



TCCON4S5P >>

First validation results of S-5P methane and update of the CO validation results using TCCON and NDACC-IRWG data

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ROYAL BELGIAN INSTITUTE
FOR SPACE AERONOMY



Sentinel-5 Precursor

Sentinel-5 Precursor (S-5 P) is the first of the ESA atm. composition of Sentinels contributing to the European Commission Copernicus Programme to improve our understanding of the planet and the environment.

S-5 P has been successfully launched on 13th October 2017. Near-polar sun-synchronous orbit at an altitude of 824 km with an ascending node equatorial crossing at 13:30. Orbit cycle is 16 days (14 orbits per day, 227 orbits per cycle). Mission duration is 7 years.

TROPOspheric Monitoring Instrument (TROPOMI) onboard S-5 P is a grating spectrometer covering 8 bands (UV – short-wave IR), common telescope for UVN and SWIR, pushbroom configuration and wide swath (108° → 2600 km on surface). The primary products measured are Ozone, NO₂, CO, CH₂O, CH₄, SO₂, Aerosol, Clouds and UV-Index. The application of the data measured will be on ozone layer monitoring, climate monitoring, air quality monitoring and forecast, volcanic plume detection and UV index forecast.

TROPOMI uses the absorption information from the Oxygen-A Band (757–774 nm) and the SWIR spectral channel (2305–2385 nm) to retrieve the CH₄ global abundance in the Earth’s atmosphere. CH₄ products has a spatial sampling of 7x7 km².

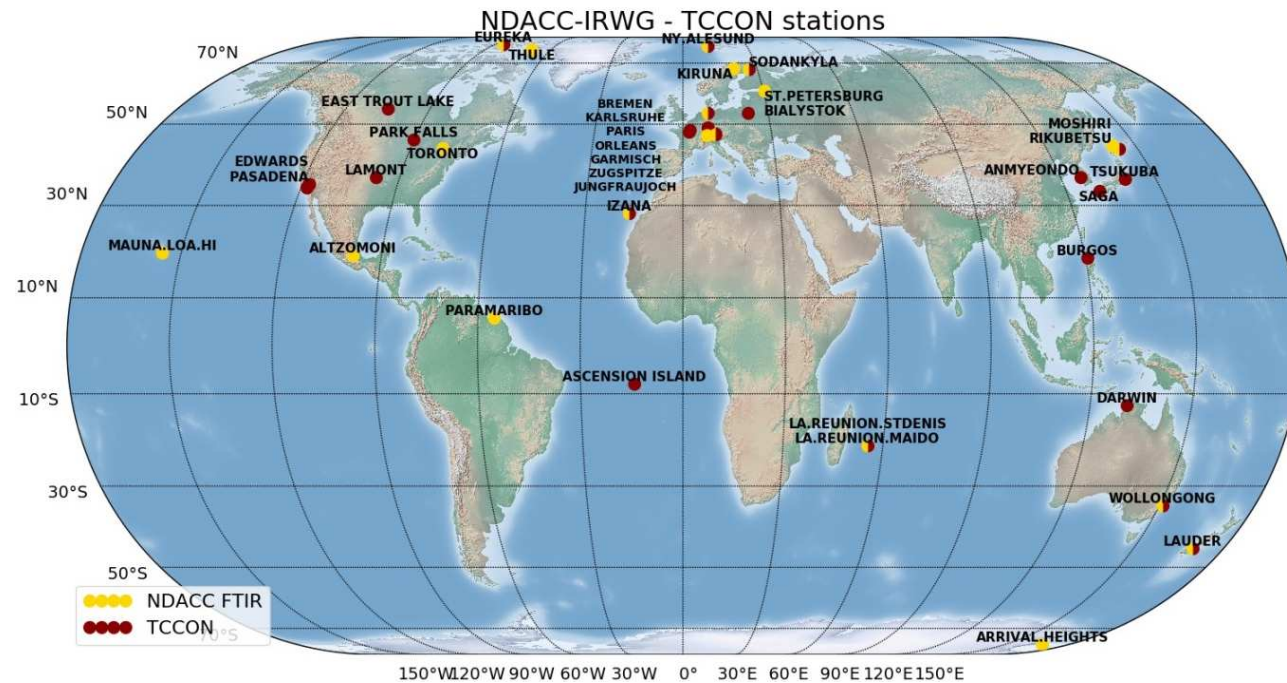
Table 1 – Sentinel-5P TROPOMI mandatory atmospheric composition data products addressed by this project

Parameter	Data Product	Vertical resolution	Systematic Uncertainty Requirement	Random Uncertainty Requirement
CH ₄	Total CH ₄	Total column	1.5%	1%
CO	Total CO	Total column	15%	<10%



Groundbased networks used for the validation study

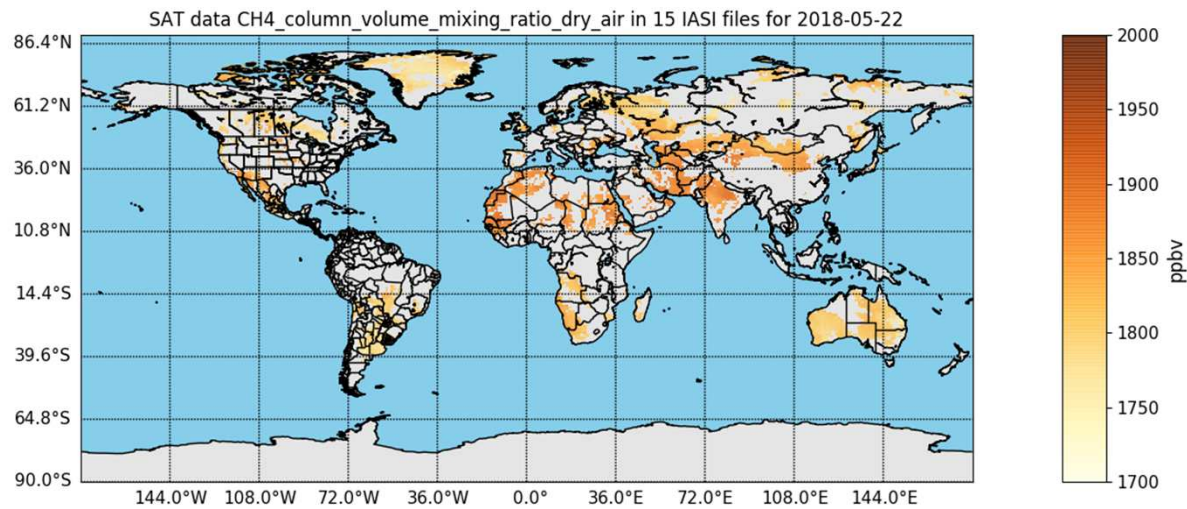
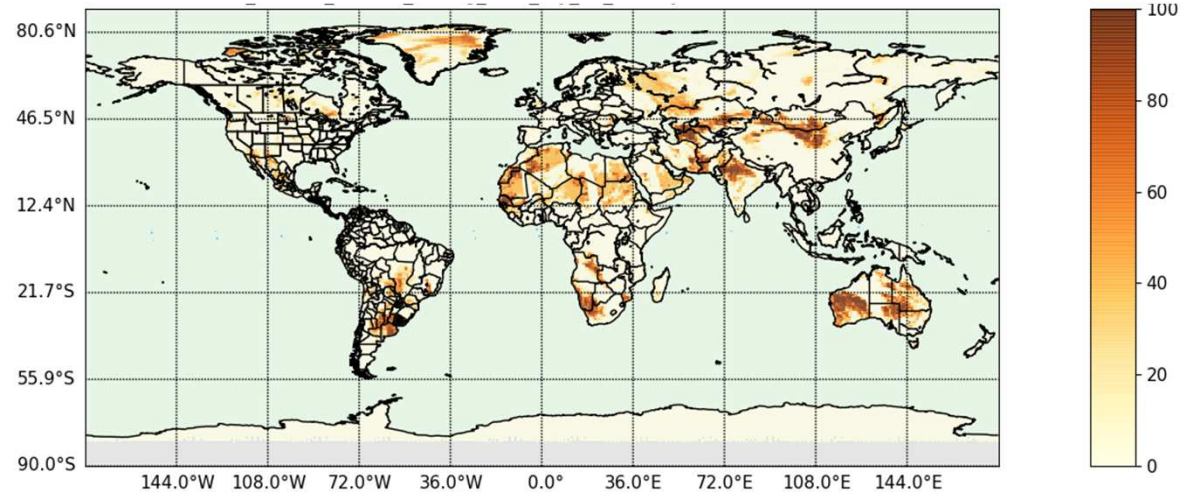
- The Total Carbon Column Observing Network (TCCON)
 - 22 stations in the northern hemisphere and 5 stations in the southern hemisphere
 - High accuracy / precision (0.2% / 0.5% for CH₄ and 2% / 1% for CO)
- The infrared Working group (IRWG) of the NDACC
 - 10 stations in the northern hemisphere and 4 stations in the southern hemisphere
 - Accuracy / precision (3% / 1.5% for CH₄ and 3% / 1% for CO)





TROPOMI global plot for Methane (CH_4)

S-5P CH_4 QA values: strict filtering
→ no island stations for validation

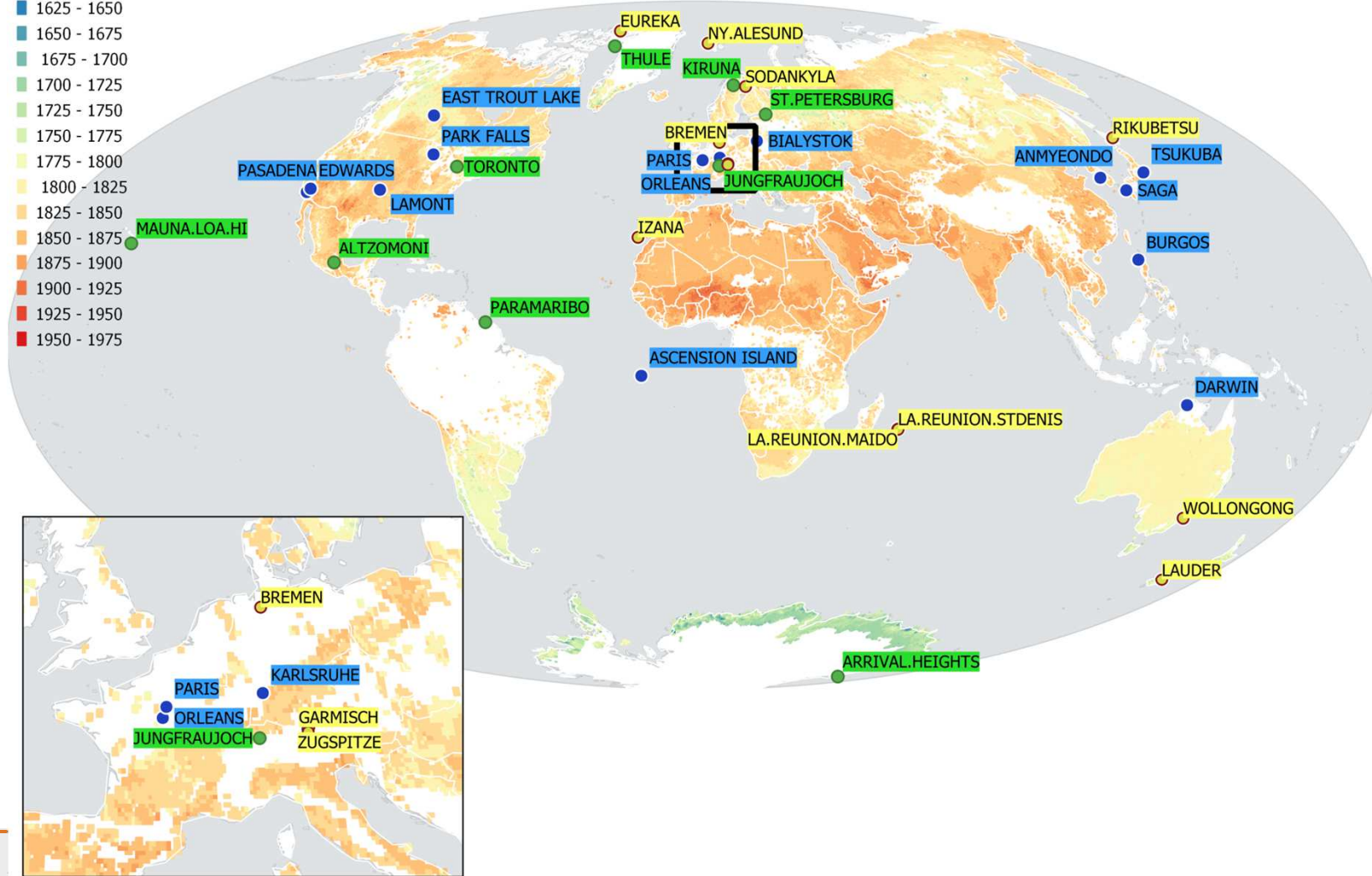




S-5P xCH₄ global plot – mean of 1-20 March 2019

S5P xCH₄ [ppb] for Mar 1-20 2019

- 1625 - 1650
- 1650 - 1675
- 1675 - 1700
- 1700 - 1725
- 1725 - 1750
- 1750 - 1775
- 1775 - 1800
- 1800 - 1825
- 1825 - 1850
- 1850 - 1875
- 1875 - 1900
- 1900 - 1925
- 1925 - 1950
- 1950 - 1975

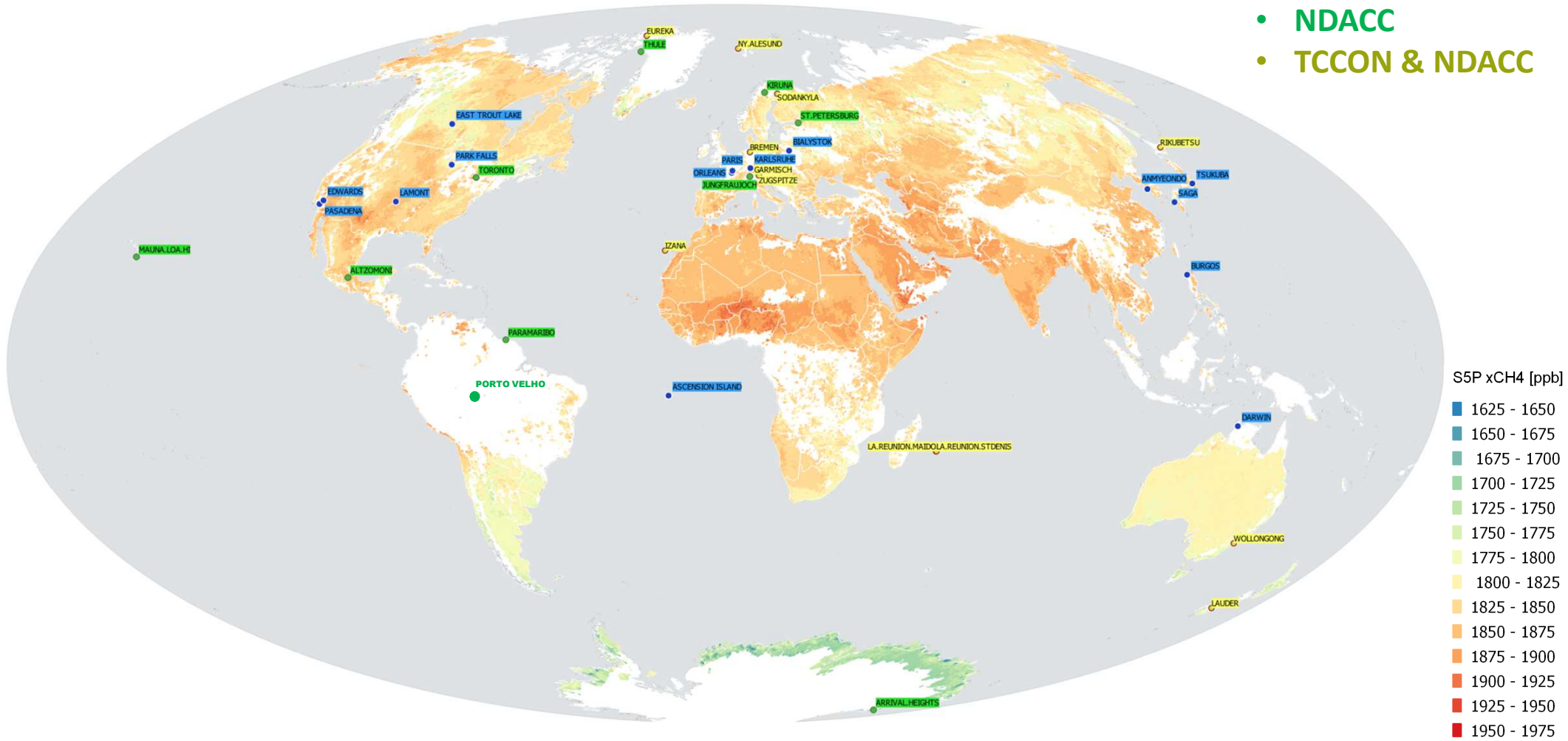


TCCON
 NDACC
 TCCON & NDACC



S-5P xCH₄ global plot – mean of 1-20 March 2019

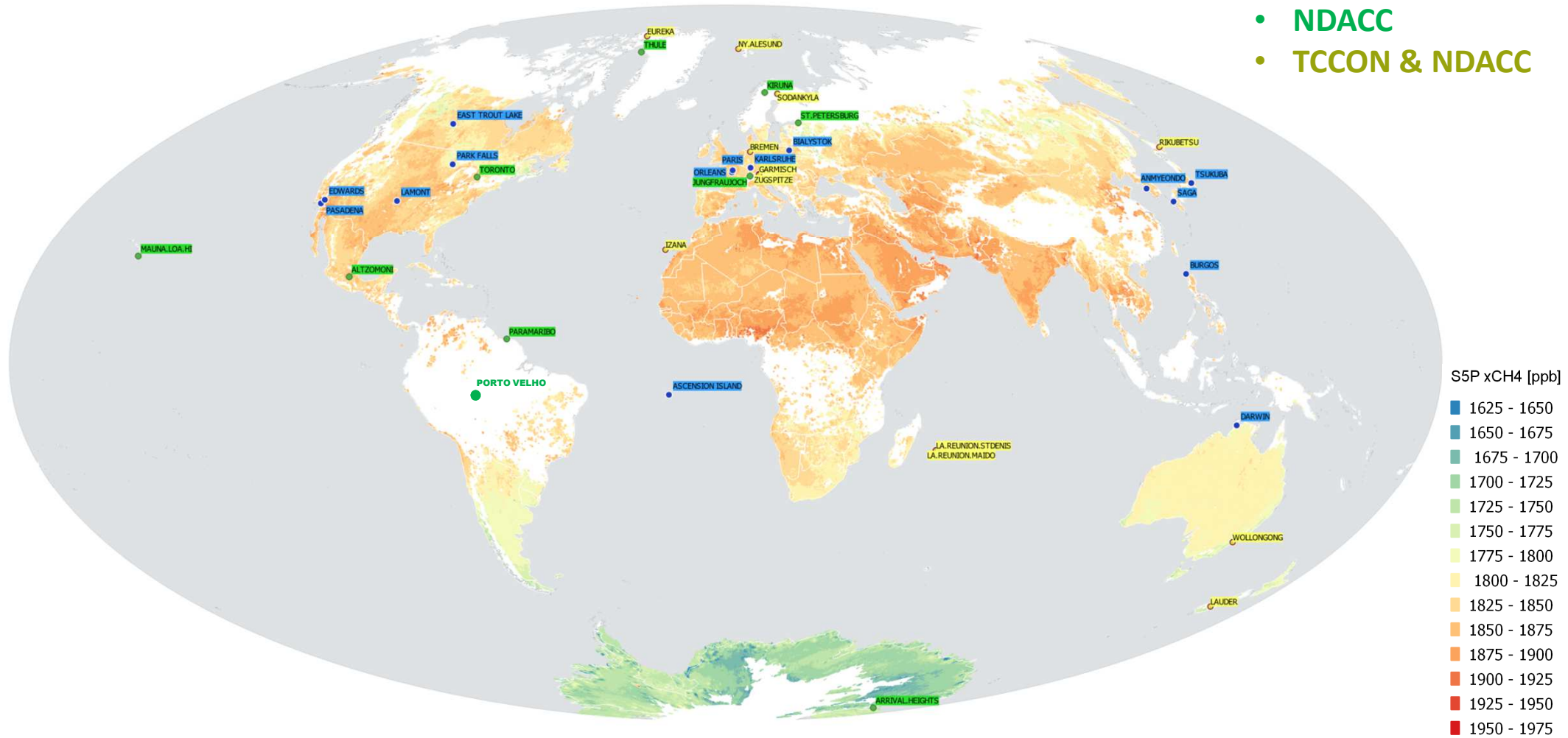
- TCCON
- NDACC
- TCCON & NDACC





S-5P xCH₄ global plot – mean of 1-28 February 2019

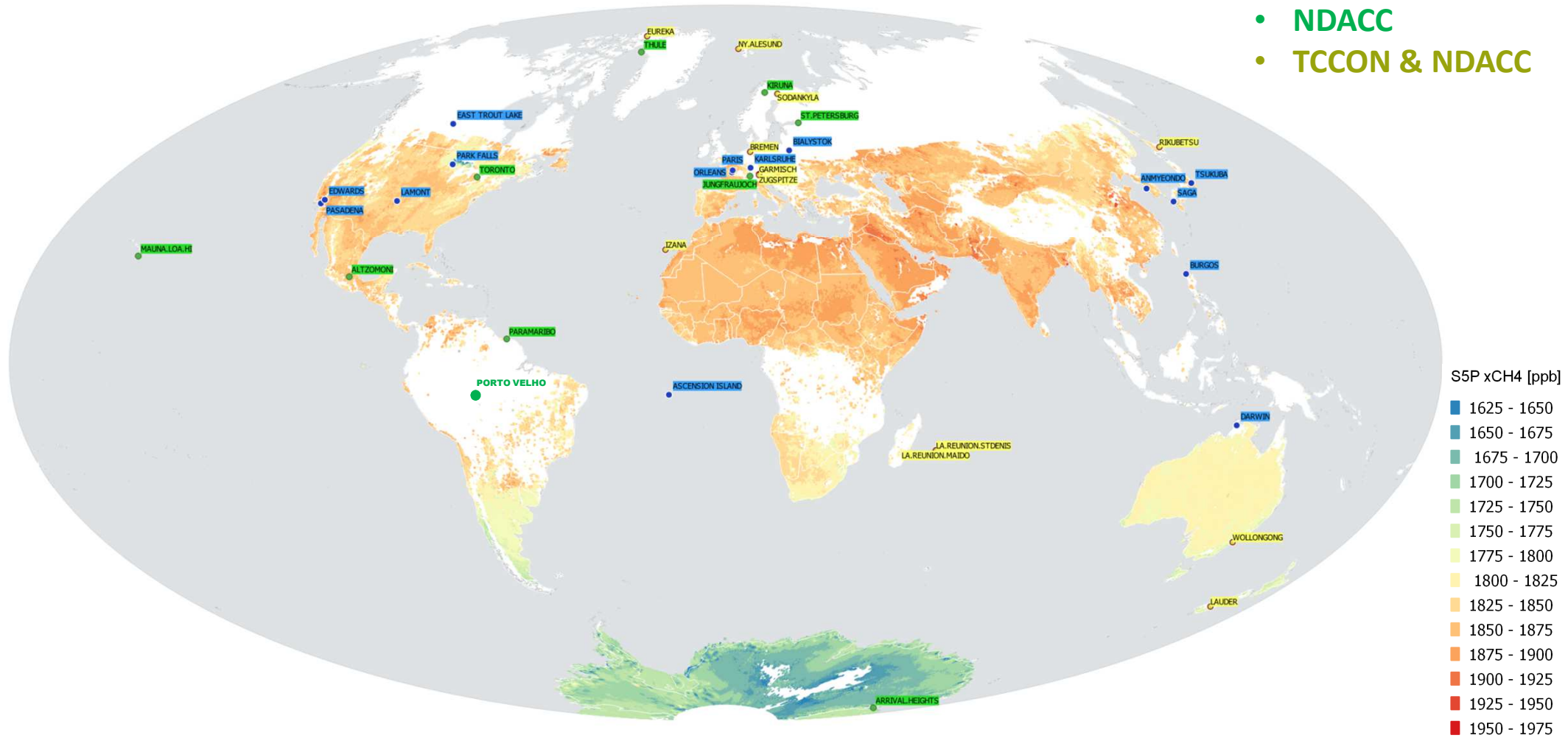
- TCCON
- NDACC
- TCCON & NDACC





S-5P xCH₄ global plot – mean of 1-31 January 2019

- TCCON
- NDACC
- TCCON & NDACC





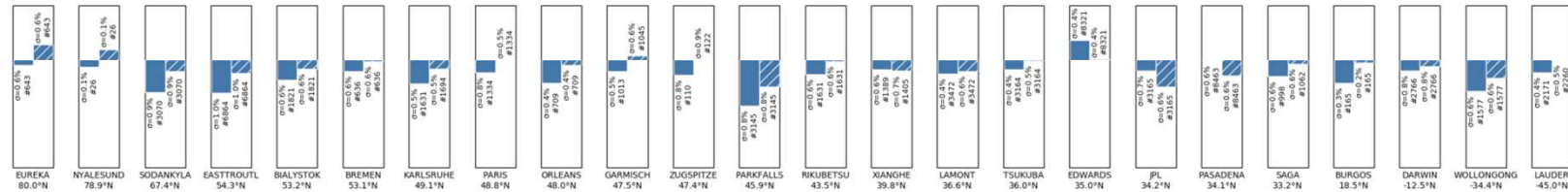
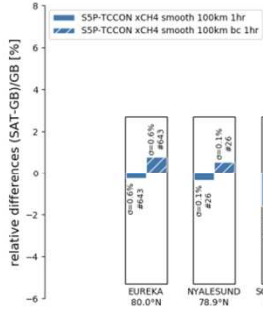
Coincidence criteria for validation study

- Period of study started with the first available data (17 November 2017 till 1 April 2019)
- TCCON data provided by 27 stations (fast data delivery and standard data) → **Many Thanks!**
- NDACC data provided by 14 stations (rapid data delivery – CAMS27 contract cams27.aeronomie.be) → **Many Thanks!**
- S-5P data from the Copernicus data hub and Mission Performance Centre (MPC) provided by the Payload Data Ground Segment (PDGS) at DLR
 - S-5P CH₄ version 01.02.02 and 01.03.00 (RPRO & OFFL)
- Coincidence criteria for CH₄ and CO: Time delta = 1h (TCCON) & 6h, 3h & 1h (NDACC); Geo-distance delta = 50 km and 100 km radius, qa_value>0.5. Normal XCH₄ product and bias-corrected XCH₄ product. From the coincident and filtered satellite measurements an average of all pixels is taken for each TCCON and NDACC measurements
- S-5P CH₄ and CO priori is used as common prior (Rodgers, 2003), altitude correction is done for each satellite pixel to the ground-based station height
- Validation using NDACC CH₄ and CO data are part of the **VDAF** study (mpc-vdaf.tropomi.eu)

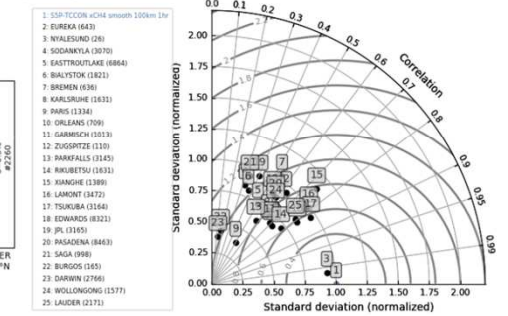


S-5P validation results - XCH₄

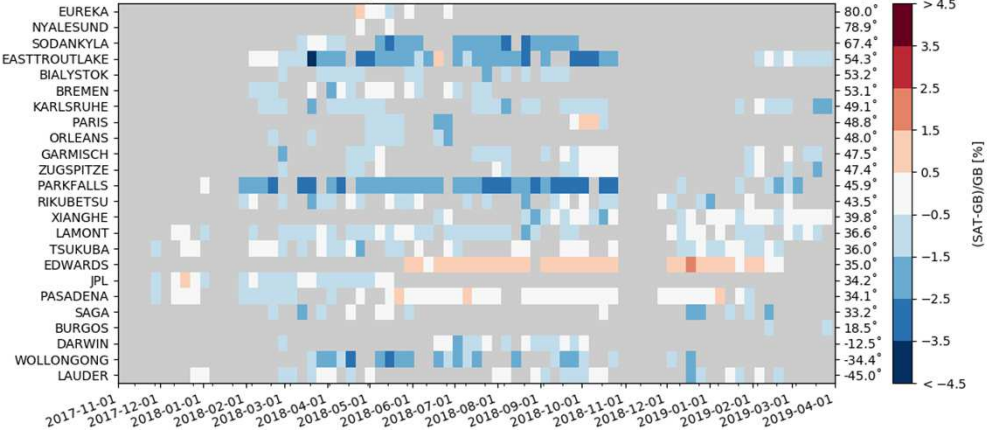
Histogram plot of relative differences (SAT-GB)/GB for S5P-TCCON xCH₄ smooth 100km 1hr, S5P-TCCON xCH₄ smooth 100km bc 1hr and FTIR CH₄ timeseries



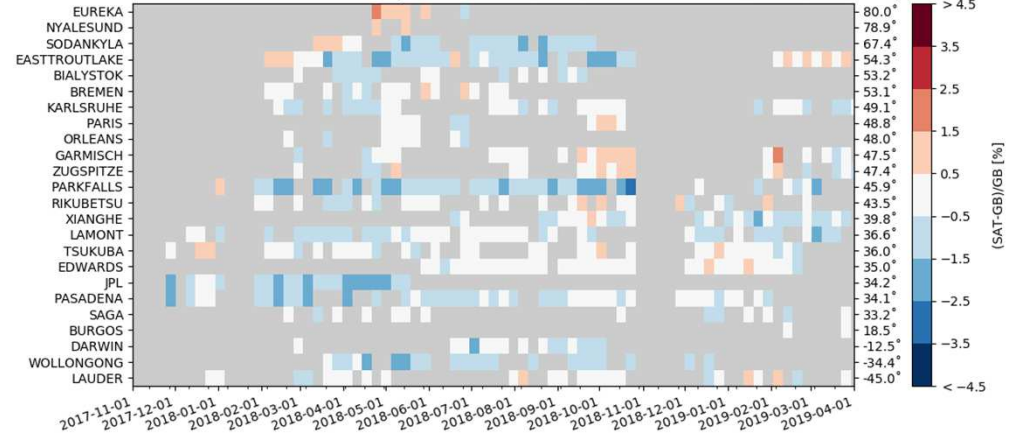
Scatter diagram for S5P-TCCON xCH₄ smooth 100km 1hr and FTIR.CH₄ timeseries



S5P-TCCON xCH₄ smooth 100km 1hr and FTIR CH₄ dry air mol fraction (xCH₄) relative differences (SAT-GB)/GB (weekly mean, surf-to-a)



S5P-TCCON xCH₄ smooth 100km bc 1hr and FTIR CH₄ dry air mol fraction (xCH₄) relative differences (SAT-GB)/GB (weekly mean, surf-to-a)



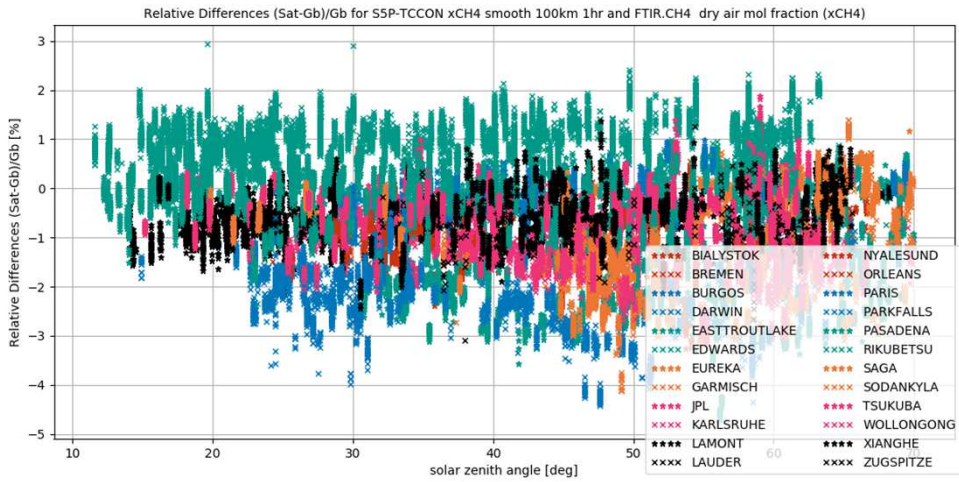
S-5P Standard product

S-5P Bias corrected product

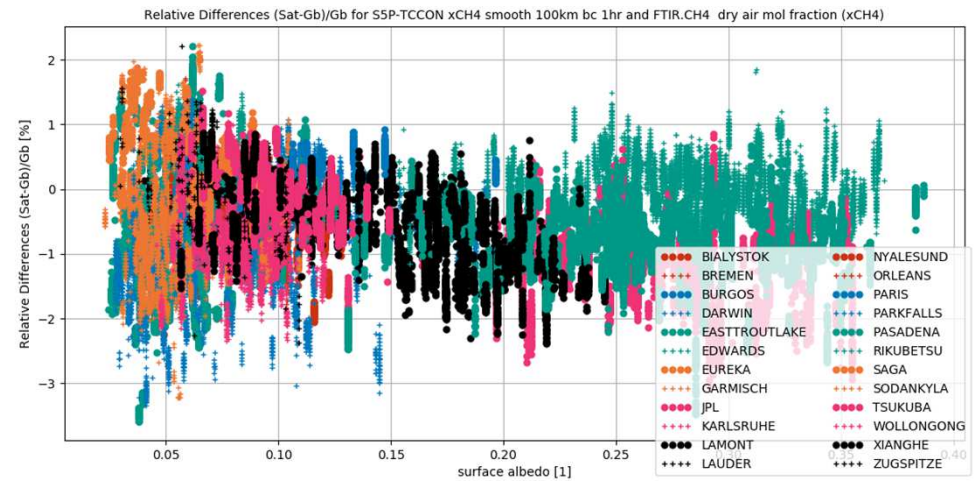
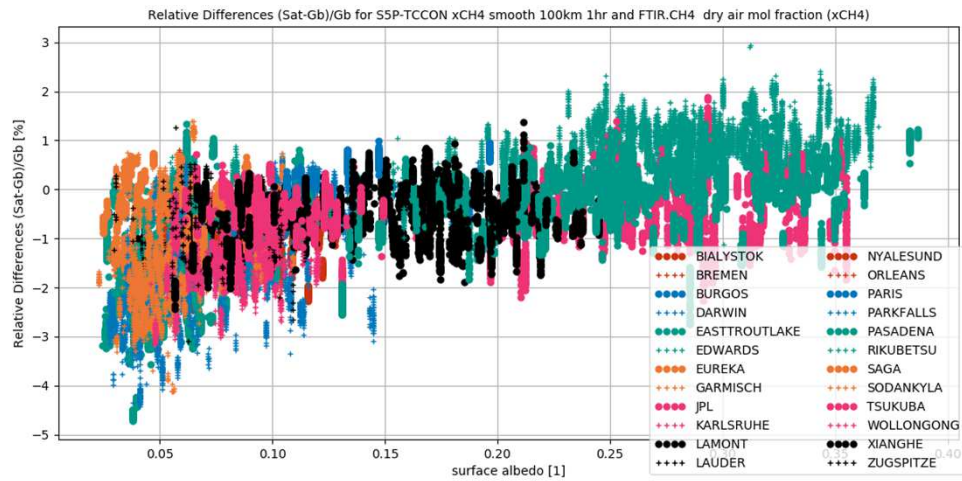
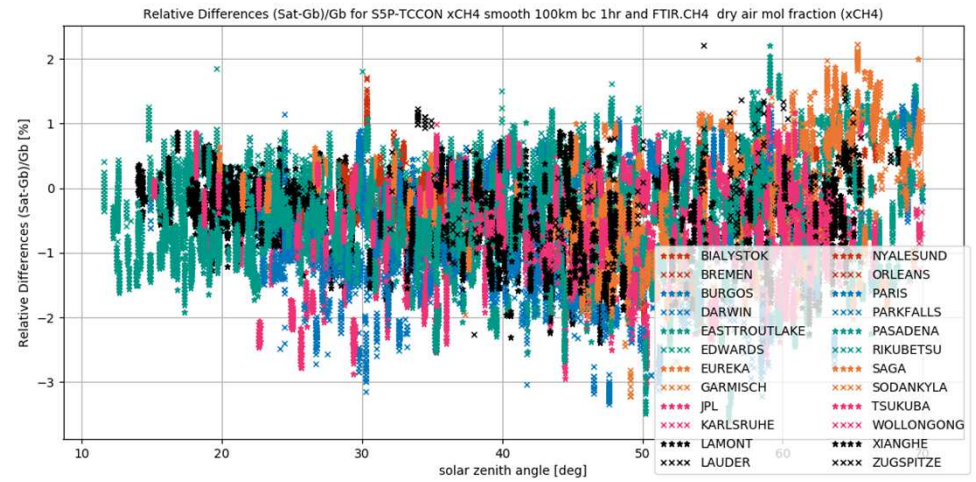


S-5P validation results – XCH₄

S-5P Standard product

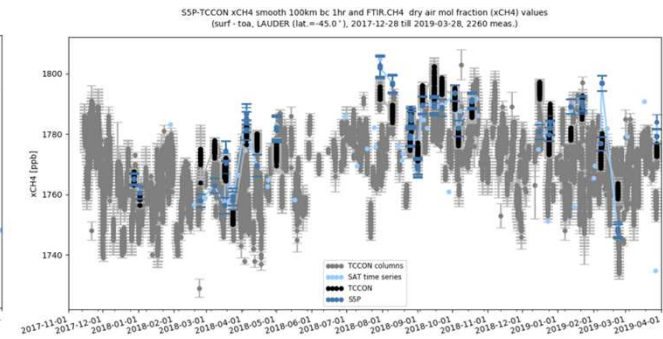
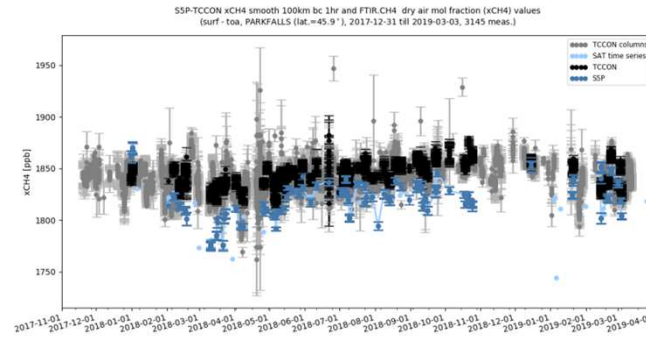


S-5P Bias corrected product

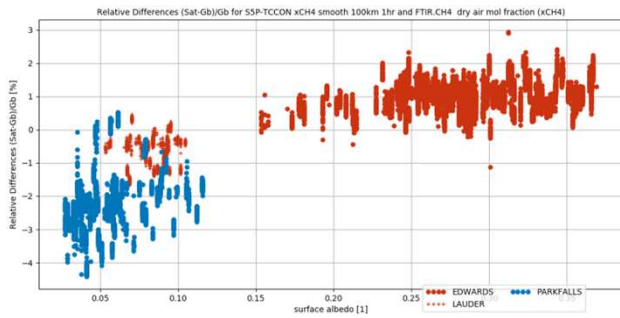
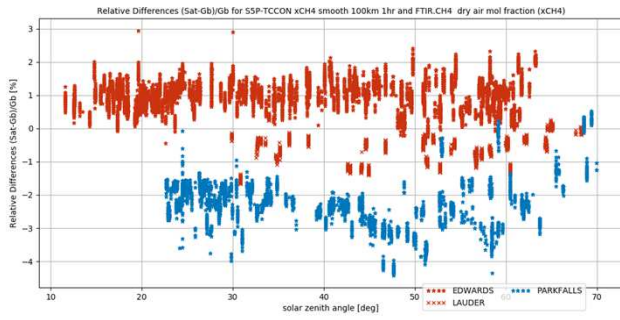




S-5P validation results – XCH₄



S-5P Standard product



S-5P Bias corrected product

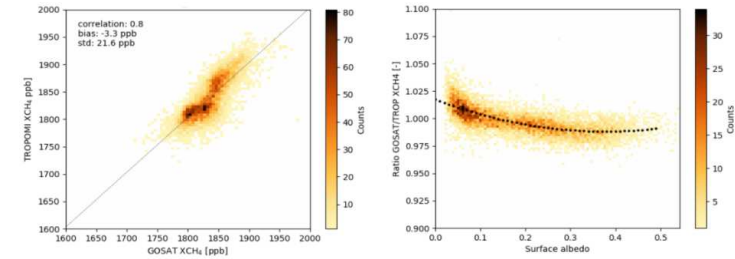
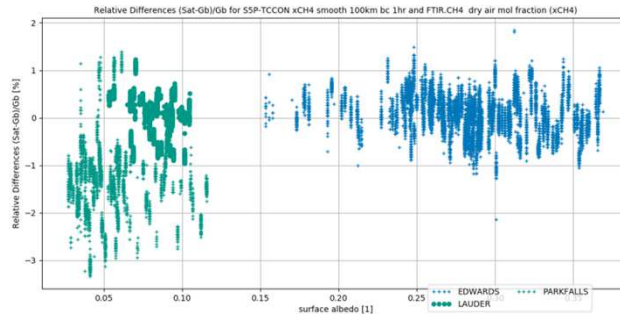
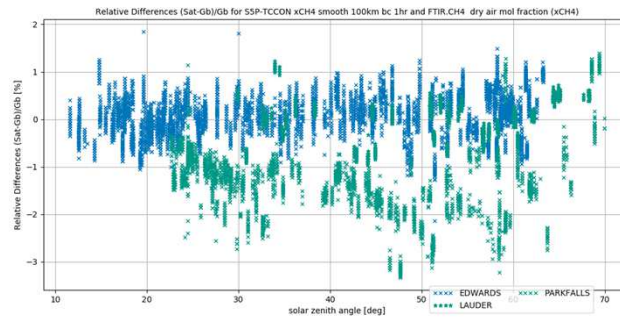
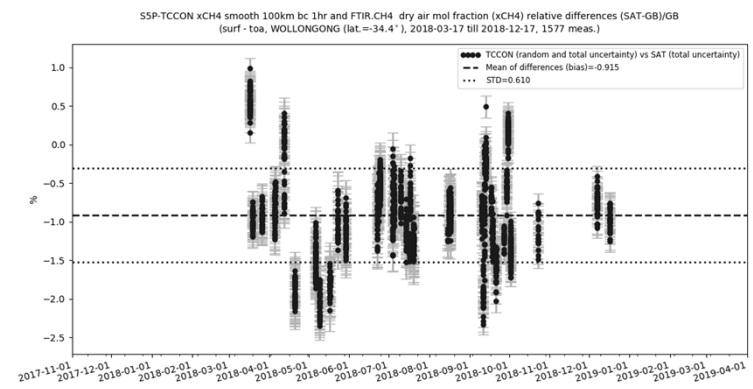
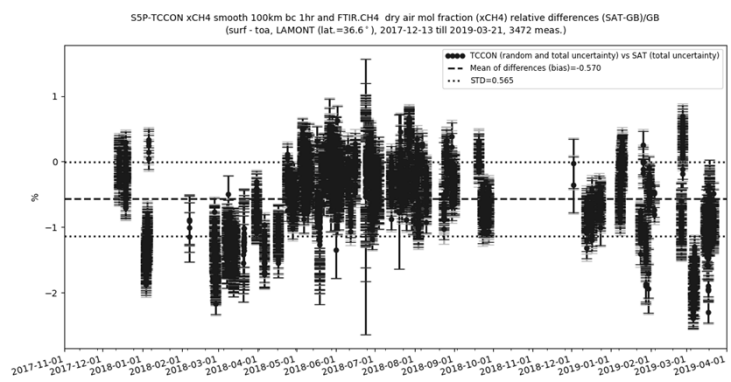
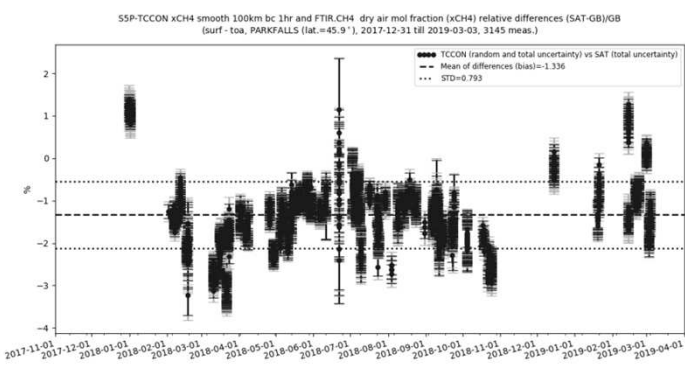
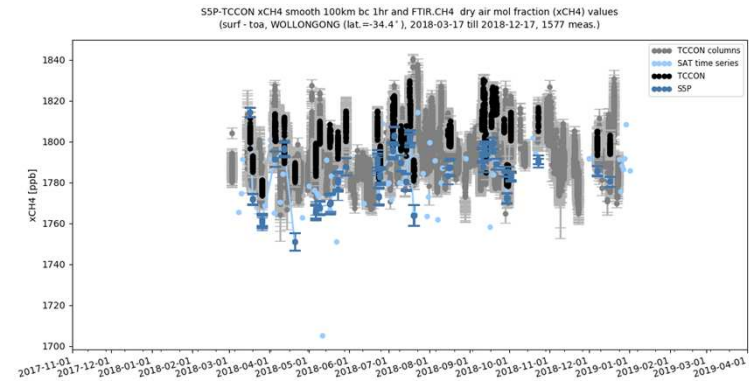
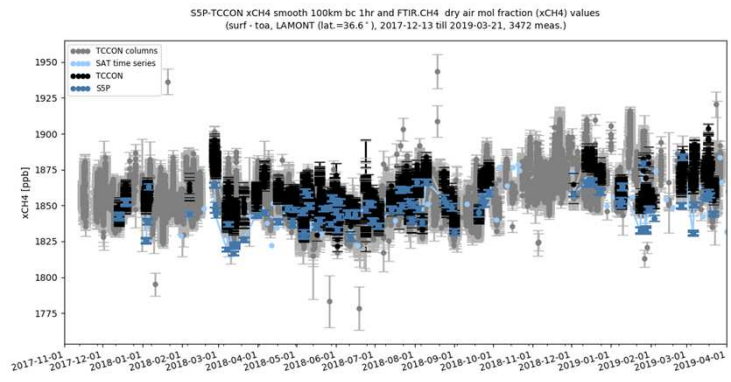
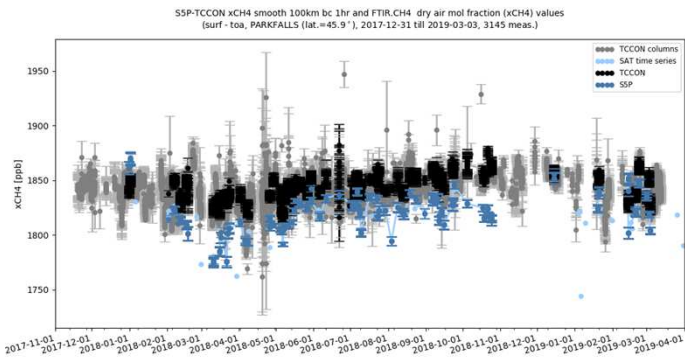


Figure 5: Left panel: correlation plot of TROPOMI and GOSAT CH₄ measurements. Right panel: ratio of GOSAT and TROPOMI CH₄ as a function of surface albedo. The black dashed line represents the second order polynomial fit from which the correction coefficients in Eq. 54 have been derived.

Reference: ATBD for Sentinel-5 Precursor Methane Retrieval



S-5P validation results – XCH₄



Parkfalls

Lamont

Wollongong



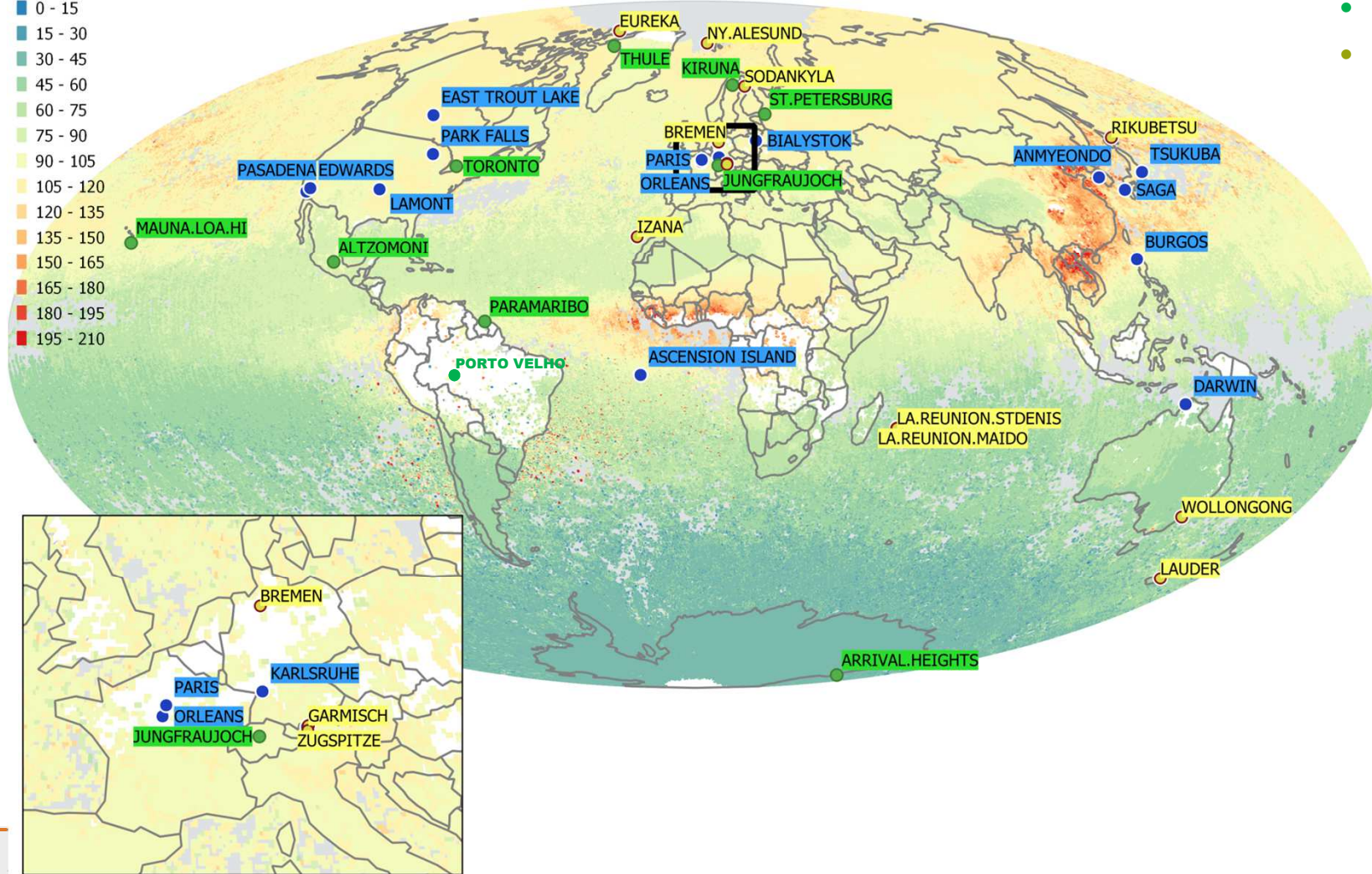
S-5P validation results – XCH₄

site	#	Std	correlation	mean relbias (%)	relbias std(%)	lat
EUREKA	643	0.8	0.75	0.77	0.57	80.0
NYALESUND	26	1.0	0.99	0.56	0.06	78.9
SODANKYLA	3070	0.8	0.32	-0.58	0.92	67.4
EASTTROUTLAKE	6864	0.8	0.51	-0.68	0.98	54.3
BIALYSTOK	1821	0.7	0.46	-0.46	0.56	53.2
BREMEN	636	0.9	0.53	-0.10	0.61	53.1
KARLSRUHE	1694	0.7	0.58	-0.47	0.54	49.1
PARIS	1334	0.6	0.53	0.01	0.51	48.8
ORLEANS	709	0.7	0.67	-0.27	0.36	48.0
GARMISCH	1045	0.7	0.65	0.25	0.56	47.5
ZUGSPITZE	122	0.9	0.43	0.01	0.90	47.4
PARKFALLS	3145	0.6	0.61	-1.34	0.79	45.9
RIKUBETSU	1631	0.7	0.79	-0.09	0.60	43.5
XIANGHE	1405	0.9	0.76	-0.56	0.68	39.8
LAMONT	3472	1.1	0.64	-0.57	0.57	36.6
TSUKUBA	3164	0.9	0.82	-0.06	0.47	36.0
EDWARDS	8321	0.8	0.83	0.06	0.42	35.0
JPL	3165	1.1	0.33	-1.35	0.64	34.2
PASADENA	8463	0.9	0.66	-0.79	0.56	34.1
SAGA	1062	1.0	0.41	-0.20	0.57	33.2
BURGOS	165	0.5	0.16	-0.16	0.22	18.5
DARWIN	2766	0.4	-0.01	-0.33	0.76	-12.5
WOLLONGONG	1577	0.9	0.63	-0.91	0.61	-34.4
LAUDER	2260	0.8	0.78	-0.03	0.46	-45.0
Mean	--	0.8	0.58	-0.30	0.58	



S-5P xCO global plot – mean of 1-20 March 2019

S5P xCO [ppb] for Mar 1-20 2019

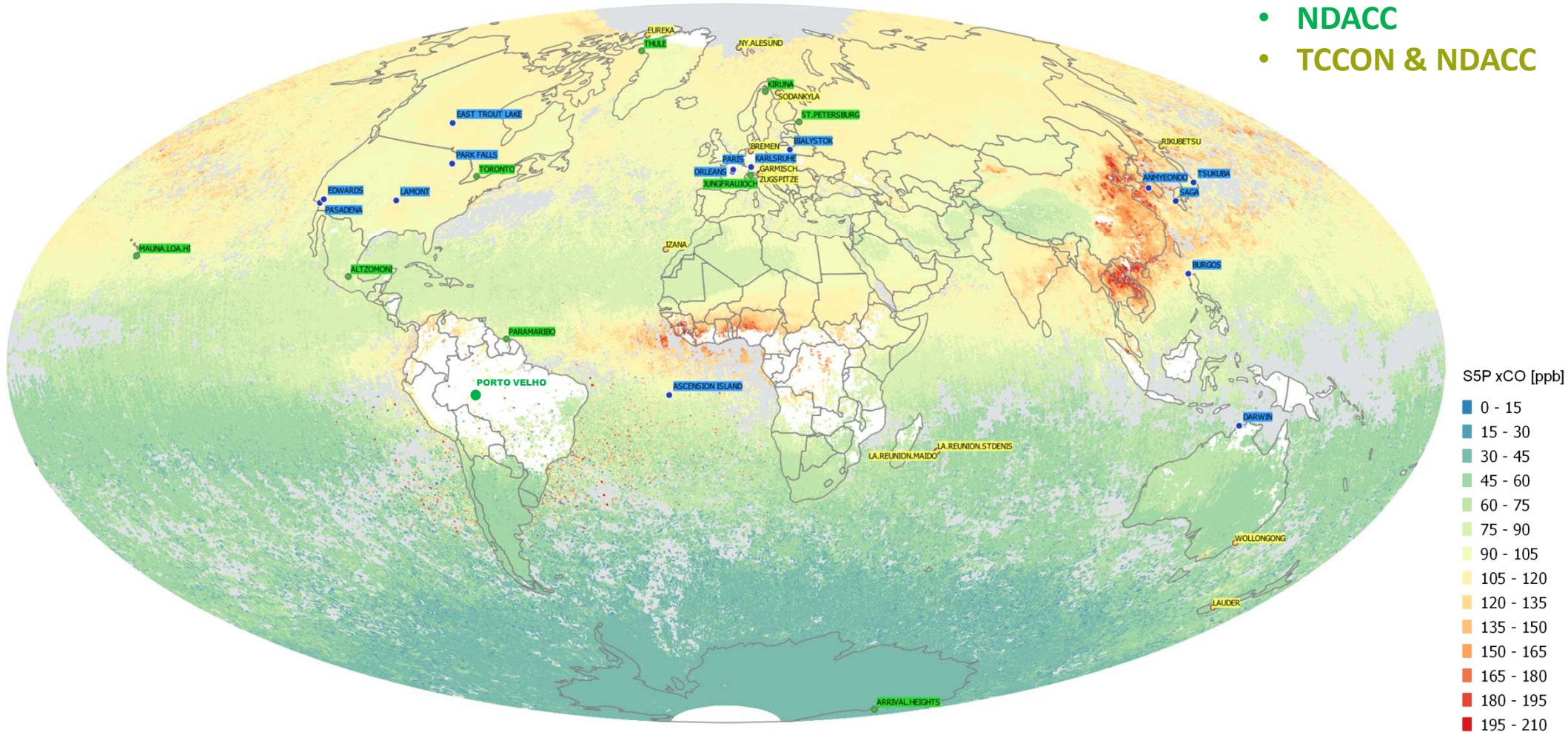


- TCCON
- NDACC
- TCCON & NDACC



S-5P xCO global plot – mean of 1-20 March 2019

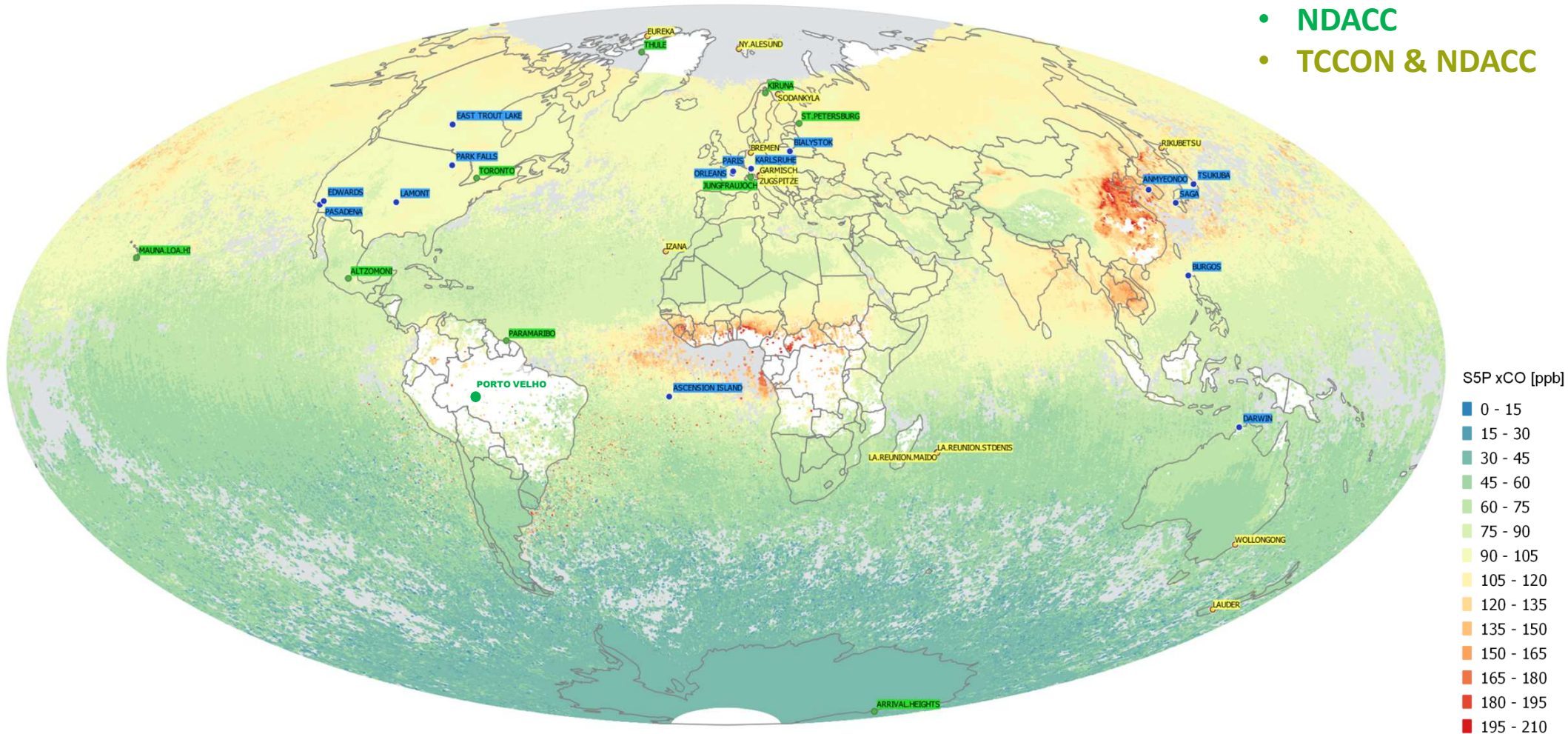
- TCCON
- NDACC
- TCCON & NDACC





S-5P xCO global plot – mean of 1-28 February 2019

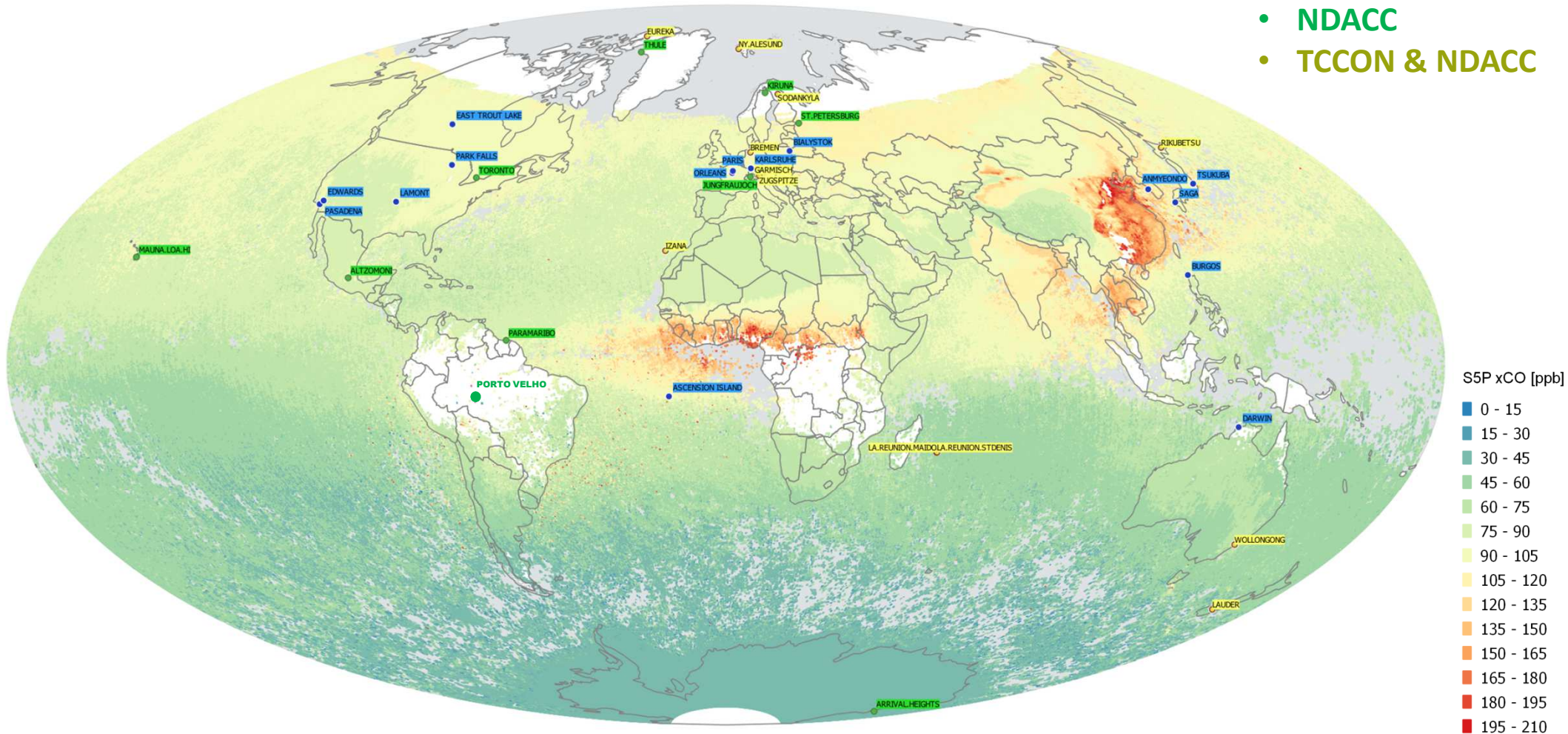
- TCCON
- NDACC
- TCCON & NDACC





S-5P xCO global plot – mean of 1-31 January 2019

- TCCON
- NDACC
- TCCON & NDACC



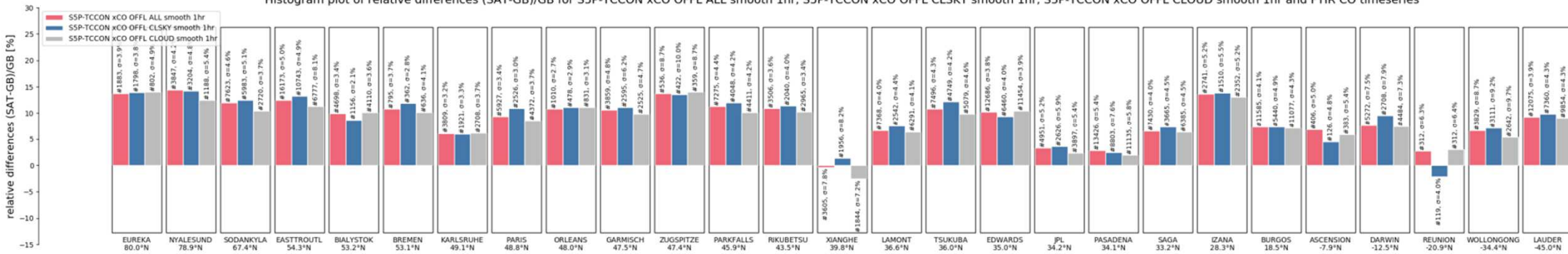


S-5P validation results using TCCON - XCO

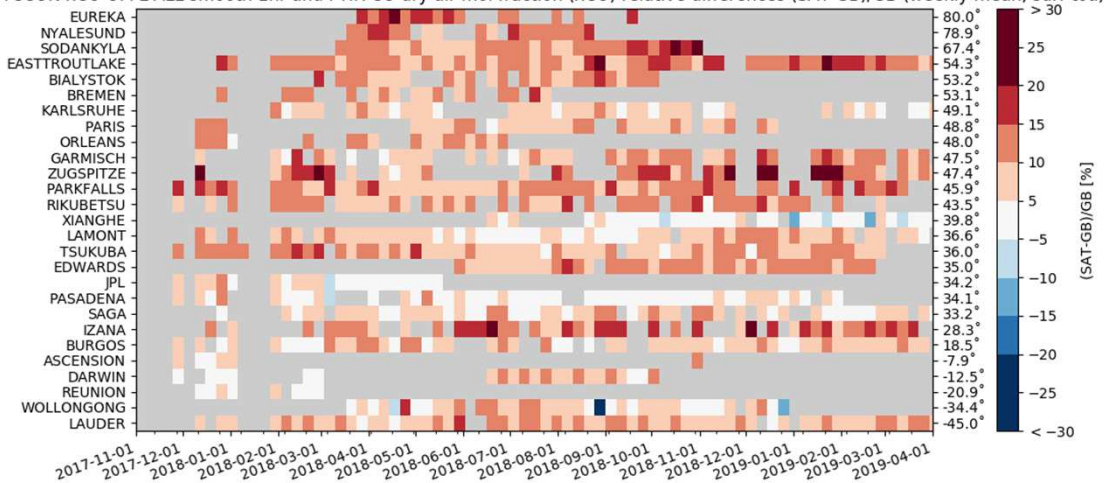
- ALL case; CLSKY case; CLOUD case

OFFLINE S-5P data

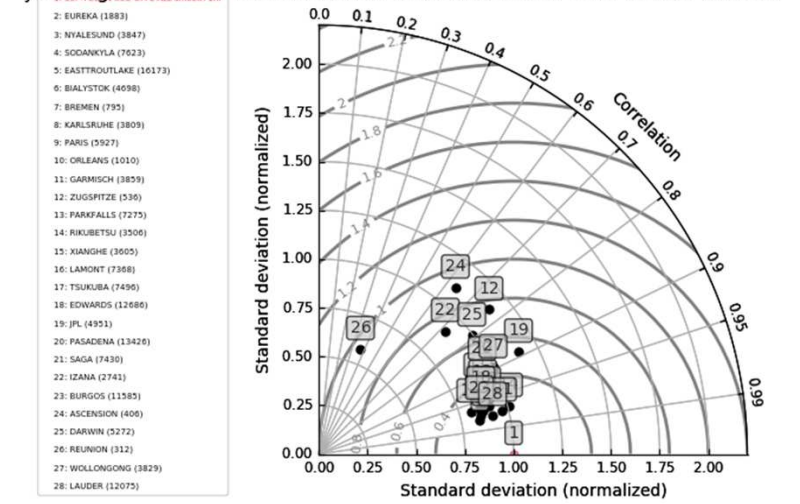
Histogram plot of relative differences (SAT-GB)/GB for S5P-TCCON xCO OFFL ALL smooth 1hr, S5P-TCCON xCO OFFL CLSKY smooth 1hr, S5P-TCCON xCO OFFL CLOUD smooth 1hr and FTIR CO timeseries



S5P-TCCON xCO OFFL ALL smooth 1hr and FTIR CO dry air mol fraction (xCO) relative differences (SAT-GB)/GB (weekly mean, surf-to-a)



yor diagram for S5P-TCCON xCO OFFL ALL smooth 1hr and FTIR.CO timeseri

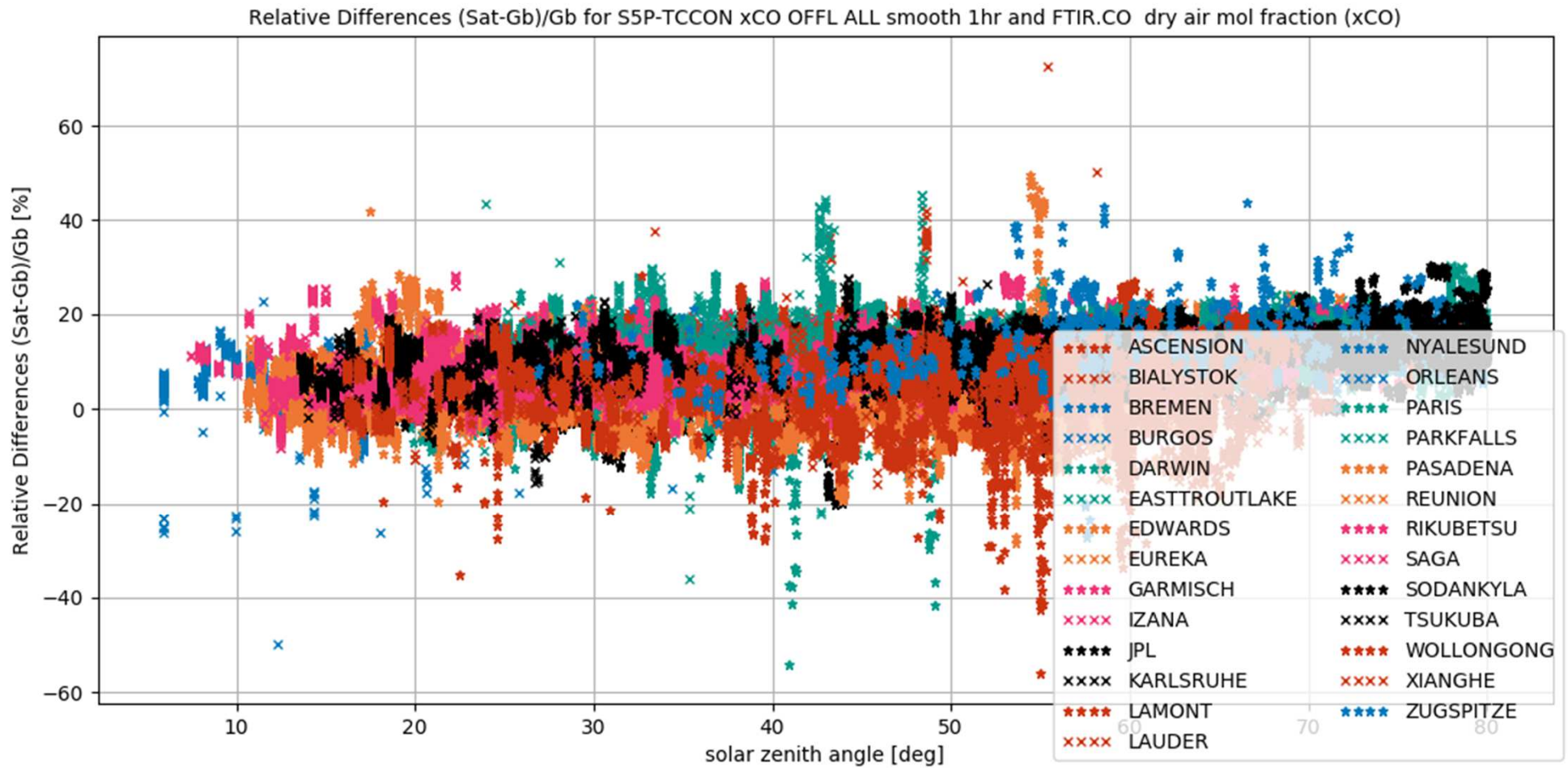




S-5P validation results using TCCON – XCO

- ALL case – SZA dependence

OFFLINE S-5P data

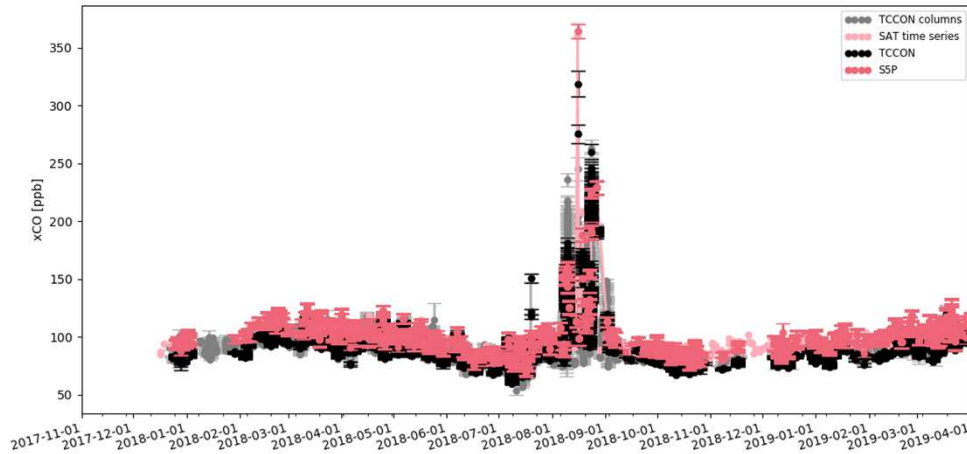




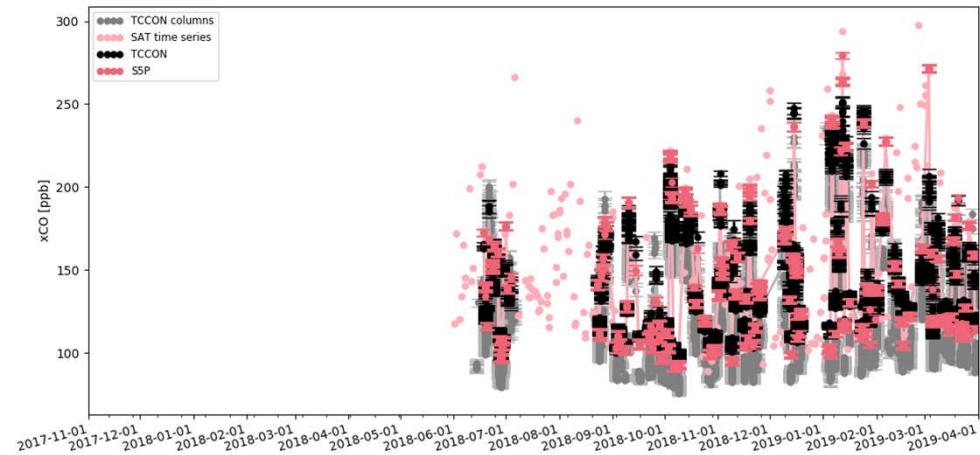
S-5P validation results using TCCON – XCO

- ALL case OFFLINE S-5P data

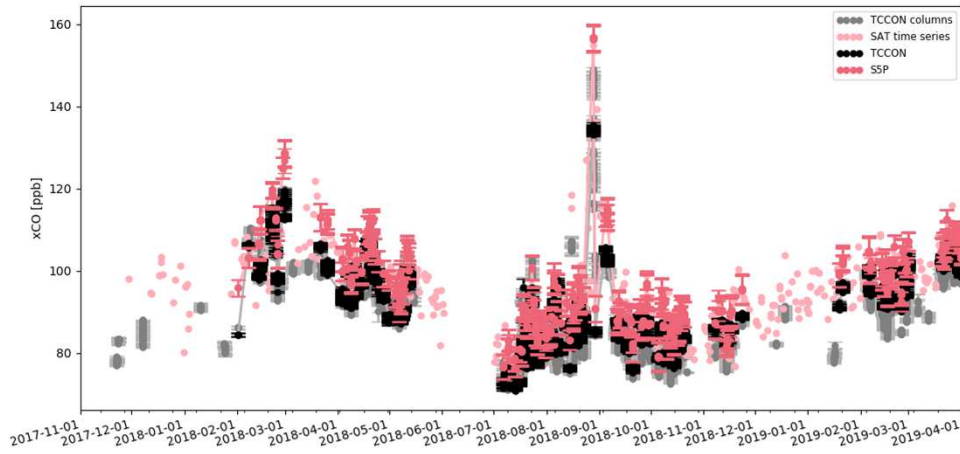
S5P-TCCON xCO OFFL ALL smooth 1hr and FTIR.CO dry air mol fraction (xCO) values (surf - toa, EASTTROUTLAKE (lat.=54.3°), 2017-12-25 till 2019-03-31, 16173 meas.)



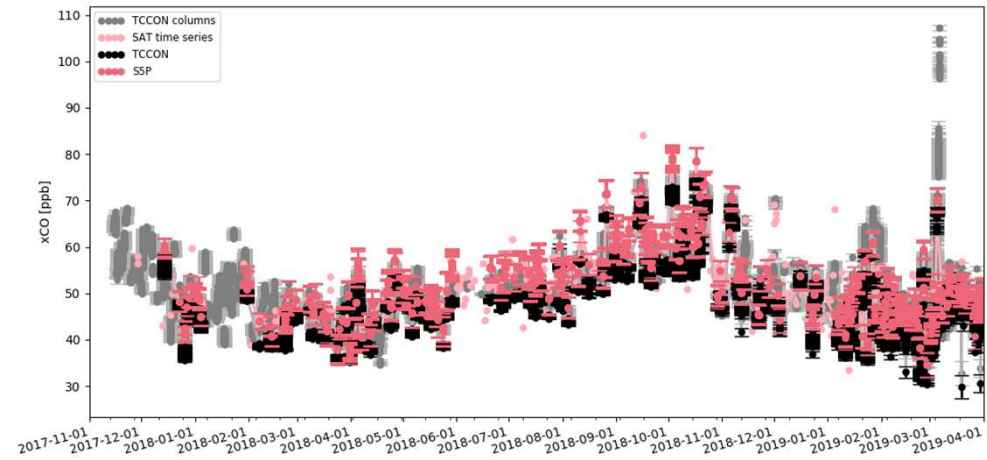
S5P-TCCON xCO OFFL ALL smooth 1hr and FTIR.CO dry air mol fraction (xCO) values (surf - toa, XIANGHE (lat.=39.8°), 2018-06-18 till 2019-03-30, 3605 meas.)



S5P-TCCON xCO OFFL ALL smooth 1hr and FTIR.CO dry air mol fraction (xCO) values (surf - toa, KARLSRUHE (lat.=49.1°), 2018-02-01 till 2019-03-31, 3809 meas.)

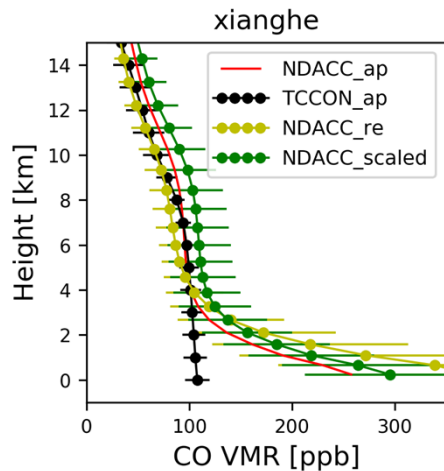
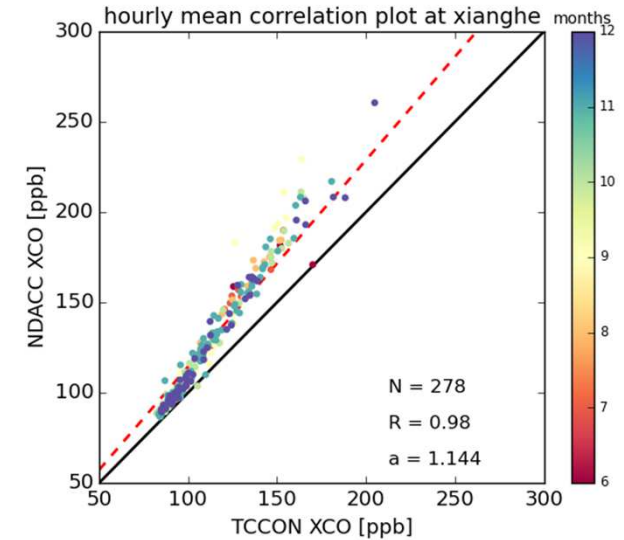
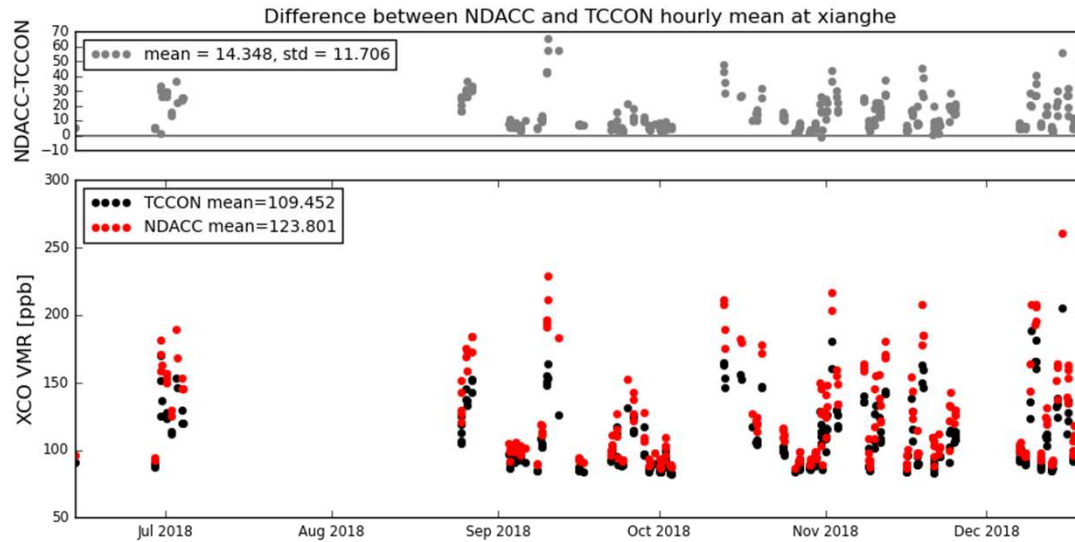


S5P-TCCON xCO OFFL ALL smooth 1hr and FTIR.CO dry air mol fraction (xCO) values (surf - toa, LAUDER (lat.=45.0°), 2017-12-14 till 2019-03-31, 12075 meas.)





XCO in a polluted site



➔ NDACC is 11.6 ± 9.5 (SD)% larger than TCCON XCO

As Xianghe is located in a polluted area, the CO VMR at the surface is relatively high (which is confirmed by the WACCM model and NDACC retrieved profiles). However, the TCCON a priori profile is too low, which will lead into a underestimation from the smoothing error.

If using the scaled WACCM as the a priori profile, NDACC XCO is 5.0 ± 6.9 % larger than TCCON XCO



S-5P validation results using TCCON – XCO – ALL case

site	#	Std	correlation	mean relbias (%)	relbias std(%)	lat
EUREKA	1883	0.9	0.96	13.69	3.86	80.0
NYALESUND	3847	0.8	0.98	14.43	4.20	78.9
SODANKYLA	7623	0.9	0.97	11.94	4.58	67.4
EASTTROUTLAKE	16173	0.9	0.95	12.49	4.99	54.3
BIALYSTOK	4698	0.9	0.97	9.89	3.39	53.2
BREMEN	795	0.9	0.96	10.77	3.72	53.1
KARLSRUHE	3809	0.9	0.96	6.09	3.20	49.1
PARIS	5927	0.9	0.94	9.32	3.40	48.8
ORLEANS	1010	0.9	0.96	10.81	2.67	48.0
GARMISCH	3859	0.9	0.92	10.60	4.76	47.5
ZUGSPITZE	536	1.1	0.76	13.76	8.69	47.4
PARKFALLS	7275	0.9	0.94	11.25	4.35	45.9
RIKUBETSU	3506	1.0	0.97	10.89	3.56	43.5
XIANGHE	3605	0.8	0.96	-0.35	7.77	39.8
LAMONT	7368	0.9	0.95	6.66	4.01	36.6
TSUKUBA	7496	0.9	0.96	10.85	4.27	36.0
EDWARDS	12686	0.9	0.95	10.20	3.75	35.0
JPL	4951	1.2	0.89	3.36	5.18	34.2
PASADENA	13426	0.9	0.89	2.83	5.36	34.1
SAGA	7430	1.0	0.97	6.50	3.95	33.2
IZANA	2741	0.9	0.72	13.59	5.23	28.3
BURGOS	11585	0.9	0.96	7.30	4.12	18.5
ASCENSION	406	1.1	0.63	6.84	5.01	-7.9
DARWIN	5272	1.0	0.79	7.63	7.46	-12.5
REUNION	312	0.6	0.37	2.74	6.29	-20.9
WOLLONGONG	3829	1.0	0.90	6.64	8.72	-34.4
LAUDER	12075	0.9	0.98	9.28	3.92	-45.0
Mean	--	0.9	0.89	8.89	4.83	

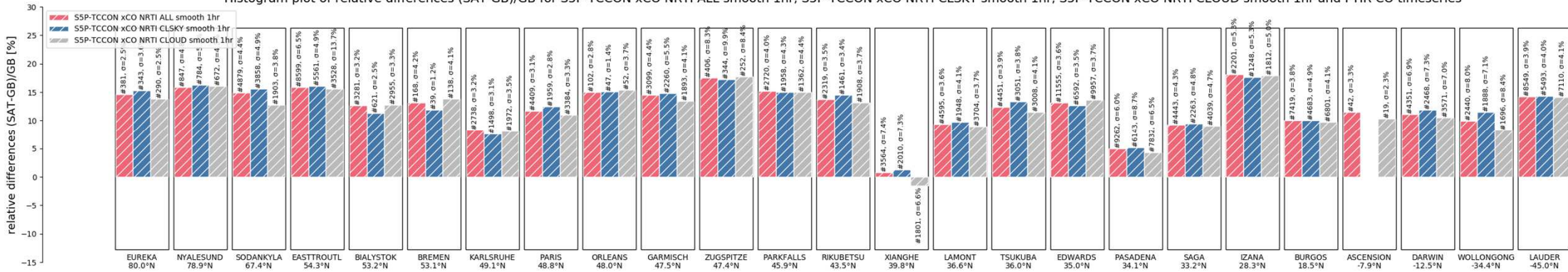


S-5P validation results using TCCON - XCO

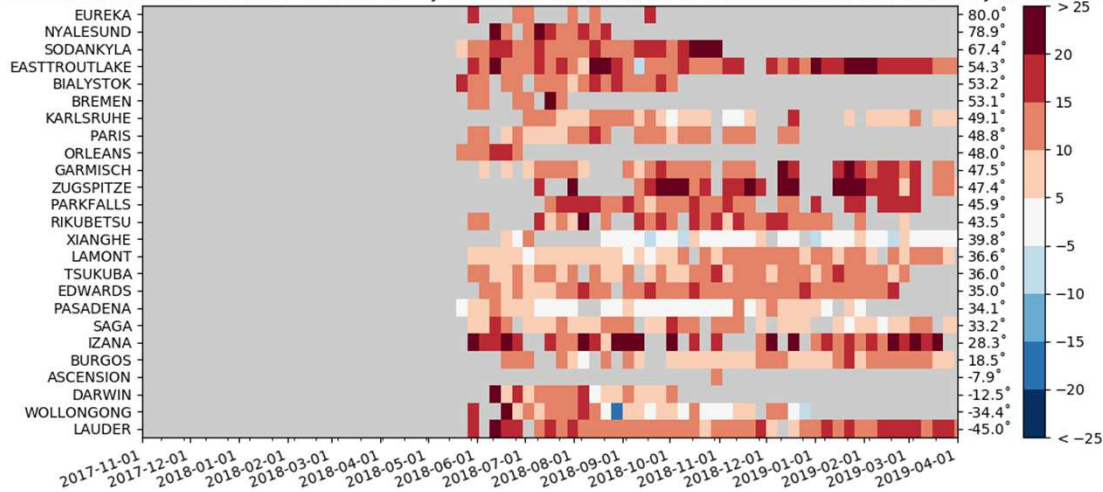
- ALL case; CLSKY case; CLOUD case

NRTI S-5P data

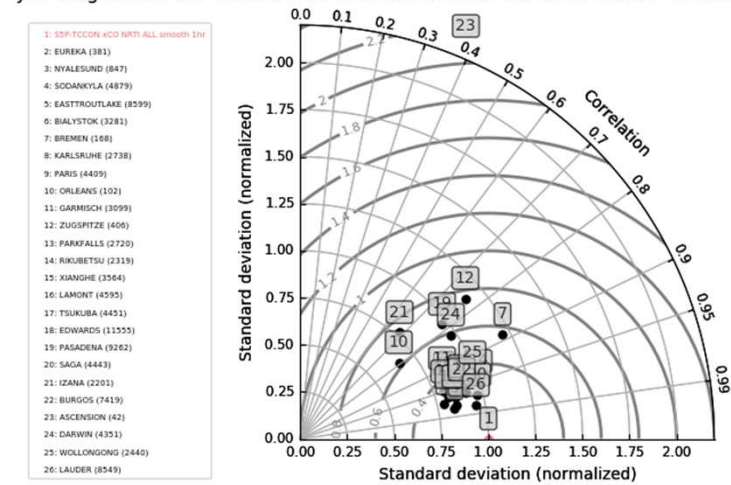
Histogram plot of relative differences (SAT-GB)/GB for S5P-TCCON xCO NRTI ALL smooth 1hr, S5P-TCCON xCO NRTI CLSKY smooth 1hr, S5P-TCCON xCO NRTI CLOUD smooth 1hr and FTIR CO timeseries



S5P-TCCON xCO NRTI ALL smooth 1hr and FTIR CO dry air mol fraction (xCO) relative differences (SAT-GB)/GB (weekly mean, surf-to-a)



ylor diagram for S5P-TCCON xCO NRTI ALL smooth 1hr and FTIR.CO timeseri



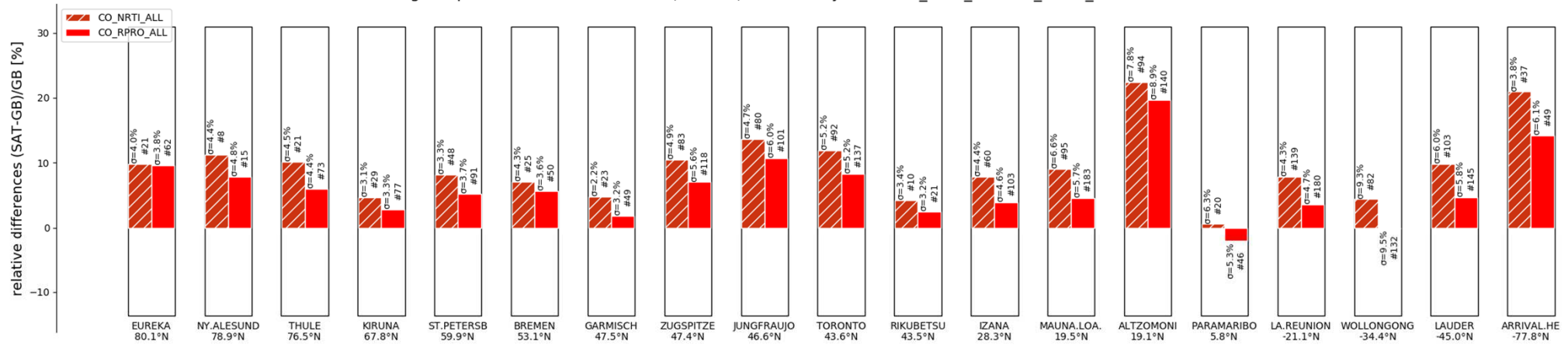


S-5P validation results using NDACC-IRWG – XCO

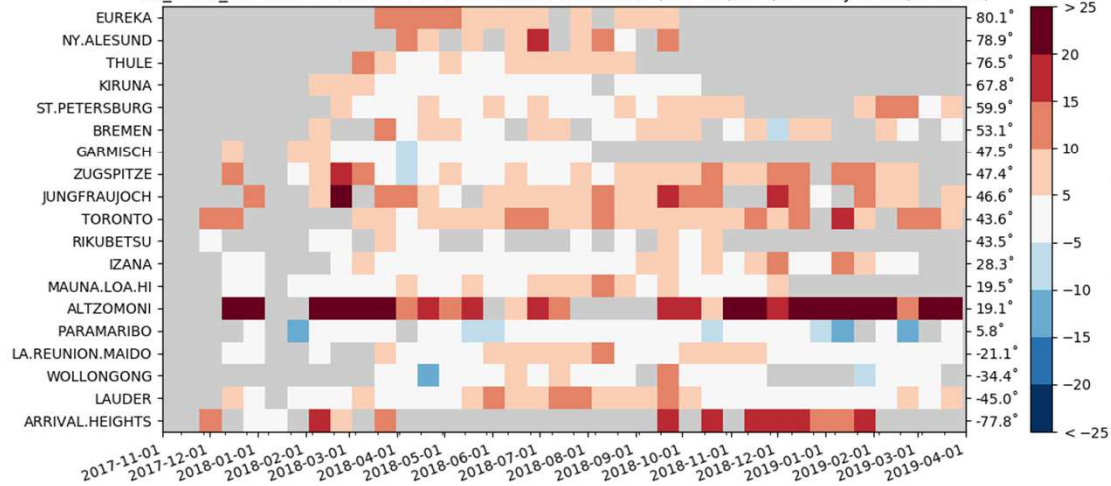
- ALL case; CLSKY case; CLOUD case

OFFLINE S-5P data

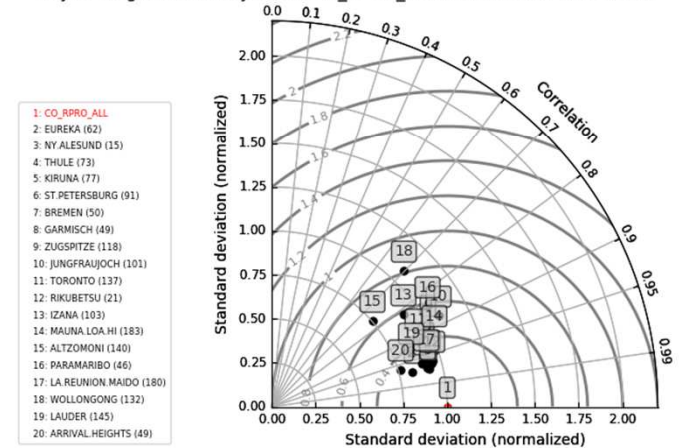
Histogram plot of relative differences (SAT-GB)/GB for daily mean CO_NRTI_ALL, CO_RPRO_ALL and FTIR CO timeseries



CO_RPRO_ALL and FTIR CO total column relative differences (SAT-GB)/GB (2-weekly mean, surf-toa)



Taylor diagram for daily mean CO_RPRO_ALL and FTIR.CO timeseries





S-5P validation results using NDACC – XCO – ALL case

site	#	Std	correlation	mean relbias (%)	relbias std(%)	lat
EUREKA	62	0.8	0.97	9.57	3.76	80.1
NY.ALESUND	15	0.9	0.94	7.86	4.81	78.9
THULE	73	0.9	0.96	5.99	4.37	76.5
KIRUNA	77	0.9	0.97	2.75	3.32	67.8
ST.PETERSBURG	91	0.9	0.96	5.16	3.75	59.9
BREMEN	50	1.0	0.96	5.66	3.61	53.1
GARMISCH	49	0.9	0.97	1.85	3.21	47.5
ZUGSPITZE	118	1.0	0.89	7.02	5.59	47.4
JUNGFRAUJOCH	101	1.1	0.88	10.70	5.99	46.6
TORONTO	137	0.9	0.91	8.24	5.16	43.6
RIKUBETSU	21	1.0	0.96	2.47	3.20	43.5
IZANA	103	0.9	0.82	3.90	4.55	28.3
MAUNA.LOA.HI	183	1.0	0.92	4.53	5.73	19.5
ALTZOMONI	140	0.8	0.76	19.69	8.93	19.1
PARAMARIBO	46	1.1	0.84	-2.16	5.26	5.8
LA.REUNION.MAIDO	180	0.9	0.96	3.53	4.72	-21.1
WOLLONGONG	132	1.1	0.70	-0.15	9.45	-34.4
LAUDER	145	0.9	0.93	4.65	5.77	-45.0
ARRIVAL.HEIGHTS	49	0.8	0.96	14.21	6.10	-77.8
-----	--	0.94	0.92	5.32	4.91	



S-5P validation results using NDACC – XCO – ALL case

site	#	Std	correlation	mean relbias (%)	relbias std(%)	lat
EUREKA	62	0.8	0.97	9.57	3.76	80.1
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-----	--	0.94	0.92	5.32	4.91	



Summary and conclusions

- First validation study covering whole TCCON and several NDACC stations
- Good coincidences for many sites but also very few coincidences for some sites
- Validation of TROPOMI XCH₄ with TCCON XCH₄:
 - Bias corrected product show better result; high negative bias for some stations are due to the way the albedo correction is currently done; bias in the high latitude sites due to the profile difference of CH₄; SZA dependence seen for the stations
 - Mean bias of $-0.3\% \pm 0.51\%$ (24 stations; median bias of -0.235%)
 - ➔ **systematic uncertainty (1.5%) compliant with mission requirement**
 - Standard deviation for all sites $< 1\%$
 - ➔ **random uncertainty (1%) compliant with mission requirement**
 - Correlation coefficient is ~ 0.6 (median)
- Validation of TROPOMI XCO with TCCON XCO:
 - Positive bias for all stations; SZA dependence seen for stations;
 - Mean bias of $8.89\% \pm 3.78\%$ (27 stations; median bias of 9.89%)
 - ➔ **systematic uncertainty compliant with mission requirement;**
 - Standard deviation for all sites $< 10\%$
 - ➔ **random uncertainty compliant with mission requirement**
 - Correlation coefficient is > 0.95 (median)



Conclusions and recommendations

- Validation of TROPOMI XCO with TCCON and NDACC CO products:
 - Mean bias of $8.89\% \pm 3.78\%$ w.r.t TCCON and $5.32\% \pm 3.94\%$ w.r.t NDACC
 - Mission requirement: $< 15\%$
 - ➔ **systematic uncertainty compliant with mission requirement;**
 - Standard deviation for all sites $\sim 0.89\%$ w.r.t TCCON and $\sim \%$ w.r.t NDACC
 - Mission requirement: $< 10\%$
 - ➔ **random uncertainty compliant with mission requirement**
- It is strongly recommended that the stripe feature be further investigated and taken into account in the processing (preferably in the L1 step).
- Overall recommendation: **Yes, the CH₄ product is ready for release** to the public along with the product readme file.



Notes

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Thank you for your attention!