Total column measurements of GHGs from ground-based low-resolution remote sensing instruments and their comparison to TCCON

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FRM4GHG campaign

Objective – perform an intercomparison of simultaneously measured total column amounts of CO_2, CH_4 and CO using different portable low-cost spectrometric instruments under different atmospheric conditions in comparison to the TCCON instrument. Assess these instruments regarding their capability to complement the existing TCCON network.

Description – perform side-by-side measurements using these low-resolution instruments next to a TCCON instrument.
Location – TCCON site at Sodankylä (Finland), Wollongong & Darwin (Australia); AirCore launches at the Sodankylä site to complement the total column measurements.
Duration – 2017 – 2019 (direct solar absorption measurements under clear-sky conditions).

http://frm4ghg.aeronomie.be/

Table 1. List of instruments participating in the FRM4GHG campaign 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
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 2014
Bruker Vertex70	Uni Bremen & BIRA-IASB	2500 – 15000 cm^{-1}	0.16 cm^{-1}	XCO_2, XCH_4, XCO XHCHO @ 0.2 cm^{-1}	GFIT 2014
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_2O CH_4, H_2O	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	

FRM4GHG campaign

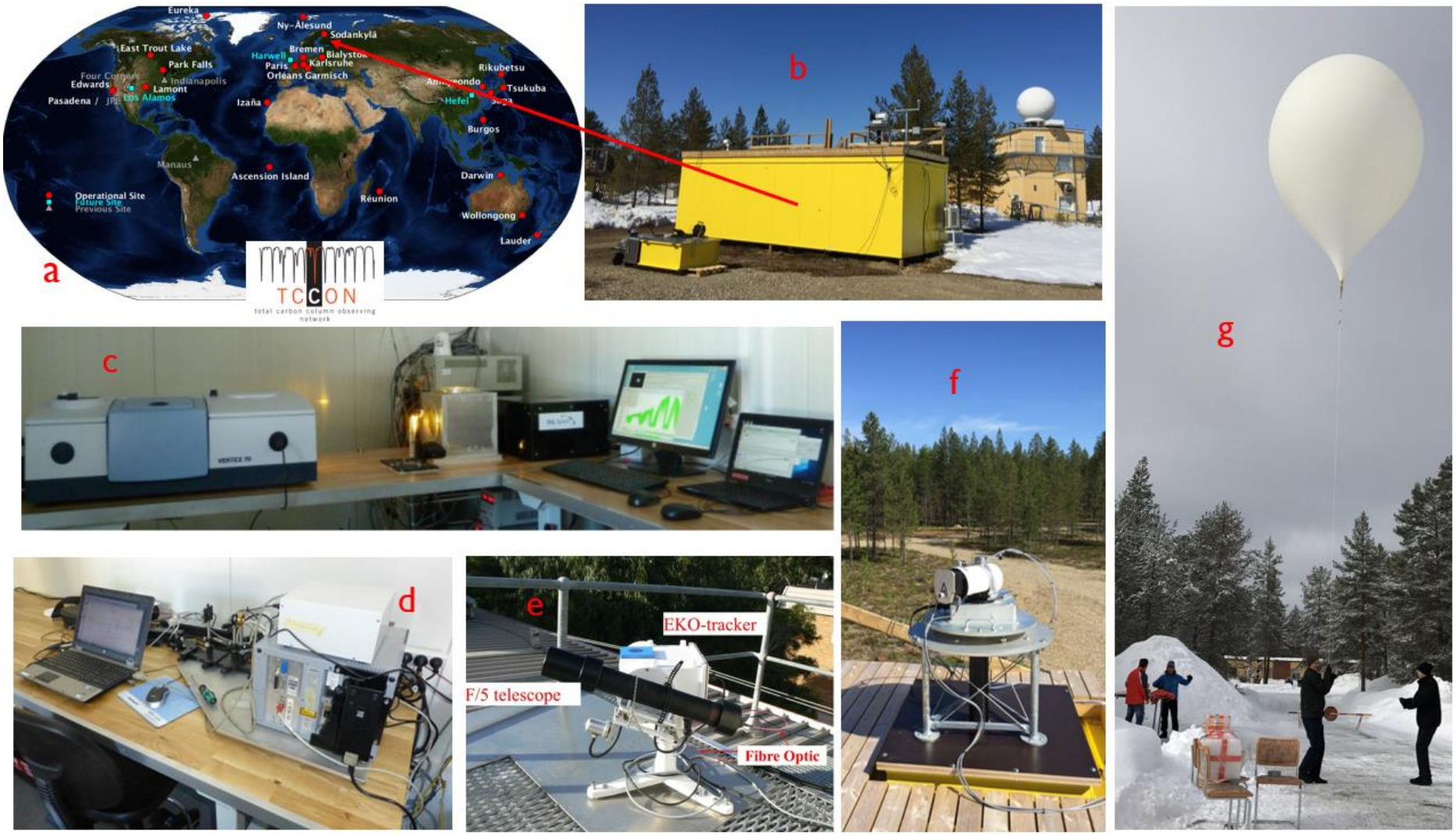
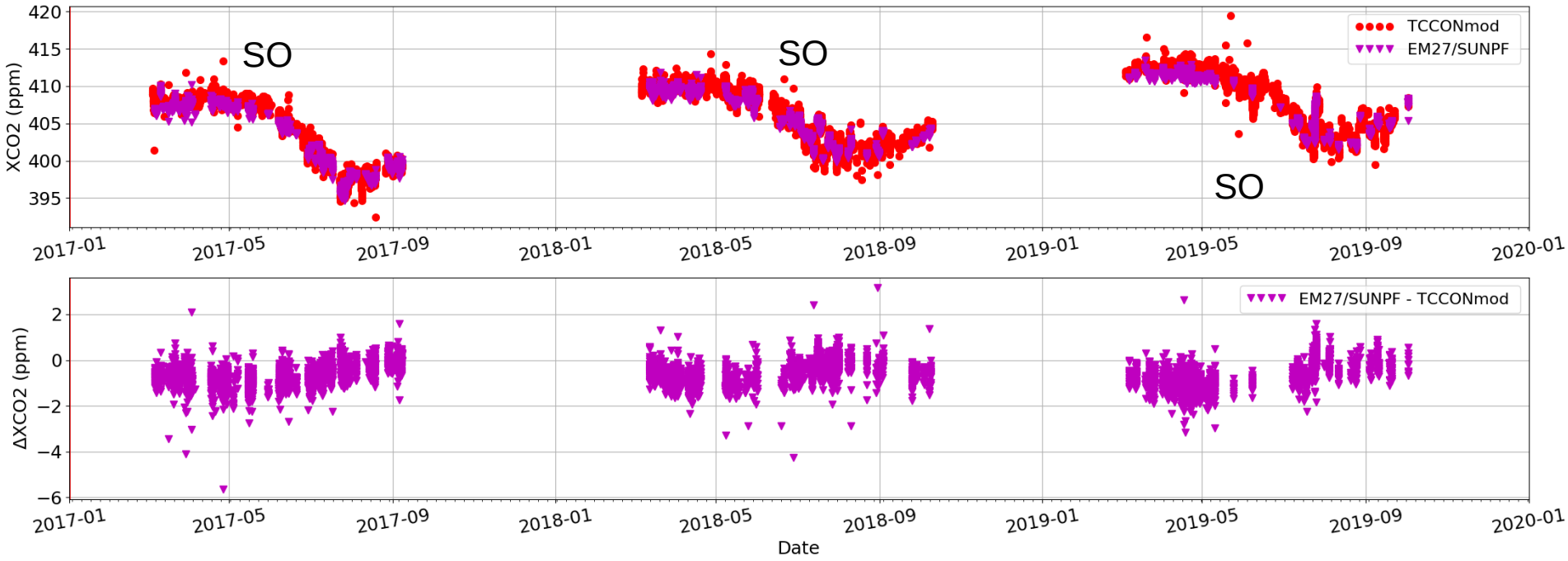


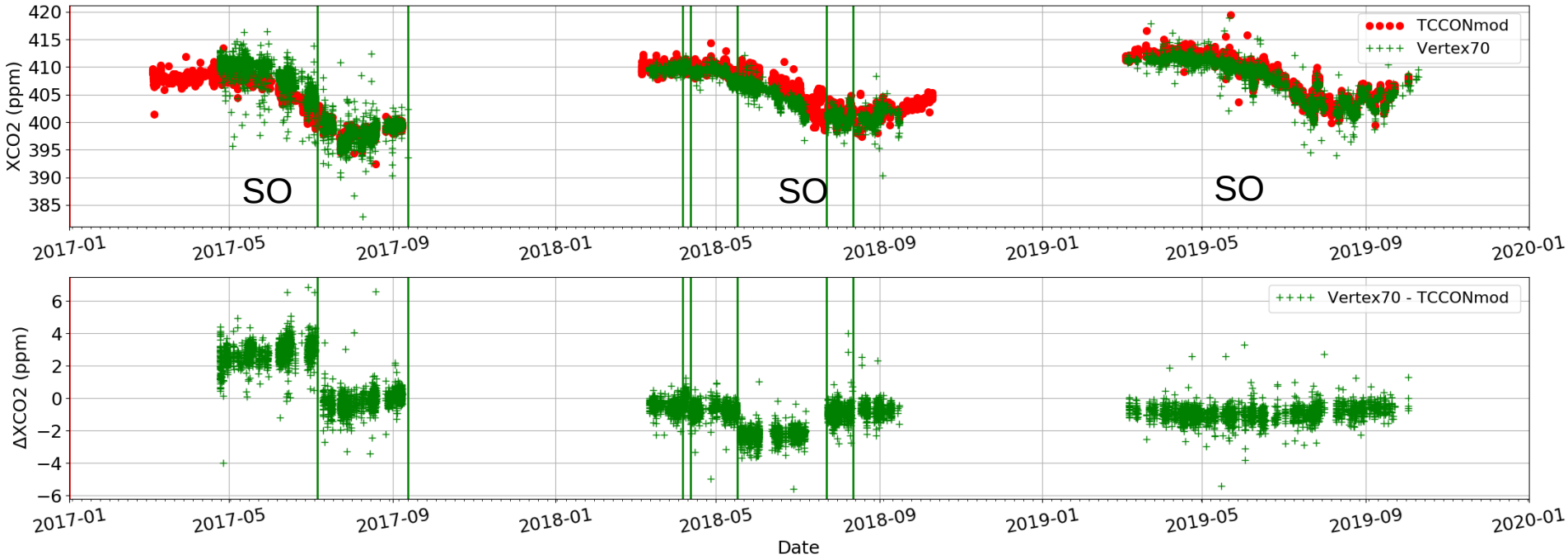
Fig. 1: (a) TCCON sites, (b) FRM4GHG container and EM27/SUN in front, (c-left) Vertex70 and (c-right) LHR, (d) IRCube, (e) suntracker for IRCube, (f) suntracker for Vertex70 and LHR, (g) Aircore launch at Sodankylä site.

EM27/SUN vs TCCON – XCO2



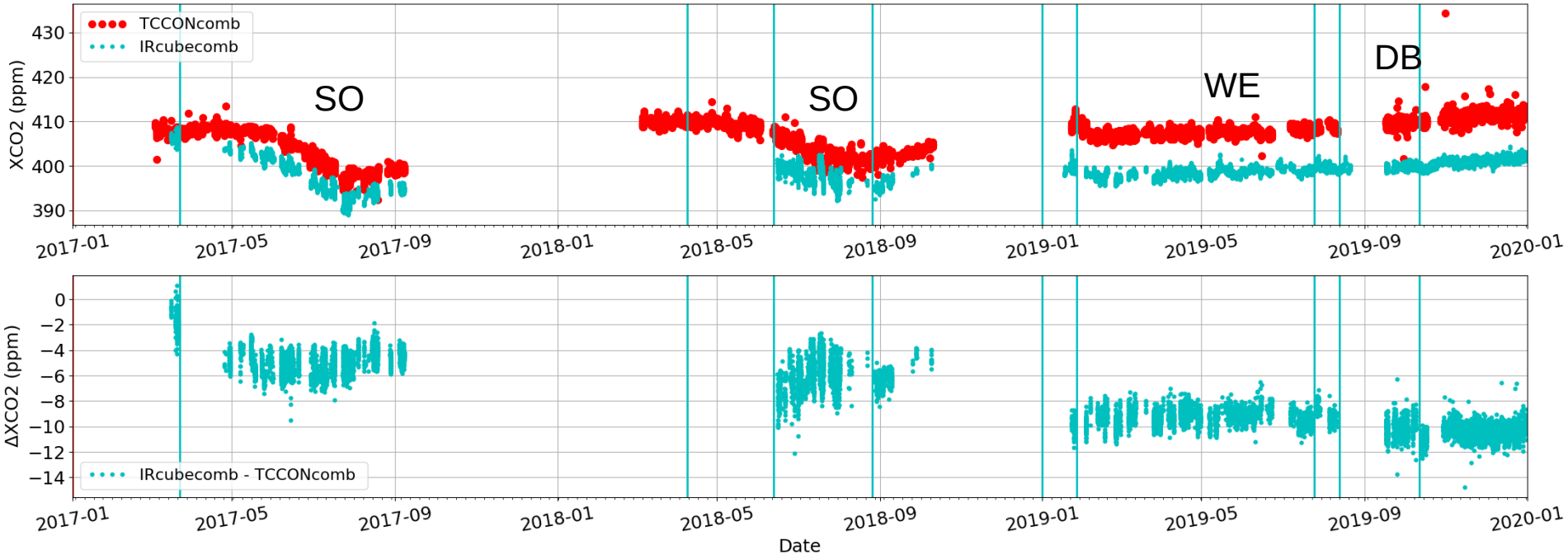
Seasonality seen in the bias (~ 1 ppm) ~ the accuracy requirement (0.25%) of TCCON.
The seasonality of the bias for other sites will depend on the variability of the profile shape during the year and their difference to the true profile.

VERTEX70 (all) vs TCCON – XCO2



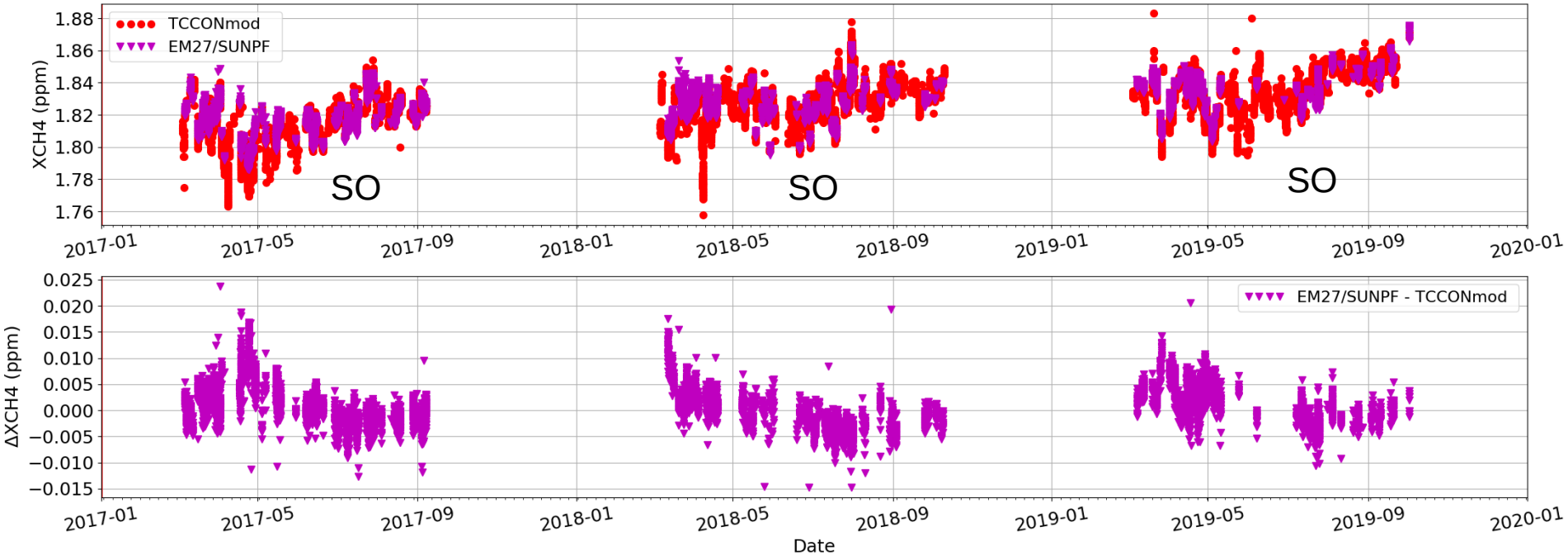
VERTEX70 is a new instrument tested at the campaign. Vertical lines indicate instrument modifications for improvements.
Seasonality seen in the bias (~ 1 ppm) ~ the accuracy requirement (0.25%) of TCCON.
The seasonality of the bias for other sites will depend on the variability of the profile shape during the year and their difference to the true profile.

IRCUBE (all) vs TCCON – XCO2



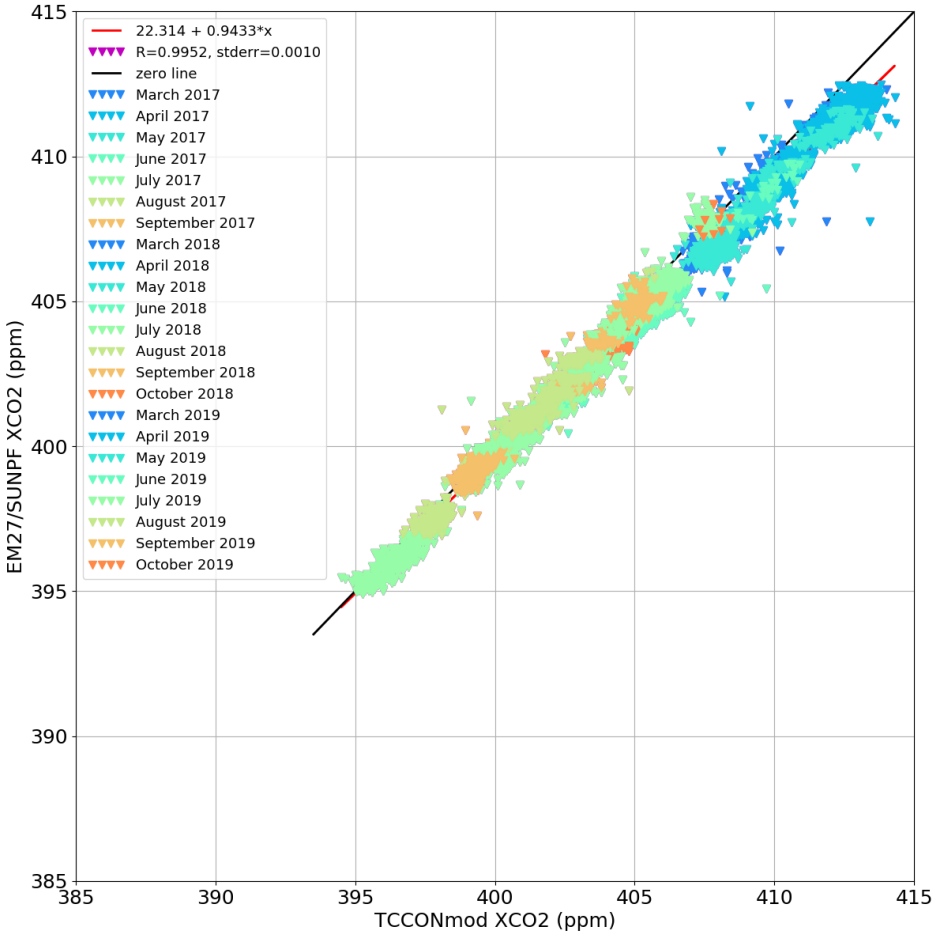
Vertical lines indicate instrument modifications for improvements.
IRCUBE measurements in 2017 and 2018 are performed in Sodankylä.
17 Jan 2019 – 21 Aug 2019 IRCUBE measurements are performed in Wollongong
17 Sep 2019 – 31 Dec 2019 IRCUBE measurements performed in Darwin

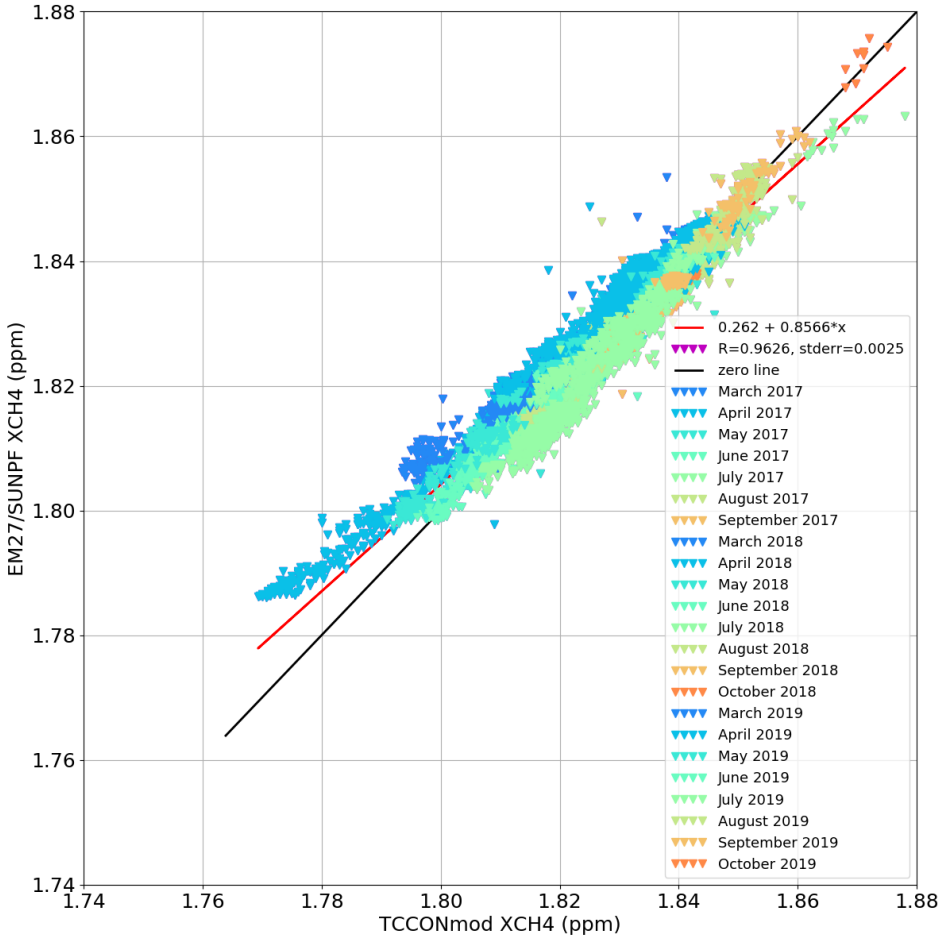
EM27/SUN vs TCCON – XCH4



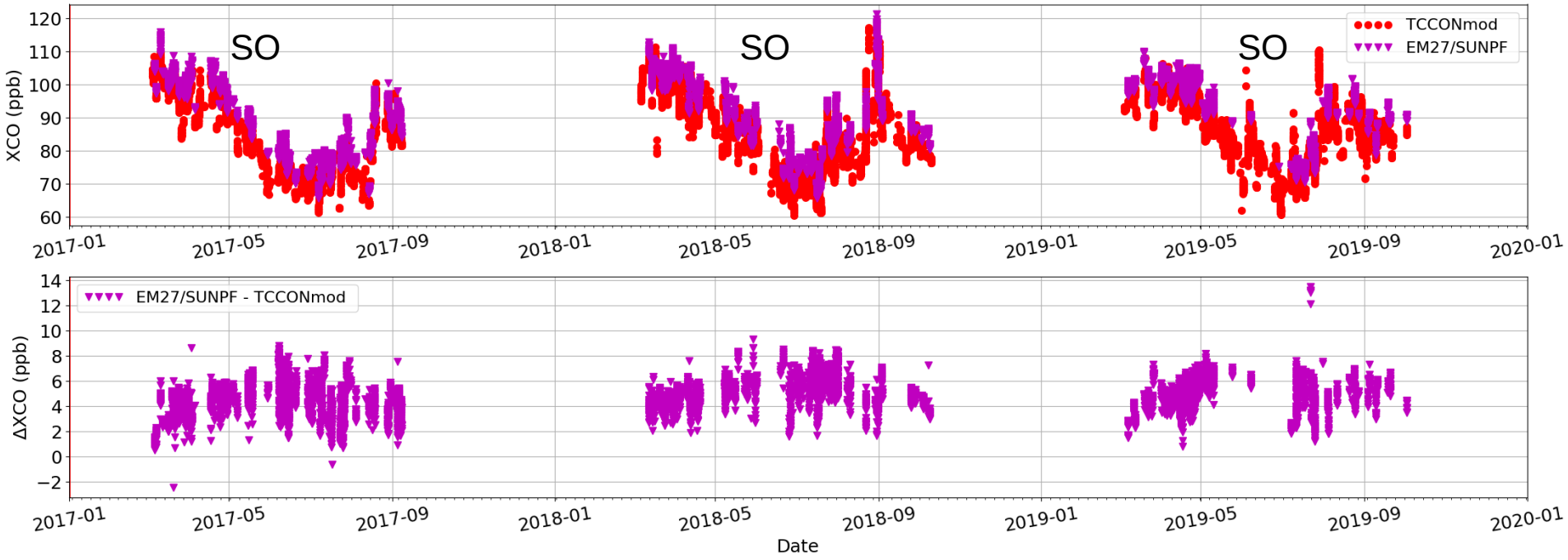
Seasonality seen in the bias. About 10 ppb during spring polar vortex conditions – not so usual for standard TCCON site, ~ 3 – 5 ppb bias during the summer – Autumn period ~ the accuracy requirement (0.2%) of TCCON.

EM27/SUN vs TCCON – XCO2 & XCH4





EM27/SUN vs TCCON – XCO



Seasonality seen in the bias. About 2 – 4 ppb bias ~ the accuracy requirement (2%) of TCCON.

Campaign statistics

Species	Duration	XCO2 / ppm	XCH4 / ppm	XCO / ppb
Bias (mean standard ± deviation) and correlation coefficient (r)				
EM27/SUN vs TCCON (Sodankylä)	2017 – 2019	-0.722±0.510 (0.995)	0.001±0.004 (0.963)	4.738±1.321 (0.994)
VERTEX70 (good) vs TCCON (Sodankylä)	2017 – 2019	-0.636±0.558 (0.996)	0.009±0.003 (0.968)	0.856±0.961 (0.995)
IRCUBE (good) vs TCCON (Darwin)	2019	-10.487±0.597 (0.73)	0.002±0.003 (0.808)	-
LHR vs TCCON (Sodankylä)	2019	-0.979±10.424 (0.315)	0.005±0.069 (0.160)	-

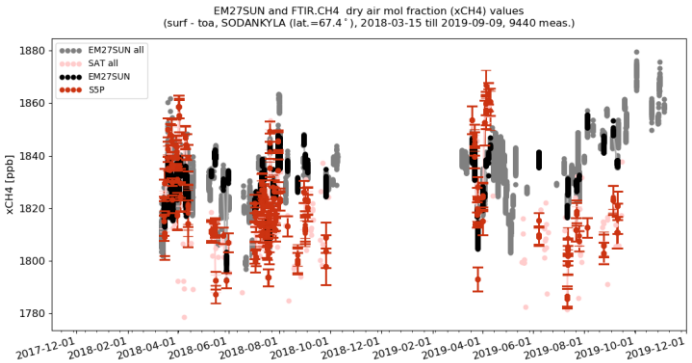
TCCON precision requirements:
XCO2: < 0.25% ~ 1 ppm | XCH4: 0.5% ~ 0.009 ppm | XCO: < 4% ~ < 4 ppb

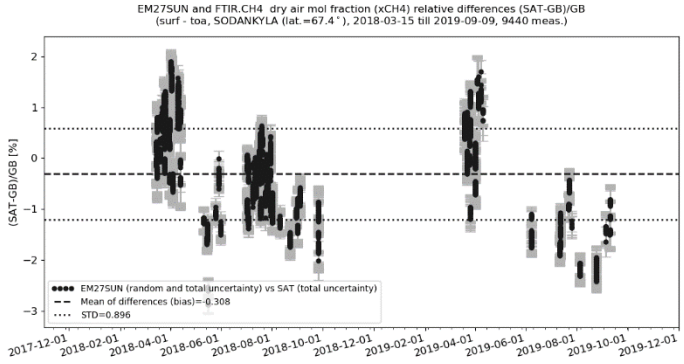
The EM27/SUN, VERTEX70 and IRCUBE fulfil the TCCON precision requirements. The calibration to the WMO will be performed by scaling the Xgas value to the TCCON.

Details on the 2017 campaign results: Sha et al., 2019, https://doi.org/10.5194/amt-2019-371

Publication of the results of 2018 & 2019 is in preparation. **Please do not share the results outside this group**

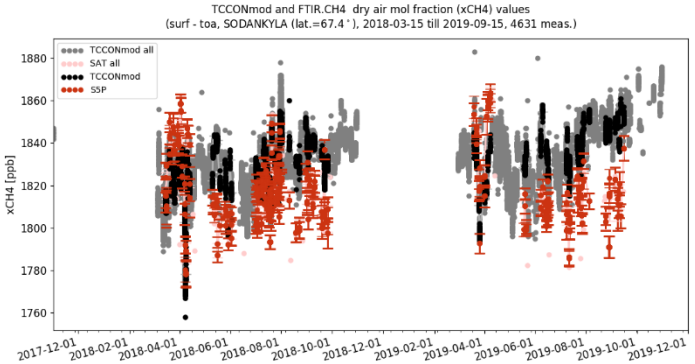
S-5P – CH4 validation using EM27/SUN @ SO

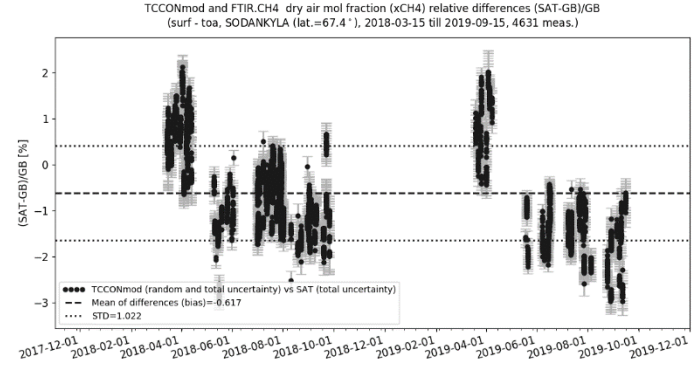


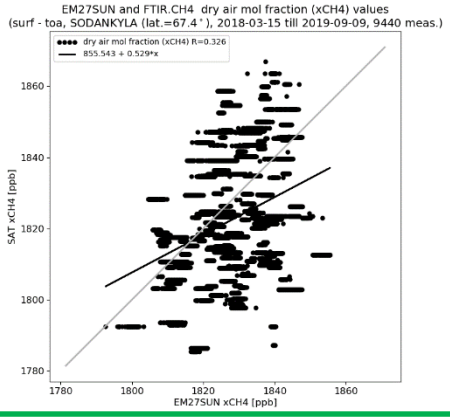


Period of study: 01 March 2018 – 31 December 2019.
S5P data from Mission Performance Centre (MPC) provided by the Payload Data Ground Segment (PDGS) at DLR.

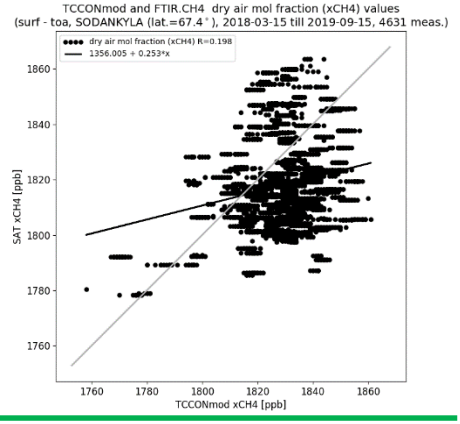
Coincidence criteria for CH4: Time delta = 1 hour; Geo-distance delta = 100 km radius. QA filtering: qa_value > 50; bias corrected S5P-CH4 product used for the study. From the coincident and filtered satellite measurements an average of all pixels is taken for each ground-based reference measurement.







Validation type	Bias %	STD %	R
EM27/SUN vs TCCONmod	0.05 (1 ppb)	0.22 (4 ppb)	0.943
S-5P vs EM27/SUN	-0.31	0.9	0.326
S-5P vs TCCONmod	-0.62	1.02	0.198



Application of low-resolution spectrometers

- COCCON (Collaborative Carbon Column Observing Network) as framework for **EM27/SUN** spectrometer
- http://www.imk-asf.kit.edu/english/COCCON.php
- More than 60 devices operated worldwide
- Long term stability check at KIT. Frey et al., AMT, 2019,
- Check for new instruments at KIT (before delivery to customer)
  - Solar measurements together with reference EM27/SUN and co-located TCCON instrument
  - Alignment check and ILS measurements
  - Determination of XCO2, XCH4, XCO and XH2O scaling factors
- Central facility for EM27/SUN spectra
  - Central data handling and processing facility
  - Retrieval algorithm available (PROFFAST) and training possible
- **COCCON applications:**
- Measurement campaign with partner institutions
  - Paris, Berlin, Boulder, Tokyo, etc.
  - City emissions fracking, dairy farms, coal mining, etc.
  - Vogel et al., ACP, 2019; Kille et al., GRL, 2019; Luther et al., AMTD, 2019; etc.

- **VERTEX70** instrument tested shows good stability, second detector in the mid-infrared spectral range provides other species e.g. HCHO in addition to CO2, CH4 and CO. Work towards operationalisation of VERTEX70 and demonstration of stability of HCHO for satellite validation.

- **IRCUBE** shows good precision, operated with a telescope and optical fibre cable for tracking the sun. Instrument can be further away from the telescope. Work towards operationalisation of IRCUBE.

- **LHR** still needs improvements to improve precision. It has the possibility to provide profile information.


Thank you for your attention!