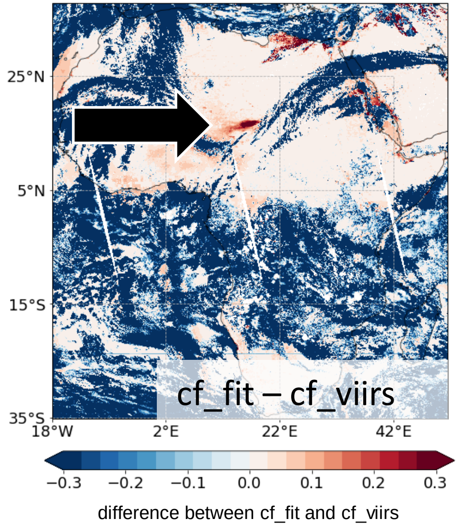
Results for Africa – Difference map of cf_fit and the OCRA/ROCINN, FRESCO, MICRU, and VIIRS products 25.12.2018, qa=0.5 (~98%), 0.03°x0.03° grid

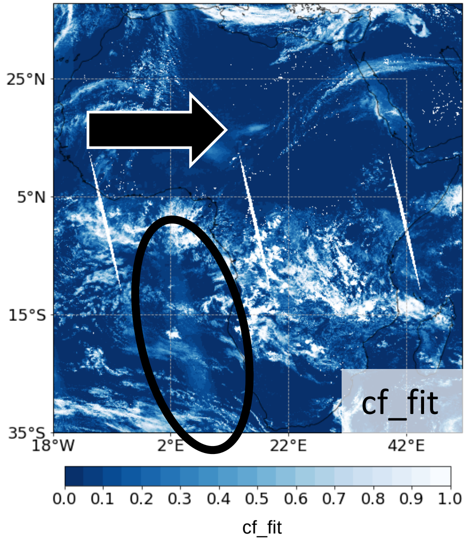




- in the difference maps of cf_fit with OCRA/ROCINN and VIIRS an artifact in the Sahara occurs, which is also found in the cloud fraction map of the NO_2 product
- the map of cf_fit and FRESCO shows larger differences in the northern part of Africa and again a pronounced land-water-contrast
- MICRU treats sun glint differently than the other products, because only the difference map of cf_fit and MICRU shows stripes over the ocean; in the cloud fraction map of the NO_2 product a cloud veil can be seen in this area







Summary & Conclusions

- the OCRA/ROCINN products CAL and CRB are very similar, therefore only CAL was shown
- there are similar differences of both OCRA/ROCCIN and VIIRS compared to the cloud fraction from the NO_2 fitting window (cf_fit) in the difference maps
  - positive differences over Norway caused by different treatment of snow/ice cover
  - an artifact in the Sahara for Africa
- FRESCO shows a pronounced land-water-contrast due to its measurement in the IR and differences over snow compared to cf_fit
- the MICRU cloud fraction and cf_fit agree well, only
  - over snow-covered regions there are distinct differences, because MICRU does not treat snow- or ice-covered regions a priori, and
  - MICRU is the only product in this study considering sun glint; this explains the stripes over the ocean in the difference map for Africa
- VIIRS differs the most from cf_fit; reasons could be
  - its strict definition of cloudy pixels corresponding to the 1-values in the frequency plots
  - VIIRS yields geometric cloud fractions while the other algorithms yield effective cloud fractions
  - the time and pixel offset of the VIIRS measurements, as the instrument is not on the same platform as TROPOMI
- these results are only first initial findings that require further research to answer the questions where and why these differences occur:
  - maybe a reason are the difficult situations like snow/ice cover, sun glint, coastlines, large SZA/VZA, high aerosol load, and different surface albedo
  - in addition, seasonal variations in the differences have been found (not shown) which need further investigation

Selected references

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