

Results of the FRM4GHG project



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<http://frm4ghg.aeronomie.be/>

Objective – perform an intercomparison of simultaneously measured total column amounts of CO₂, CH₄ and CO using several different portable low-cost spectrometric instruments under different atmospheric conditions in comparison to the TCCON instrument. These instruments can then be used to complement the existing TCCON network.

Description – perform side-by-side low-resolution measurements using test instruments next to a TCCON station.

Location – TCCON site at Sodankylä, Finland (67.37 N, 26.63 E, 188 m.a.s.l); possibilities of AirCore launches at the site

Duration – 2017 – 2019 (solar measurements during spring-summer-autumn period)

Table 1. List of instruments participating in the FRM4GHG campaign in 2018 and their properties.

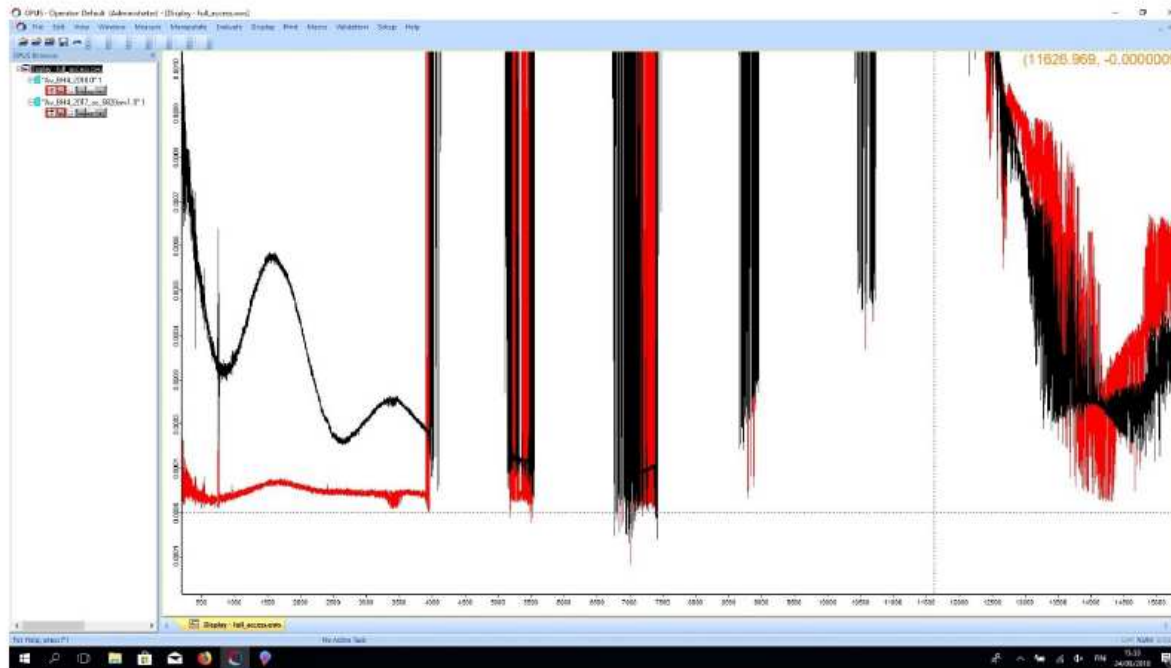
Instrument	Institute	Spectral range	Resolution	Main species	Retrieval code
Bruker IFS 125HR (TCCON)	FMI	1800 – 15000 cm ⁻¹	0.004 cm ⁻¹	XCO ₂ , XCH ₄ , XCO @ 0.02 cm ⁻¹	GFIT 2014, TCCON standard
Bruker EM27/SUN (COCCON)	KIT	4000 – 9000 cm ⁻¹	0.5 cm ⁻¹	XCO ₂ , XCH ₄ , XCO	PROFFAST
Bruker IRCube	Uni Wollongong	4500 – 15000 cm ⁻¹	0.5 cm ⁻¹	XCO ₂ , XCH ₄	GFIT 2016
Bruker Vertex70	Uni Bremen & BIRA-IASB	2500 – 15000 cm ⁻¹	0.16 cm ⁻¹	XCO ₂ , XCH ₄ , XCO @ 0.2 cm ⁻¹	GFIT 2014, TCCON standard
Bruker IFS 125HR (HR125LR)	FMI & KIT	1800 – 15000 cm ⁻¹	0.004 cm ⁻¹	XCO ₂ , XCH ₄ , XCO @ 0.5 cm ⁻¹	PROFFAST
LHR (Laser Heterodyne Radiometer)	RAL	954 – 960 cm ⁻¹ 1233.5 cm ⁻¹	0.002 and 0.02 cm ⁻¹	CO ₂ , H ₂ O CH ₄ , H ₂ O	own code, optimal estimation
AirCore	Uni Groningen & FMI	In-situ sampling	13.4 mbar (Amb.P. > 232 mbar) 3.9 mbar (Amb.P. < 232 mbar)	CO ₂ , CH ₄ , CO vertical profiles calibrated to WMO standards	

Nonlinearity issue with the TCCON

NONLINEARITY

2017

2018

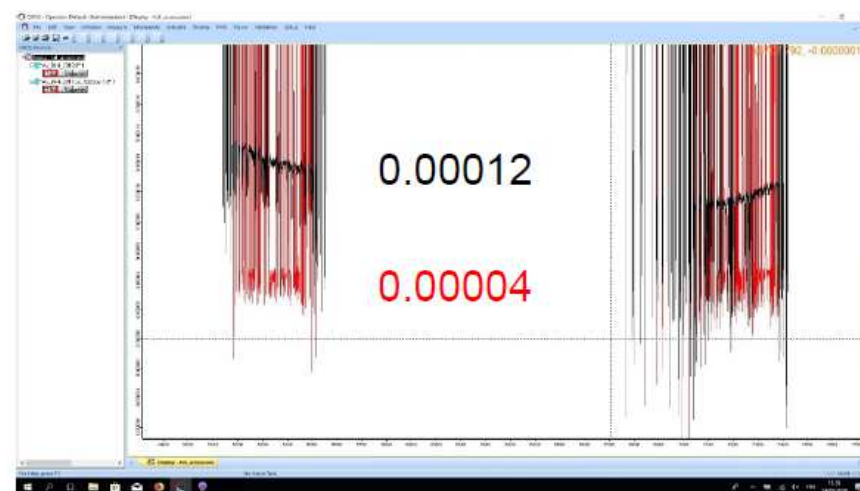
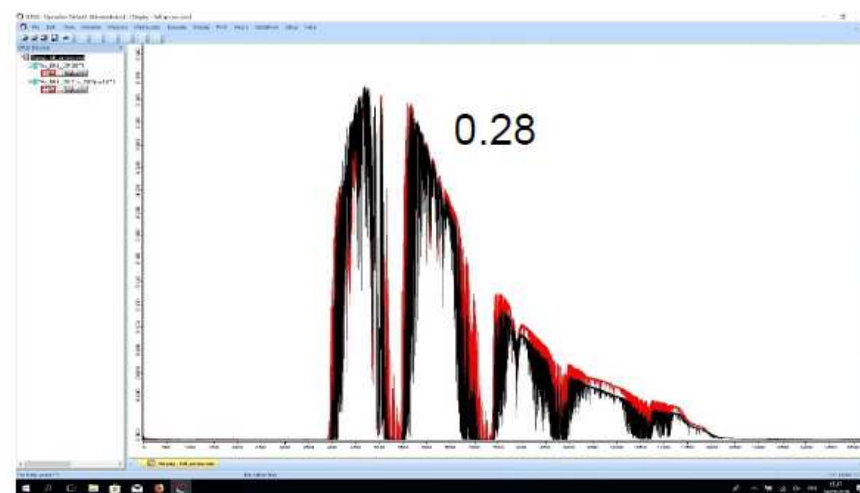


In 2017 comparisons revealed that there is a nonlinearity issue in the measurement. We tried to decrease the effect for the second phase of the project. First by defocusing the InGaAs detector but finally we had to lower the signal level entering on the sensor surface. We changed the aperture stop in the instrument entrance from 32 mm to 16 mm.

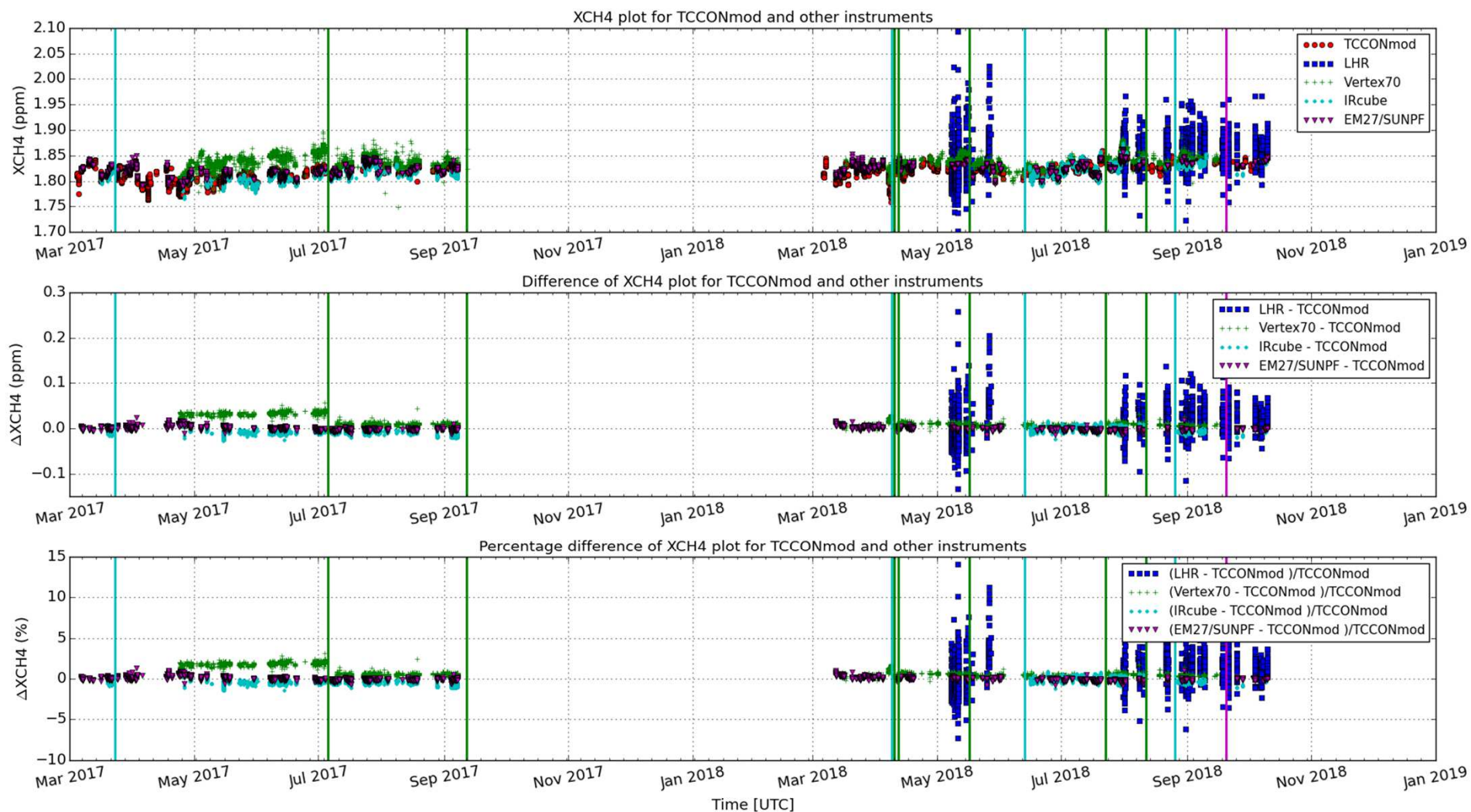
Nonlinearity issue with the TCCON

NONLINEARITY

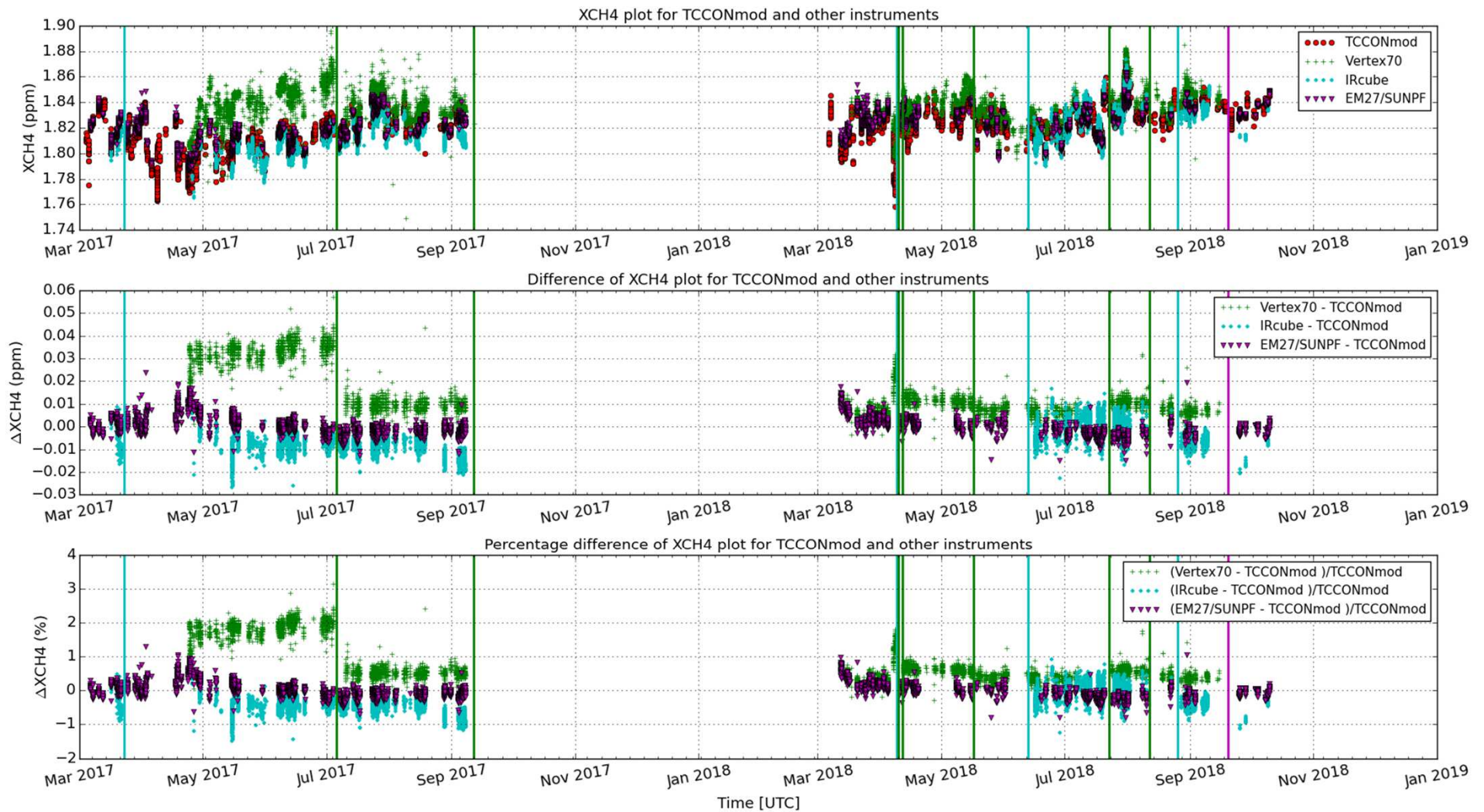
After the changes the zero level offsets are significantly lower now, by the factor of 3. The offset is also much less dependent on the wavenumber. It stays rather constant through the whole wavenumber range. In 2017 the offset was clearly increasing toward 0 cm^{-1} (previous slide).



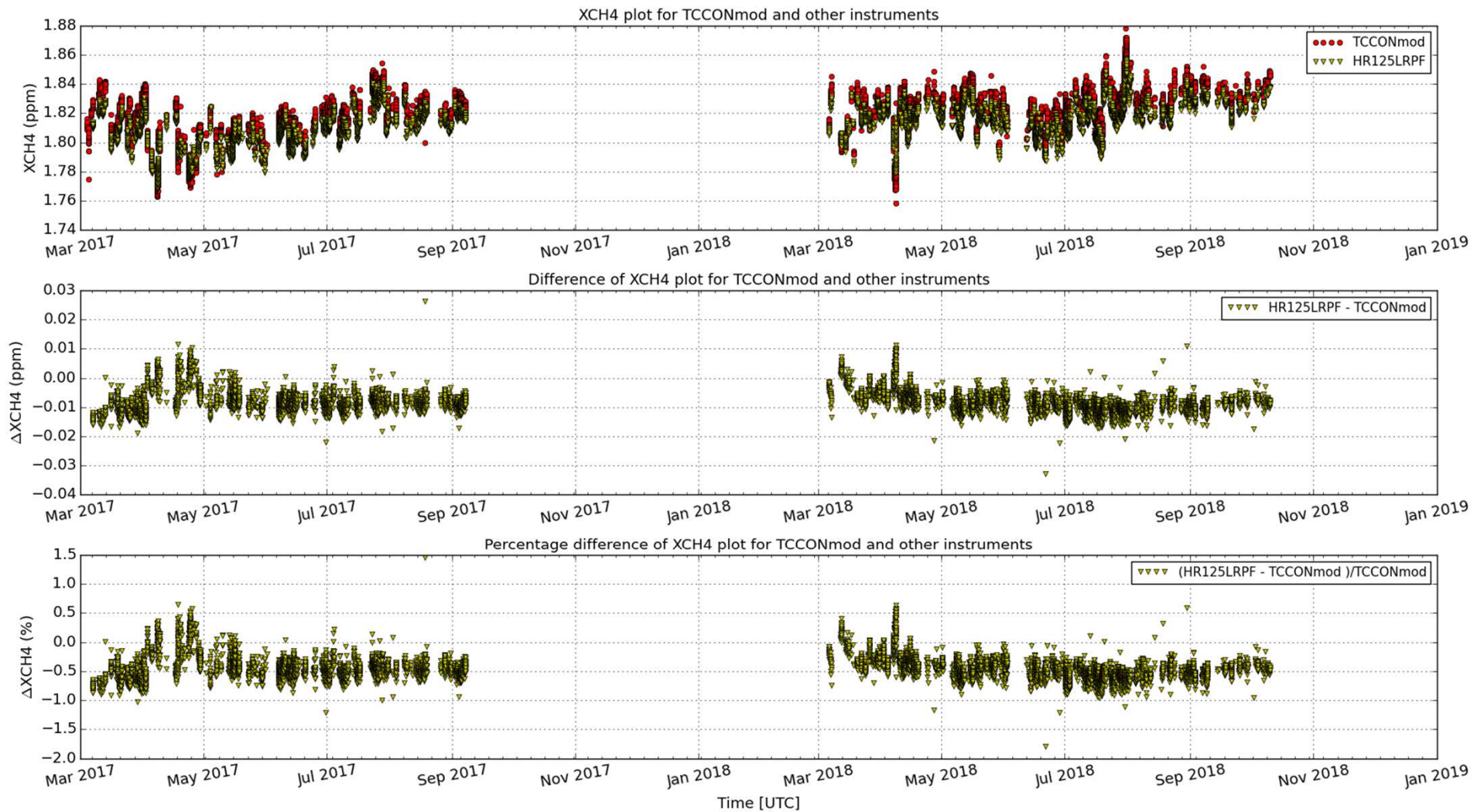
All instruments vs TCCONmod – XCH₄



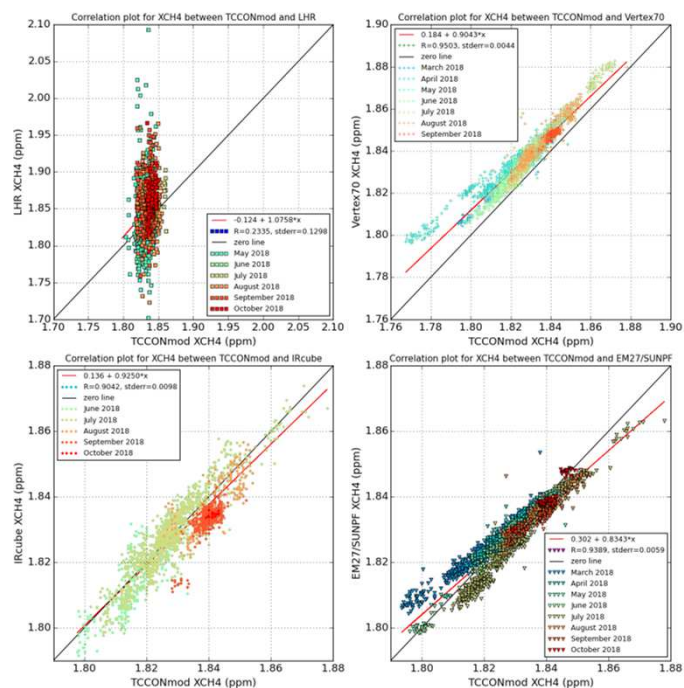
3 instruments vs TCCONmod – XCH4



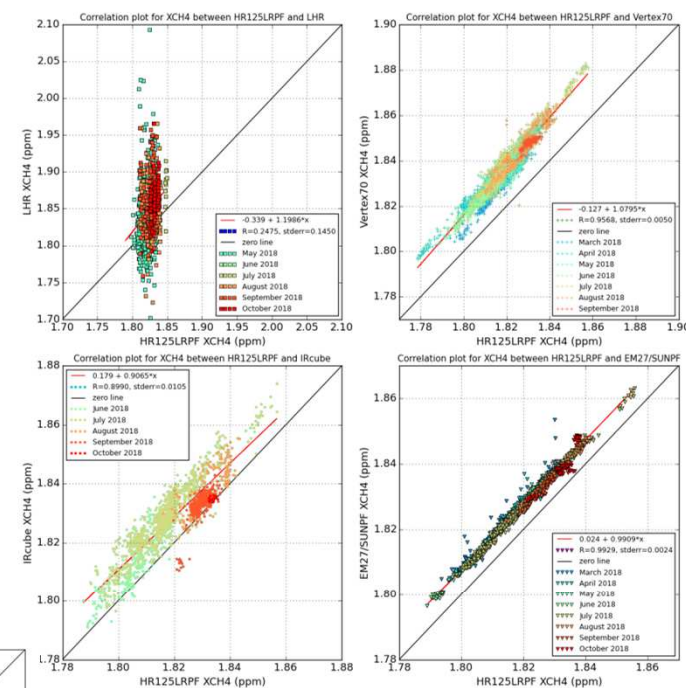
HRI25LR vs TCCONmod – XCH4



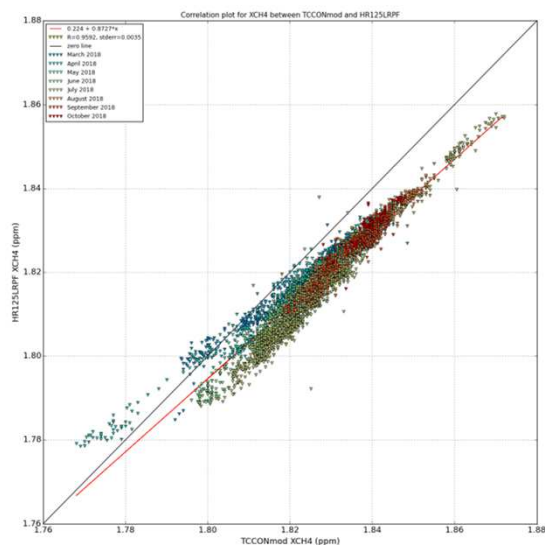
Correlation – XCH₄ for 2018



TCCONmod comparison



HR125LR comparison



TCCONmod vs HR125LR

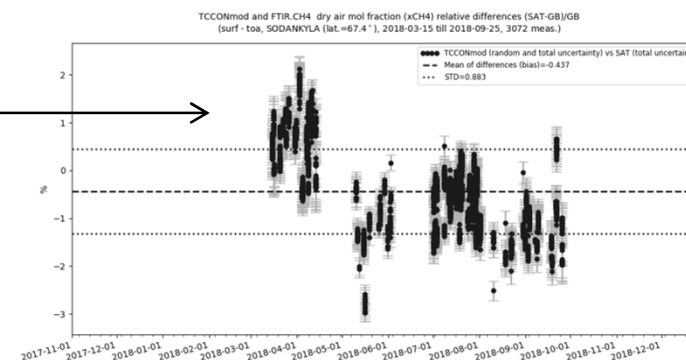
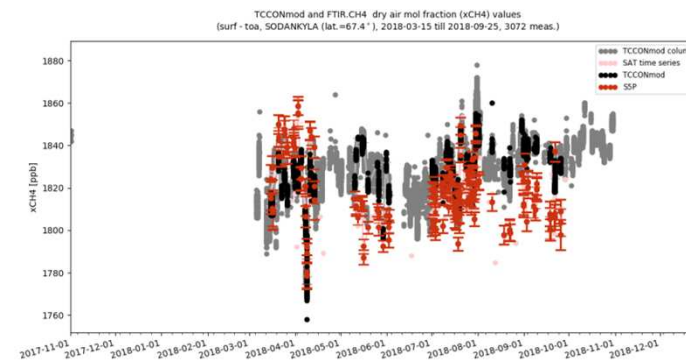
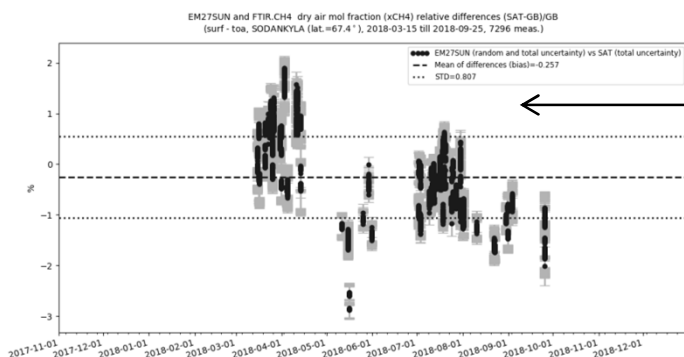
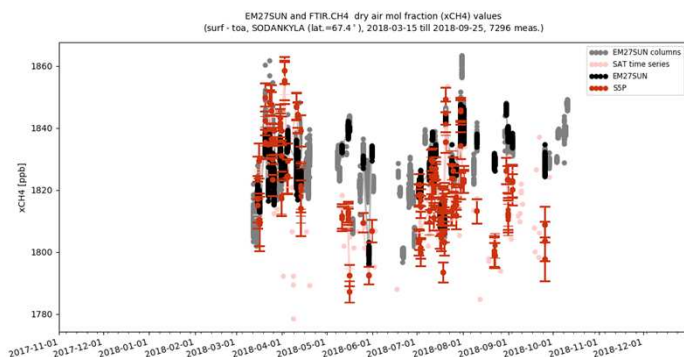
Coincidence criteria for validation study



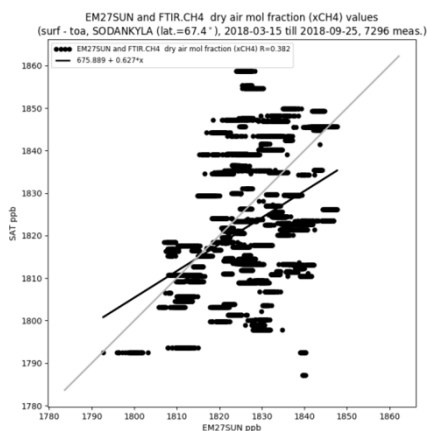
- Period of study: 01 March 2018 – 31 October 2018.
- S5P data from Mission Performance Centre (MPC) provided by the Payload Data Ground Segment (PDGS) at DLR.
- Coincidence criteria for CH₄: Time delta = 1 hours; Geo-distance delta = 100 km radius. QA filtering: qa_value > 50; bias corrected S5P-CH₄ product used for the study. From the coincident and filtered satellite measurements an average of all pixels is taken for each ground-based reference measurements.
- S-5P requirements for CH₄ total column: target bias = 1.5 %; target precision : < 1 %
- Coincidence criteria for CO: Time delta = 1 hours; Geo-distance delta = 50 km radius. QA filtering: qa_value > 50;. From the coincident and filtered satellite measurements an average of all pixels is taken for each ground-based reference measurements.
- S-5P requirements for CO total column: target bias = 15 %; target precision : < 10 %

S5P-XCH4 bias corrected product vs EM27/SUN

(COCCON network instrument)



Note: different number of measurements
EM27/SUN data scaled to WMO via TCCON



S5P vs TCCONmod

Mean bias = -0.44%, STD = 0.88%, R = 0.36

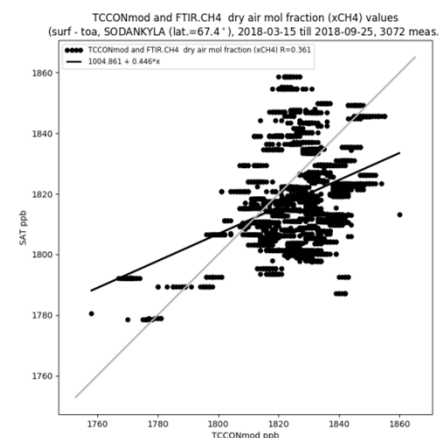
S5P vs EM27/SUN

Mean bias = -0.26%, STD = 0.81%, R = 0.38

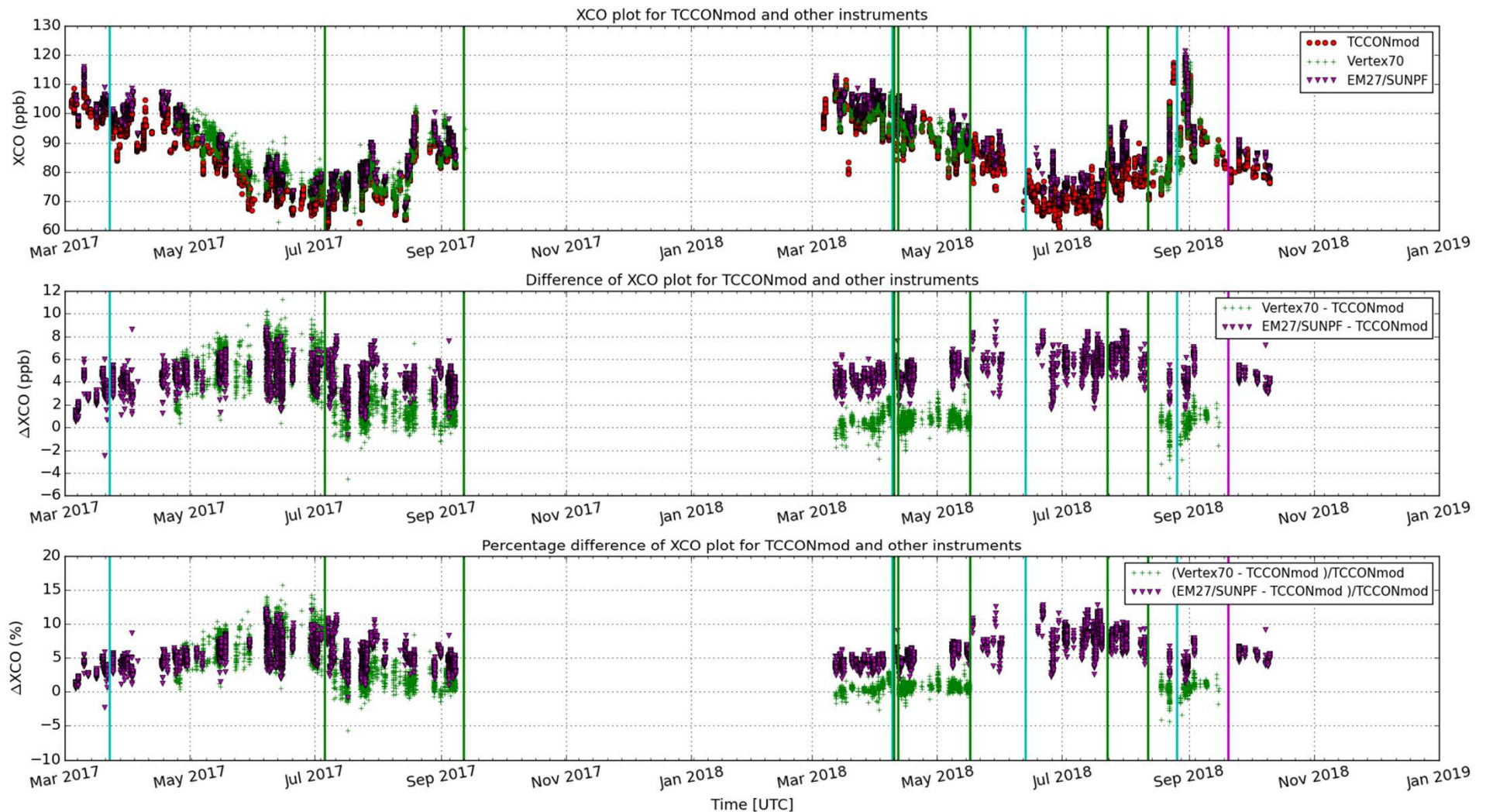


EM27/SUN vs TCCONmod

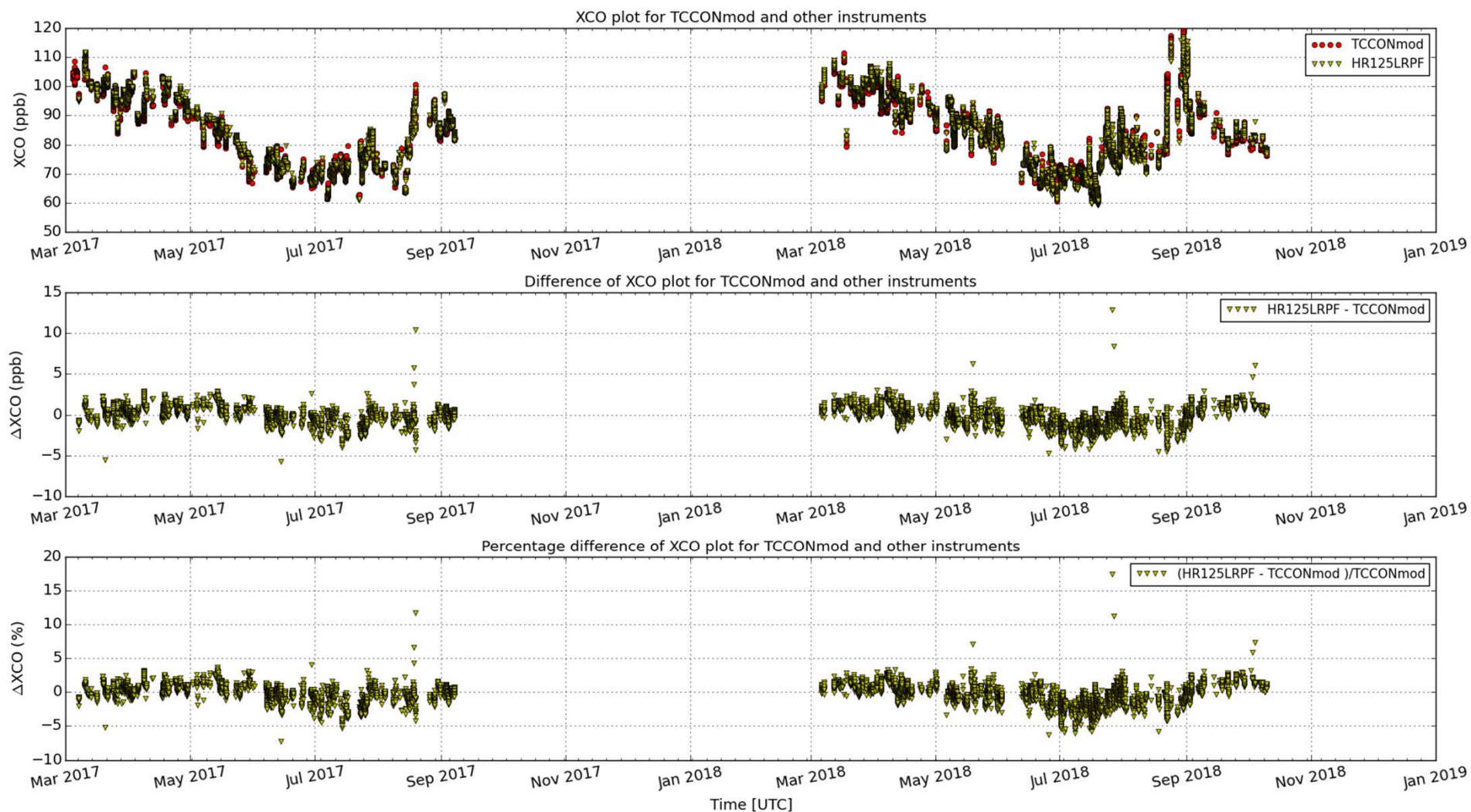
Mean bias = -0.05% (-1 ppb), STD = 0.22% (4 ppb), R = 0.94



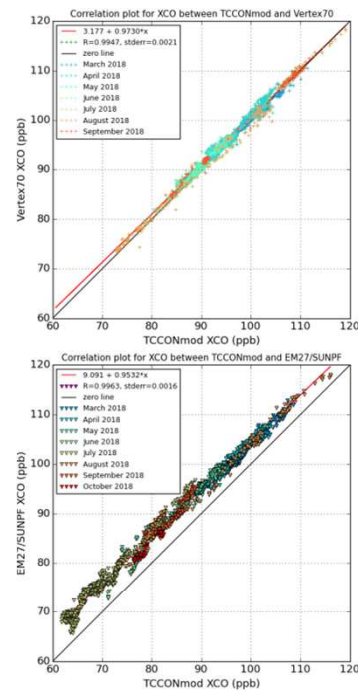
EM27SUN, VERTEX70 vs TCCONmod – XCO



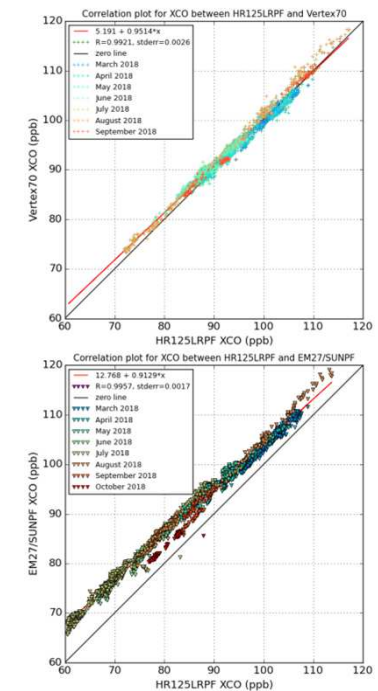
HRI25LR vs TCCONmod – XCO



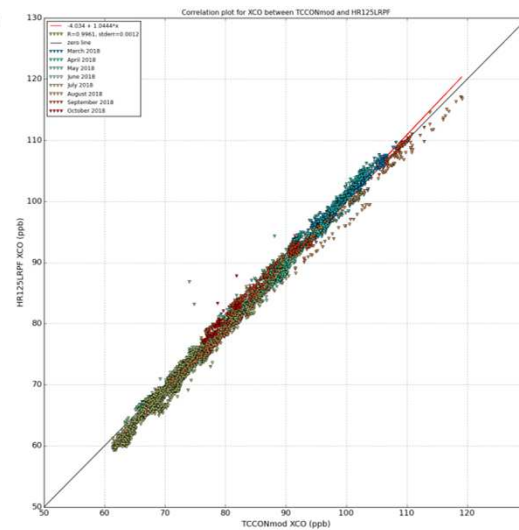
Correlation – XCO for 2018



TCCONmod comparison

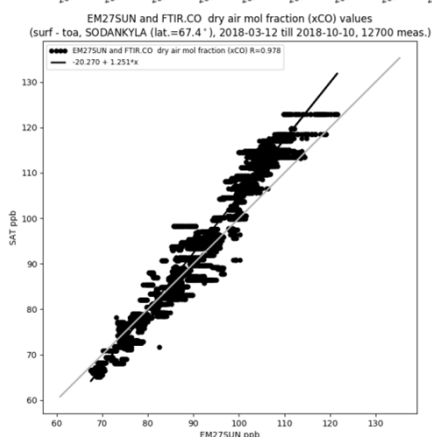
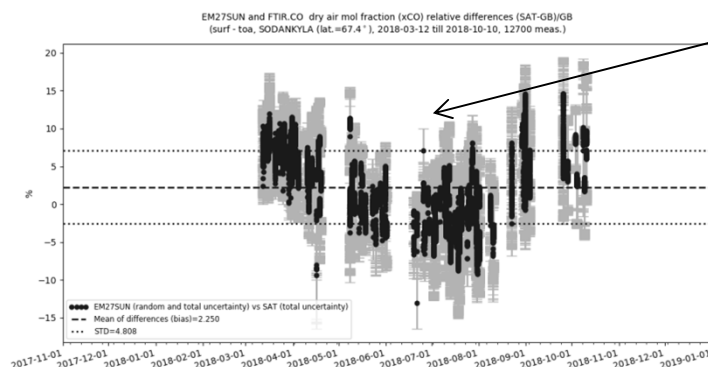
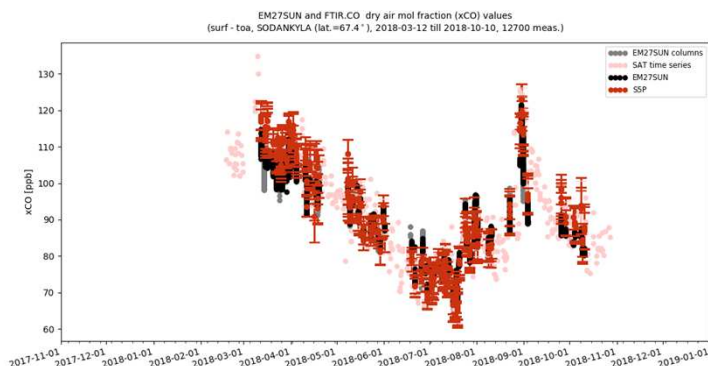


HR125LR comparison



TCCONmod vs HR125LR

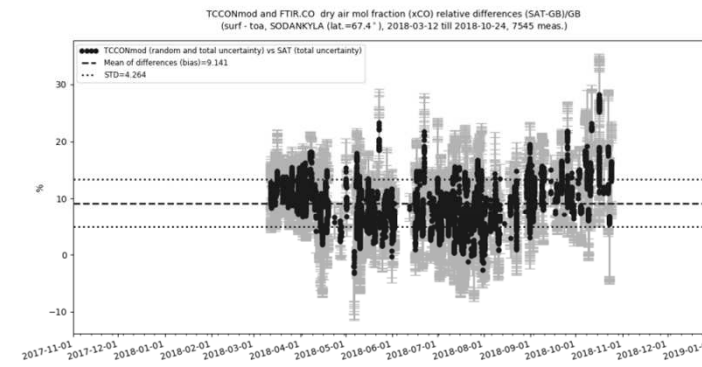
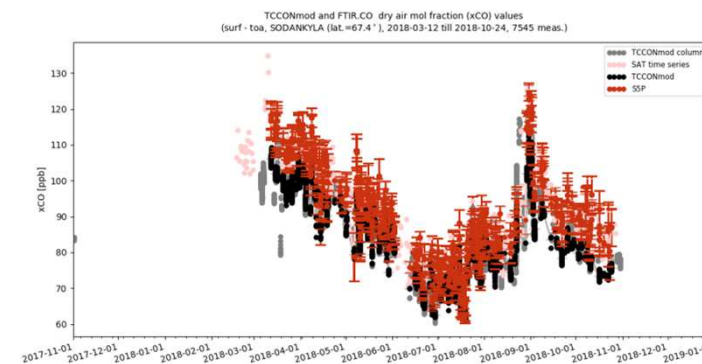
S5P-CO validation results using EM27/SUN (COCCON network instrument)



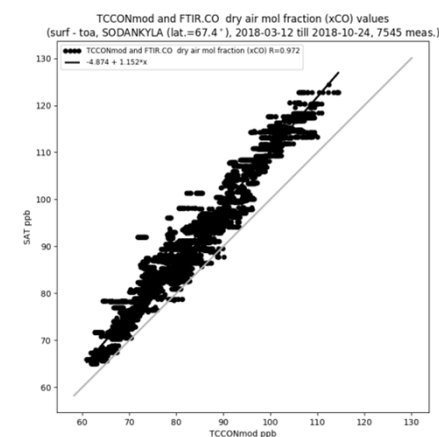
S5P vs EM27SUN
Mean bias = 2.25%, STD = 4.81%, R = 0.978

EM27/SUN vs TCCONmod
Mean bias = 5.66% (5.09 ppb), STD = 1.37% (1.23 ppb), R = 0.996

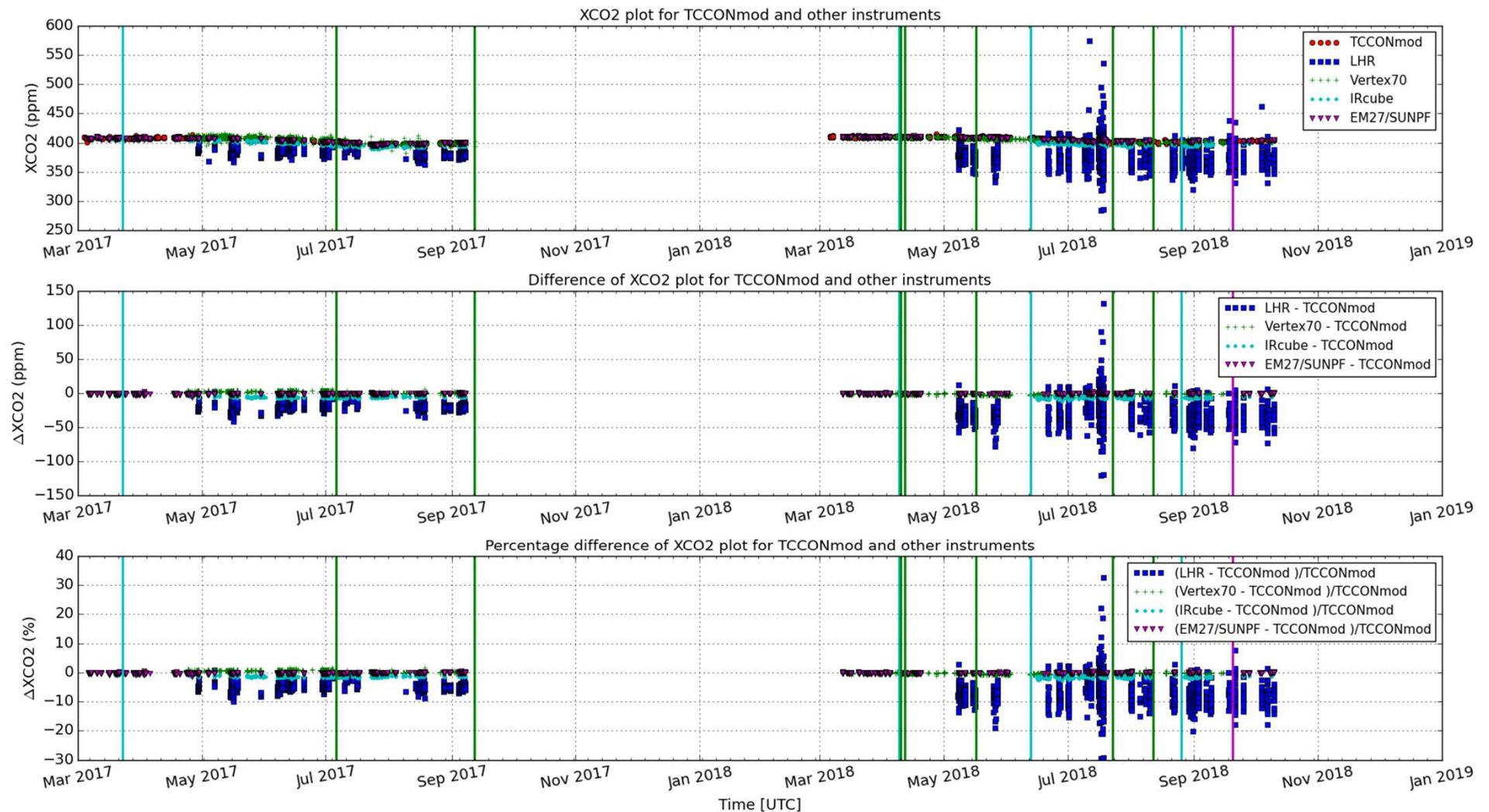
Note:
EM27SUN data not yet
corrected for
spectroscopic errors



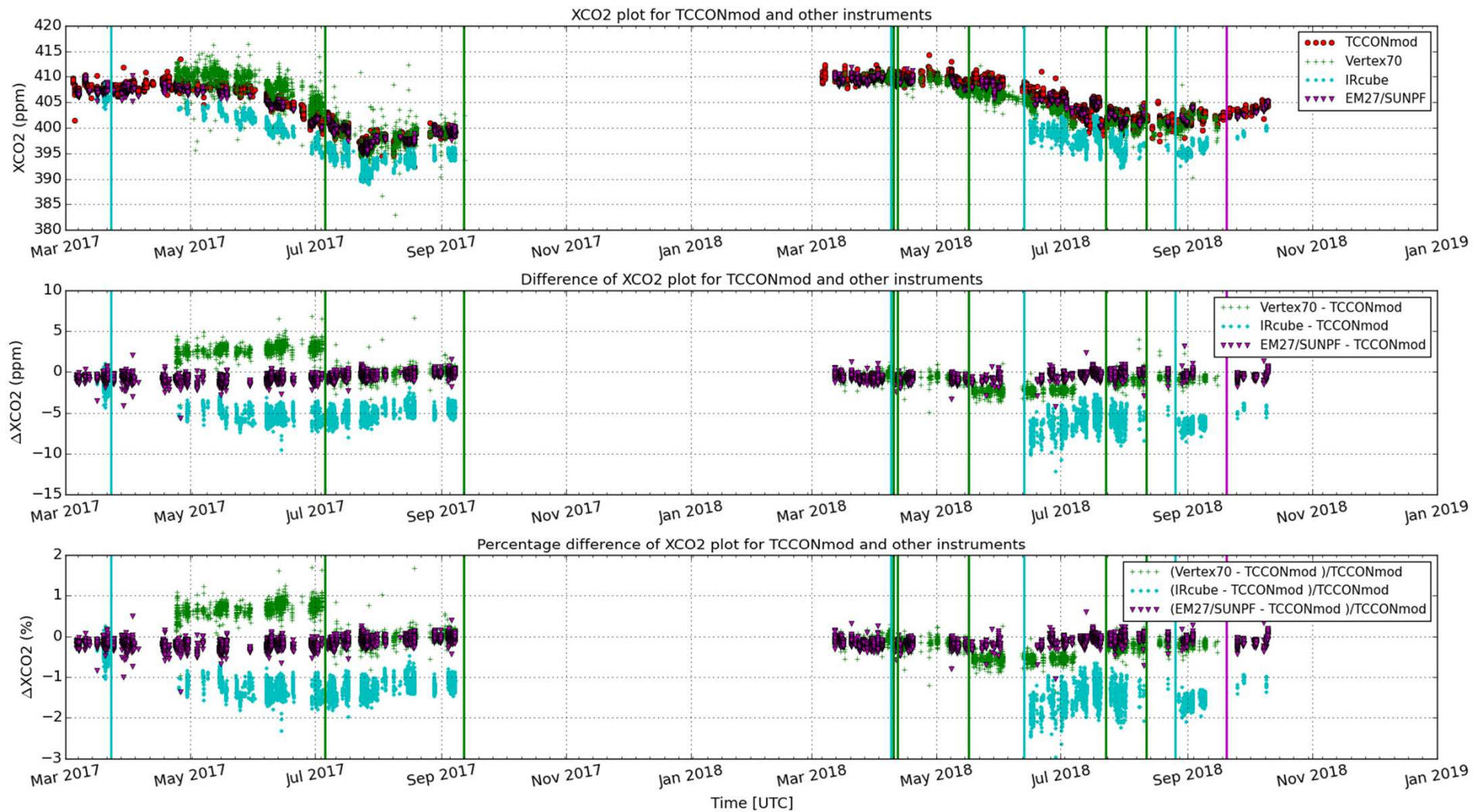
S5P vs TCCONmod
Mean bias = 9.14%, STD = 4.26%, R = 0.972



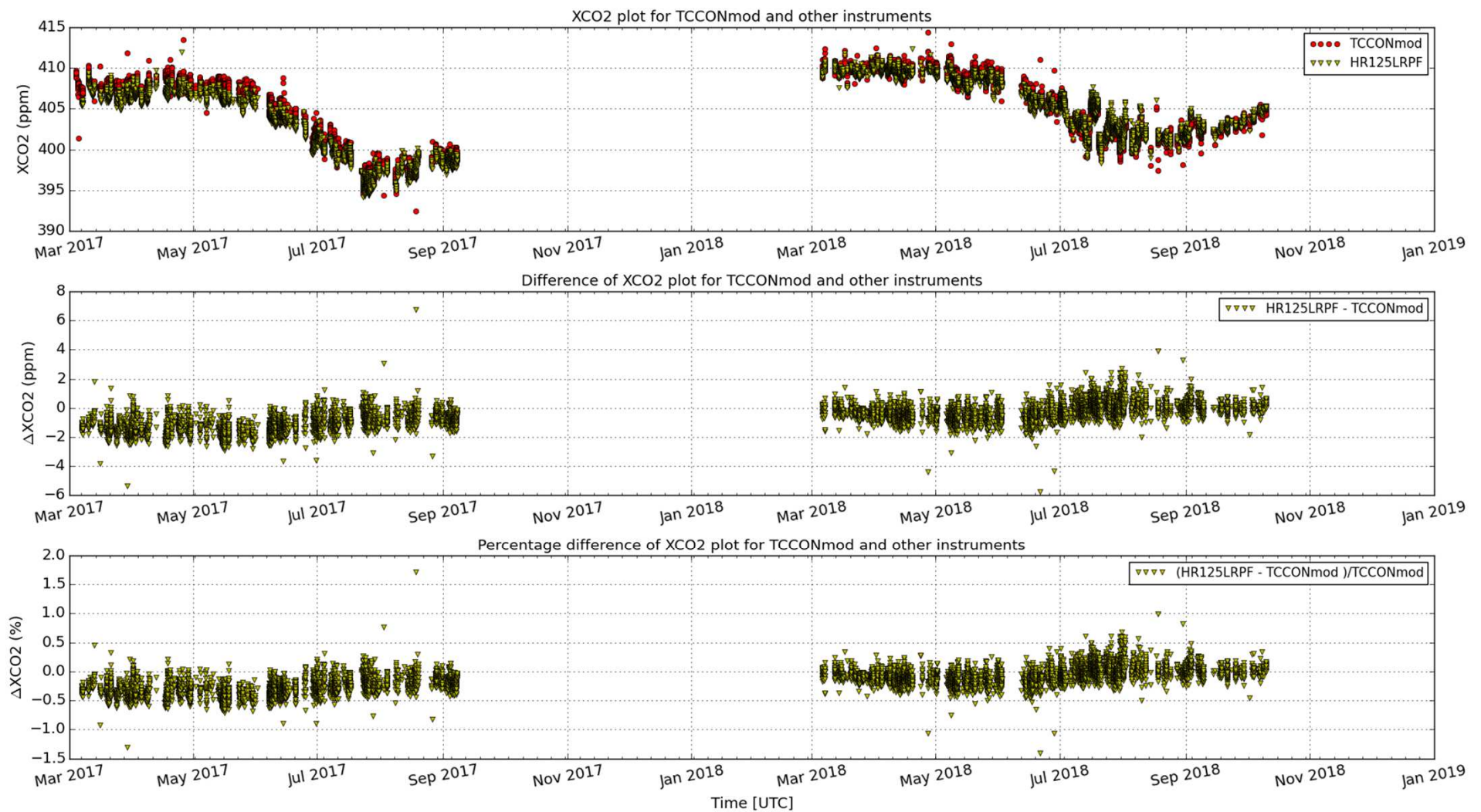
All instruments vs TCCONmod – XCO₂



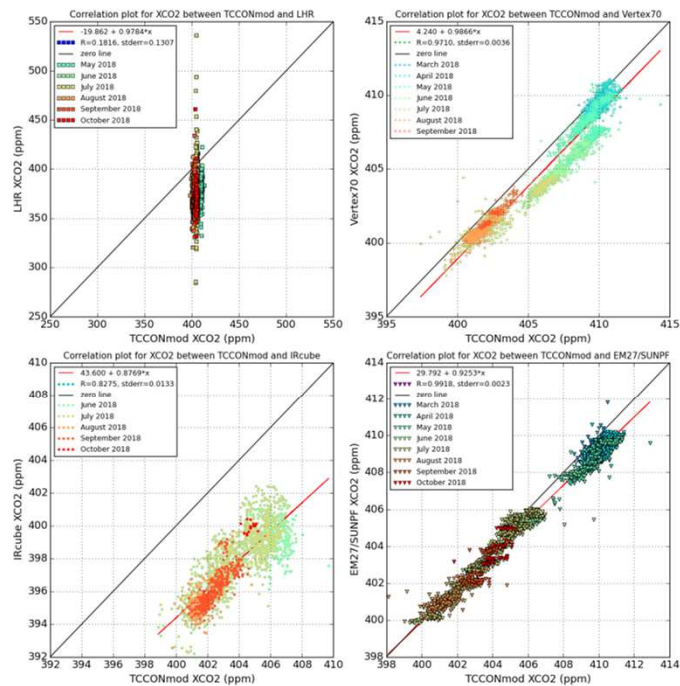
3 instruments vs TCCONmod – XCO₂



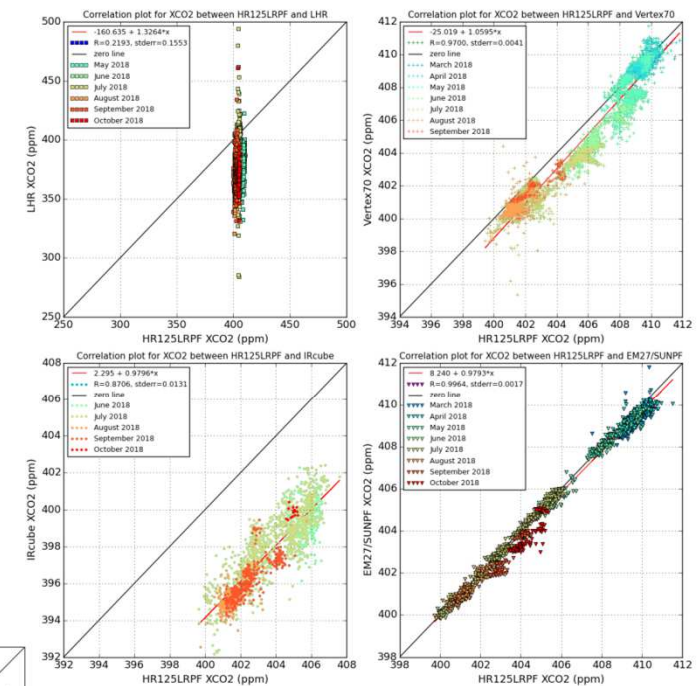
HRI25LR vs TCCONmod – XCO₂



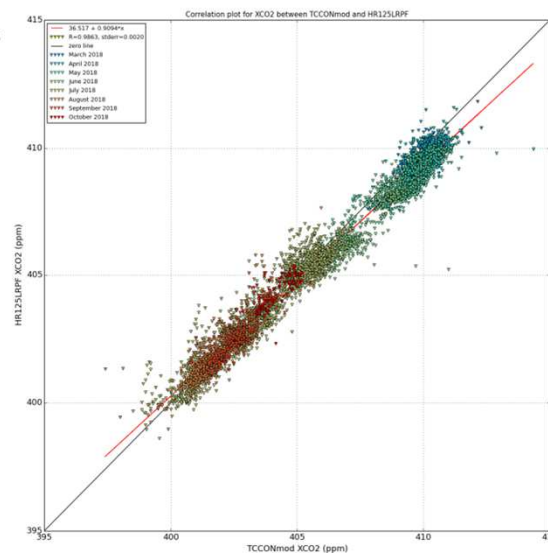
Correlation – XCO₂ for 2018



TCCONmod comparison



HR I25LRPF comparison



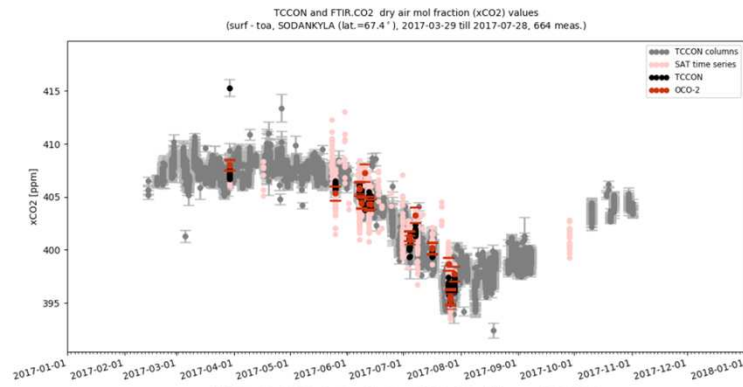
TCCONmod vs HR I25LRPF

Coincidence criteria for CO₂ validation study

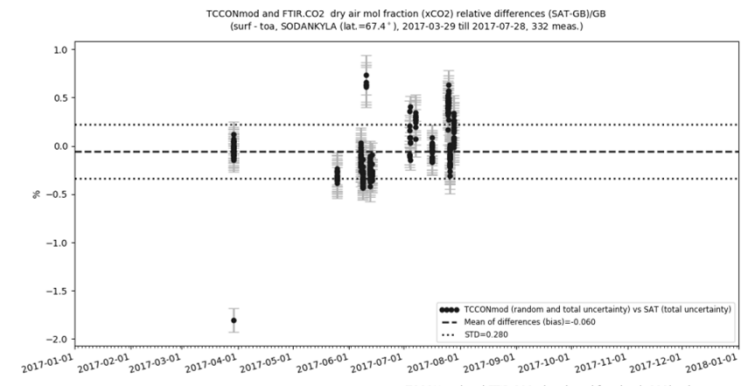
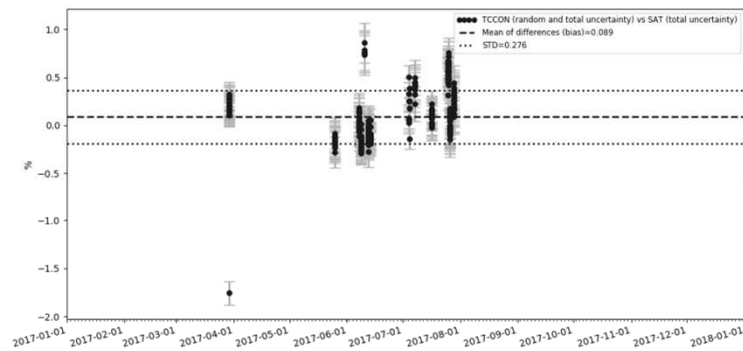
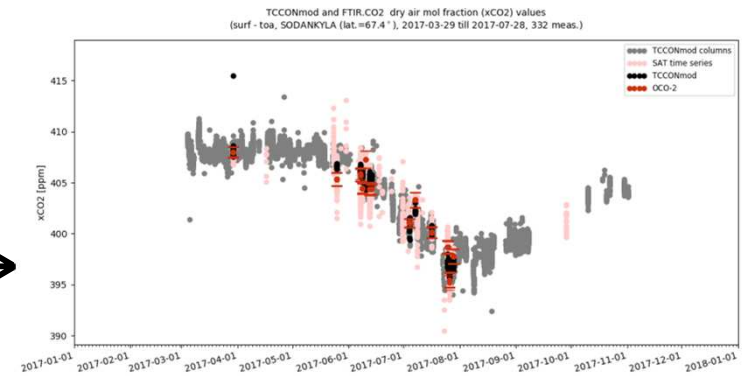


- Period of study: 01 March 2017 – 31 October 2018.
- OCO-2 data OCO2_L2_Lite_FP: OCO-2 Science Team/Michael Gunson, Annmarie Eldering (2018), OCO-2 Level 2 bias-corrected XCO₂ and other select fields from the full-physics retrieval aggregated as daily files, Retrospective processing V9r, Greenbelt, MD, USA, Goddard Earth Sciences Data and Information Services Center (GES DISC), Accessed: 08/04/2019, [10.5067/W8QGIYNKS3JC](https://doi.org/10.5067/W8QGIYNKS3JC)
- OCO-2 spatial coverage: -180, -90, 180, 90; Spatial resolution: 2.25 km x 1.29 km; Temporal: 16 days
- Coincidence criteria for CO₂: Time delta = 1 hours; Geo-distance delta = $\pm 5^\circ$ lon, $\pm 2.5^\circ$ lat. xco2_quality_flag = 0. From the coincident satellite measurements an average of all pixels is taken for each ground-based reference measurements.

OCO-2 CO₂ validation results using TCCON for 2017

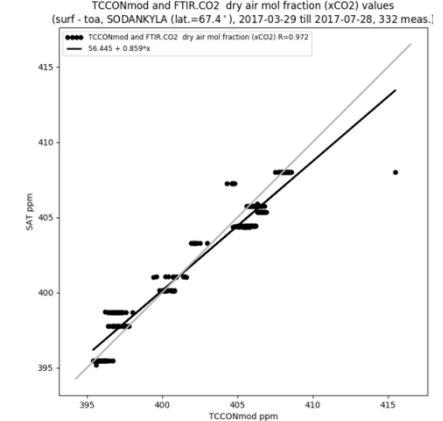
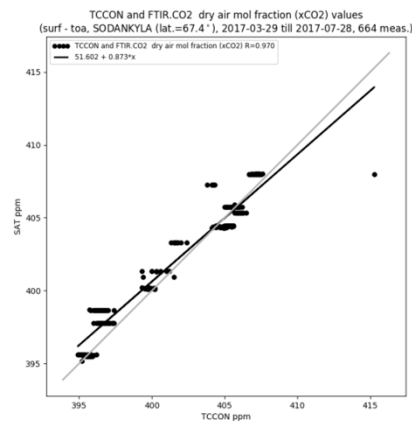


TCCONmod comparison
2017 non-linearity corrected



OCO-2 vs TCCONmod

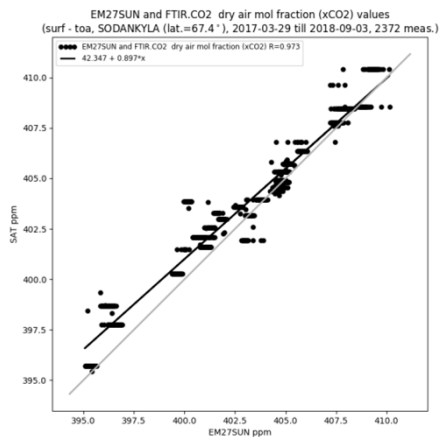
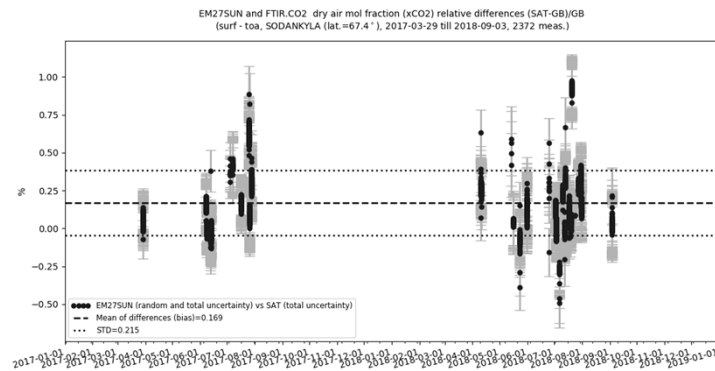
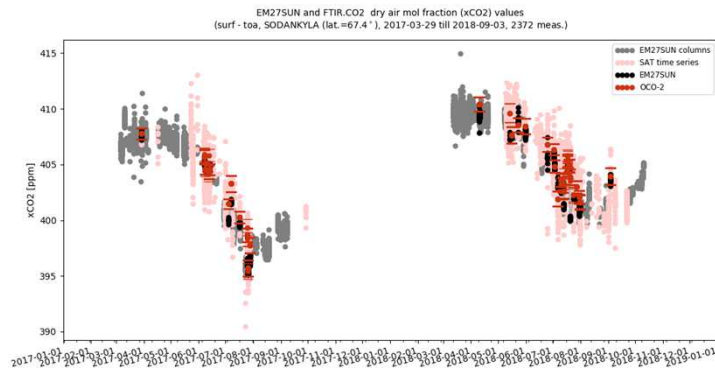
Mean bias = -0.060%, STD = 0.280%, R = 0.972



OCO-2 CO₂ validation results using EM27/SUN

Year: 2018

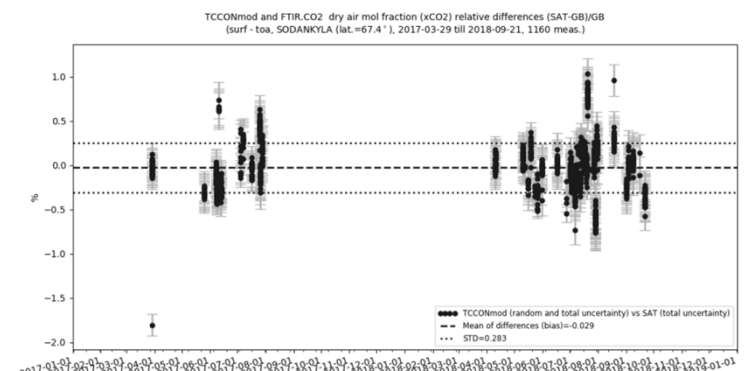
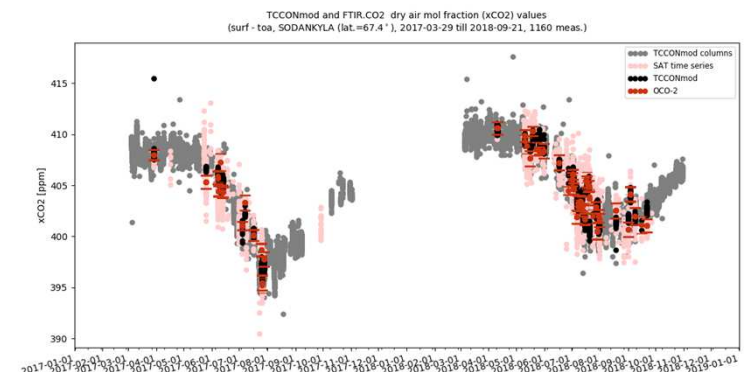
(COCCON network instrument)



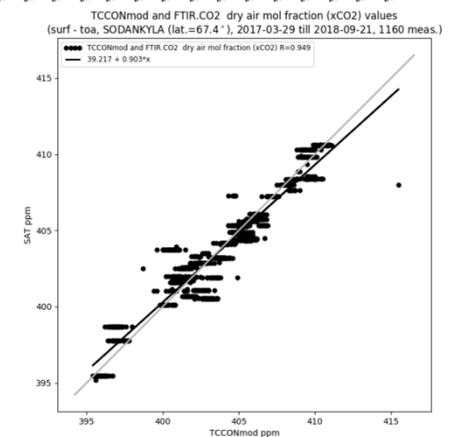
OCO-2 vs EM27/SUN
Mean bias = 0.169%, STD = 0.215%, R = 0.973

EM27/SUN vs TCCONmod
Mean bias = -0.164% (-0.666 ppm), STD = 0.120% (0.486 ppm), R = 0.995

EM27/SUN data scaled to
WMO via TCCON



OCO-2 vs TCCONmod
Mean bias = -0.029%, STD = 0.283%, R = 0.949



- The low-resolution datasets are able to capture the seasonal cycle of CO₂, CH₄ and CO as seen by the TCCON.
- A small bias in CH₄ is observed during spring due to the high difference between the prior relative to the true atmospheric state, the column averaging kernel at high solar zenith angles and the retrieval sensitivities.
- The difference seen in the CH₄ intercomparison with respect to the TCCON and the HRI25LR highlights the impact of the different spectral resolutions. The scatter of the intercomparison results are within the limit of the TCCON precision (0.3%) with a high correlation between the two datasets. The low-resolution instruments (except EM27/SUN) are not yet scaled to the WMO reference which is the reason for the bias.
- The bias seen in the CO intercomparison is because the low-resolution instruments are not yet scaled to the WMO reference.
- Validation results of CH₄ and CO from S-5P and CO₂ from OCO-2 using low resolution instruments show comparable scatter and correlation similar to the TCCON.
- ➔ **EM27/SUN (COCCON network instrument), IRCube, and Vertex70 can complement the TCCON network and can be considered suitable reference networks / instruments for the satellite validation of CO₂, CH₄ and CO products.**

Disclaimer: The presented work has been performed in the frame of the FRM4GHG project. Results are based on preliminary (not fully calibrated/validated) Sentinel-5 Precursor data that will still change.

Acknowledgements: Sentinel-5 Precursor is a European Space Agency (ESA) mission on behalf of the European Commission (EC). The TROPOMI payload is a joint development by ESA and the Netherlands Space Office (NSO). The Sentinel-5 Precursor ground-segment development has been funded by ESA and with national contributions from The Netherlands, Germany, and Belgium.

This validation work has been performed within the FRM4GHG project which received funding from the European Space Agency's FRM Programme under grant agreement no. ESA-IPL-POE-LG-cl-LE-2015-1129.

Thank you for your attention!

