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# *Comparison of one year of $XCH_4$ and XCO measurements using a EM27/SUN low resolution FTIR spectrometer to S5P/TROPOMI methane and carbon monoxide columns at Thessaloniki, Greece (revised results)*

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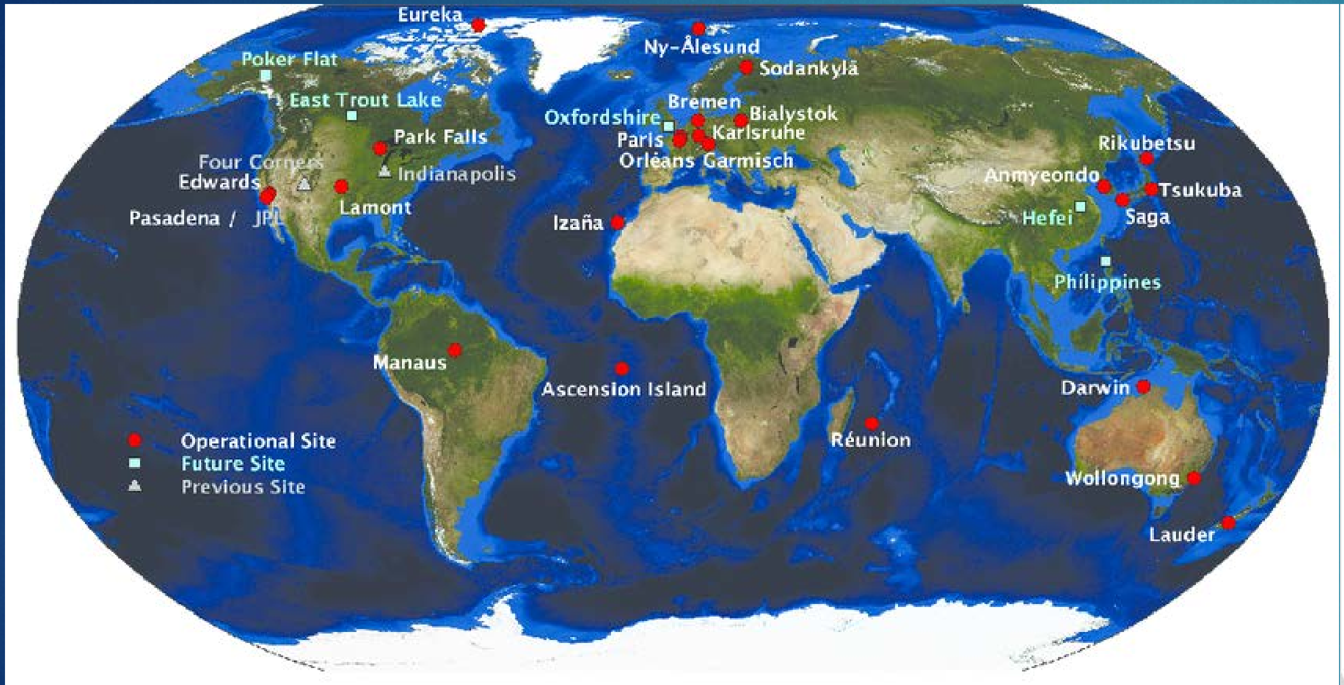
The Total Carbon Column Observing Network (TCCON) (Wunch et al., 2011) measures total columns of $CO_2$ and $CH_4$, using Bruker IFS 125HR spectrometers. These high resolution instruments instruments are rather expensive and need large infrastructure to be set up and expert maintenance, which has to be performed on site. (Frey et al, 2019)

The **Bruker EM27/SUN** portable FTIR spectrometer (Gisi et al., 2011; Frey et al., 2015; Hedelius et al., 2016) developed by KIT in collaboration with Bruker Optics™ , is a promising instrument to overcome the above-mentioned shortcomings as it is a mobile, reliable, easy-to-deploy and low-cost supplement to the Bruker IFS 125HR spectrometer used in the TCCON network (Frey et al, 2019)

The **COllaborative Carbon Column Observing Network (COCCON),** constituted by 60 EM27/SUN spectrometers, with stations around the globe, produces greenhouse gas observations based on common instrumental standards and data analysis procedures, working as an important supplement of TCCON for the quantification of local sinks and sources, to increase the global density of column-averaged greenhouse gas observations

# TCCON- COCCON NETWORK




# The Bruker EM27/SUN FTIR spectrometer


It consists of a spectrometer body with dimensions of 35x40x27cm and a solar tracker directly mounted on the spectrometer. It weighs approximately 25 kg and its design achieves high stability and is resistant to thermal influences and mechanical disturbances.

# The Bruker EM27/SUN FTIR spectrometer

| | Spectral window (cm-1) | Spectral resolution (cm-1) | Semi-FOV (mrad) | Detector | Retrieval software | Spectroscopy | A priori profiles & averaging kernels |
|---|---|---|---|---|---|---|---|
| $O_2$ | 7765-8005 | 0.5 | 2.36 | InGaAs<br>Spectral range:<br><br>main channel standard (5000 cm-1 low wavenumber cut off)<br><br>CO channel extended (4000 cm-1 low wavenumber cut off). | PROFFAST (Sha et al. 2019) | HITRAN<br>$O_2$: 2007 (Geoff Toon's ATM line list)<br><br>$H_20$ : 2009 +empirical corrections<br><br>$CH_4$: 2008<br><br>CO: 2012 | TCCON map files<br>Column sensitivities from retrieval software |
| $CH_4$ | 5897-6145 | | | | | | |
| CO | 4208-4318 | | | | | | |

# EM27/SUN PRODUCTS

In this study, column-averaged dry-air mole fractions $XCH_4$ and XCO are presented for one year of measurements in Thessaloniki, Greece, an urban site (40.5N°, 22.9E, 60 m a.s.l). For a gas G:

$$X_{Gas} = \frac{Column_{Gas}}{Column_{dryair}}$$

Since $O_2$ 's mixing ratio in the atmosphere can be considered stable

$$Column_{dryair} = \frac{Column_{O_2}}{0.2095}$$

the column-averaged dry-air mole fractions (DMF), denoted $X_G$ for gas G, are computed using the retrieved $O_2$ columns as a measure of the dry air column

$$X_{Gas} = \frac{Column_{Gas}}{Column_{O_2}} \cdot 0.2095$$

Dividing by $O_2$ improves the precision of the measurement by significantly reducing the effects of instrumental or measurement errors that are common to both the gases (tracker problems leading to mis-pointing and zero-level offsets) or by errors the use of in the surface pressure

# EM27/SUN PRODUCTS

EM27/SUN measurements have undergone correction with air mass dependent (ADCF) and air mass independent (AICF) factors in order to bring COCCON data in agreement with TCCON (https://www.imk-asf.kit.edu/)

| Species | MW | AICF $a_{gas}$ | ADCF $b_{gas}$ |
|---|---|---|---|
| $XH_2O$ | $(8353.4, 8463.1)$ | 0.8300 | 0.000 |
| XAIR | $(7765.0, 8005.0)$ | 0.9737 | −0.007 |
| $XCO_2$ | $(6173.0, 6390.0)$ | 0.9862 | 0.005 |
| $XCH_4$ | $(5897.0, 6145.0)$ | 0.9905 | −0.014 |
| XCO | $(4208.7, 4318.8)$ | 0.9250 | 0.103 |
| $XCH_4^{(b)}$ | $(4208.7, 4318.8)$ | 0.9727 | −0.017 |

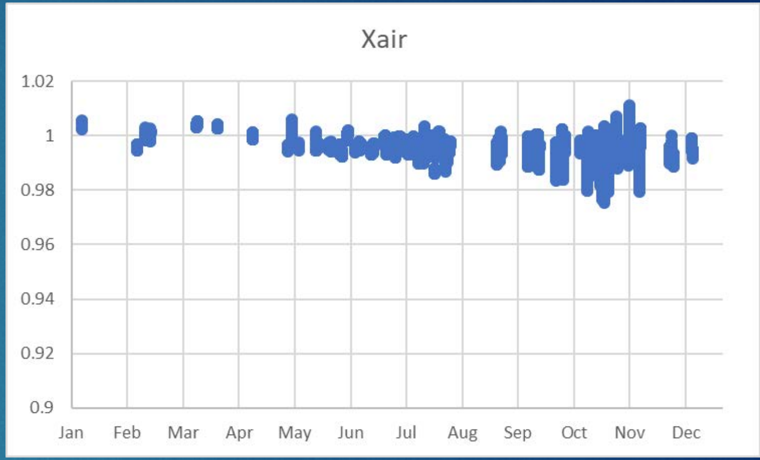
($b$) $XCH_4$ S5P (Sentinel-5 Precursor)

# EM27/SUN PRODUCTS

Xair is defined as

$$X_{air} = \frac{0.2095}{VC_{O_2} \cdot \overline{\mu}} \cdot \left( \frac{P_S}{g} - VC_{H_2O} \cdot \mu_{H_2O} \right)$$

where μ and $\mu_{H2O}$ are molecular masses of dry air and water vapor
g is column averaged gravitational acceleration, Ps is the surface pressure and $VC_{O_2}$, $VC_{H_2O}$ are the total columns of oxygen and water vapor




For an ideal measurement and retrieval with accurate $O_2$ and $H_2O$ spectroscopy and surface pressure, Xair would be 1.

Due to a 2.0% bias in the $O_2$ spectroscopy,

- TCCON measurements Xair is typically ~ 0.98 (Wunch et al., 2015).
- EM27/SUN measurements show a factor of ~ 0.97 (Frey et al., 2015; Hase et al., 2015; Klappenbach et al., 2015).

Large deviations (~ 1 %) from these values indicate severe problems, e.g., errors with the surface pressure, pointing errors, timing errors or changes in the optical alignment of the instrument. (Frey et al, 2019)

Xair at Thessaloniki passes TCCON standard quality check (between 0.96 and 1.04) with a mean value of 0.996 and a STD of ~ 0.003

# EM27/SUN PRODUCTS

Two methane products of EM27/SUN measurements:

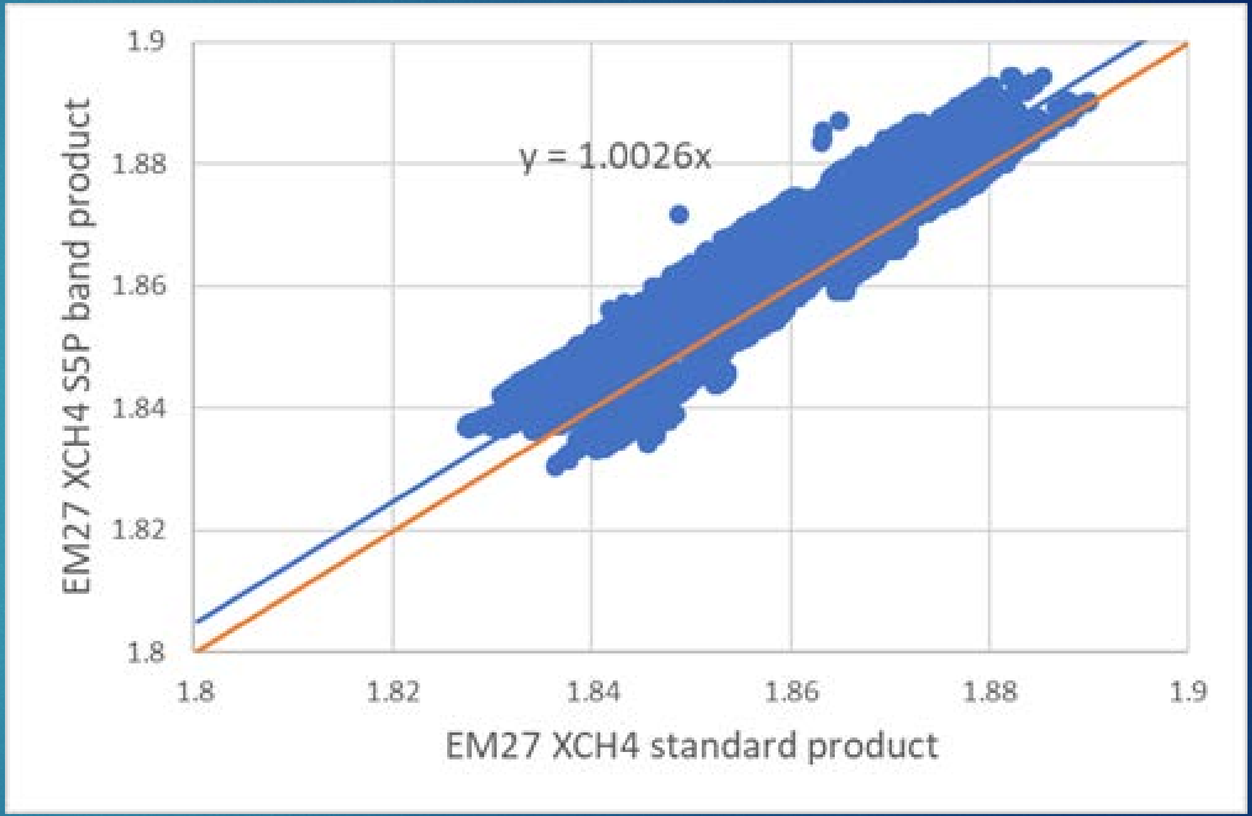
- in the 1.6μm band (standard product)
- in the S5P band (2.6μm) (not official)

are in good agreement, with a mean ratio of 1.0026 ( between 0.993 and 1.012 and a std <0.003)

Differences can be attributed to

- inconsistent spectroscopic linelists between bands
- different vertical sensitivity of the retrievals
- spectral interference of water vapor on the S5P band being stronger

A new linelist to be implemented into PROFFAST will be available soon, for an improved $XCH_4$ S5P band product (Framk Hase, personal



# EM27/SUN comparison to TROPOMI

| **Methane** | **Carbon monoxide** |
|---|---|
| *TROPOMI*: $XCH_4$ OFFL product, no bias-corrected, qa=100<br><br>*EM27/SUN*: $XCH_4$ standard (1.6µm)<br>$XCH_4$S5P using S5P band (2.3µm)<br><br>Mission data requirements for $XCH_4$: 1.5% ±1% | *TROPOMI*: XCO OFFL product, qa=100<br><br>*EM27/SUN*: XCO<br><br>Mission data requirements for XCO: 15% ±10% |
| **100km & 1h co-location criteria[1]** | **50km & 1h co-location criteria[1]** |
| **[1] as used in TROPOMI Validation Reports** | |

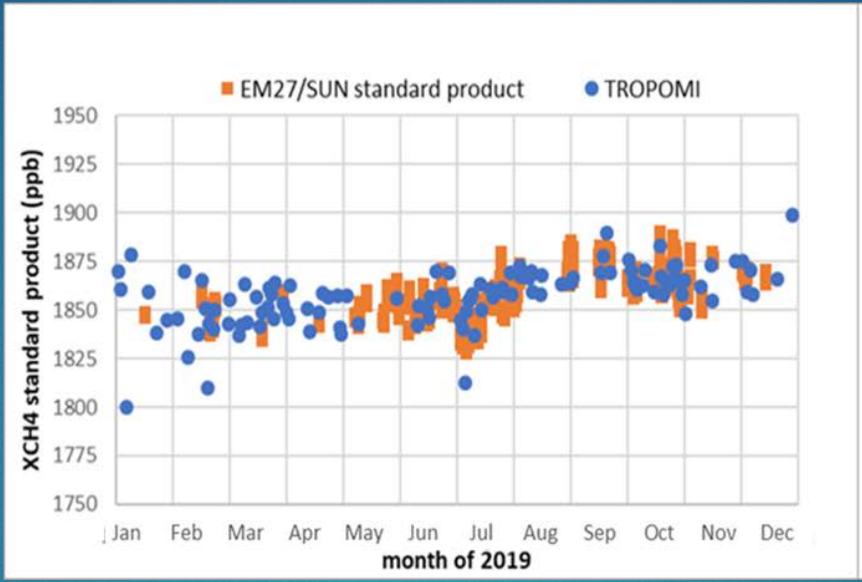
# EM27/SUN vs TROPOMI full time series

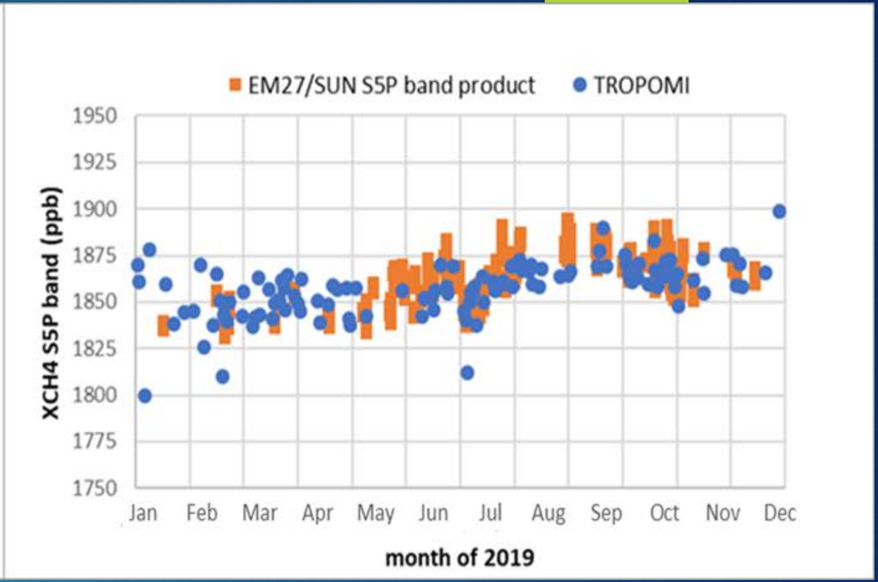
Examining the full time series with no spatial/time criteria, TROPOMI seems to show

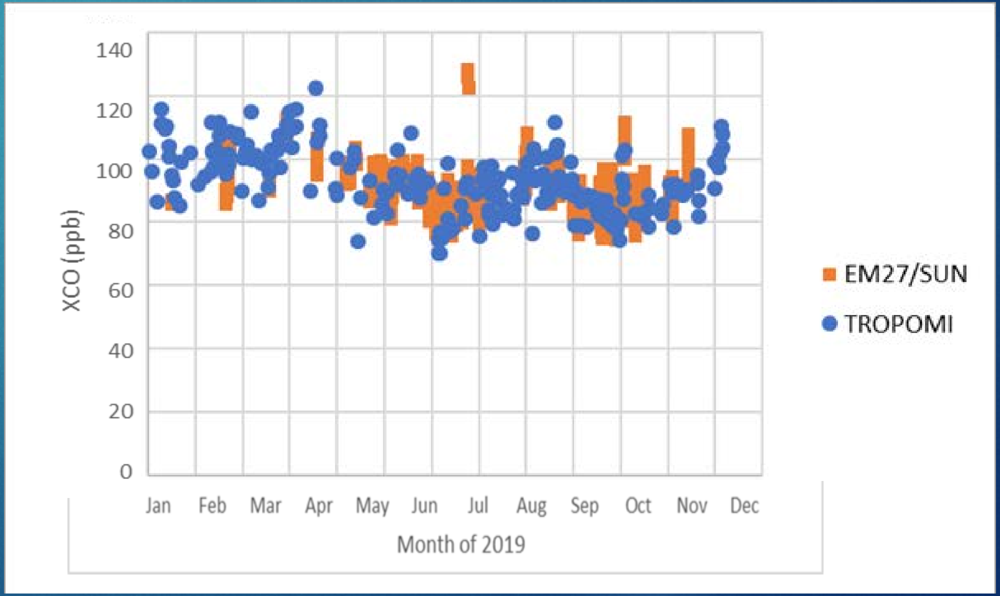
- higher CO values compared to ground based measurements

- lower $XCH_4$ values than the standard ground based $XCH_4$ and almost similar to the S5P band $XCH_4$

Seasonal variations captured by EM27 are reproduced by TROPOMI

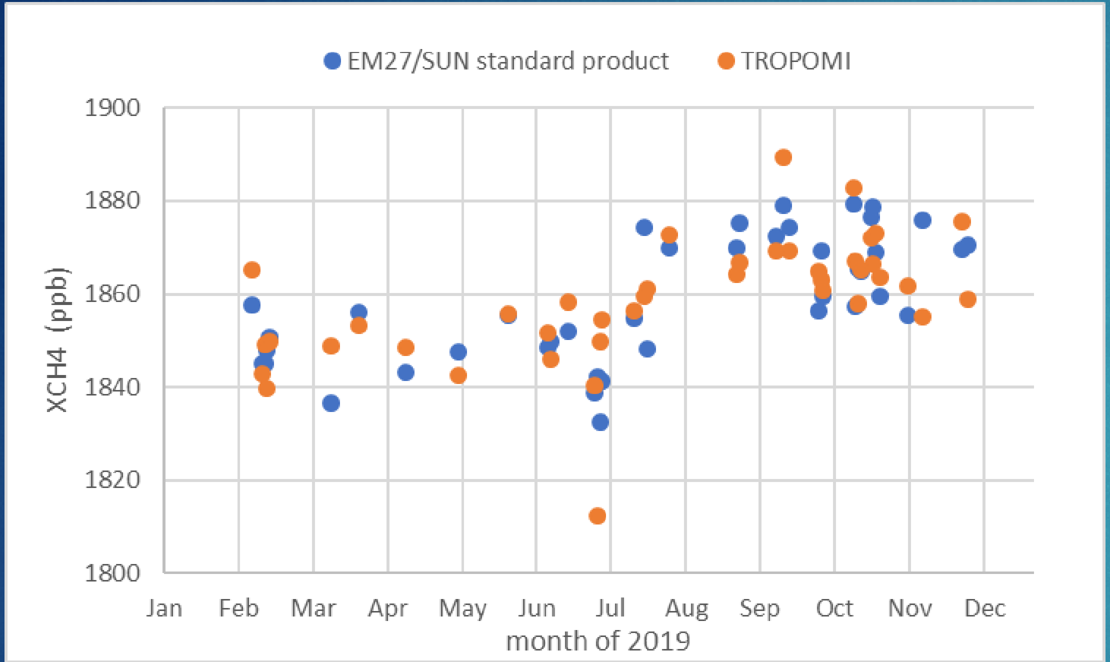


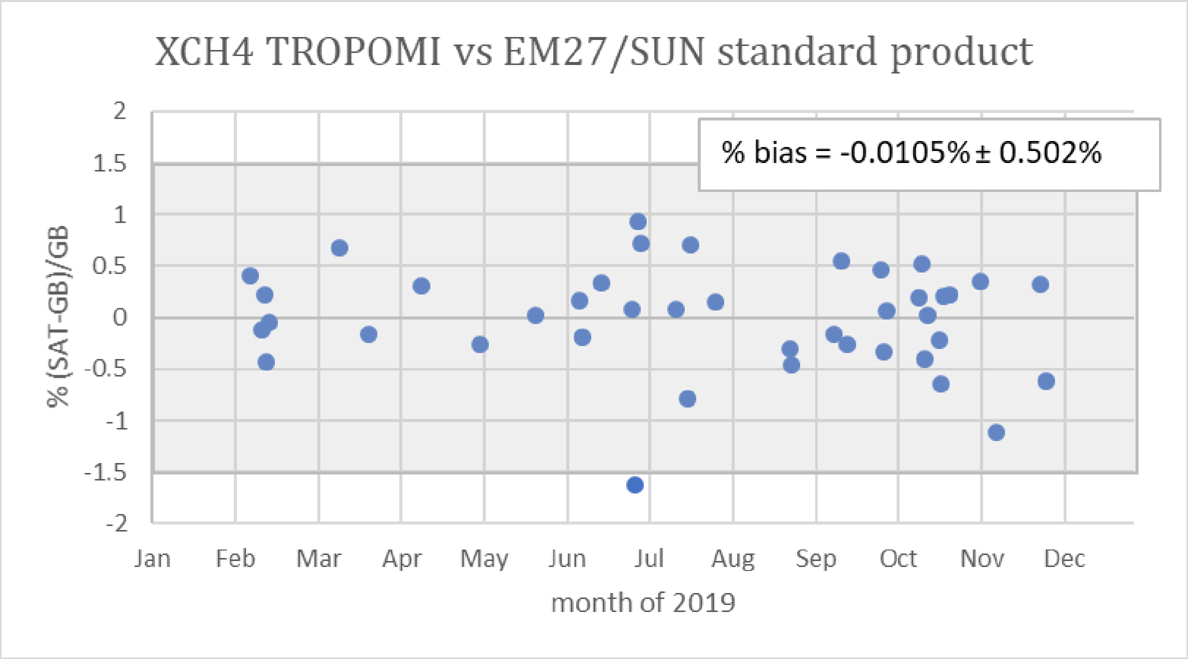



# EM27/SUN vs TROPOMI (co-located measurements)

## Methane (XCH$_4$ EM27/SUN standard product)



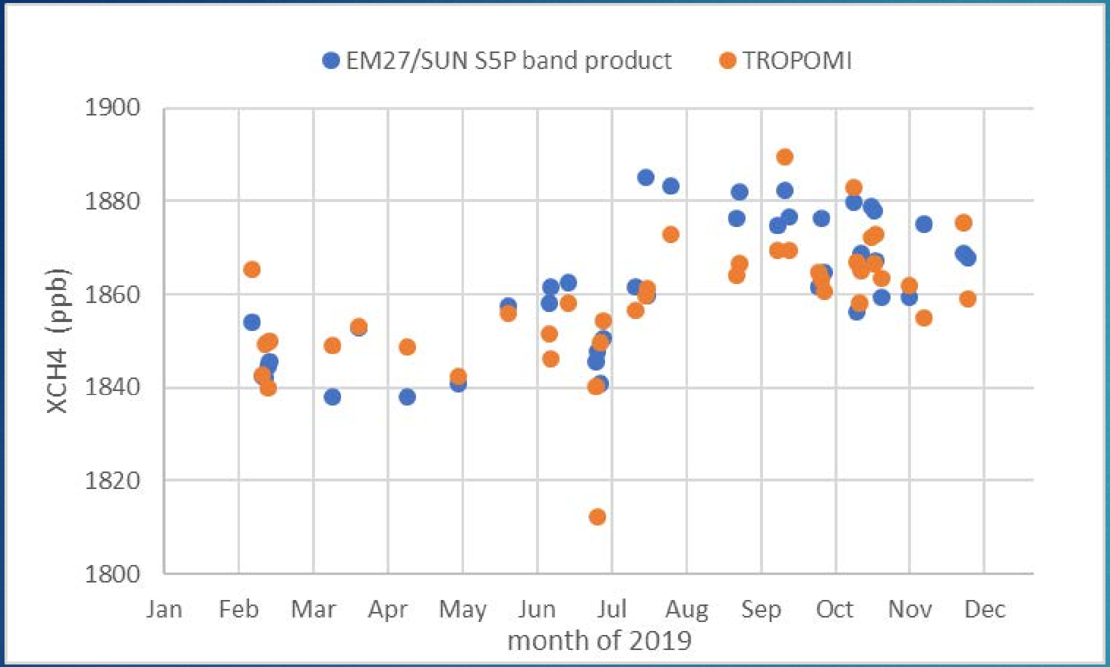



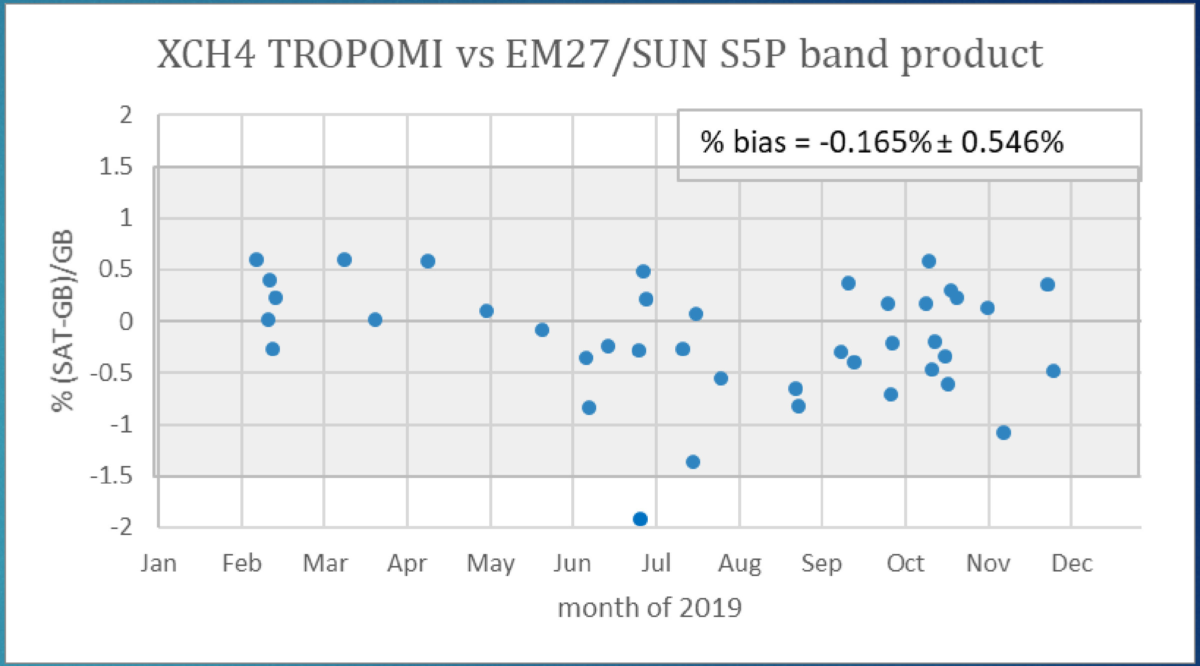

% bias = -0.0105% ± 0.502%, well within mission requirements (1.5% ± 1.0%)

Results in agreement with those of the Validation Reports of the Copernicus Sentinel-5 Precursor Operational Data Products that show TROPOMI 's underestimation of XCH$_4$ vs NDACC and TCCON data with an overall agreement of -0.68% (negative bias) for not bias-corrected TROPOMI XCH$_4$ and a standard deviation of the relative bias is on an average 0.6%

# EM27/SUN vs TROPOMI (co-located measurements)

## Methane (XCH$_4$ EM27/SUN standard product)



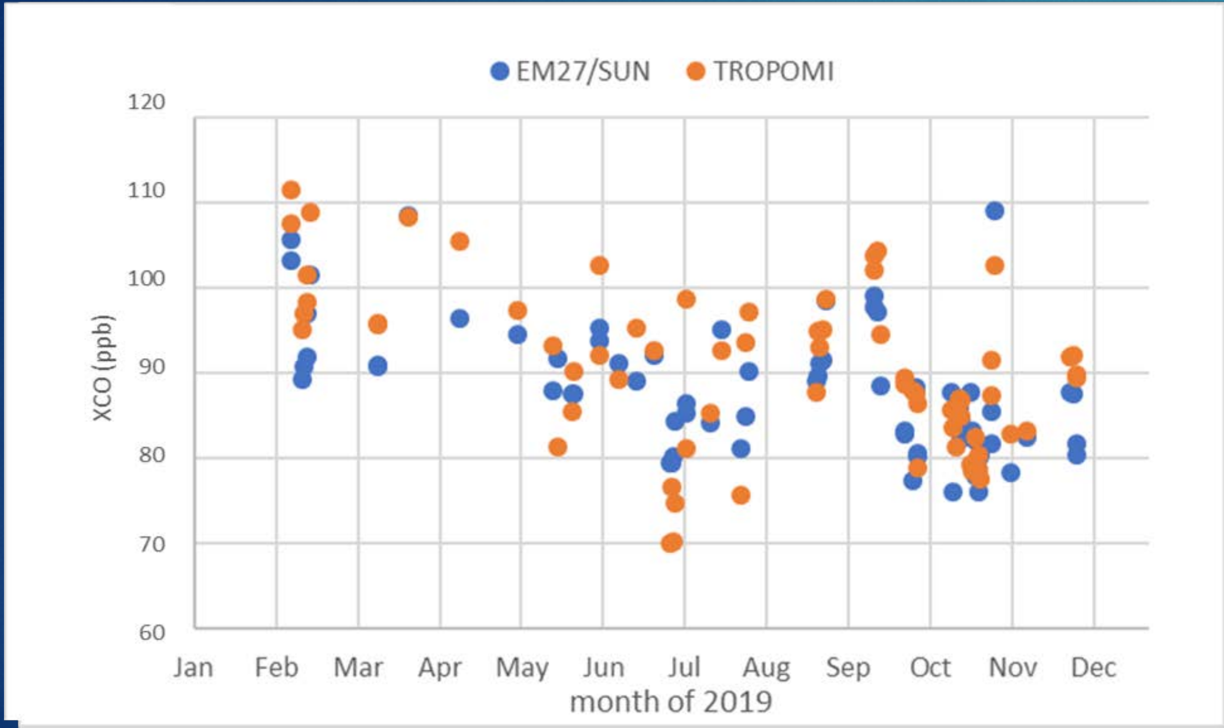



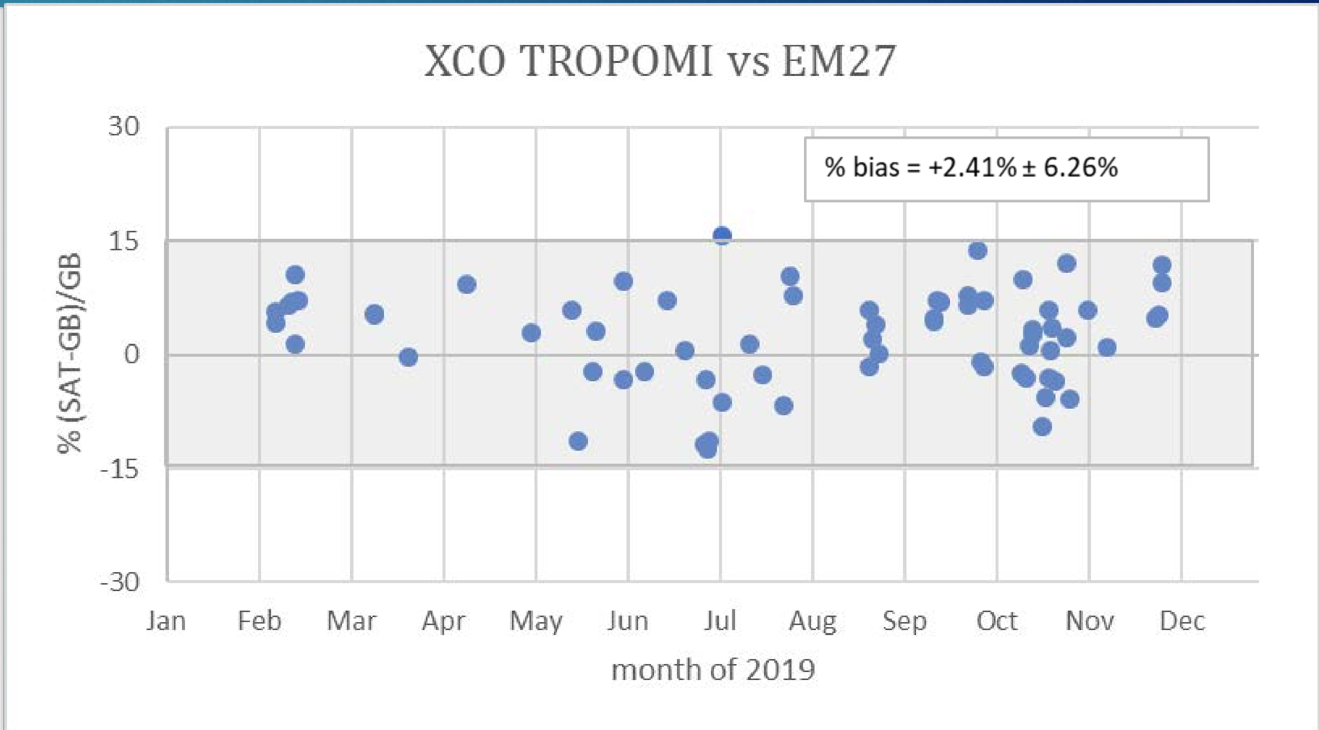

% bias = -0.165% ± 0.546%, well within mission requirements (1.5% ± 1.0%)

Results in agreement with those of the Validation Reports of the Copernicus Sentinel-5 Precursor Operational Data Products that show TROPOMI ‘s underestimation of XCH$_4$ vs NDACC and TCCON data with an overall agreement of -0.68% (negative bias) for not bias-corrected TROPOMI XCH$_4$ and a standard deviation of the relative bias is on an average 0.6%

# EM27/SUN vs TROPOMI (co-located measurements)

## Carbon monoxide (XCO)




XCO % bias = +2.41% ± 6.26%, well within mission requirements (15% ± 10%)

Results in agreement with those of the Validation Reports of the Copernicus Sentinel-5 Precursor Operational Data Products that show TROPOMI 's overestimation of XCO vs NDACC and TCCON data with an overall agreement of 7-10% (positive bias) and a standard deviation of the relative bias is on an average 5%

# EM27/SUN vs TROPOMI comparison for other distances

| Distance (km) | $XCH_{4standard}$ (1h, qa=1) %bias | XCO (1h, qa=1) % bias |
|---|---|---|
| 30 | -0.0946 | +4.416 |
| 50 | +0.2088 | +2.411 |
| 100 | -0.0105 | +0.736 |

- As the distance from Thessaloniki overpass increases, the bias decreases demonstrating a lower value of TROPOMI average value for this area, probably caused by fewer CO sources in the surrounding area of Thessaloniki, which is a high polluted urban site.

- For methane, it is not clear whether conclusions can be drawn mainly due to a very low number of common measurement days between EM27/SUN and TROPOMI. A detailed recording of CO and $CH_4$ sources in the area of Thessaloniki and within 100km, could provide more insight

# Summary

- The very first year of measurements of $XCH_4$ and XCO using a Bruker EM27/SUN low resolution spectrometer provided by Karlsruhe Institute of Technology, are presented for Thessaloniki, an urban site in Northern Greece. Our measurements show similar levels of XCH4 and XCO for similar sites

- Comparison to TROPOMI measurements show that seasonal variations are captured. Mission requirements are met for both the bias level and the standard deviation:
  - ⇨ $XCH_4$ (1 hour, 100km) : % bias = -0.0105% ± 0.502% (within 1.5% ± 1.0%)
  - ⇨ XCO (1 hour, 50km ) : % bias = +2.41% ± 6.26% (within 15% ± 10%)

**(these are revised results compared to the positive TROPOMI bias for methane stated in the abstract)**

- Data set will be re evaluated after incorporating improved parameters such as ME and PE for ILS function and new linelists for secondary $XCH_4$ products

- Important to establish a dense data set of ground based measurements in order to
  - to confirm the comparison to TROPOMI in the future
  - provide more common days for comparison to the satellite (especially for methane)
  - explore variability of the measurements

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