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

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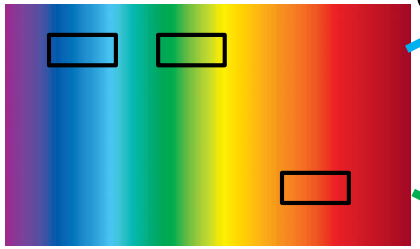
Sentinel-5P: 5 Years Anniversary
Taormina, Italy
13 October 2022

OCRA & ROCINN – Algorithm Overview

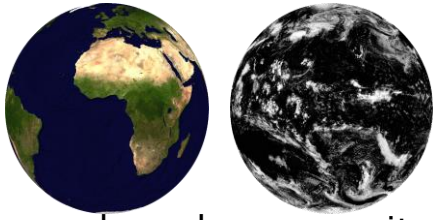
OCRA
Optical Cloud Recognition Algorithm



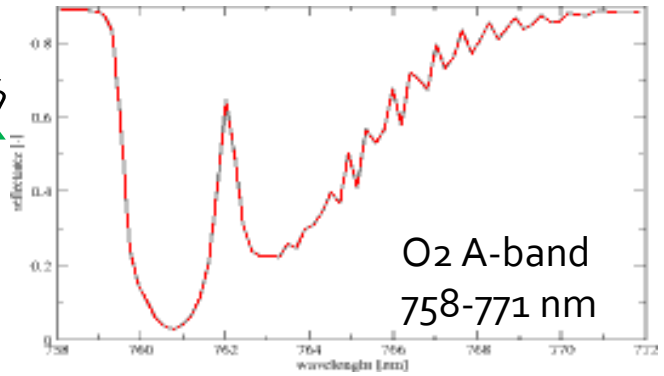
ROCINN
Retrieval of Cloud Information using Neural Networks

color space approach

neural network approach

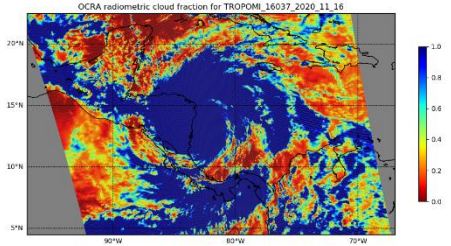


clear-sky composite

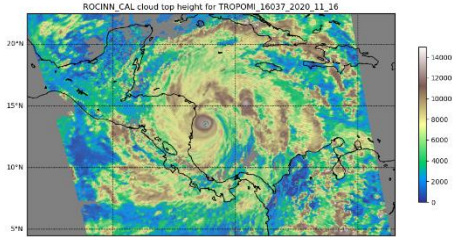


CAL
Clouds as layers

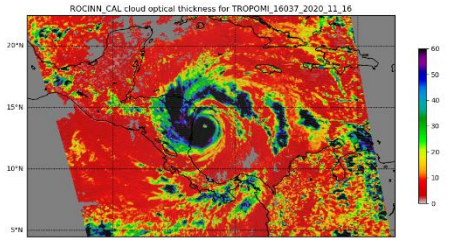
CRB
Clouds as reflecting boundaries



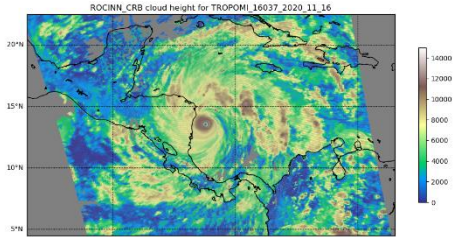
Radiometric cloud fraction



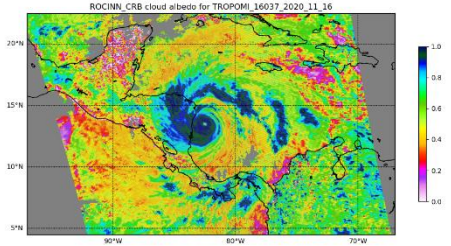
cloud top height



cloud opt. thickness



eff. cloud height

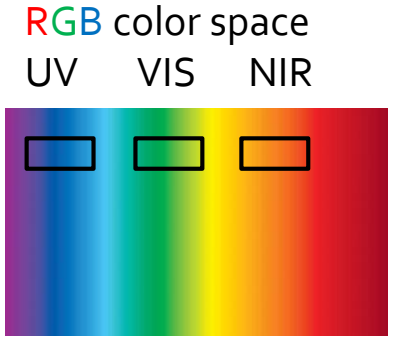


eff. cloud albedo

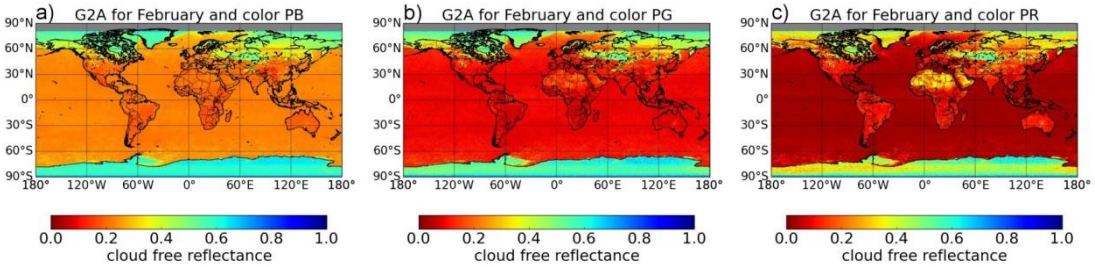
Hurricane Iota
©NASA worldview

OCRA Overview

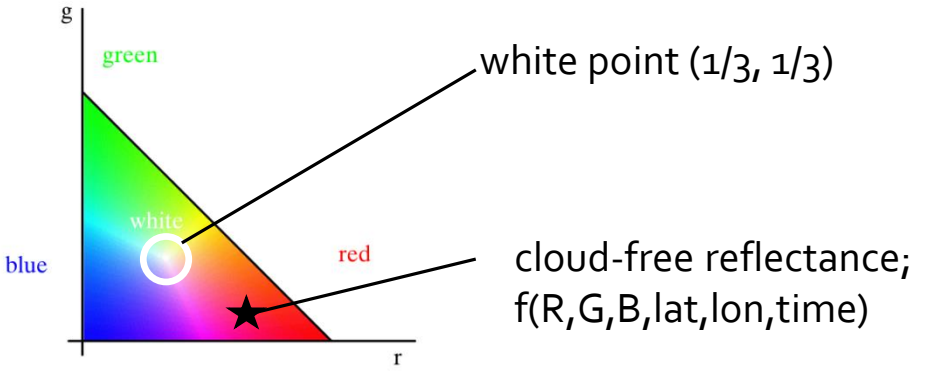
- map measured reflectances to RGB color space



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



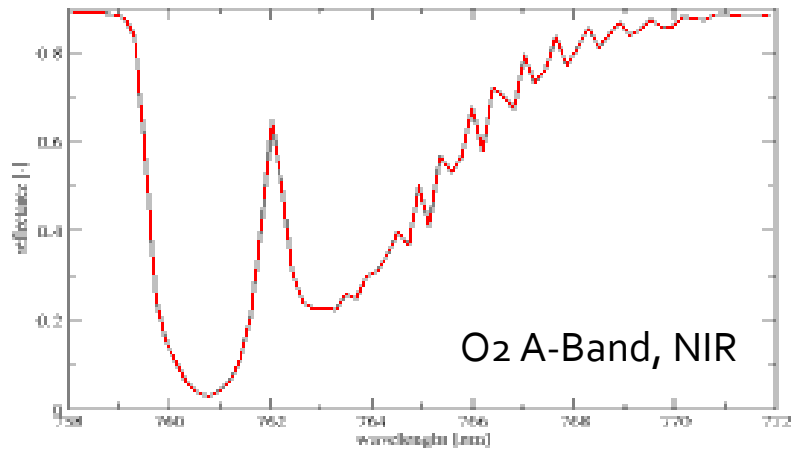
- assume a cloud to be „white" in RGB
  - white point defines fully cloudy condition



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

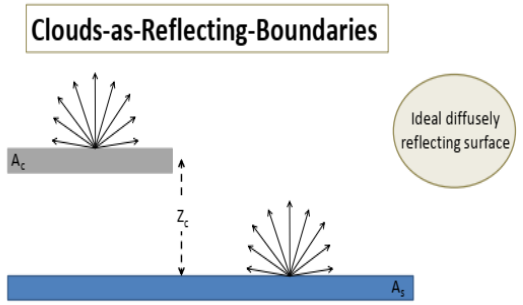
Lutz et al. (2016): OCRA radiometric cloud fractions for GOME-2 on MetOp-A/B, Atmos. Meas. Tech., 9, 2357-2379, https://doi.org/10.5194/amt-9-2357-2016

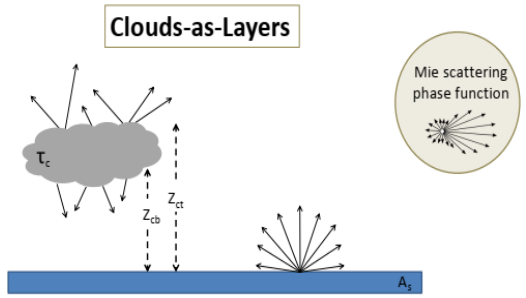
ROCINN Overview



Fitting window: [758-771] nm

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



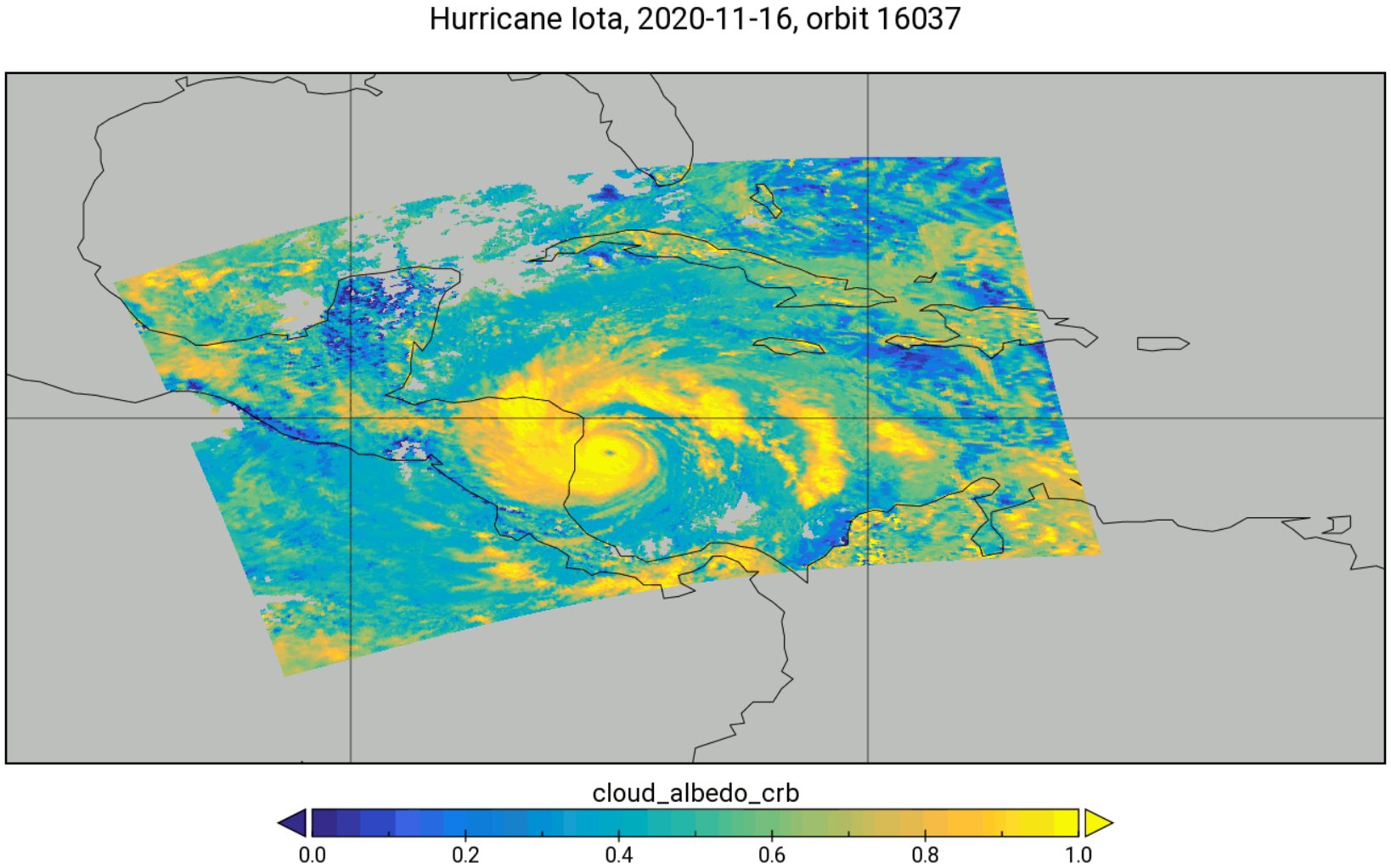


- Usage of neural networks and machine learning techniques

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!**

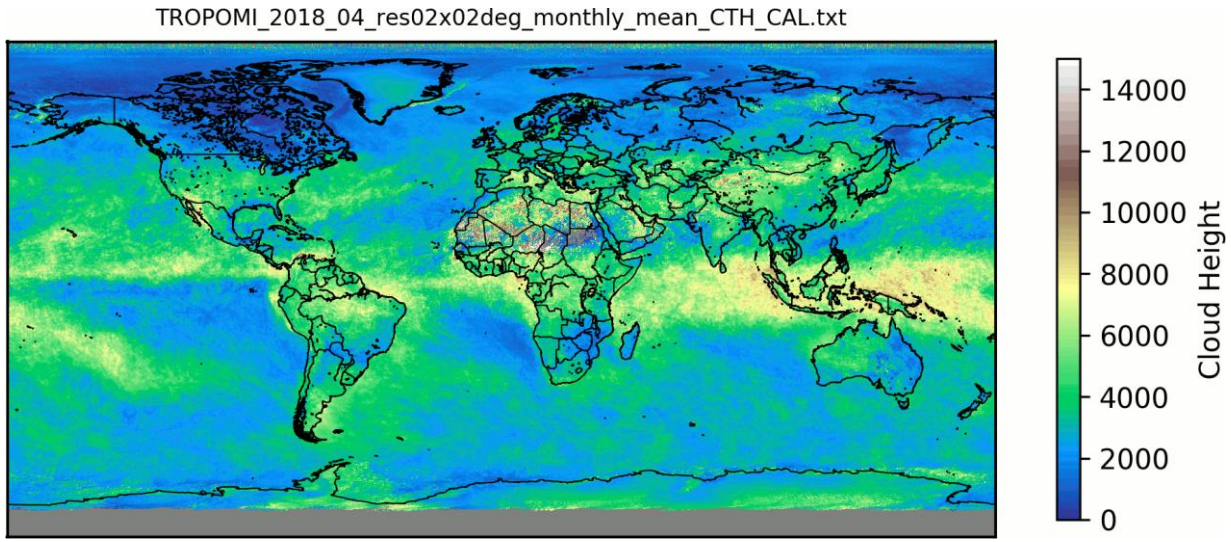
Loyola et al. (2018): The operational cloud retrieval algorithms from TROPOMI on board Sentinel-5 Precursor, Atmos. Meas. Tech., 11, 409-427. https://doi.org/10.5194/amt-11-409-2018
Loyola et al. (2016): Smart sampling and incremental function learning for very large high dimensional data, Neural Networks,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

S5P – operational cloud products

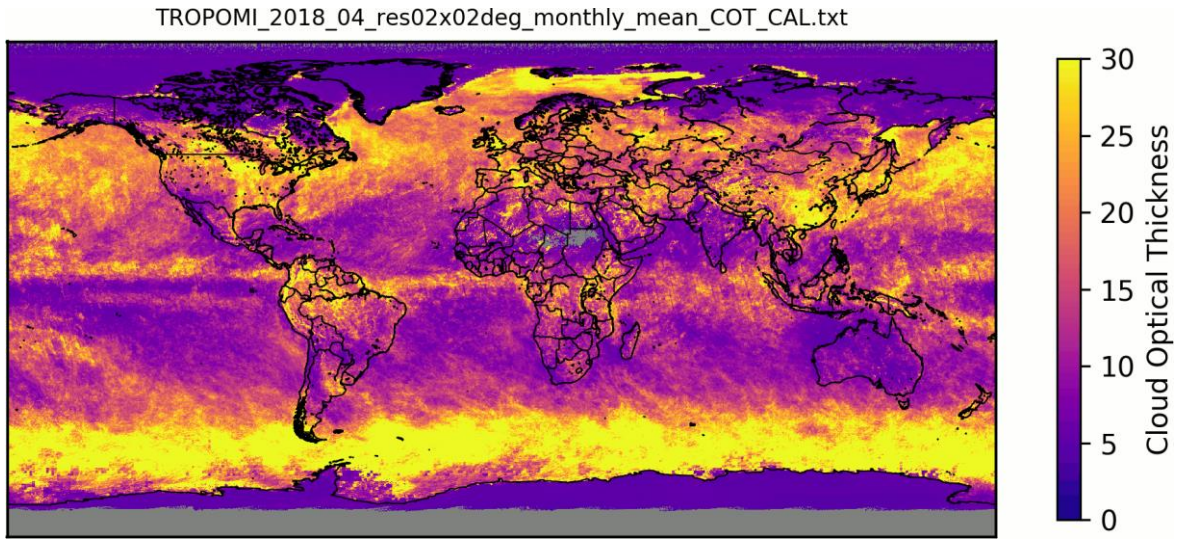


Hurricane Iota
©NASA worldview

S5P – yearly temporal evolution



ROCINN CAL cloud top height

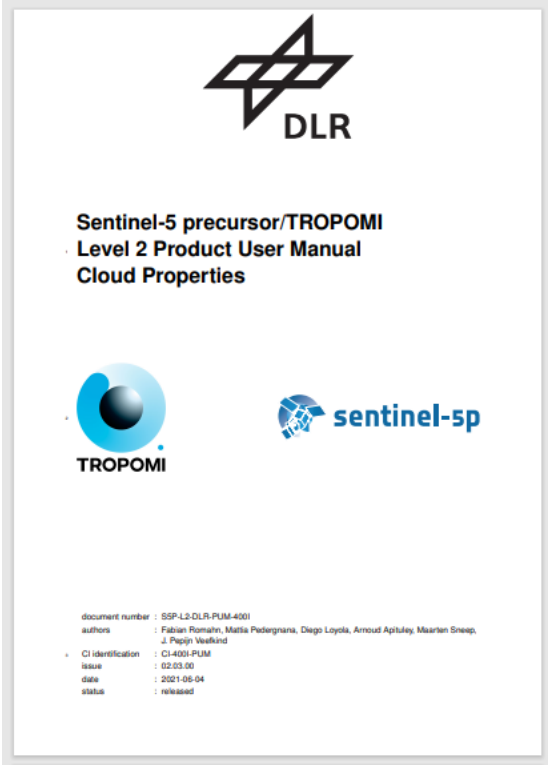


ROCINN CAL cloud optical thickness

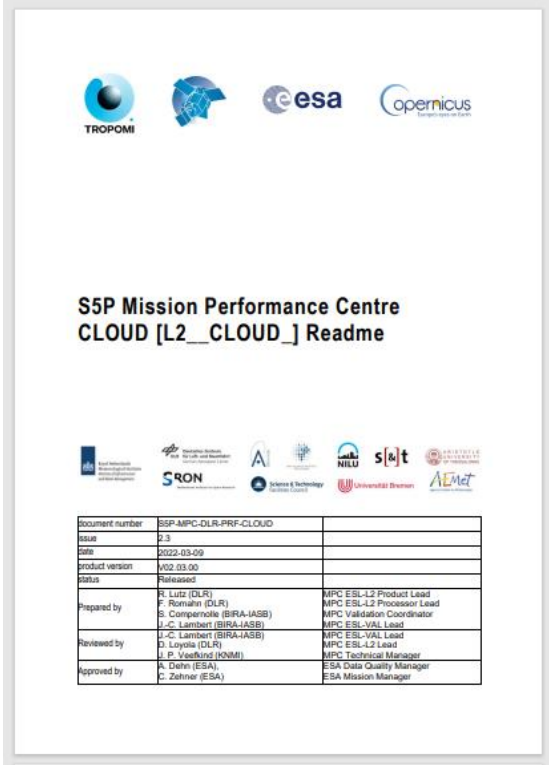
OCRA & ROCINN – documentation

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

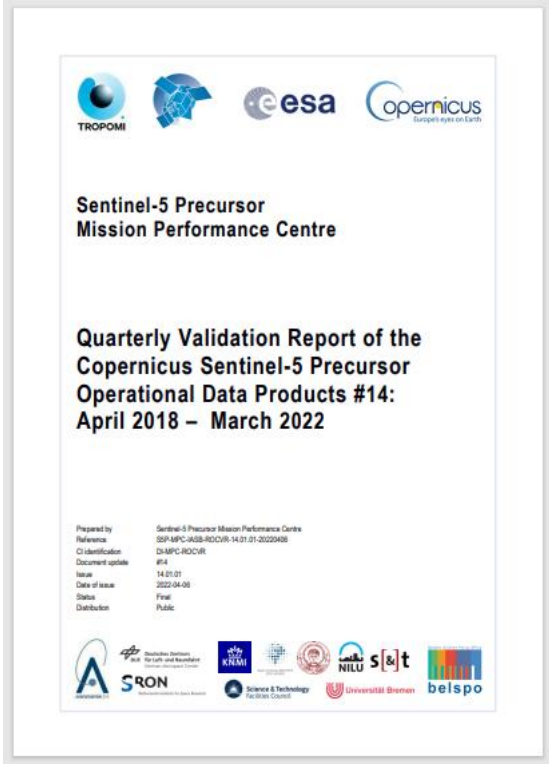
ATBD



PUM



PRF



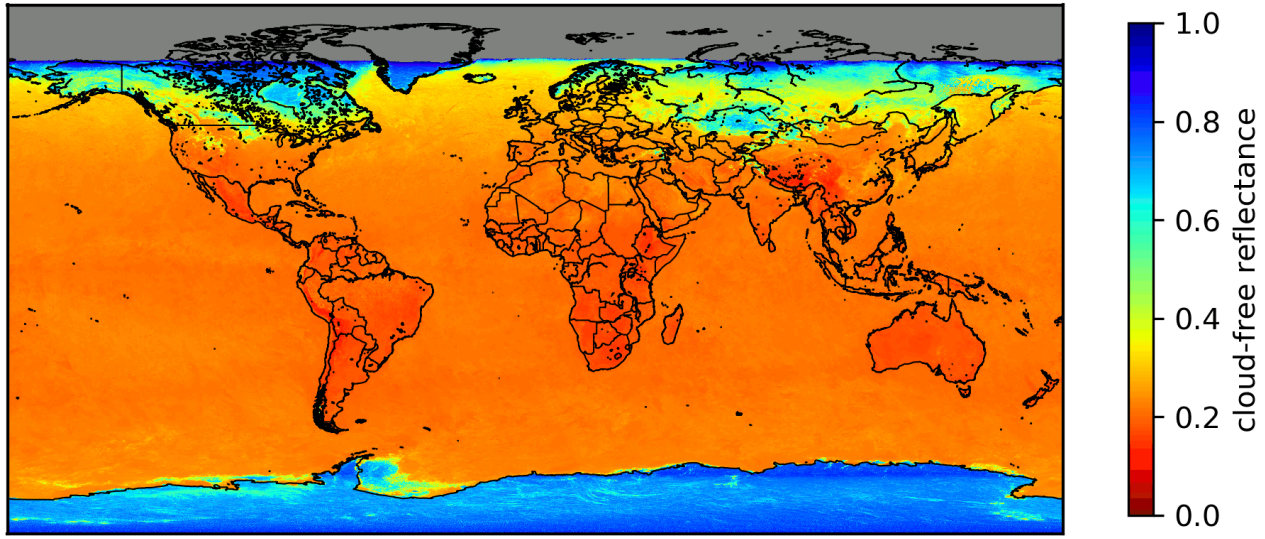
ROCVR

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

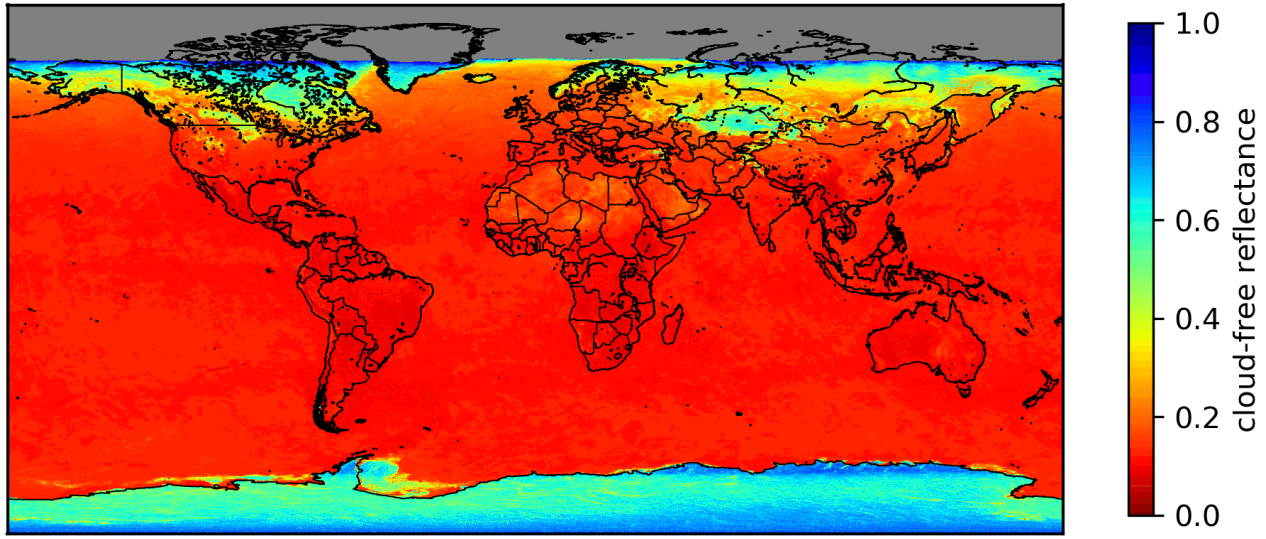
→ this improved the cloud fraction retrieval, particularly at low cloud coverages

TROPOMI_01_monthly_cloudfree_res02x02deg_3years_mincol_B.txt



OCRA blue channel

TROPOMI_01_monthly_cloudfree_res02x02deg_3years_mincol_G.txt

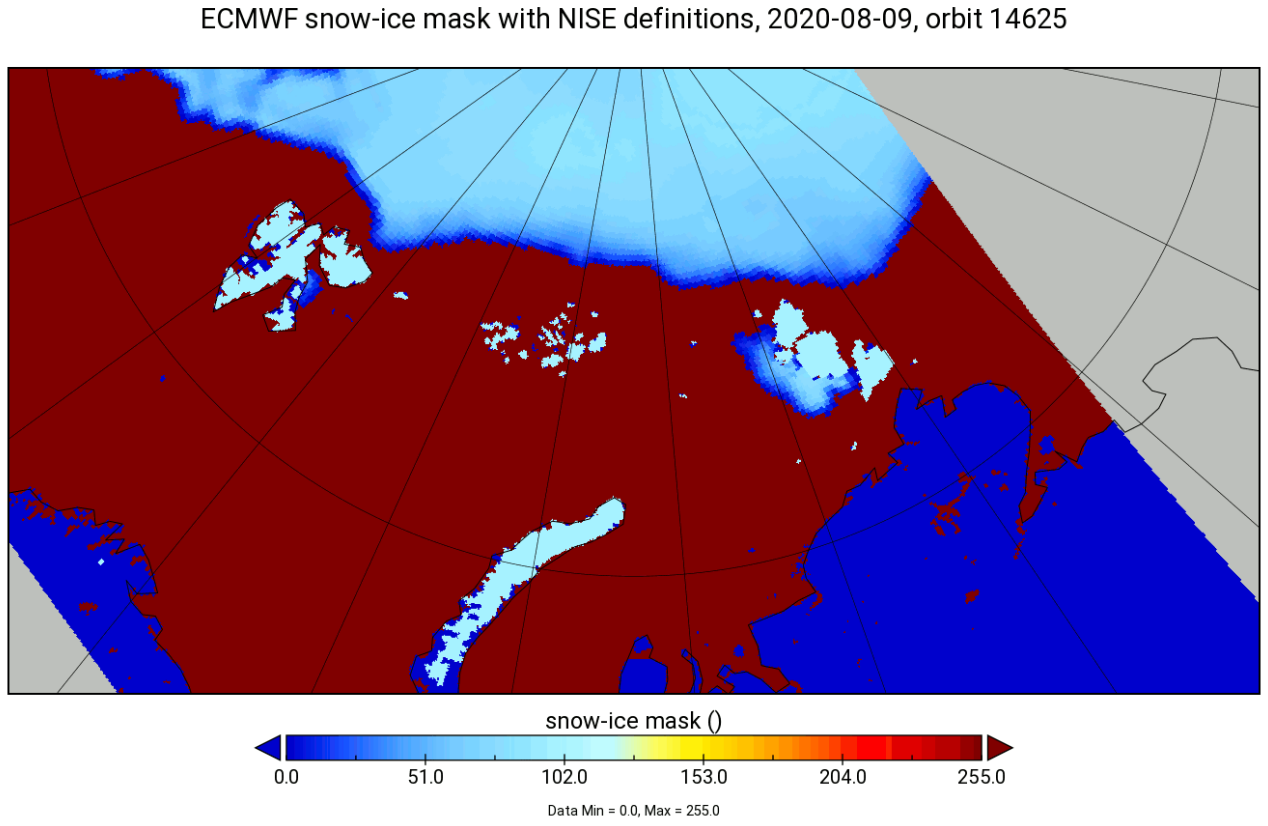


OCRA green channel

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



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

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

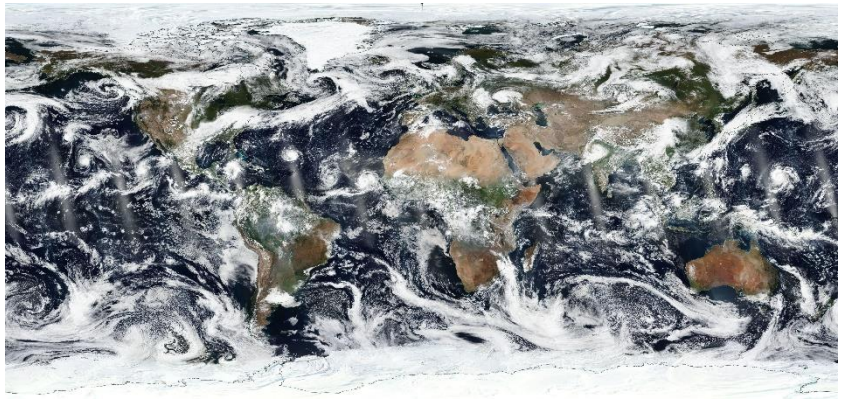
Validation with satellite data

- 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 %)

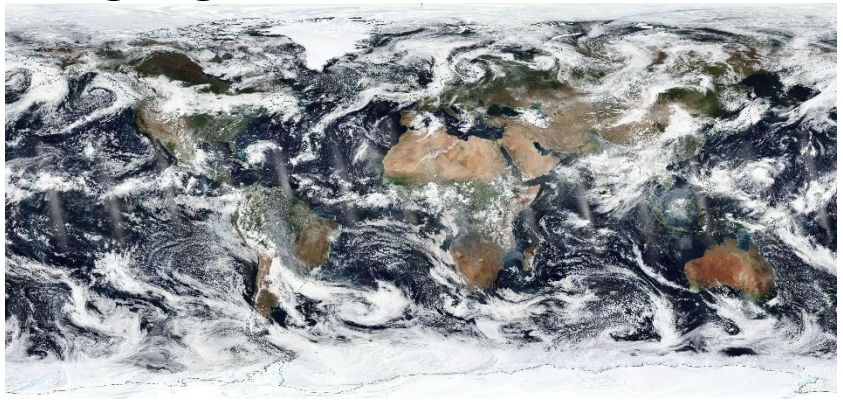
Comparison with satellite data from VIIRS/S-NPP – Global

SZA < 70°, qa > 0.5, most recent UPAS version 2.4

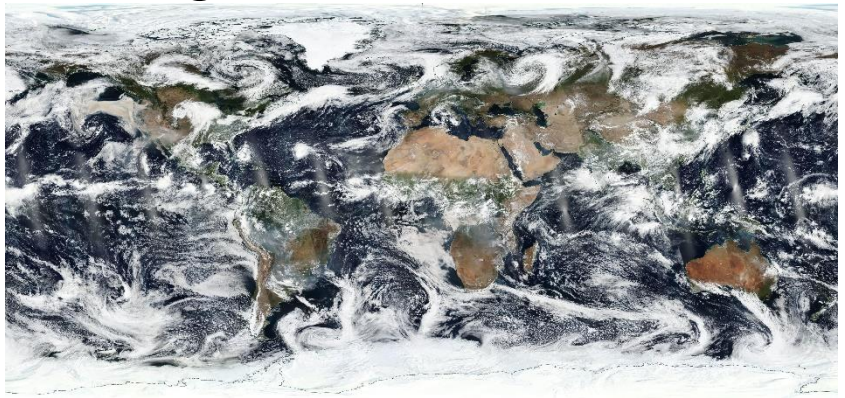
2018-09-09



2019-09-11



2020-09-11



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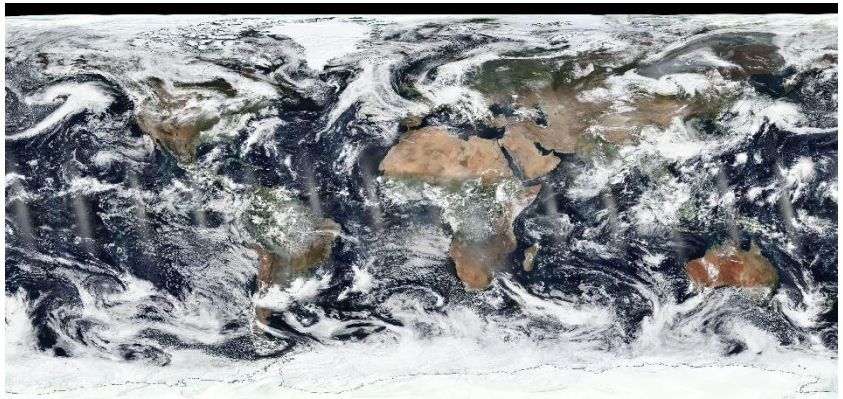
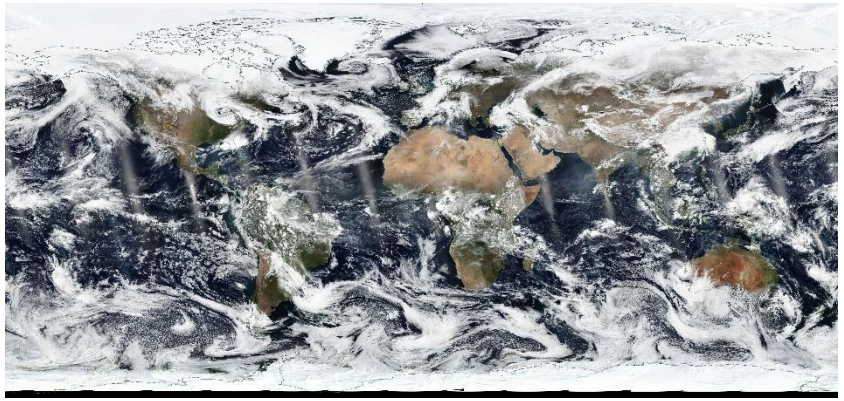


2021-04-11



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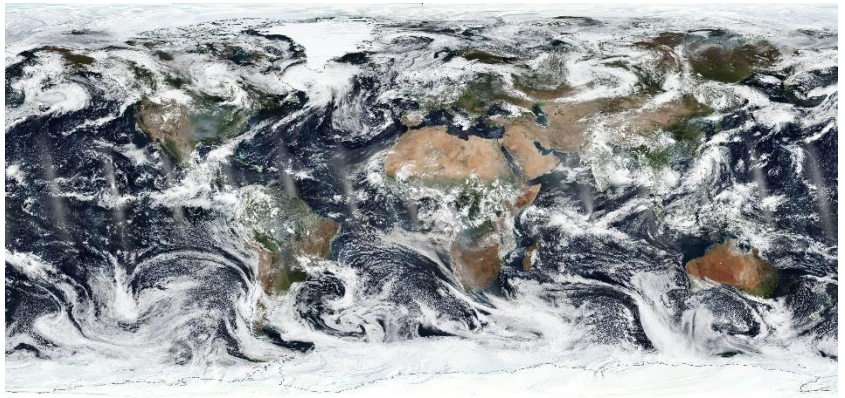
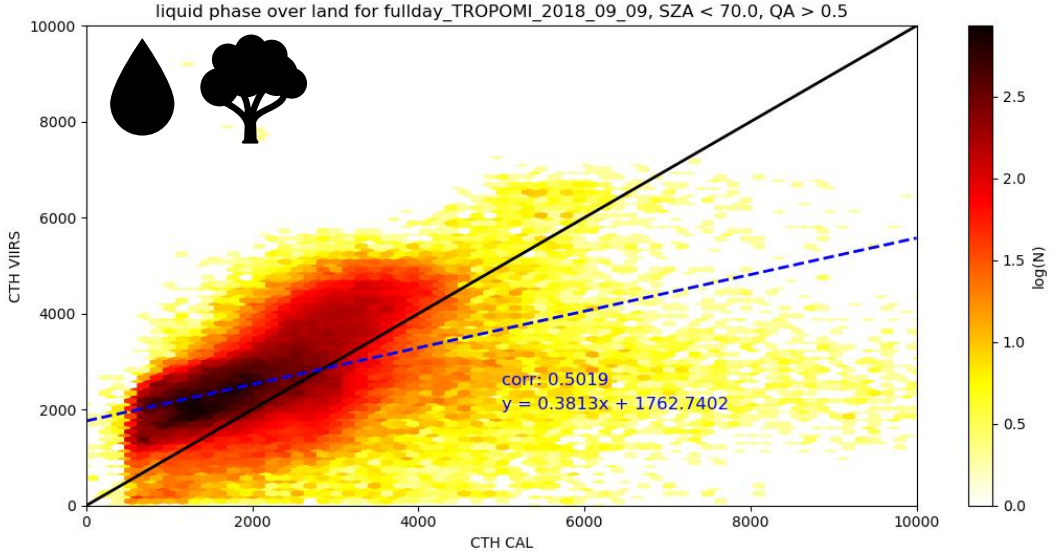
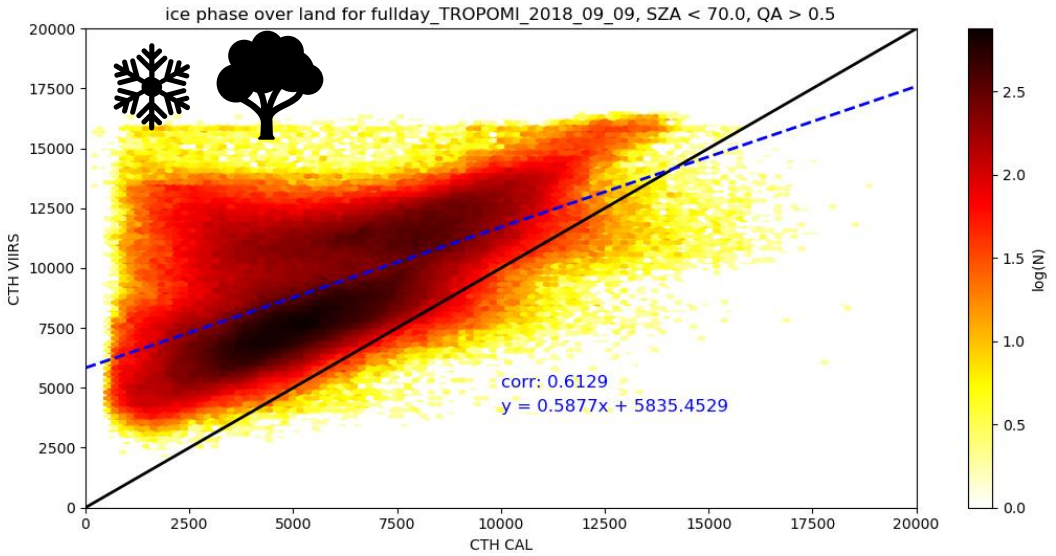
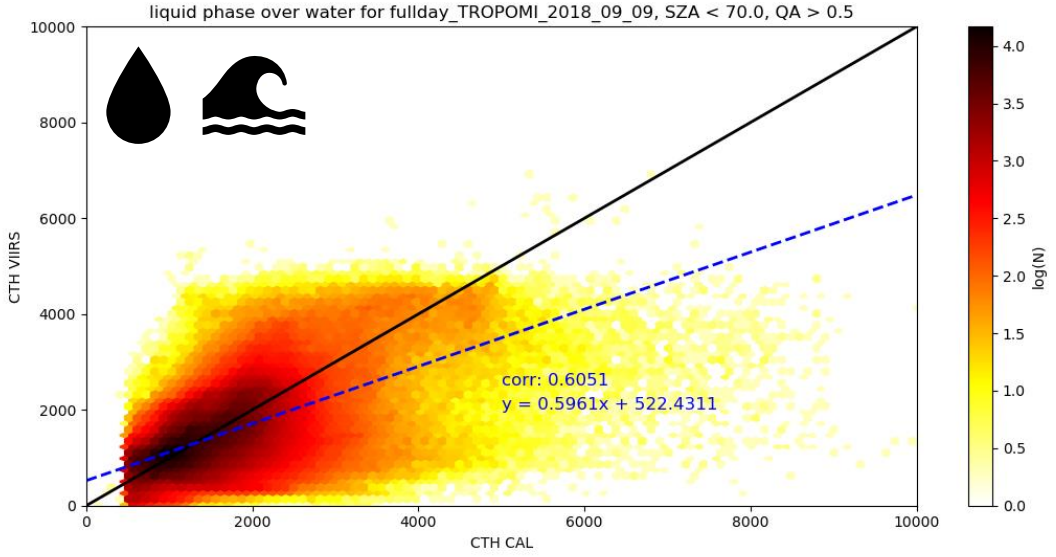
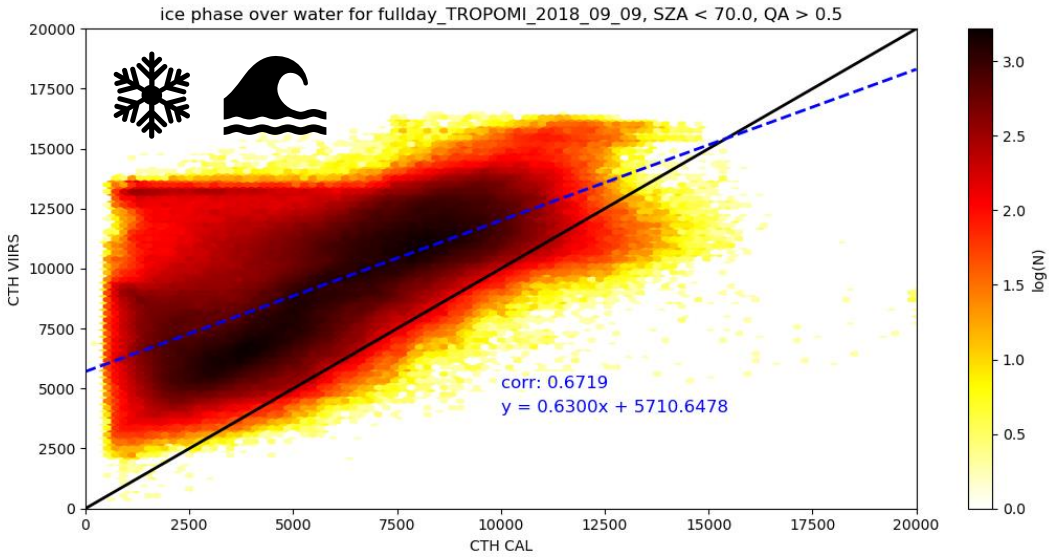


Comparison with satellite data from VIIRS/S-NPP – Global – Cloud Top Height

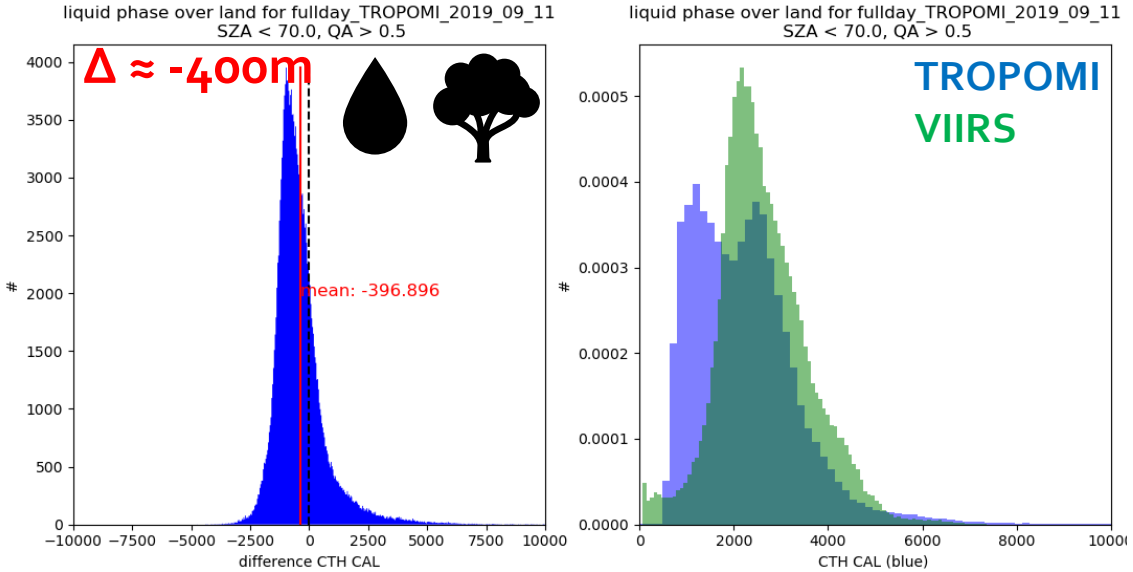


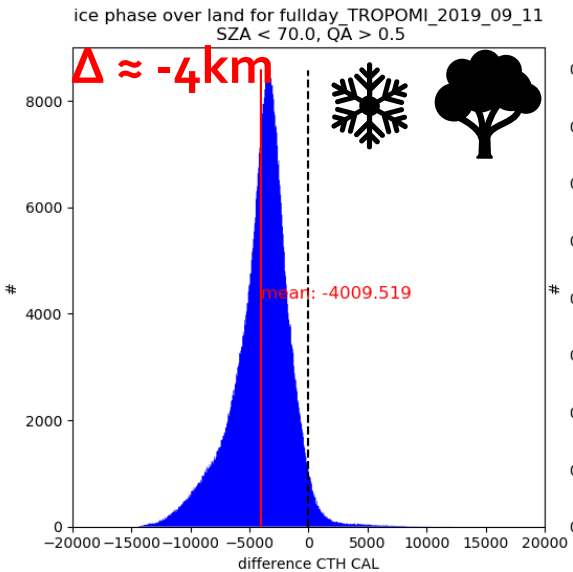


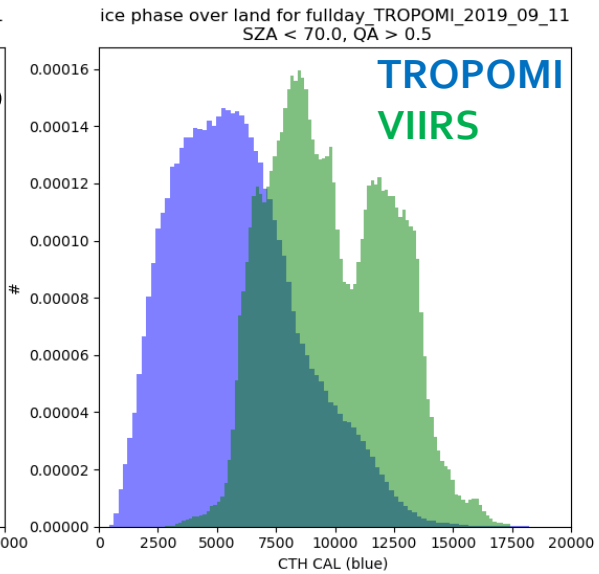


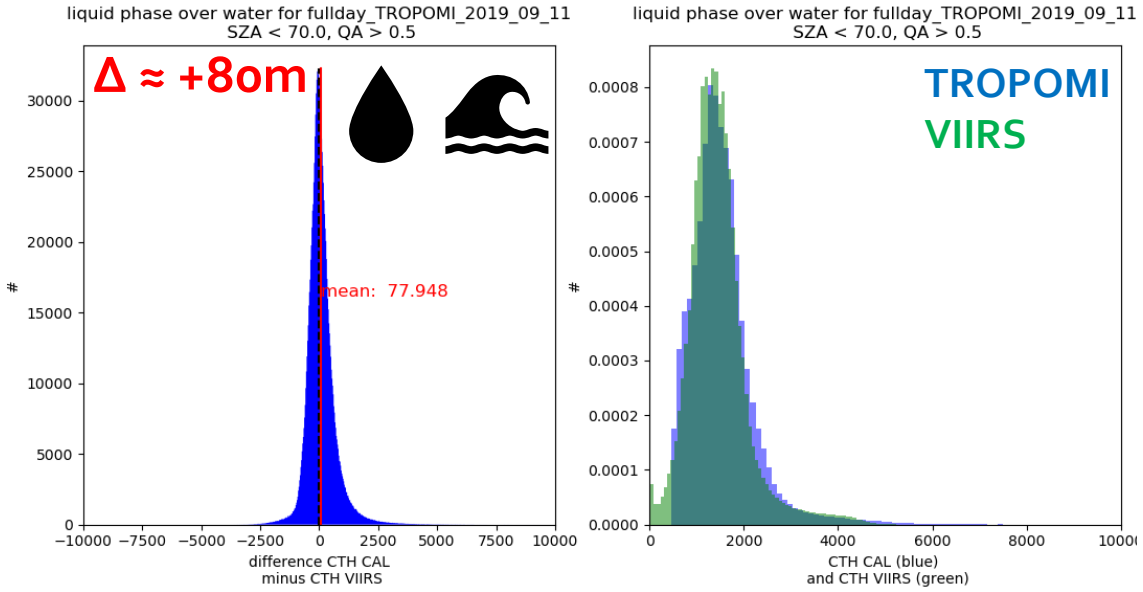


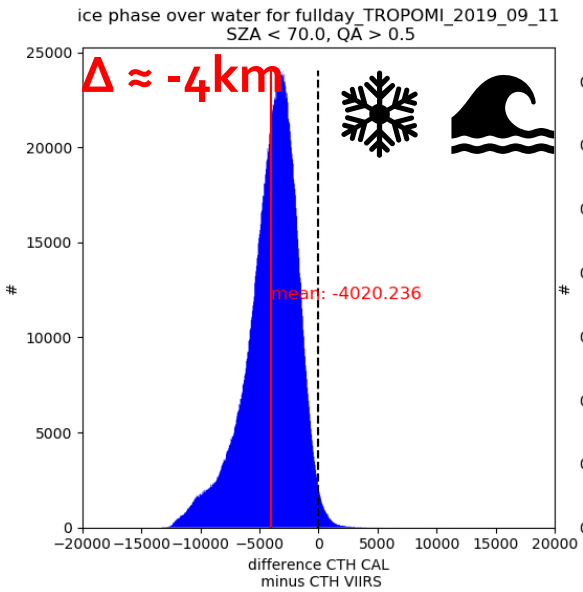
Comparison with satellite data from VIIRS/S-NPP – Global – Cloud Top Height

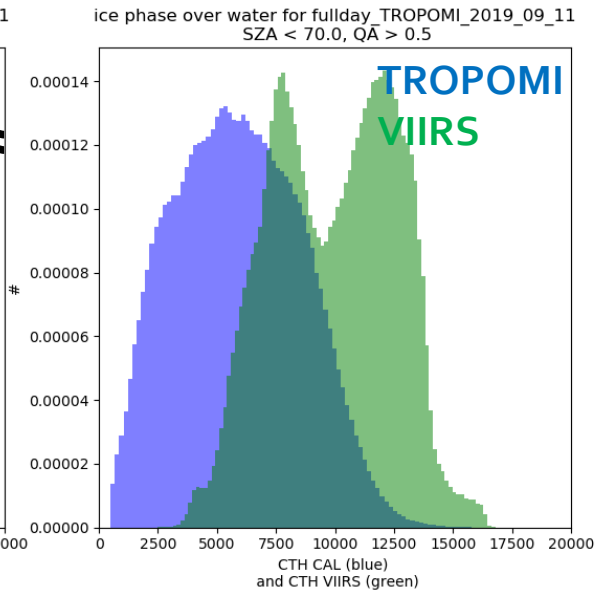




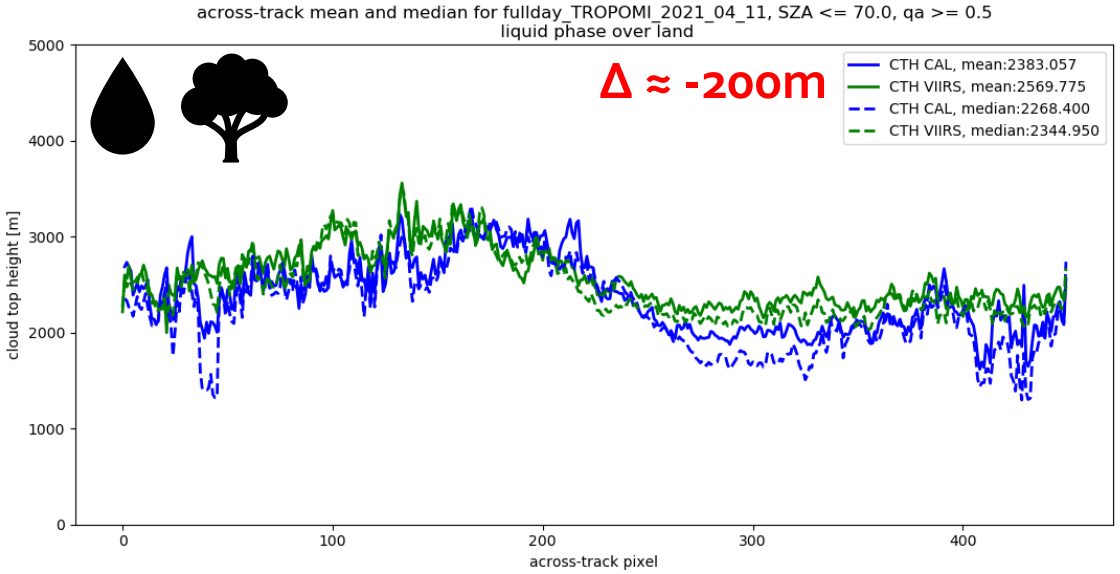


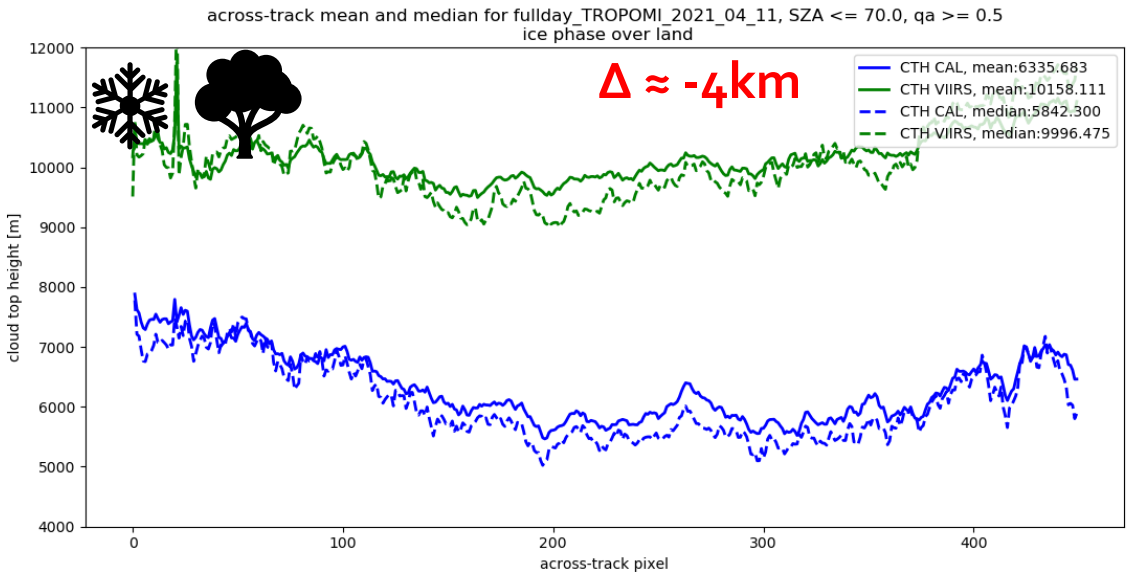


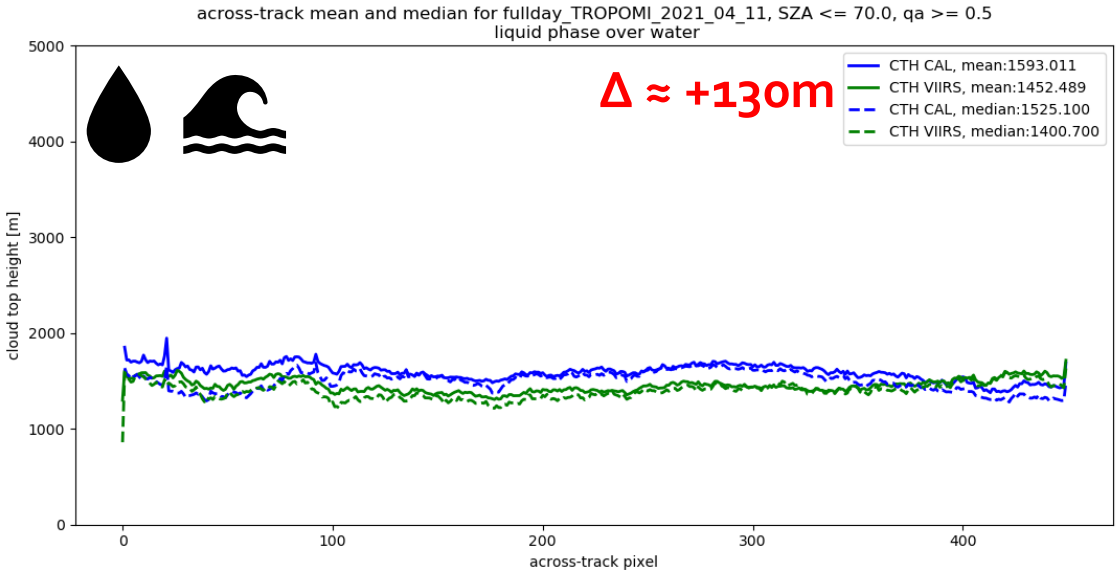


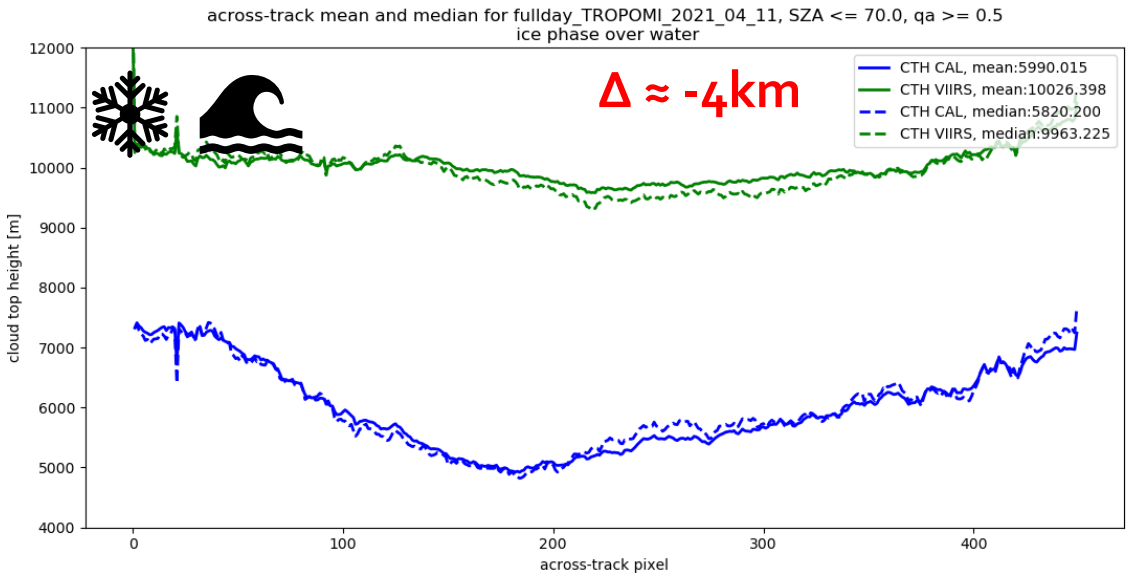


Comparison with satellite data from VIIRS/S-NPP – Global – Cloud Top Height

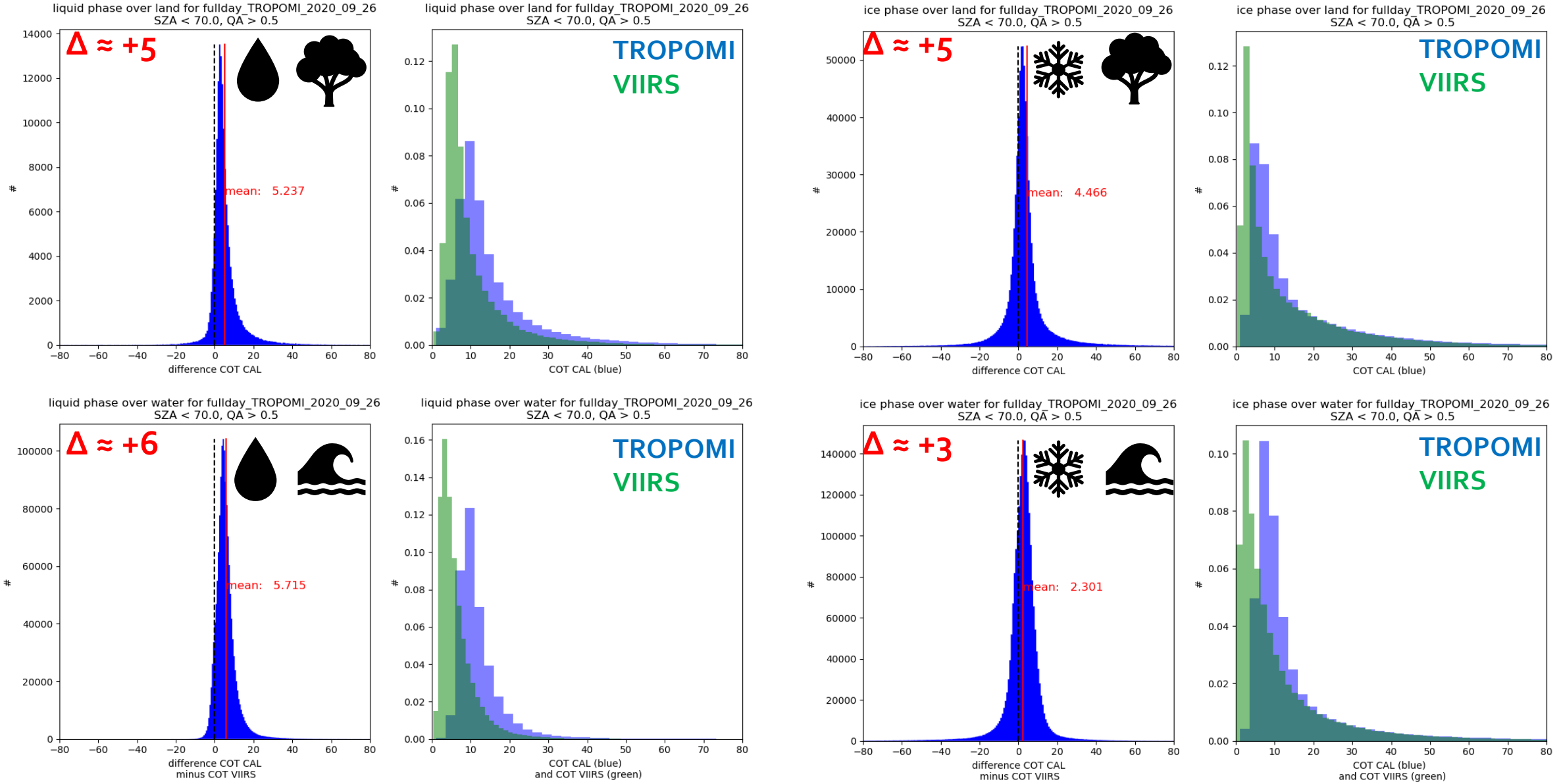




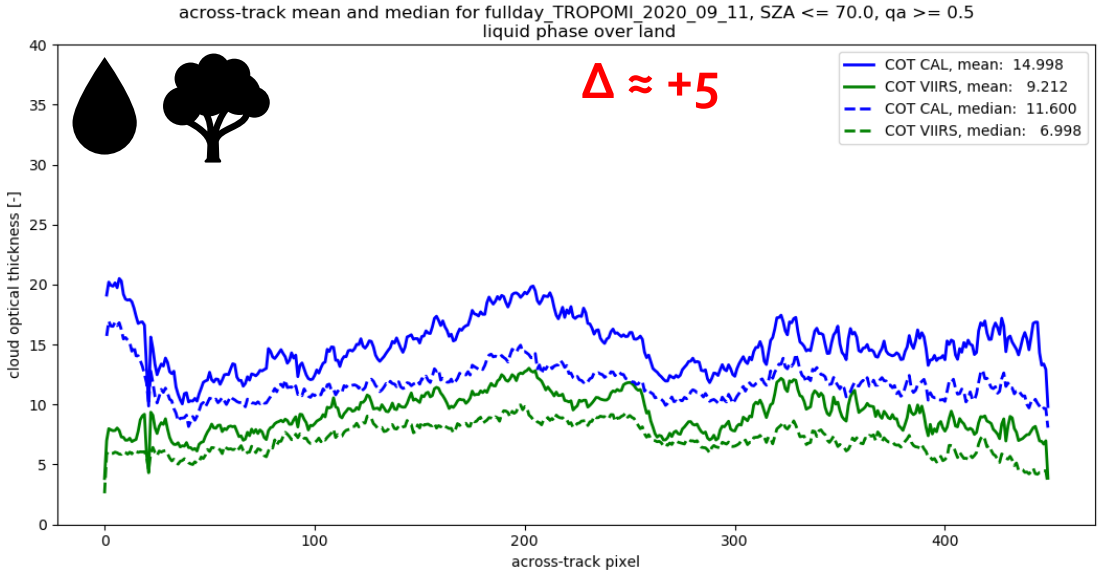


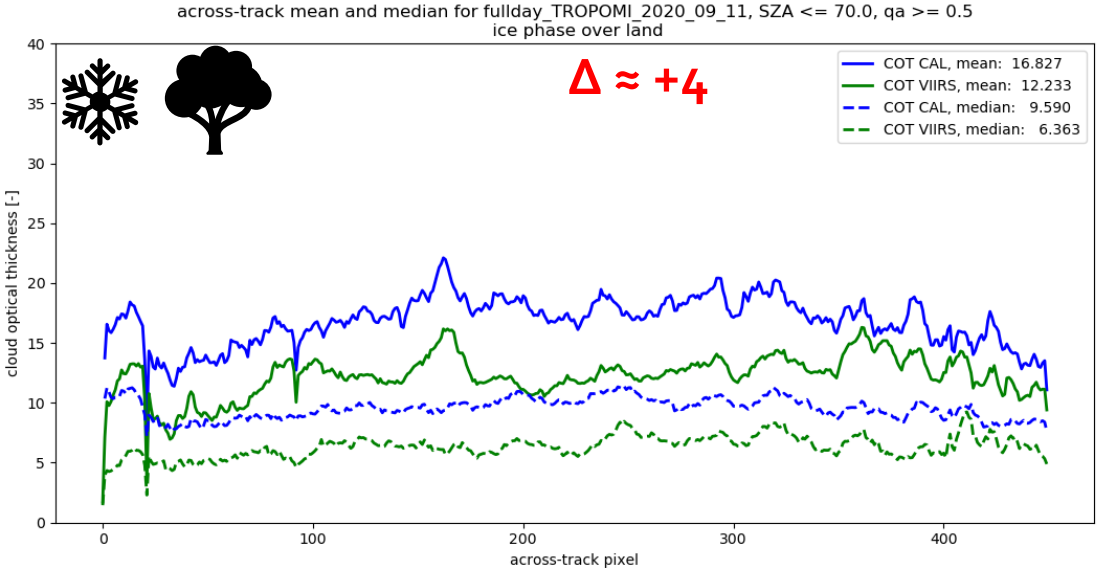


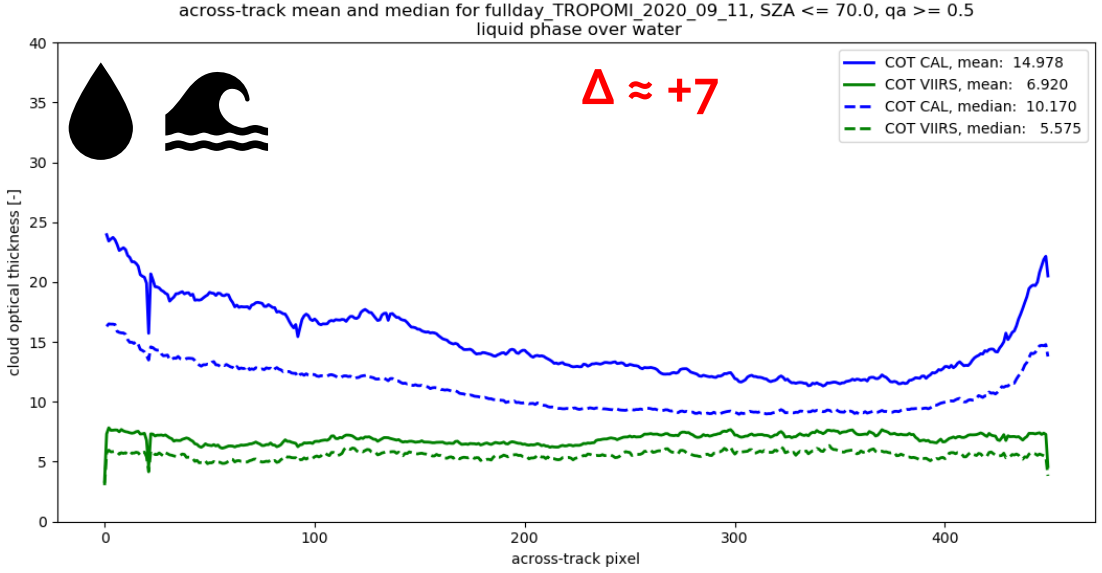
Comparison with satellite data from VIIRS/S-NPP – Global – Cloud Optical Thickness

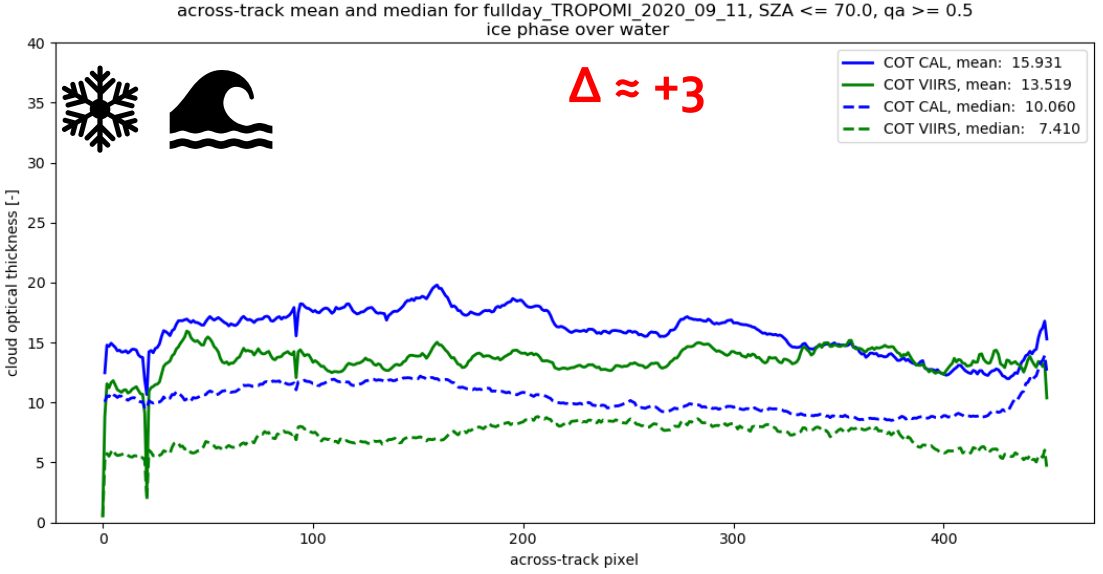


Comparison with satellite data from VIIRS/S-NPP – Global – Cloud Optical Thickness









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**

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!

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