# Supplement to "Validation of the Sentinel-5 Precursor TROPOMI cloud data with Cloudnet, Aura OMI O <sub>2</sub>-O<sub>2</sub>, MODIS and Suomi-NPP VIIRS"

#### S1 Geographical patterns: supplementary material

## S1.1 S5P OCRA/ROCINN

5 In addition to the material from Section 4.1.1, we here include more examples of artificial geographical patterns for S5P OCRA/ROCINN. Fig. S1 presents the enhanced cloud fraction at the east swath edge, and Fig. S2 the North-South gradient in S5P OCRA/ROCINN\_CRB cloud albedo.



**Figure S1.** S5P OCRA CF of parts of orbits 03614, 03615, 03616 and 03617 on 2018-06-25 for the released product S5P CLOUD OFFL 1.1.5 (left) and the to-be-released S5P CLOUD version 2 (right). Note the sharper contrast in CF at an orbit edge for the released version.



**Figure S2.** S5P ROCINN\_CRB albedo for all orbits within the day 2019-08-08 for the released product CLOUD OFFL 1.1.7 (left) and the to-be-released S5P CLOUD version 2 (right). Note the higher North-South gradient for the released version.

## S1.2 S5P FRESCO

As addition to Section 4.1.2, we include here more material.



**Figure S3.** S5P ALH RPRO 1.3.1 aerosol altitude offset, for the same orbit and place as in Fig. 4: orbit 7062 at 2019-02-23, 1200x1200 km<sup>2</sup> square centered at  $38^{\circ}$ N,  $120^{\circ}$ E.

#### S2 Comparison of zonal means: supplementary material

This section contains supplementary material for section 4.2.



Figure S4. Similar as 6, but for days 2020-01-25 and 2020-03-29.



Period: Apr. 2018, Number of days: 30

**Figure S5.** Zonal means for S5P OCRA/ROCINN\_CAL (blue) and MODIS (green). The comparison refers to data from April 2018 (MODIS cloud fraction is a geometrical cloud fraction whereas the S5P OCRA cloud fraction is a radiometric one).

#### S3 Comparison between S5P OCRA/ROCINN\_CAL and NPP VIIRS: supplementary material

This section contains extra material for Section 4.3.



Figure S6. S5P OCRA/ROCINN\_CAL effective COT (left) and VIIRS COT (right), for orbit 01080.



**Figure S8.** Histograms of the CTH for S5P OCRA/ROCINN\_CAL and VIIRS. Top: only clouds over land are considered. For S5P OCRA/ROCINN\_CAL mean and standard deviation is  $5.0 \pm 3.3$  km and for VIIRS it is  $7.5 \pm 3.8$  km. Bottom: Only clouds over water are considered: For S5P OCRA/ROCINN\_CAL mean and standard deviation is  $3.5 \pm 2.8$  km and for VIIRS it is  $4.9 \pm 4.0$  km.



Figure S7. Box plots for the COT and CTH of S5P OCRA/ROCINN\_CAL (top) and re-gridded NASA VIIRS (bottom). The dataset consists of orbits from 6 complete days.



Figure S9. Taylor diagram for CTH and COT. The complete dataset of 6 days is considered.

Table S1. Clouds classified according to the ISCCP scheme. The bias is shown for the two cloud quantities. In brackets, the mean values for both sensors are included.

Low-level	Cumulus		Stratocumulus		Stratus		
	Land [2.5%]	Water [13%]	Land [10%]	Water [32%]	Land [3.4%]	Water [3.5%]	
COT[]	+0.1	+0.5	+2.4	+5.6	+1.7	+11.2	
	[VIIRS 2.3,	[VIIRS 2.3,	[VIIRS 10.7,	[VIIRS 9.6,	[VIIRS 38.8,	[VIIRS 33.5,	
	TROPOMI	TROPOMI	TROPOMI	TROPOMI	TROPOMI	44.7]	
	2.4]	2.8]	13.1]	15.2]	40.5]		
CTH [km]	-0.1	-0.5	-0.7	-0.2	-0.9	-0.4	
	[VIIRS 1.8,	[VIIRS 1.3,	[VIIRS 2.2,	[VIIRS 1.7,	[VIIRS 2.2,	[VIIRS 1.9,	
	TROPOMI	TROPOMI	TROPOMI 1.5]	TROPOMI	TROPOMI	TROPOMI	
	1.7]	1.8]		1.5]	1.3]	1.5]	
Mid-level	Altocu	imulus	Altost	Altostratus		Nimbostratus	
	Land [2.8%]	Water [2.9%]	Land [14%]	Water [10%]	Land [4.8%]	Water [2.6%]	
COT []	+0.7	+3.3	+3.9	+10.7	+0.5	+13.2	
	[VIIRS 2.4,	[VIIRS 2.3,	[VIIRS 10.8,	[VIIRS 10.8,	[VIIRS 41.4,	[VIIRS 37.6,	
	TROPOMI	TROPOMI	TROPOMI	TROPOMI	TROPOMI	50.8]	
	3.1]	5.6]	14.7]	21.5]	41.9]		
CTH [km]	-0.8	-0.5	-1.5	-1.6	-1.7	-1.9	
	[VIIRS 4.6,	[VIIRS 4.5,	[VIIRS 4.4,	[VIIRS 4.5,	[VIIRS 4.3,	[VIIRS 4.6,	
	TROPOMI	TROPOMI	TROPOMI 2.9]	TROPOMI	TROPOMI	TROPOMI	
	3.8]	4.0]		2.9]	2.6]	2.7]	
High-level	Cir	rus	Cirrost	ratus	Deep co	nvective	
	Land [15%]	Water [10%]	Land [38%]	Water [21%]	Land [9%]	Water [5%]	
COT[]	+1.6	+3.3	+8.3	+15.5	+10.1	+21.8	
	[VIIRS 2.3,	[VIIRS 2.2,	[VIIRS 9.9,	[VIIRS 10.2,	[VIIRS 42.0,	[VIIRS 39.2,	
	TROPOMI	TROPOMI	TROPOMI	TROPOMI	TROPOMI	61.0]	
	3.9]	5.5]	18.2]	25.7]	52.1]		
CTH [km]	-2.4	-2.5	-3.7	-3.6	-4.1	-3.8	
	[VIIRS 10.1,	[VIIRS 10.2,	[VIIRS 10.0,	[VIIRS 9.5,	[VIIRS 9.9,	[VIIRS 9.6,	
	TROPOMI	TROPOMI	TROPOMI 6.3]	TROPOMI	TROPOMI	TROPOMI	
	7.7]	7.7]		5.9]	5.8]	5.8]	



Figure S10. Schematic representation of ISCCP classification based on CTH and COT ranges.

#### S4 Comparison of S5P cloud height with CLOUDNET: supplementary material

This section contains extra material for Section 4.4.

### S4.1 Satellite vs CLOUDNET comparison pairs, ordered along CLOUDNET CTH



Figure S11. Same as Fig. 9, but for the site Ny-Alesund.



Figure S12. Same as Fig. 9, but for the site Summit.



Figure S13. Same as Fig. 9, but for the site Hyytiala.



Figure S14. Same as Fig. 9, but for the site Norunda.



Figure S15. Same as Fig. 9, but for the site Mace Head.



Figure S16. Same as Fig. 9, but for the site Lindenberg.



Figure S17. Same as Fig. 9, but for the site Leipzig.



Figure S18. Same as Fig. 9, but for the site Chilbolton.



Figure S19. Same as Fig. 9, but for the site Palaiseau.



Figure S20. Same as Fig. 9, but for the site Munich.



Figure S21. Same as Fig. 9, but for the site Schneefernerhaus.



Figure S22. Same as Fig. 9, but for the site Bucharest.



Figure S23. Same as Fig. 9, but for the site Potenza.



Figure S24. Same as Fig. 9, but for the site Graciosa island.



Figure S25. Same as Fig. 9, but for the site Iquique.



Figure S26. Same as Fig. 9, but for the site Villa Yacanto.

#### S4.2 Satellite vs CLOUDNET CTH: normed histograms and distribution estimates

OMCLDO2 CH vs CLOUDNET CTH distribution plots, and S5P OCRA/ROCINN\_CAL CTH vs CLOUDNET CTH distribution plots, similar as Fig. 10 for the site Juelich, are presented here. Note that sites with less than 70 co-location pairs, and the site Summit, where satellite cloud height retrievals are problematic, are skipped.



Figure S27. Same as Fig. 10, but for the sites Ny-Alesund, Hyytiala and Norunda.



Figure S28. Same as Fig. 10, but for the sites Mace Head, Lindenberg and Chilbolton.



Figure S29. Same as Fig. 10, but for the sites Palaiseau, Munich and Schneefernerhaus.



Figure S30. Same as Fig. 10, but for the site Graciosa Island