# Current Status and Future Plans for the TROPOMI/Sentinel-5P L2 Cloud Product

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(1) German Aerospace Center (DLR)

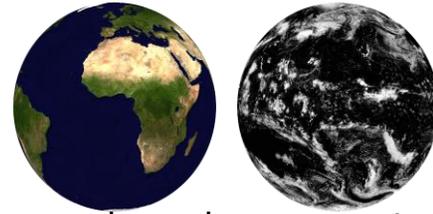(2) Rutherford Appleton Laboratory (RAL)

(3) Technical University Munich (TUM)

Sentinel-5P: 5 Years Anniversary
Taormina, Italy
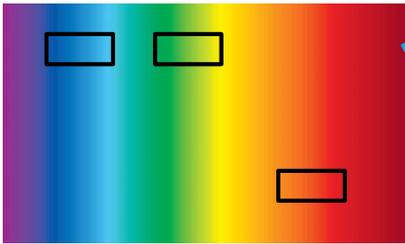13 October 2022

Wissen für Morgen

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# OCRA & ROCINN – Algorithm Overview
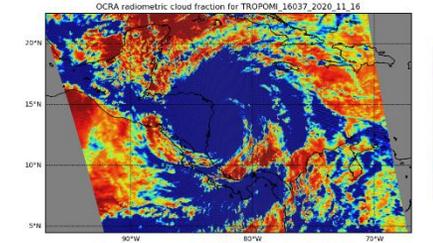
**OCRA**
Optical Cloud
Recognition Algorithm

**ROCINN**
Retrieval of Cloud Information
using Neural Networks

color space approach

neural network approach

clear-sky composite

$O_2$ A-band
758-771 nm

Hurricane Iota
©NASA worldview

CAL
Clouds as layers

CRB
Clouds as reflecting boundaries

Radiometric cloud fraction
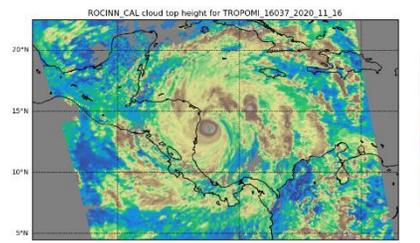
cloud top height
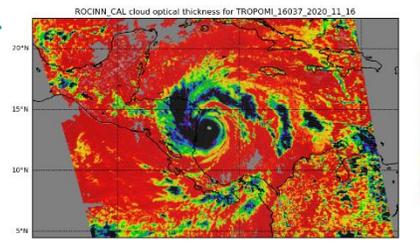
cloud opt. thickness
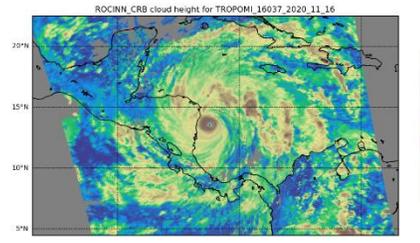
eff. cloud height

eff. cloud albedo

## OCRA Overview

RGB color space

UV    VIS    NIR
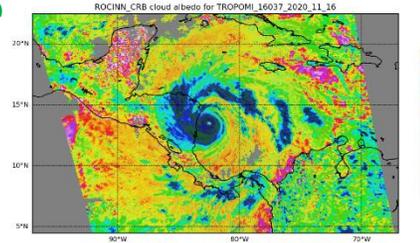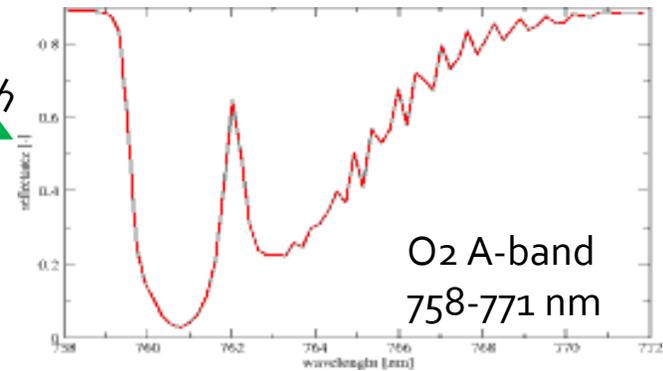


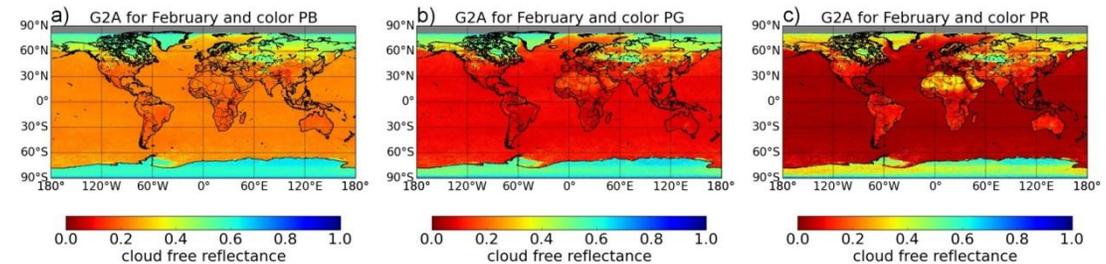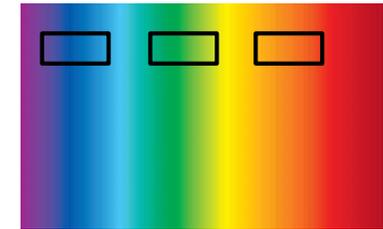- map measured reflectances to RGB color space

- generate cloud-free reflectance composite maps
  - monthly resolution
  - based on several years of data



- assume a cloud to be „white" in RGB
  - white point defines fully cloudy condition

- radiometric cloud fraction is scaled between the cloud-free reflectance (CF=0) and the „white point" (CF=1)



white point (1/3, 1/3)

cloud-free reflectance; f(R,G,B,lat,lon,time)

Lutz et al. (2016): OCRA radiometric cloud fractions for GOME-2 on MetOp-A/B, Atmos. Meas. Tech., 9, 2357-2379, https://doi.org/10.5194/amt-9-2357-2016

# ROCINN Overview

- two cloud models:
  **CRB**: clouds as reflecting boundaries (Lambertian reflector)
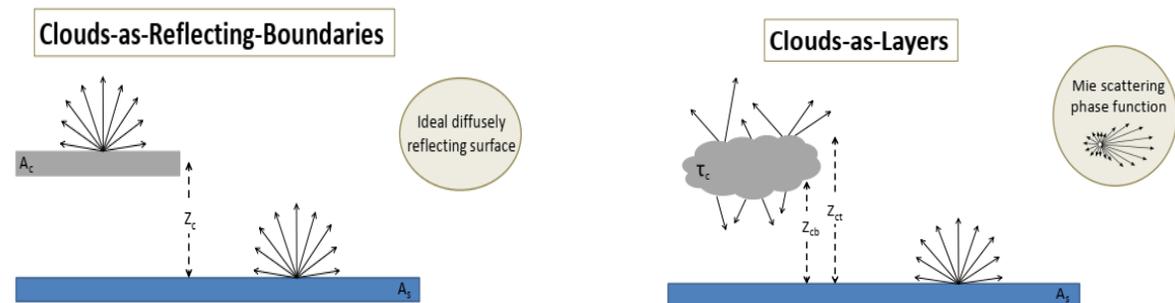  **CAL**: clouds as layers (Mie-scattering liquid water droplets)
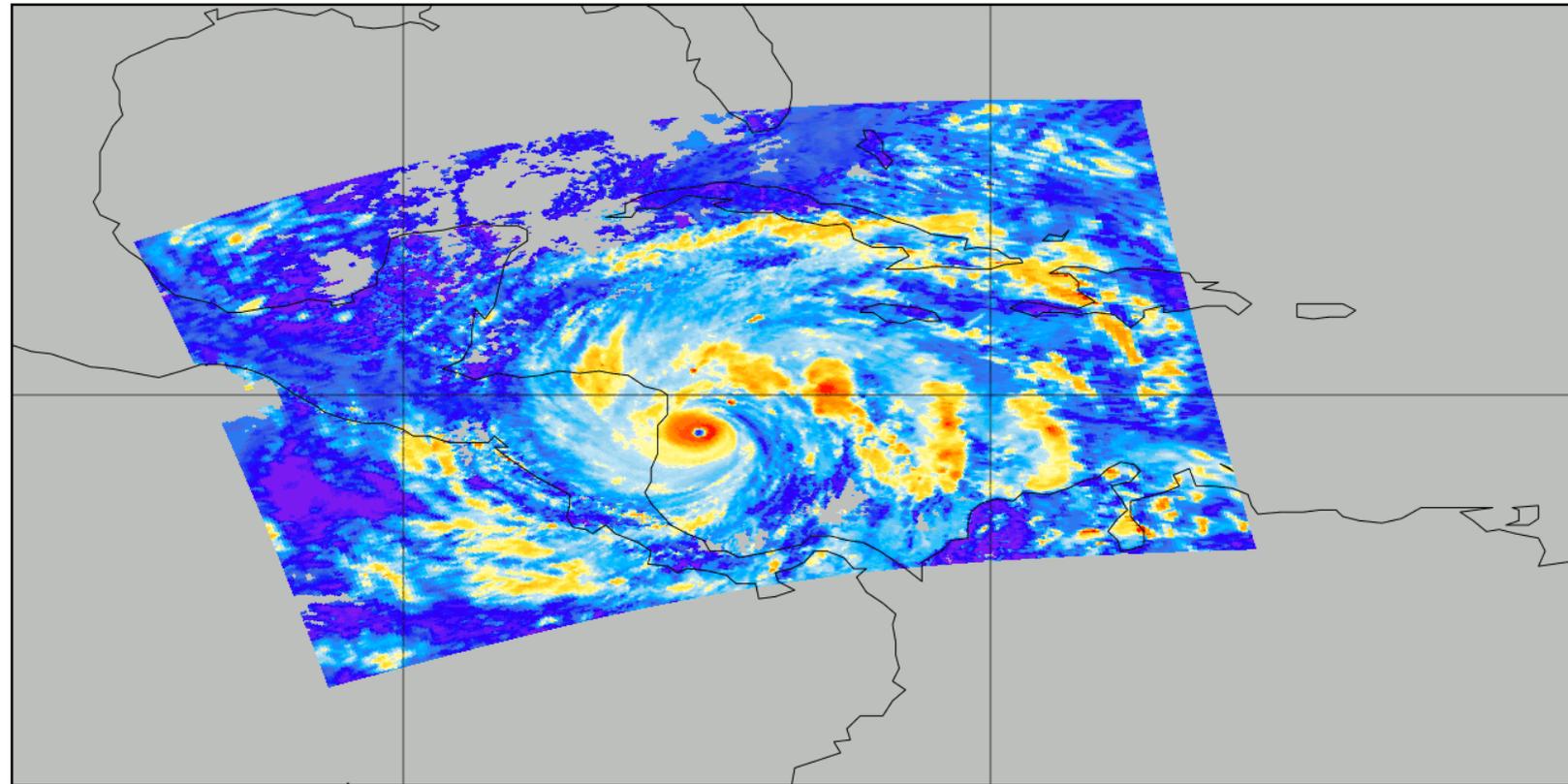


O$_2$ A-Band, NIR

**Fitting window: [758-771] nm**

- Usage of neural networks and machine learning techniques

| 10:00-10:15 | **Advances in the application of deep neural networks for the retrieval of cloud properties for TROPOMI / Sentinel-5 Precursor (S5P)** |
| --- | --- |
| | Fabian Romahn (DLR)  **See presentation tomorrow!** |

Loyola et al. (2018): The operational cloud retrieval algorithms from TROPOMI on board Sentinel-5 Precursor, Atmos. Meas. Tech., 11, 409-427. https://doi.org/10.5194/amt-11-409-2018
Loyola et al. (2016): Smart sampling and incremental function learning for very large high dimensional data, Neural Networks, Vol. 78, 75-87. https://doi.org/10.1016/j.neunet.2015.09.001

# S5P – operational cloud products

Hurricane Iota, 2020-11-16, orbit 16037



cloud_height_crb

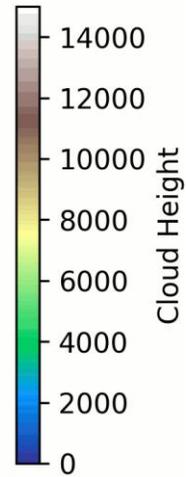

Hurricane Iota
©NASA worldview

# S5P – yearly temporal evolution
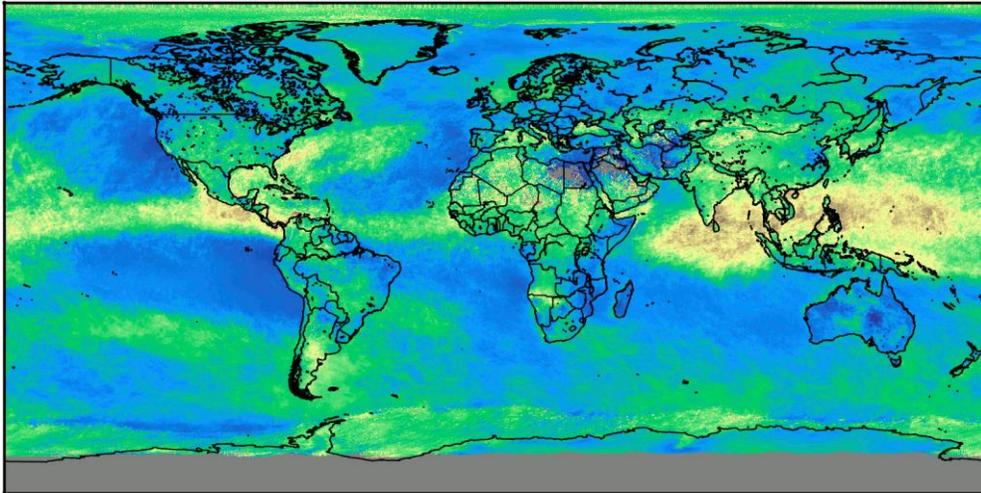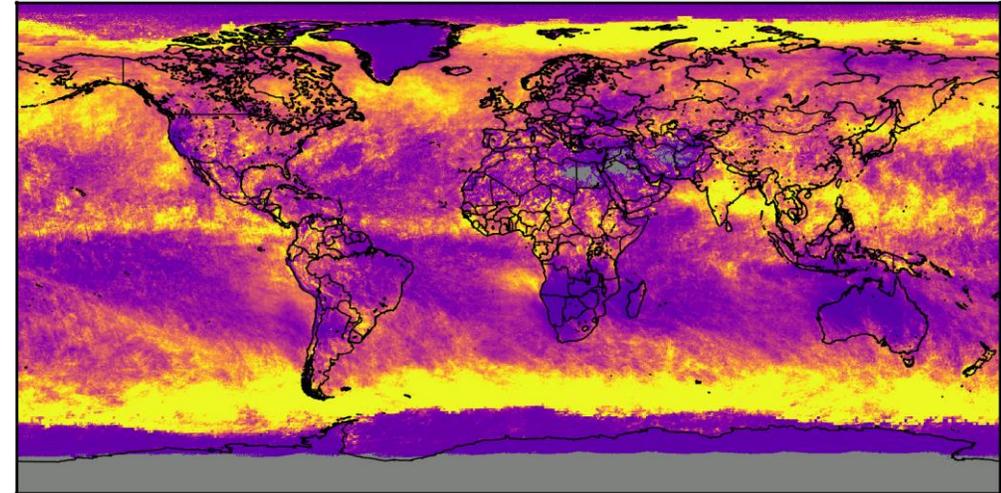


ROCINN CAL cloud top height
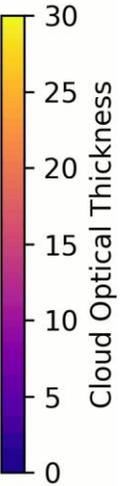
ROCINN CAL cloud optical thickness

# OCRA & ROCINN – documentation

https://sentinel.esa.int/web/sentinel/technical-guides/sentinel-5p/products-algorithms
https://mpc-vdaf.tropomi.eu/index.php/clouds



ATBD



PUM



PRF



ROCVR

# OCRA & ROCINN – recent improvements and upcoming developments (I)

- OCRA clear-sky maps have been updated based on 3 years of TROPOMI data and to include L1 degradation

  → this improved the cloud fraction retrieval, particularly at low cloud coverages



TROPOMI_04_monthly_cloudfree_res02x02deg_3years_mincol_B.txt
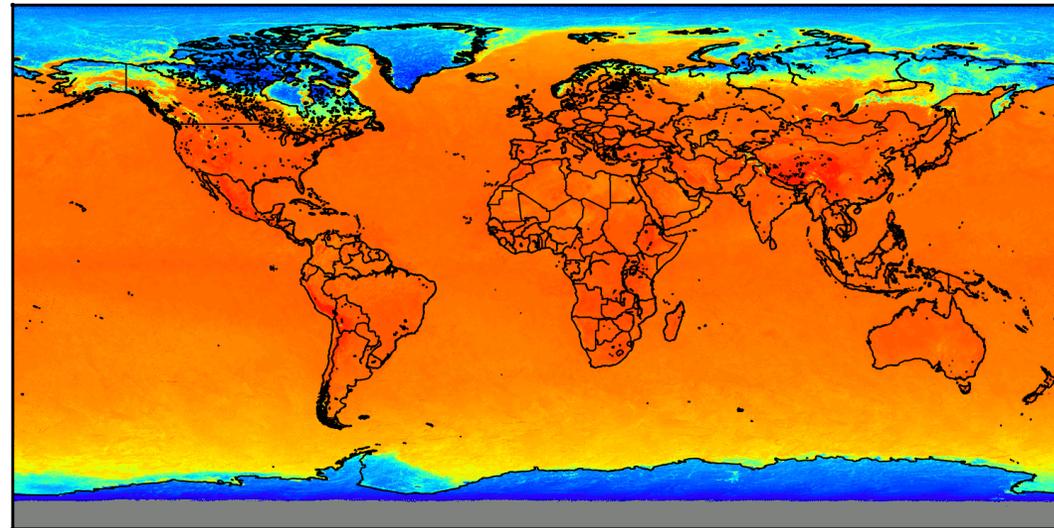
TROPOMI_04_monthly_cloudfree_res02x02deg_3years_mincol_G.txt

**OCRA blue channel**
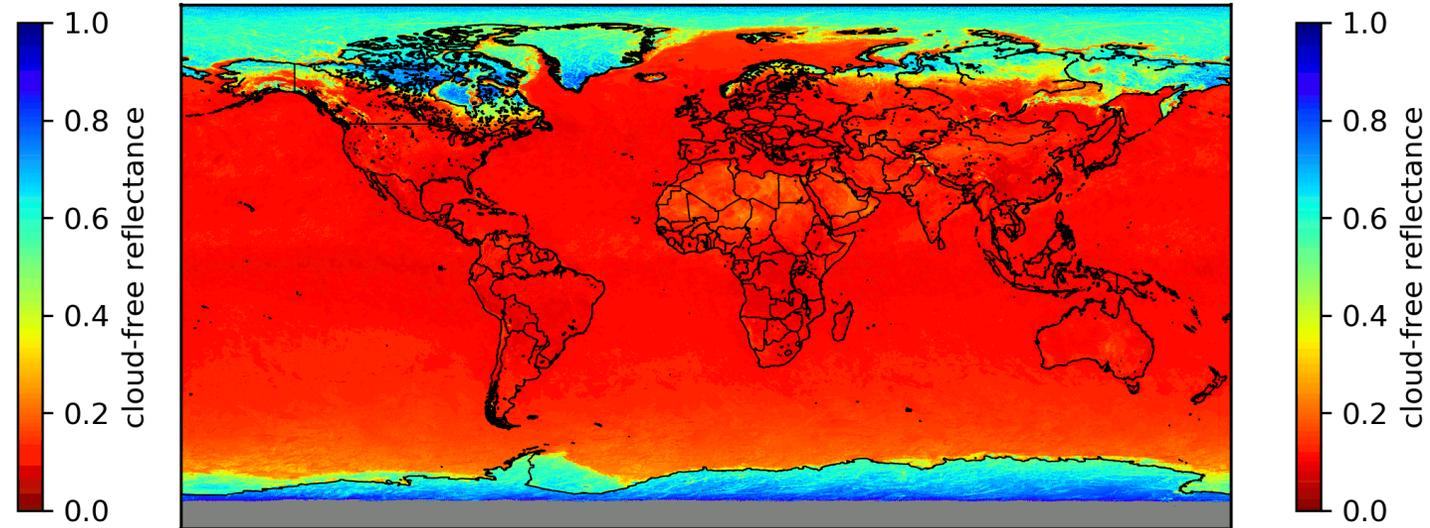
**OCRA green channel**

# OCRA & ROCINN – recent improvements and upcoming developments (II)

- ROCINN surface albedo climatology is replaced by daily surface albedo retrieval (GE_LER) using TROPOMI measurements and the surface albedo map is updated on a daily basis (G3_LER)

    → this improved the cloud retrieval particularly over snow/ice surfaces

ECMWF snow-ice mask with NISE definitions, 2020-08-09, orbit 14625



snow-ice mask ()

0.0    51.0    102.0    153.0    204.0    255.0

Data Min = 0.0, Max = 255.0
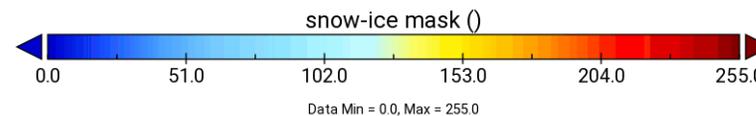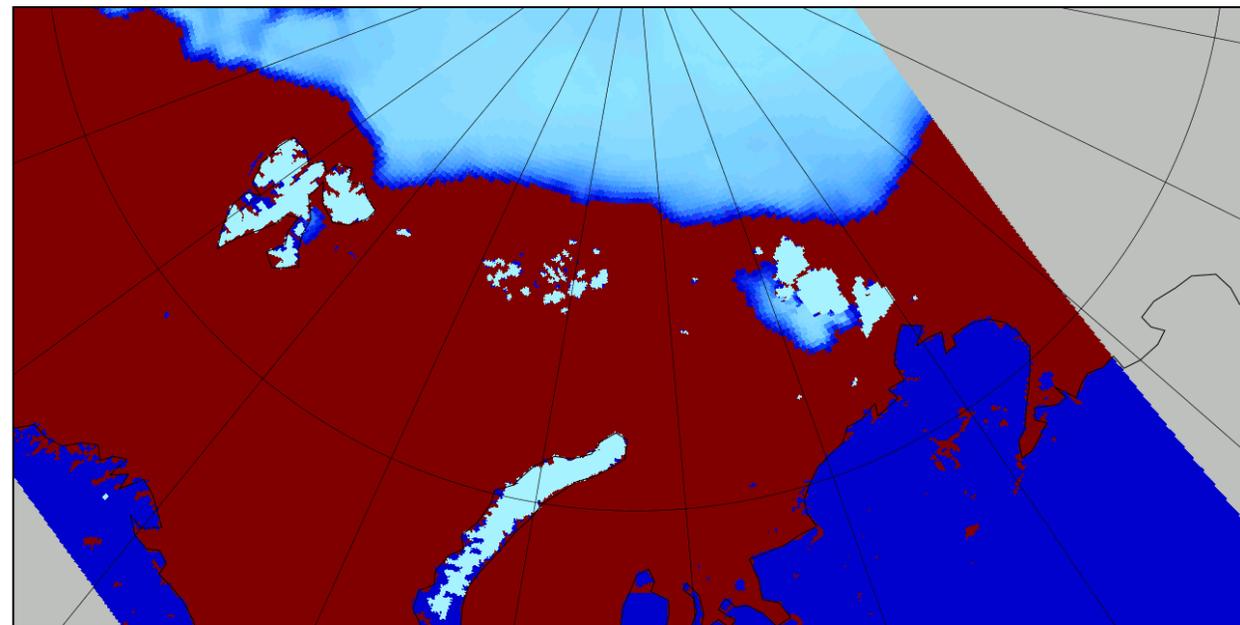
# OCRA & ROCINN – recent improvements and upcoming developments (III)

- ROCINN neural networks have been updated
    - → this improved ROCINN in general

| 10:00-10:15 | **Advances in the application of deep neural networks for the retrieval of cloud properties for TROPOMI / Sentinel-5 Precursor (S5P)** |
| --- | --- |
| | Fabian Romahn (DLR)   **See presentation tomorrow!** |

## Upcoming developments:

- Extension of the clear-sky composite maps from 3 years to 5 years

- ROCINN ice cloud parameterisation

    → this will improve both the cloud top height and optical thickness retrievals when ice clouds are present

    → the following slides will show why this is necessary

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# Routine validation with ground based data

- Routine validation of the TROPOMI L2_CLOUD product is performed with ground based CLOUDNET data in the framework of the ATM MPC: VDAF validation facility: https://mpc-vdaf.tropomi.eu/index.php/clouds

  **Compernolle et al.:** Validation of the Sentinel-5 Precursor TROPOMI cloud data with Cloudnet, Aura OMI O2–O2, MODIS, and Suomi-NPP VIIRS, Atmos. Meas. Tech., 14, 2451–2476, https://doi.org/10.5194/amt-14-2451-2021, 2021

# Validation with satellite data

- VIIRS/S-NPP allows for reasonable spatio-temporal comparability due to close formation with S5P

- Re-gridded VIIRS cloud test products have been generated by RAL in the framework of the S5P MPC

- Comparisons for ROCINN_CAL CTH and COT

- data subsets:
    - surface condition: land (🌳) and water (🏊)

    - cloud phase: liquid phase (💧) and ice phase (❄), based on VIIRS cloud phase probability (>90 %)

# Comparison with satellite data from VIIRS/S-NPP – Global
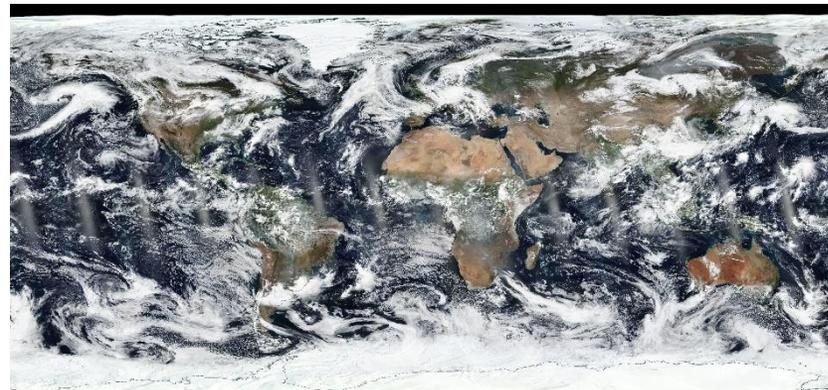
**SZA < 70°, qa > 0.5, most recent UPAS version 2.4**

**2018-09-09**

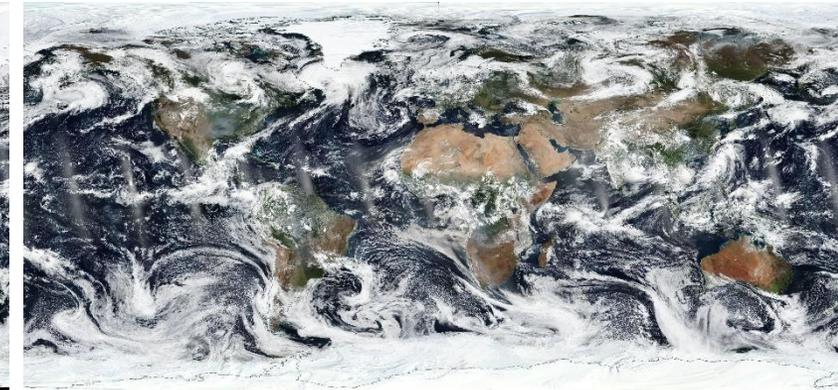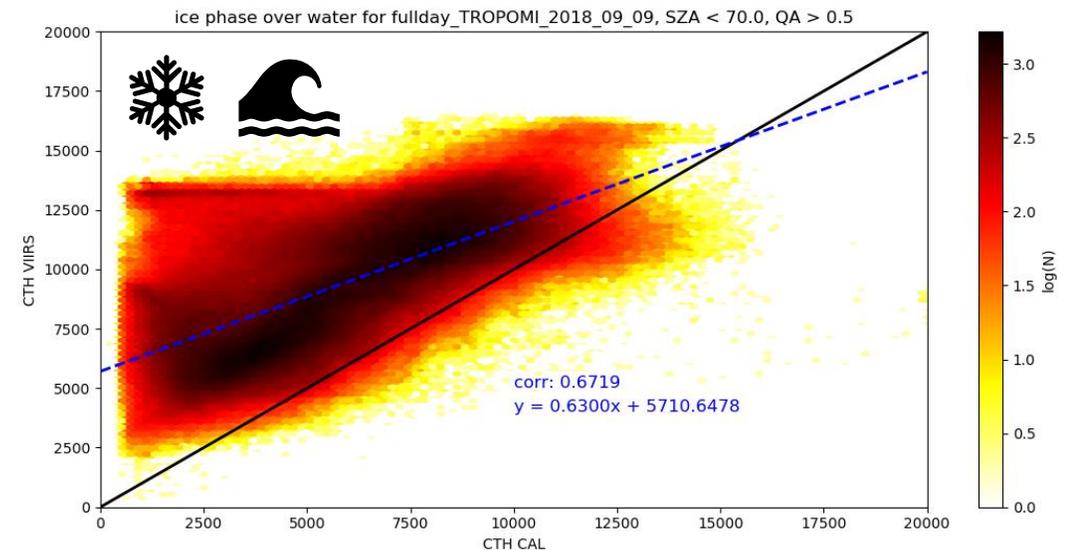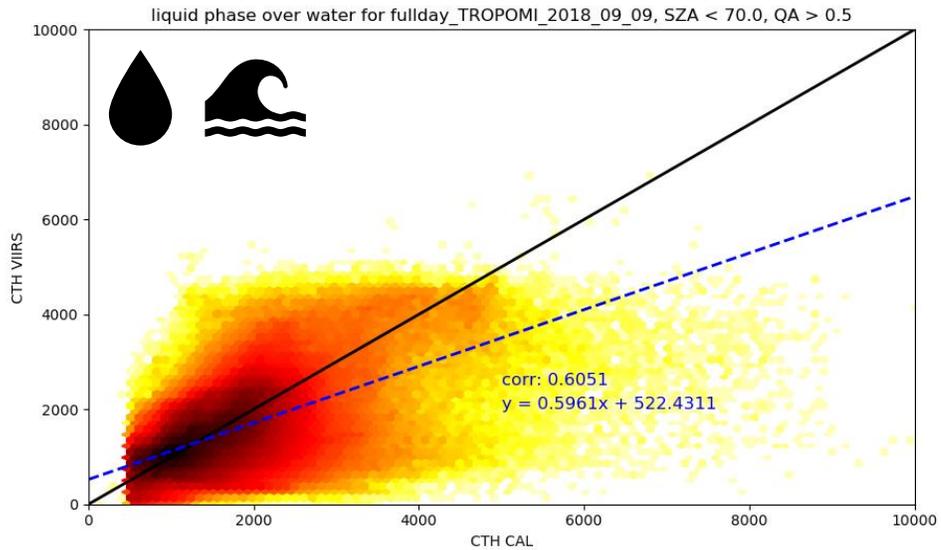**2019-09-11**

**2020-09-11**

**2020-09-26**

**2021-04-11**

**2021-09-11**

# Comparison with satellite data from VIIRS/S-NPP – Global – Cloud Top Height
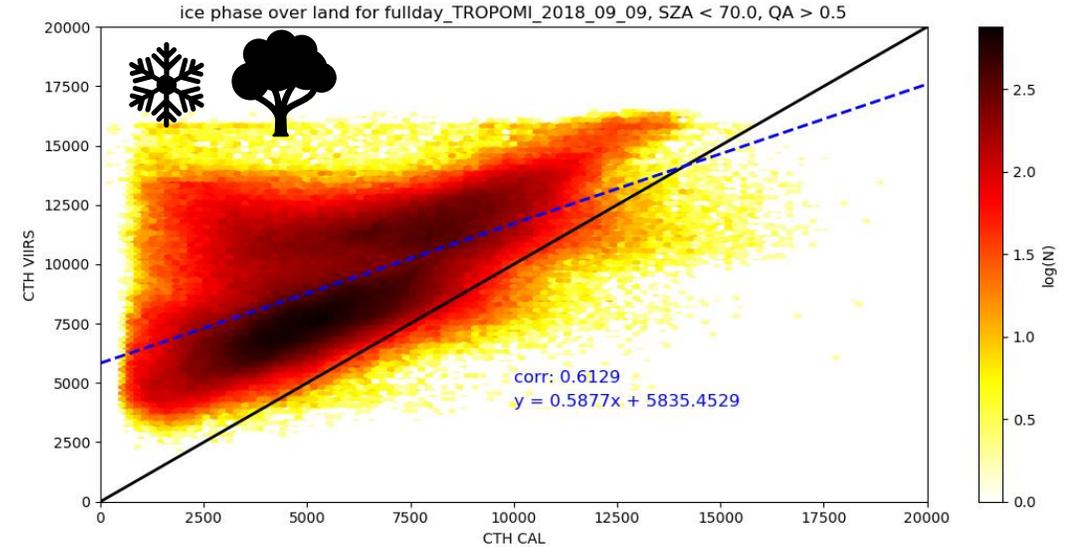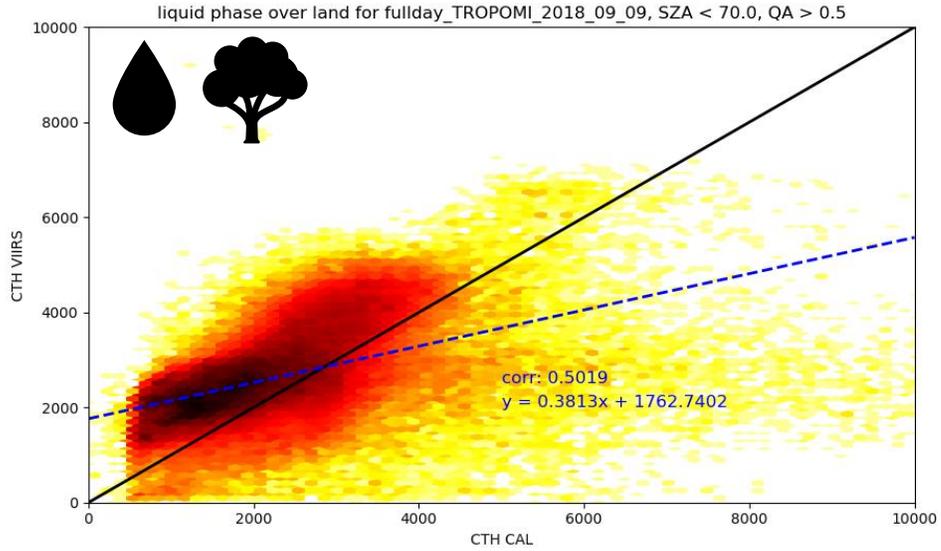
# Comparison with satellite data from VIIRS/S-NPP – Global – Cloud Top Height
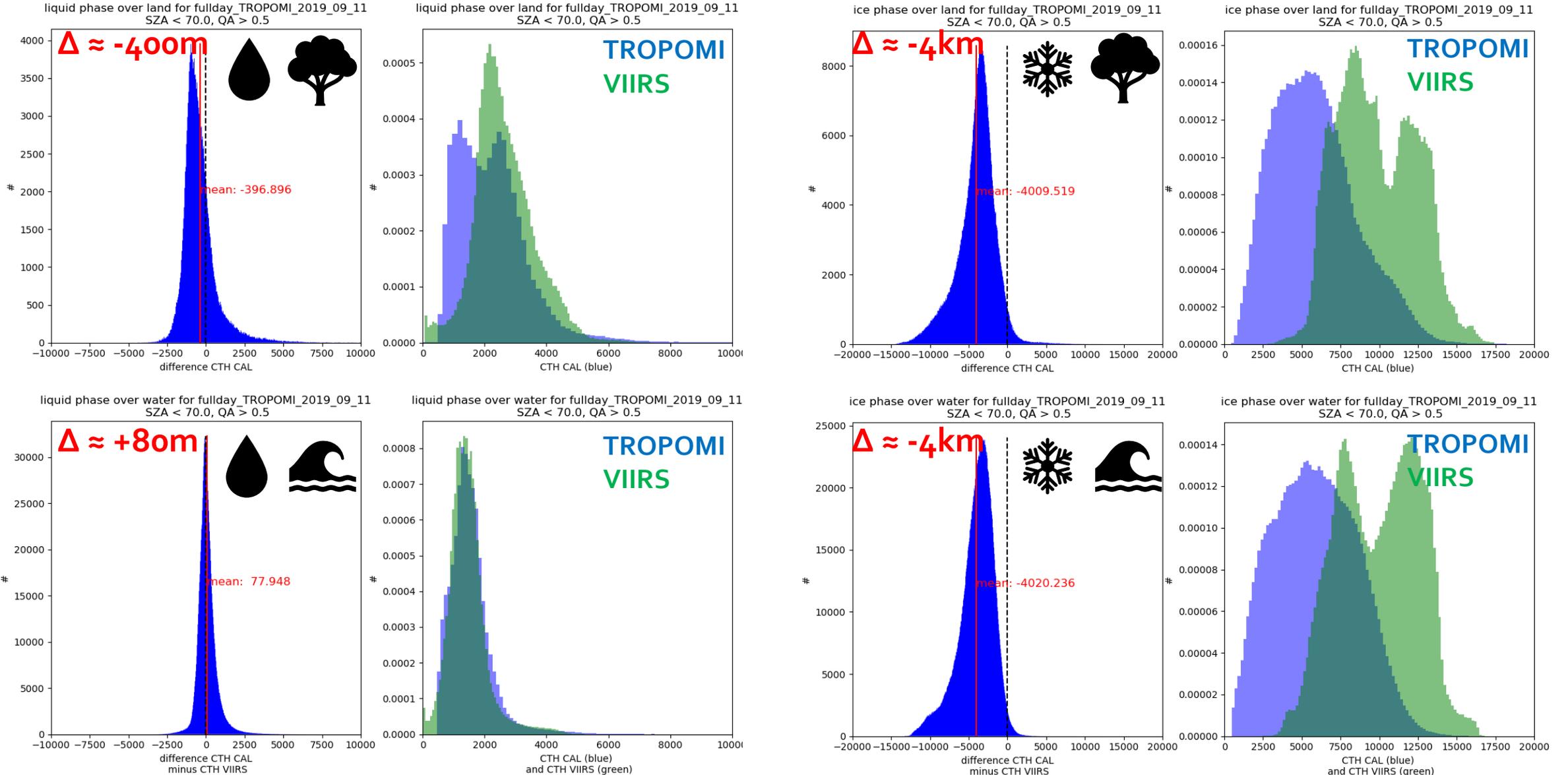
# Comparison with satellite data from VIIRS/S-NPP – Global – Cloud Top Height
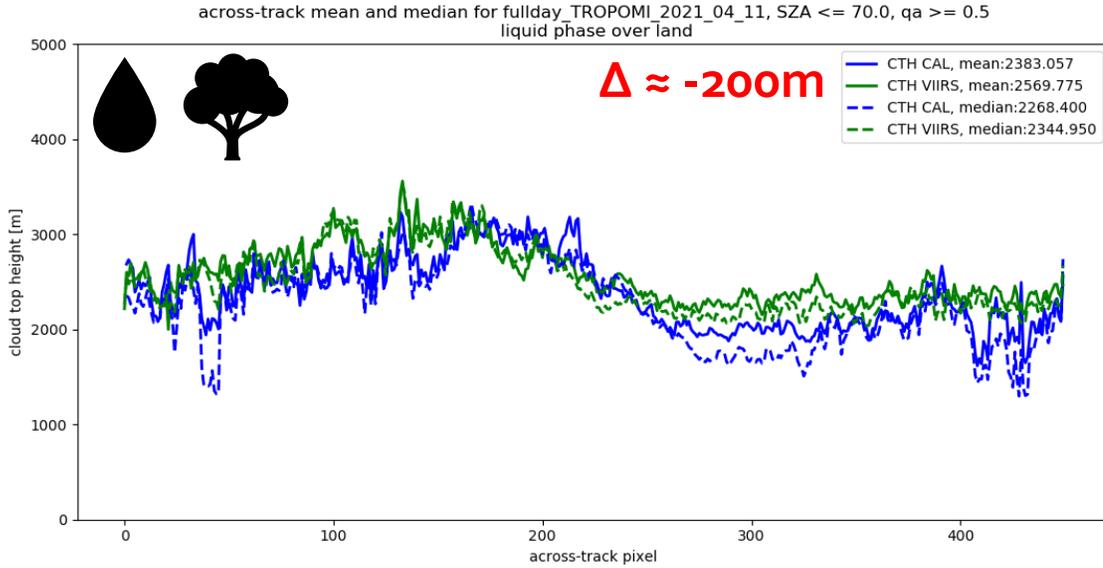
# Comparison with satellite data from VIIRS/S-NPP – Global – Cloud Optical Thickness
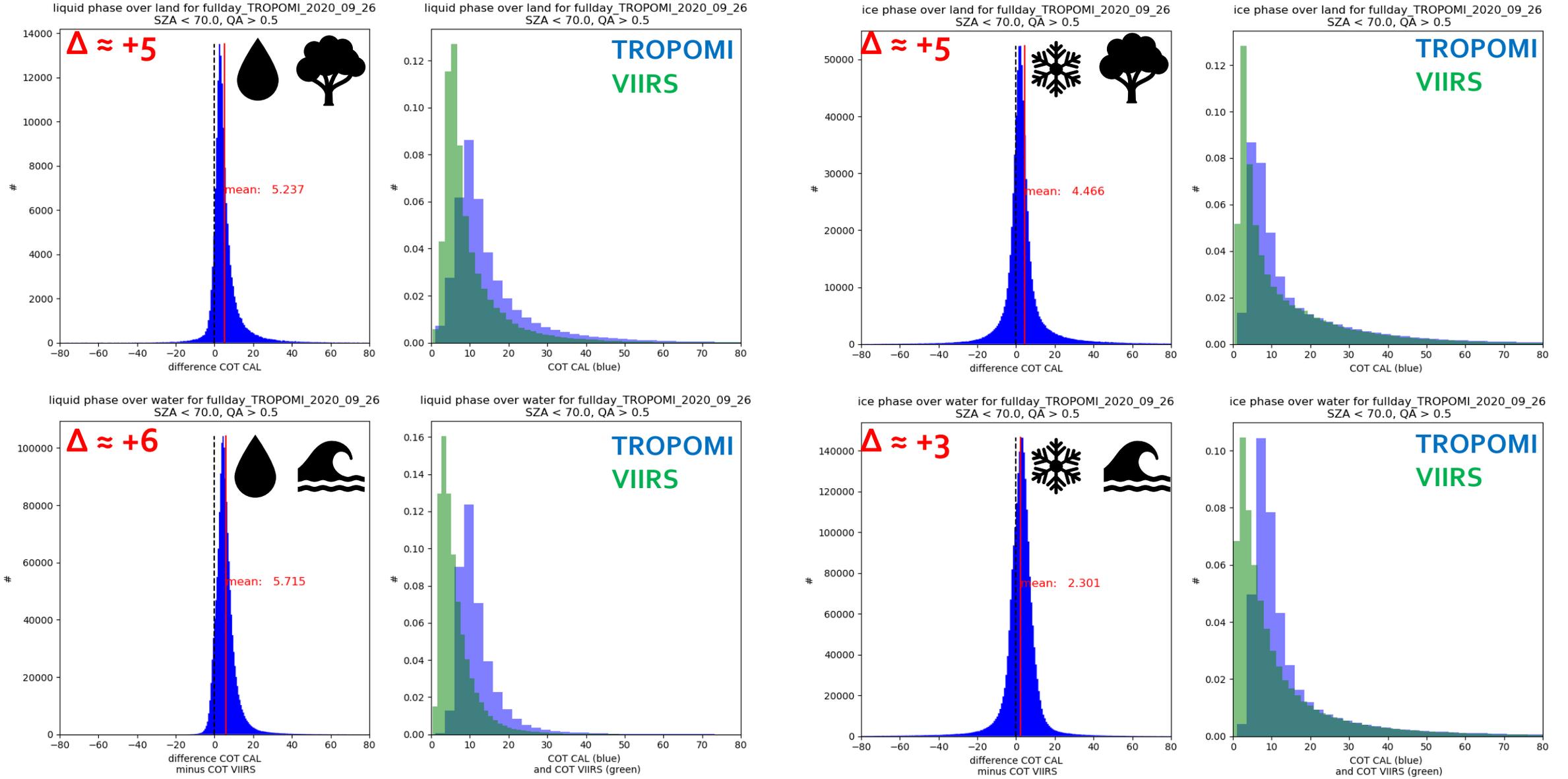
# Comparison with satellite data from VIIRS/S-NPP – Global – Cloud Optical Thickness
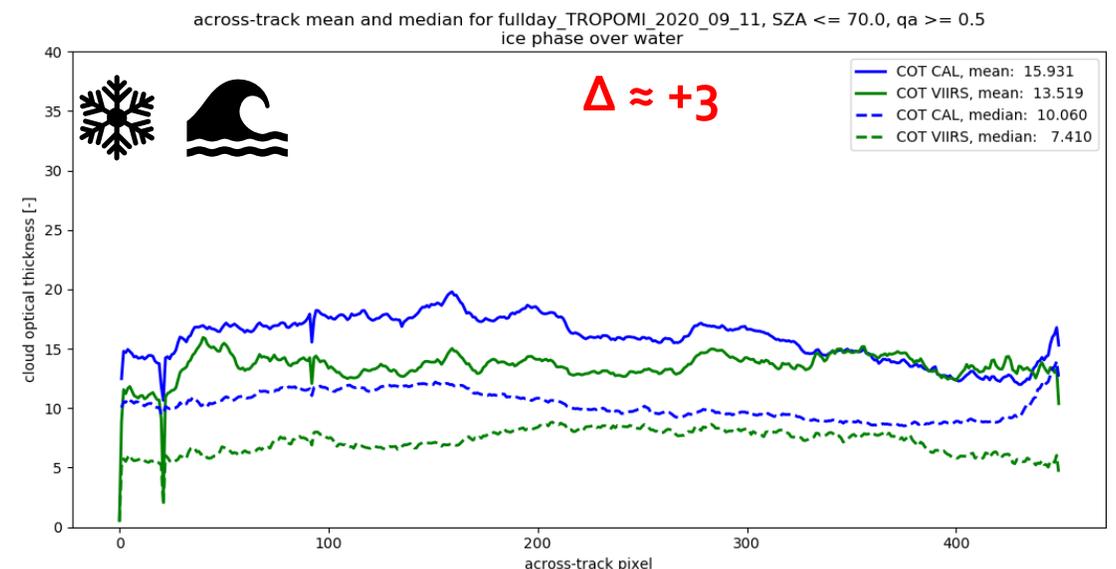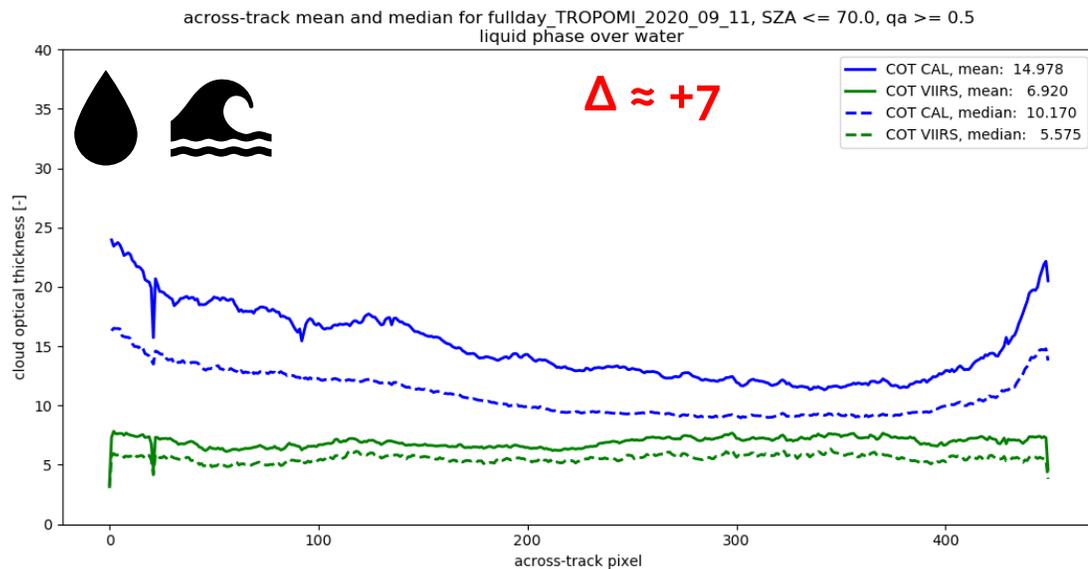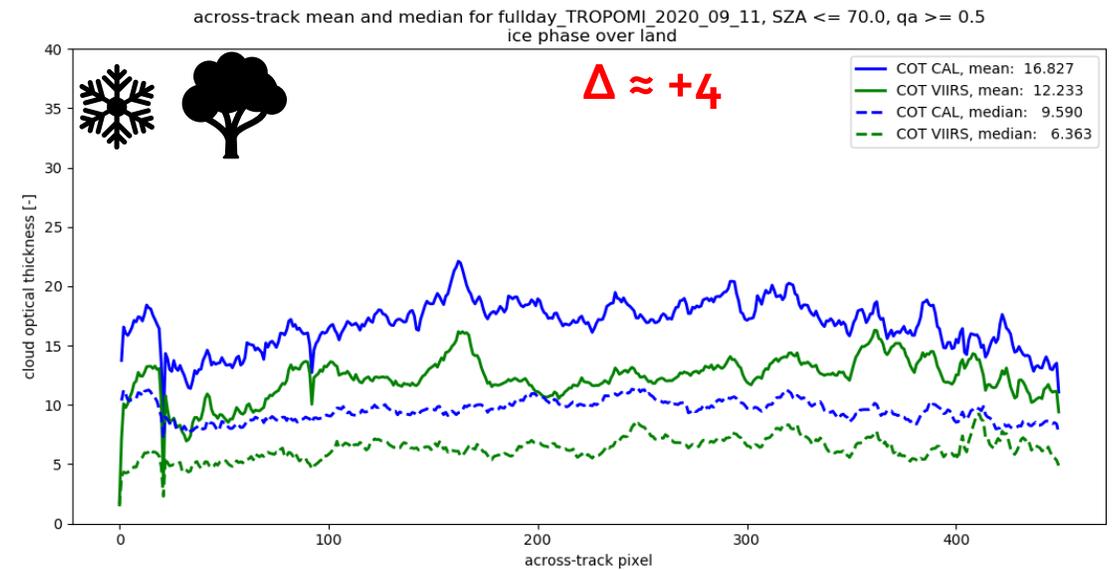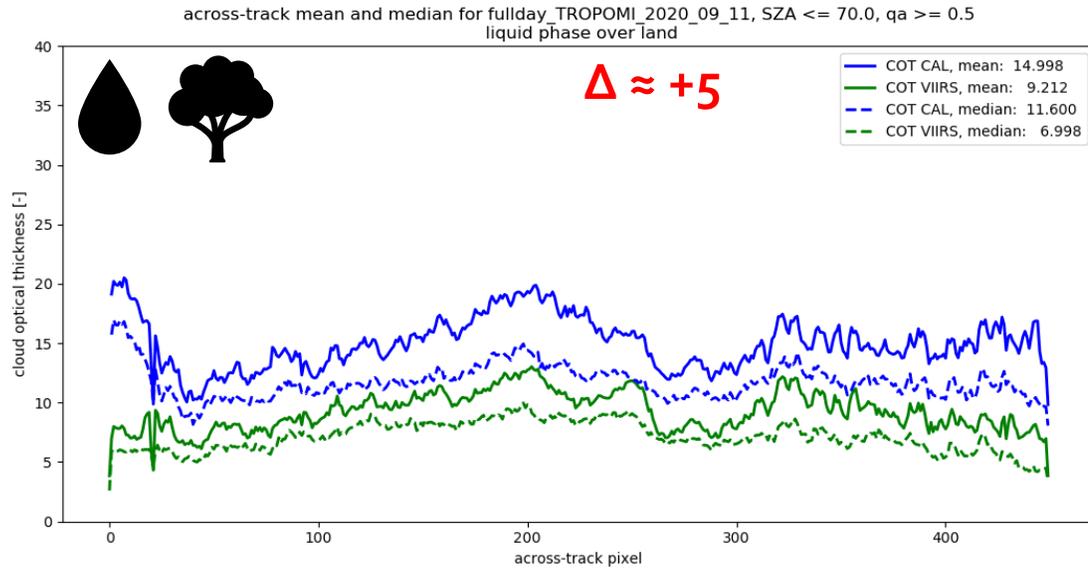
# Comparison with satellite data from VIIRS/S-NPP – Cloud masking

Compare OCRA/ROCINN and VIIRS cloud fractions as tool for cloud masking:

Assumption "clear": CF < 0.05

Assumption "cloudy": CF >= 0.05

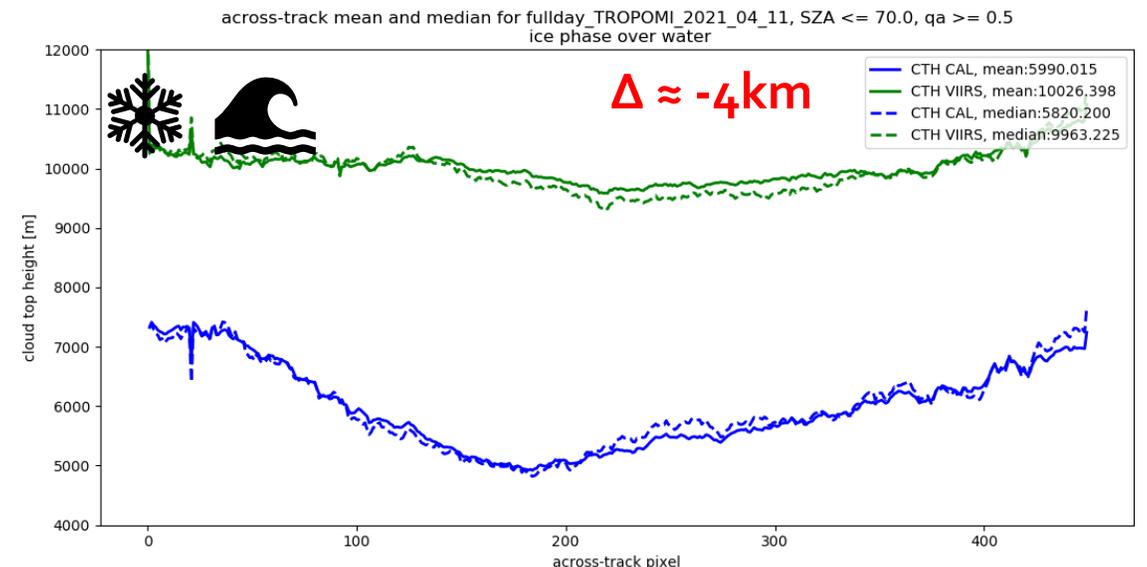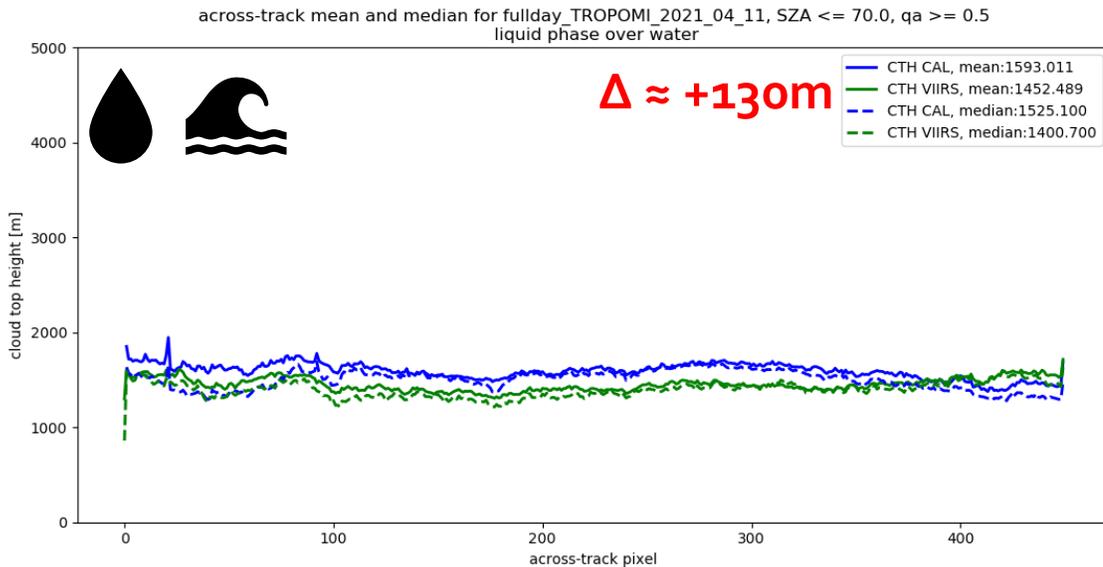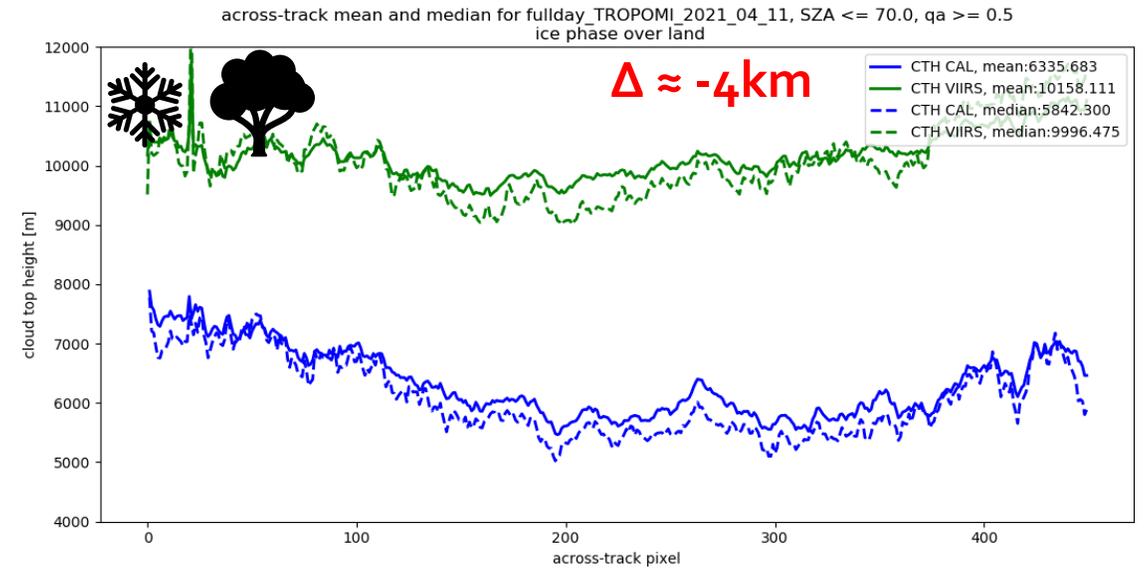For the global data, we find an agreement in **88%** of the cases assuming the threshold 0.05

| Cloud fraction threshold 0.05 | TROPOMI clear | TROPOMI cloudy |
|---|---|---|
| VIIRS clear | 24% True Positives | 5% False Negatives |
| VIIRS cloudy | 7% False Positives | 64% True Negatives |

→ Cloud fractions agree well when used for cloud masking

# Summary

– Cloud top heights agree better over water than over land for liquid clouds and in general much better for liquid phase clouds than for ice phase clouds. Mean differences TROPOMI minus VIIRS are:

| | liquid ph. over land | liquid ph. over water | ice phase over land | ice phase over water |
|---|---|---|---|---|
| 2018-09-09 | -373 m | +88 m | -3420 m | -3546 m |
| 2019-09-11 | -397 m | +78 m | -4010 m | -4020 m |
| 2020-09-11 | -311 m | +92 m | -3954 m | -3874 m |
| 2020-09-26 | -1044 m | -46 m | -3755 m | -3523 m |
| 2021-04-11 | -239 m | +123 m | -3856 m | -3967 m |
| 2021-09-11 | -542 m | +45 m | -3784 m | -4048 m |
| **Mean difference** | **-400 m** | **+80 m** | **-3800 m** | **-3830 m** |

# Summary

– Cloud optical thickness of TROPOMI is in general larger as for VIIRS, irrespective of surface type and cloud phase. Mean differences TROPOMI minus VIIRS are:

| | liquid ph. over land | liquid ph. over water | ice phase over land | ice phase over water |
|---|---|---|---|---|
| 2018-09-09 | +5.9 | +5.5 | +3.7 | +1.9 |
| 2019-09-11 | +7.9 | +5.7 | +3.7 | +2.3 |
| 2020-09-11 | +5.3 | +7.7 | +4.5 | +2.1 |
| 2020-09-26 | +5.2 | +5.7 | +4.5 | +2.3 |
| 2021-04-11 | +4.8 | +5.4 | +2.3 | +2.7 |
| 2021-09-11 | +6.4 | +5.7 | +4.6 | +1.9 |
| **Mean difference** | **+5.9** | **+6.0** | **+3.9** | **+2.2** |

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# Conclusion and Outlook

Conclusion

- **OCRA/ROCINN** is running succesfully for several LEO missions in an **operational environment**

- several **features** have been **added** and evolved during the last 5 years of the S5P operational phase

- comparisons with the **VIIRS** cloud product look very **good for liquid phase** clouds

- larger **differences** appear **for ice phase** clouds due to lack of an ice cloud parameterisation in ROCINN_CAL

- usage for **cloud masking** is very consistent (88% agreement)

Outlook

- work on **ice cloud parameterisation** for ROCINN_CAL

*Thank you for your attention!*

**DLR-Atmos:**

*https://atmos.eoc.dlr.de/calendar*

**Interested in quicklooks and L3 data?**
**Check the INPULS project:**

*https://atmos.eoc.dlr.de/inpuls/*