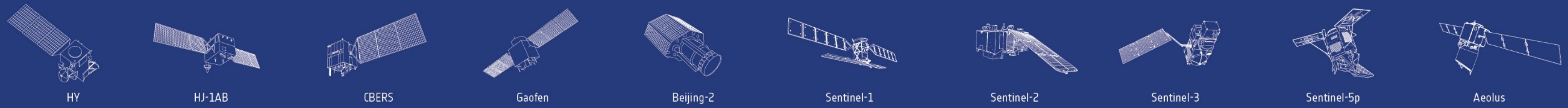


2023 DRAGON 5 SYMPOSIUM

3rd YEAR RESULTS REPORTING

11-15 SEPTEMBER 2023

PROJECT ID. 59327

VALIDATION OF CHINESE CO_2-MEASURING SENSORS AND EUROPEAN TROPOMI/SENTINEL-5 PRECURSOR USING FTIR AND MAX-DOAS DATA AT XIANGHE (VCEX)

WEDNESDAY, 13/SEPT/2023

ID. 59327

PROJECT TITLE: VALIDATION OF CHINESE CO_2-MEASURING SENSORS AND EUROPEAN TROPOMI/SENTINEL-5 PRECURSOR USING FTIR AND MAX-DOAS DATA AT XIANGHE (VCEX)

PRINCIPAL INVESTIGATORS: DR. BART DILS, PROF. DR. PUCAI WANG

CO-AUTHORS: BART DILS, PUCAI WANG, MINQIANG ZHOU, MICHEL VAN ROOZENDAEL, MARTINE DE MAZIÈRE, MARTINA FRIEDRICH, FRANCOIS HENDRICK, BAVO LANGEROCK, WEIDONG NAN, GAIA PINARDI, MAHESH KUMAR SHA, CORINNE VIGOUROUX, TING WANG

PRESENTED BY: PUCAI WANG (QICHEN NI)

Dragon 5 3rd Year Results Reporting

- Inform on the project's objectives
- Detail the Copernicus Sentinels, ESA, Chinese and ESA Third Party Mission data utilised after 3 years (complete slide 4)
- Detail the in-situ data measurements and requirements
- Provide details on field data collection campaigns and periods in P.R. China or other study areas
- Inform on the results after 3 years of activity
- Inform on the project's schedule, planning & contribution of the partners for the following year
- Report on the level and training of young scientists on the project achievements, including plans for academic exchanges
- Report on the peer reviewed publications (nr. of papers, journal name and publication title) after 3 years of activity

Outline

1. Brussels-Xianghe collaboration

2. Atmospheric remote sensing activities at Xianghe

3. Validation activities at Xianghe

4. Intercomparison of CH_4 products in China from GOSAT, TROPOMI, IASI and AIRS satellites

5. Future plans

Outline

1. **Brussels-Xianghe collaboration**

2. **Atmospheric remote sensing activities at Xianghe**

3. **Validation activities at Xianghe**

4. **Intercomparison of CH_4 products in China from GOSAT, TROPOMI, IASI and AIRS satellites**

5. **Future plans**

Collaboration

Royal Belgian Institute
for Space Aeronomy

- UV-VIS DOAS group (Dr. M. Van Roozendael)
- FTIR group (Dr. M. De Mazière)

Institute of Atmospheric Physics –
Chinese Academy of Sciences

Prof P. Wang

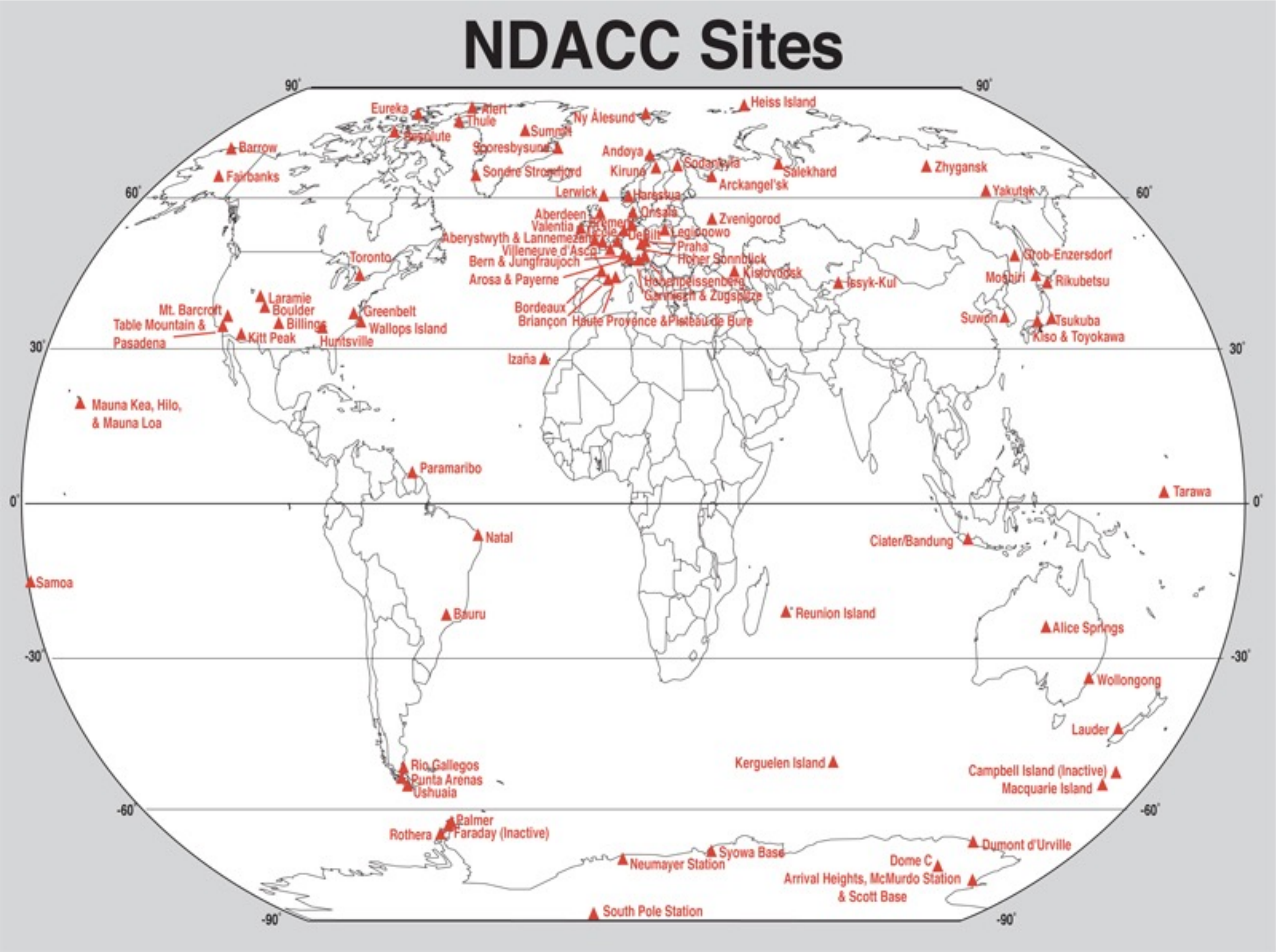
Collaboration background

TOTAL CARBON COLUMN OBSERVING NETWORK (TCCON)

BIRA

- Snapshot 2008
- Little to no coverage in South America, Africa and mainland Asia

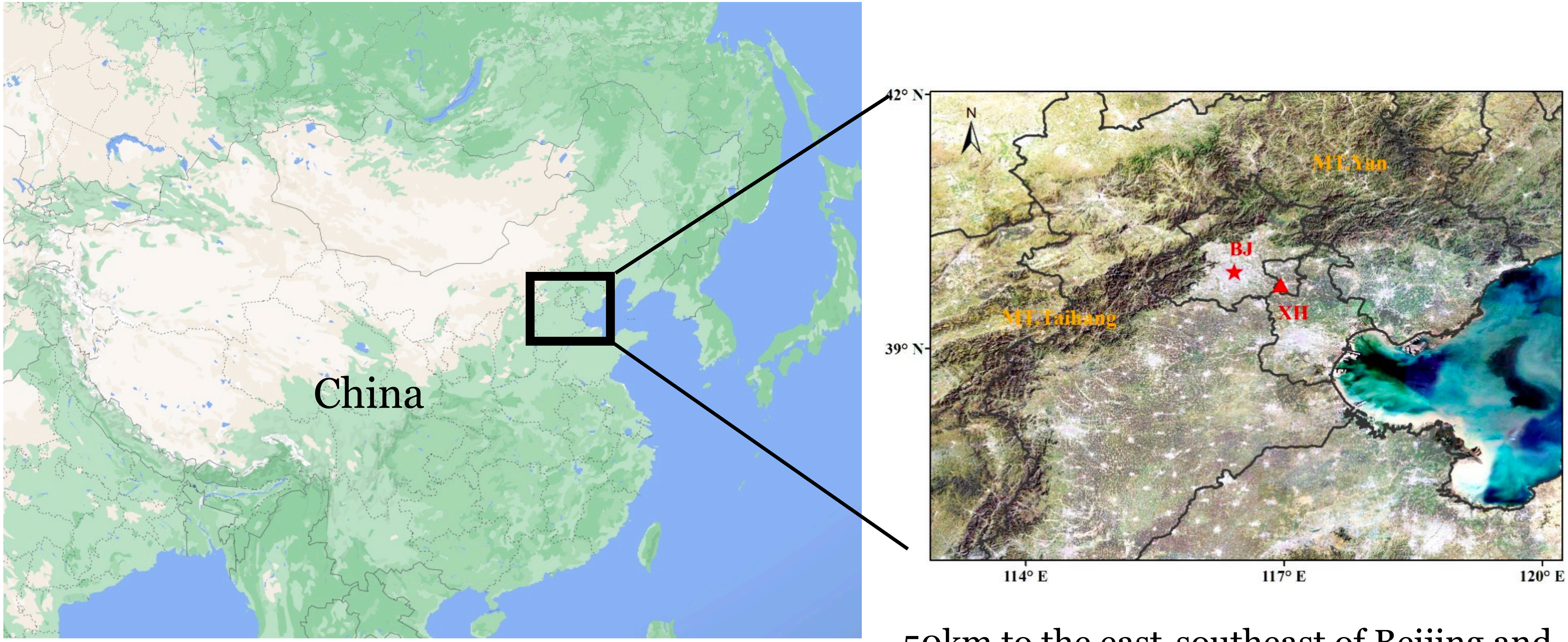
Collaboration background



Network for the Detection of Atmospheric Composition Change (NDACC)

- Quasi-Global coverage is vital for model assimilation, satellite validation etc.
- Strong need for these networks to incorporate sites in China

The measurement site



50km to the east-southeast of Beijing and 70 km to the north-northwest of Tianjin

First Collaboration

BIRA-IASB MAX-DOAS instrument

- 2-channel MAX-DOAS spectrometer developed at BIRA in 2008 and permanently installed in Xianghe in Feb. 2010
- Continuously operated until Aug. 2022 in collaboration with IAP/CAS
- Instrument due to be replaced
- Total columns of O_3 and NO_2
- Tropospheric profiles of NO_2, HCHO, glyoxal, HONO and SO_2
- Aerosol AOD and extinction profile

Bruker 125HR FTIR at Xianghe

- TCCON type measurements since 2018
- **Became a formal TCCON site 3 September 2021!**
- Dr. Minqiang Zhou (ex-BIRA [2015-2021], currently at IAP in the team of Prof. Wang) became a member of the Steering Committee of TCCON on the same day

- 2^{nd} Chinese TCCON site after Hefei (Anhui Institute of Optics and Fine Mechanics (AIOFM), Hefei Institutes of Physical Science) formally a TCCON site since 2018

- This allows Xianghe to become part of global TCCON validation efforts for Tansat, OCO-2, GOSAT, S5P, …

Outline

1. Brussels-Xianghe collaboration

2. Atmospheric remote sensing activities at Xianghe

3. Validation activities at Xianghe

4. Intercomparison of CH_4 products in China from GOSAT, TROPOMI, IASI and AIRS satellites

5. Future plans

Remote sensing instruments

Bruker 125HR FTIR | Pandora | Microwave | CIMEL-318

Bruker EM27/SUN | Brewer | MIN-DOAS | MAX-DOAS

Remote sensing instruments

Xianghe remote sensing activities affiliated or collabrated with international networks

Instrument	Networks	Status	Insturment note (last year)
Bruker 125HR	TCCON	Operational	-
Bruker 125HR	NDACC	Application	-
Bruker EM27/SUN	COCCON	Operational	Moved to other place
Pandora	PNG	Application	Moved to other place
Cimel 318	AERONET	Operational	-
Brewer	WMO	Operational	-
MAX-DOAS	NDACC	Broken down	Detector fail since Aug 2022

Remote sensing instruments

Bruker 125HR FTIR | Pandora | Microwave | CIMEL-318

Bruker EM27/SUN | Brewer | MIN-DOAS | MAX-DOAS

MAX-DOAS

- Optimisation and standardization of retrieval strategies for NO_2, HCHO, glyoxal and SO_2
- Operational centralized processing of Xianghe UV-Vis MAX-DOAS data for NO_2 and HCHO using FRM_4DOAS system
- Exploitation of Xianghe MAX-DOAS data series for the validation of GOME-2, OMI, TROPOMI and GEMS satellite data, with a focus on NO_2, HCHO, glyoxal and SO_2 data products
- Important to have a wide range of stations operating under different conditions!

Fiducial Reference Measurements for Ground-Based DOAS Air-Quality Observations

FRM4DOAS

Home | Project overview | Documents | FRM4DOAS questionnaire | FRM4DOAS guidelines | Data | Links | Partners | Contact us

Welcome to the FRM_4DOAS website

Fiducial Reference Measurements (FRM) are a suite of independent, fully characterized, and traceable ground measurements that follow the guidelines outlined by the GEO/CEOS Quality Assurance framework for Earth Observation (see http://qa4eo.org). These FRM provide the required confidence in data products, in the form of independent validation results and satellite measurement uncertainty estimation, over the entire end-to-end duration of a satellite mission (more information available here).

The Fiducial Reference Measurements for Ground-Based DOAS Air-Quality Observations (FRM_4DOAS) is a 2-year ESA project which started in July 2016. It aims at further harmonization of MAX-DOAS systems and data sets, through the

- specification of best practices for instrument operation
- demonstration of a centralised NRT (near-real-time/6-24h latency) processing system for MAX-DOAS instruments operated within the international Network for the Detection of Atmospheric Composition Change (NDACC)
- establishment of links with other UV-Visible instrument networks, e.g. PGN

The target species for the first phase of the project are tropospheric and stratospheric NO_2 vertical profiles, total O_3 columns, and tropospheric HCHO profiles. The aim is to produce homogenous ground-based reference datasets from instruments being operated at long-term monitoring sites (e.g. NDACC) or during field campaigns. Such reference data sets will play a crucial role in the validation of future atmospheric composition satellite missions, in particular the ESA Copernicus Sentinel missions S-5P, S-4, and S-5.

Image courtesy of A. Piters (KNMI)

The FRM_4DOAS project was funded under the ESA contract n°4000118181/16/I-EF.

MAX-DOAS Replace

MAX-DOAS Disassembling

MAX-DOAS packing

Box 1

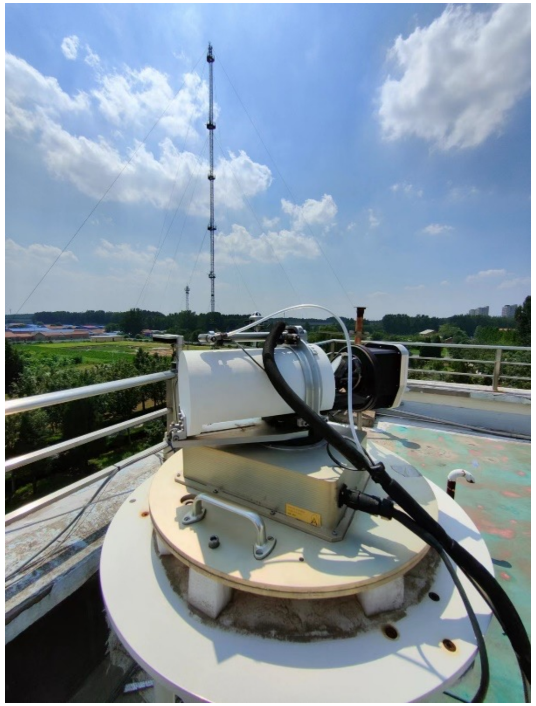
66*66*48 cm
57.0 kg

Box 2

80*60*63 cm
47.3 kg

Remote sensing instruments

Clean the sun tracker mirror

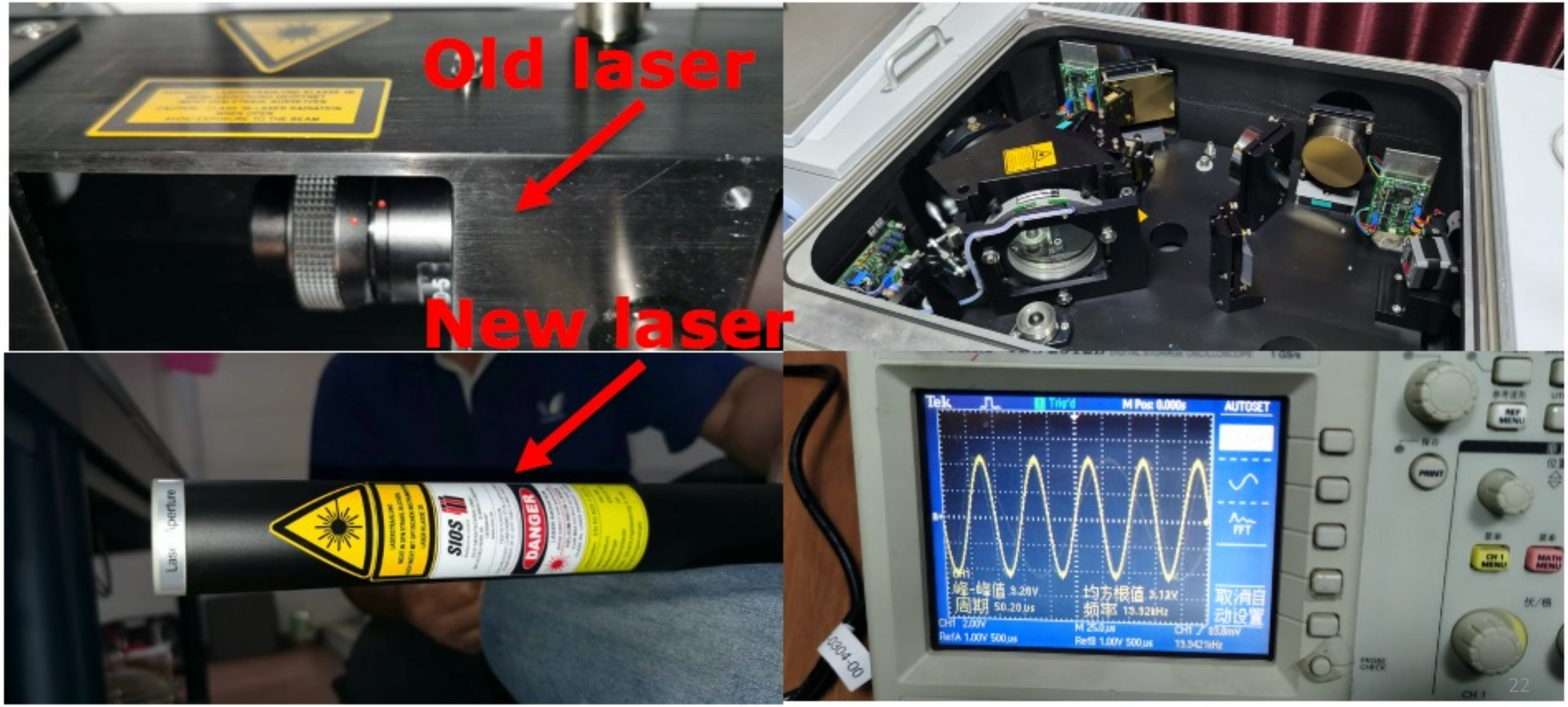


125HR FTIR operation and maintenance

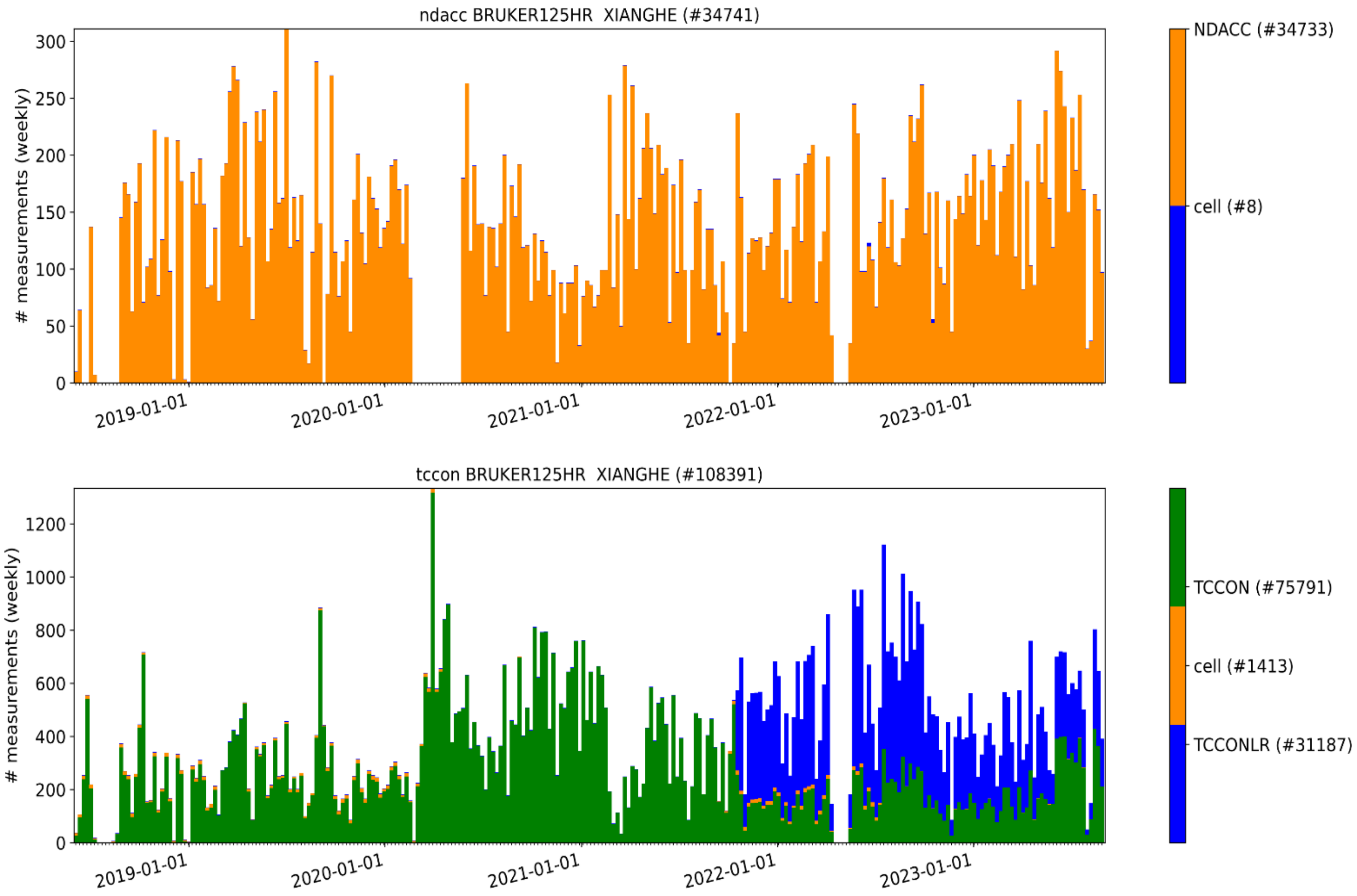
Add liquid nitrogen regularly

125HR FTIR operation and maintenance

LASER replacement for Bruker 125HR instrument



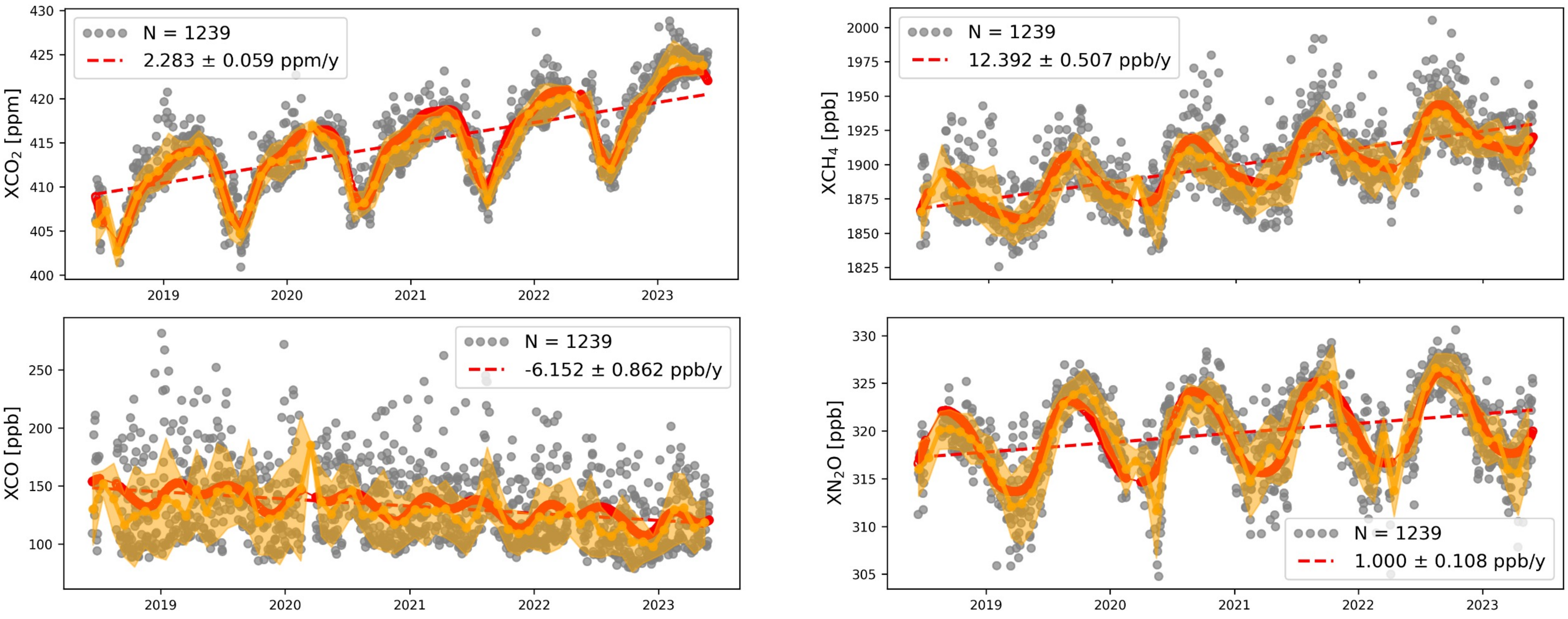
Bruker 125HR FTIR at Xianghe counts



- TCCON – LR mode added since Nov 2011
- ~150 spectra for NDACC per week
- ~ 200 spectra for TCCON per week
- ~ 400 spectra for TCCON- LR per week

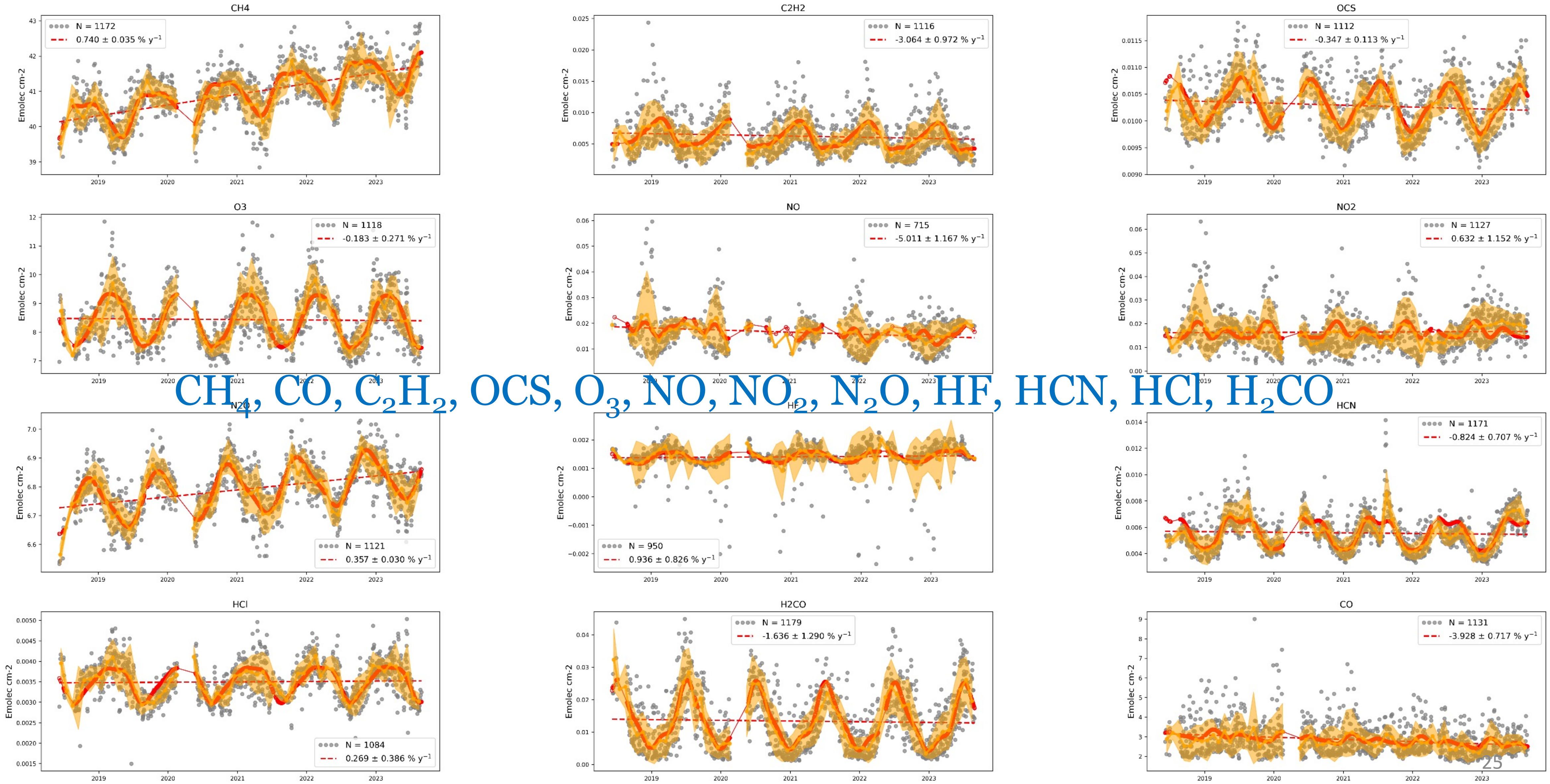
Bruker 125HR FTIR in TCCON type

CO_2, CH_4, CO, N_2O concentration at Xianghe



Bruker 125HR FTIR in NDACC type

CH_4, CO, C_2H_2, OCS, O_3, NO, NO_2, N_2O, HF, HCN, HCl, H_2CO



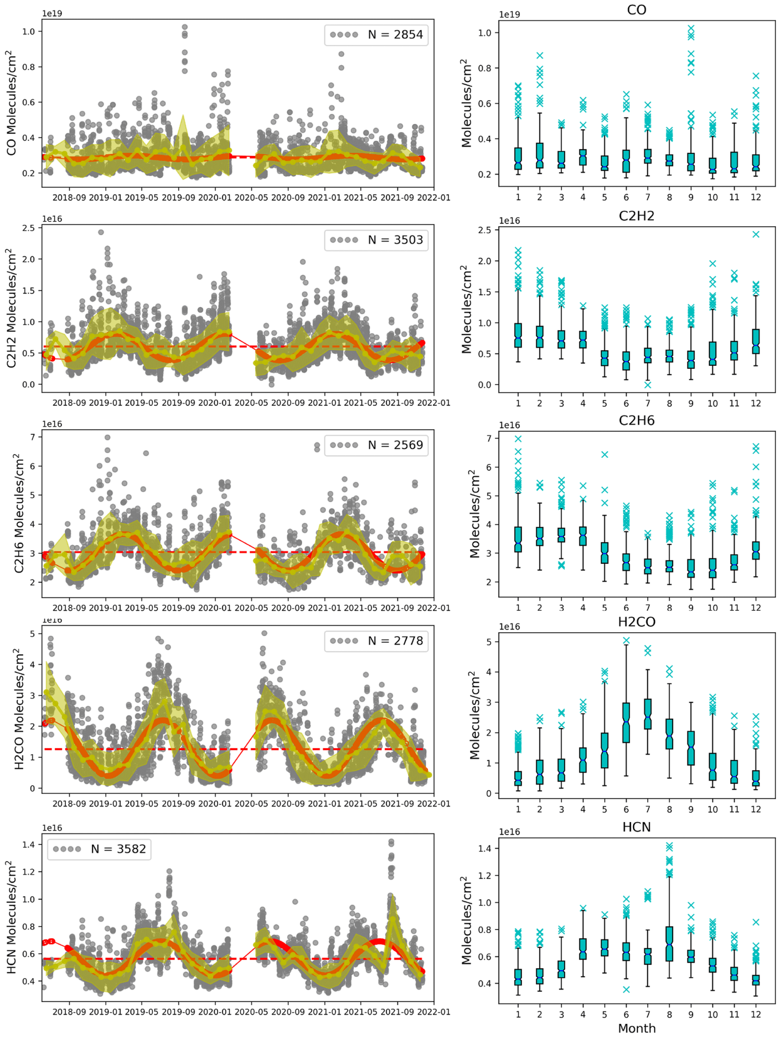
Bruker 125HR FTIR

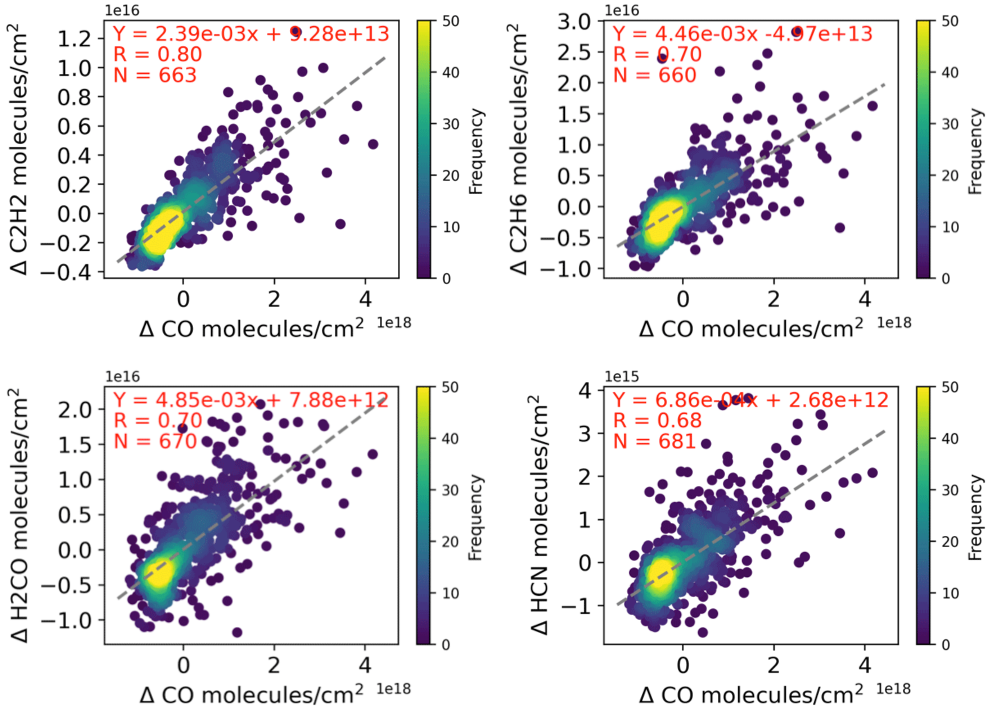
For the first time, the time series, variations, and correlations of five species (CO, C_2H_2, C_2H_6, H_2CO, and HCN) are analyzed at a typical polluted site in northern China.

- CO has no clear seasonal variation

- C_2H_2 and C_2H_6
a maximum in winter–spring and a minimum in autumn

- H_2CO and HCN
a maximum in summer and a minimum in winter





- High correlations are found between ΔCO and the other four species
- affected by common sources

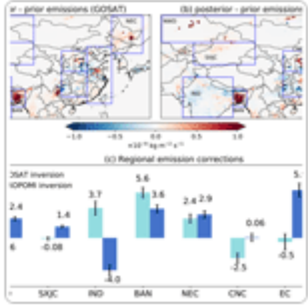
Zhou et al., AMT, 2023

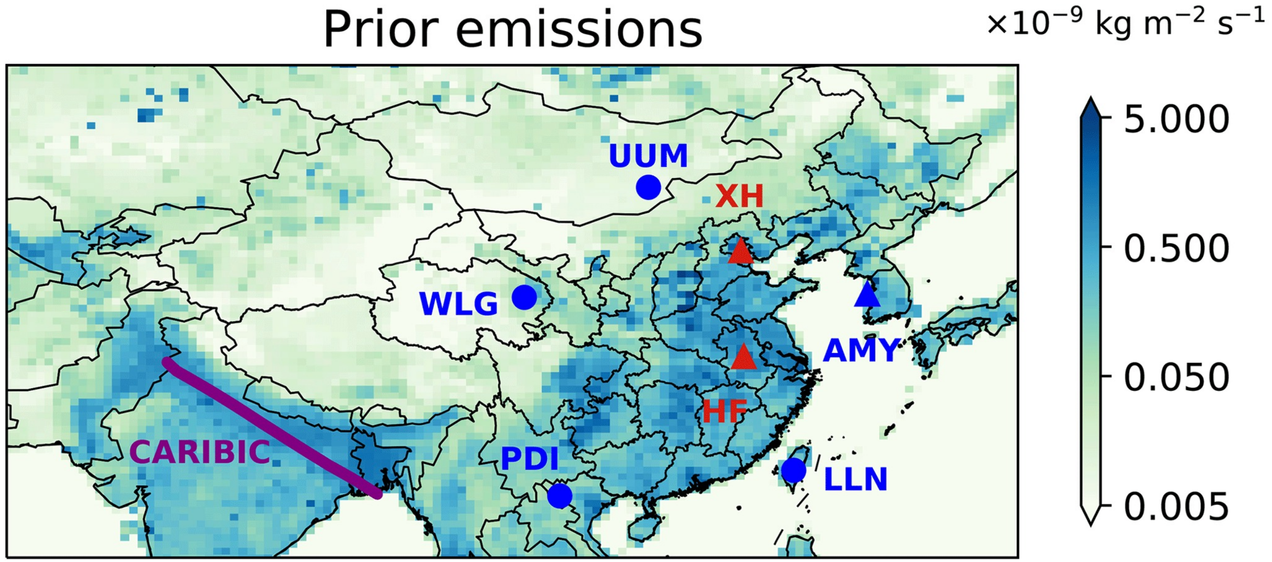
Bruker 125HR FTIR

Research article | 19 Jul 2023

East Asian methane emissions inferred from high-resolution inversions of GOSAT and TROPOMI observations: a comparative and evaluative analysis

Ruosi Liang, Yuzhong Zhang, Wei Chen, Peixuan Zhang, Jingran Liu, Cuihong Chen, Huiqin Mao, Guofeng Shen, Zhen Qu, Zichong Chen, Minqiang Zhou, Pucai Wang, Robert J. Parker, Hartmut Boesch, Alba Lorente, Joannes D. Maasakkers, and Ilse Aben

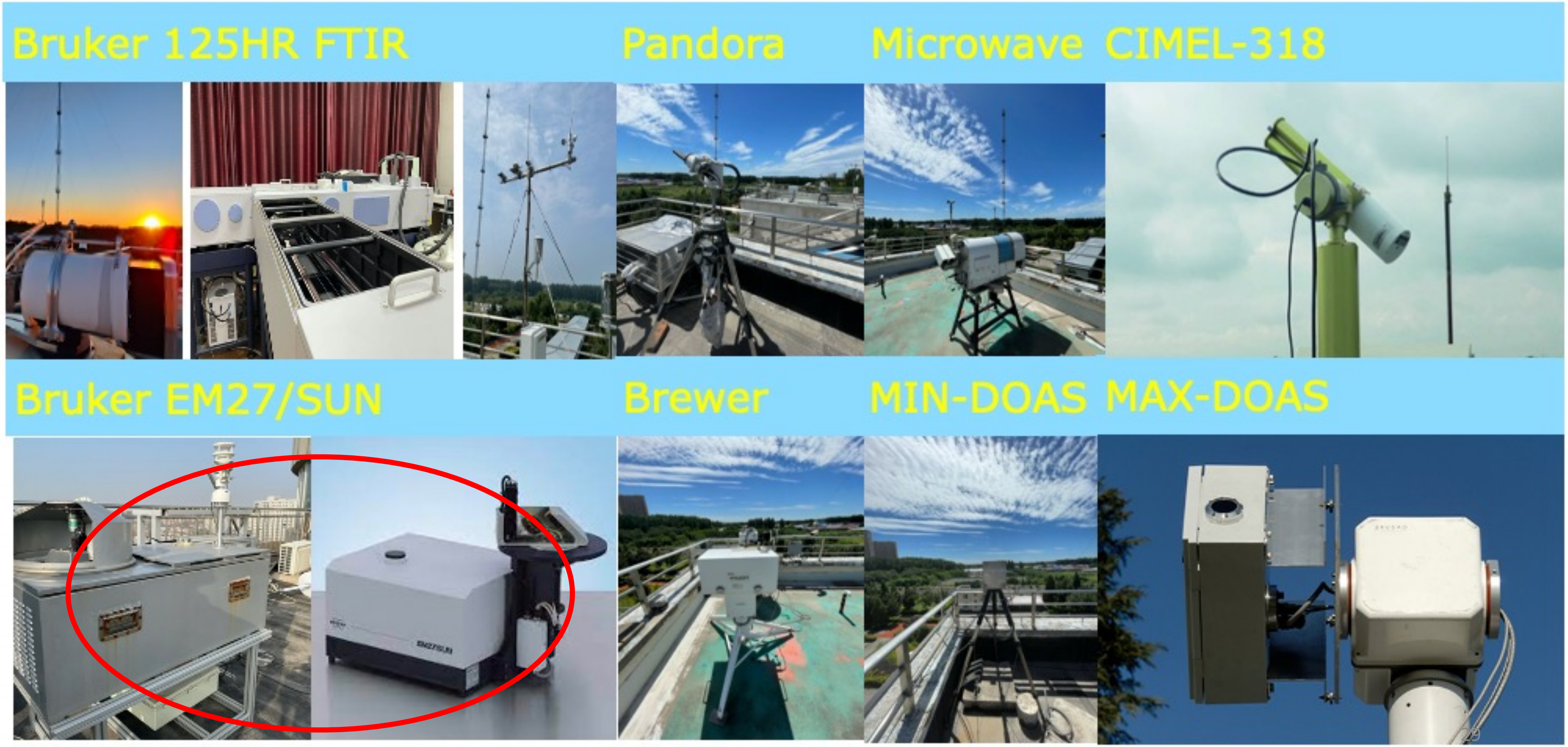




Xianghe 125HR data used as an independent evaluation data to evaluate the posterior emissions inferred from satellite observations

Liang et al., ACP, 2023

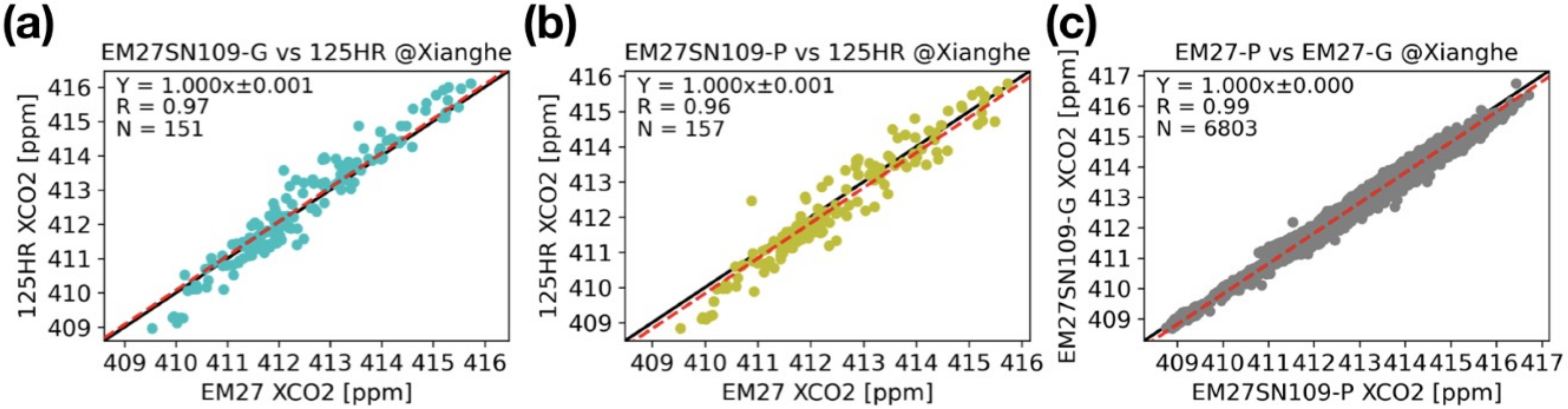
Remote sensing instruments



Bruker EM27 experiments

three EM27 parallel comparison experiments at Xianghe, 125HR as reference

Bruker EM27 experiments



- The Bruker EM27/SUN SN109 XCO_2 measurements retrieved by GGG2020 and PROFFAST v1.0 are very similar
- both datasets have high correlations against the TCCON measurements

(Zhou et al., 2022)

Outline

1. Brussels-Xianghe collaboration

2. Atmospheric remote sensing activities at Xianghe

3. Validation activities at Xianghe

4. Intercomparison of CH_4 products in China from GOSAT, TROPOMI, IASI and AIRS satellites

5. Future plans

Xianghe satellite validation activities

FTIR - TCCON – TROPOMI/OCO

- CO (Sha et al., 2021; Tian et al., 2022)
- CH_4 (Sha et al., 2021; Tian et al., 2022; Zhou et al., 2023)
- CO_2 (Zhou et al., 2022)

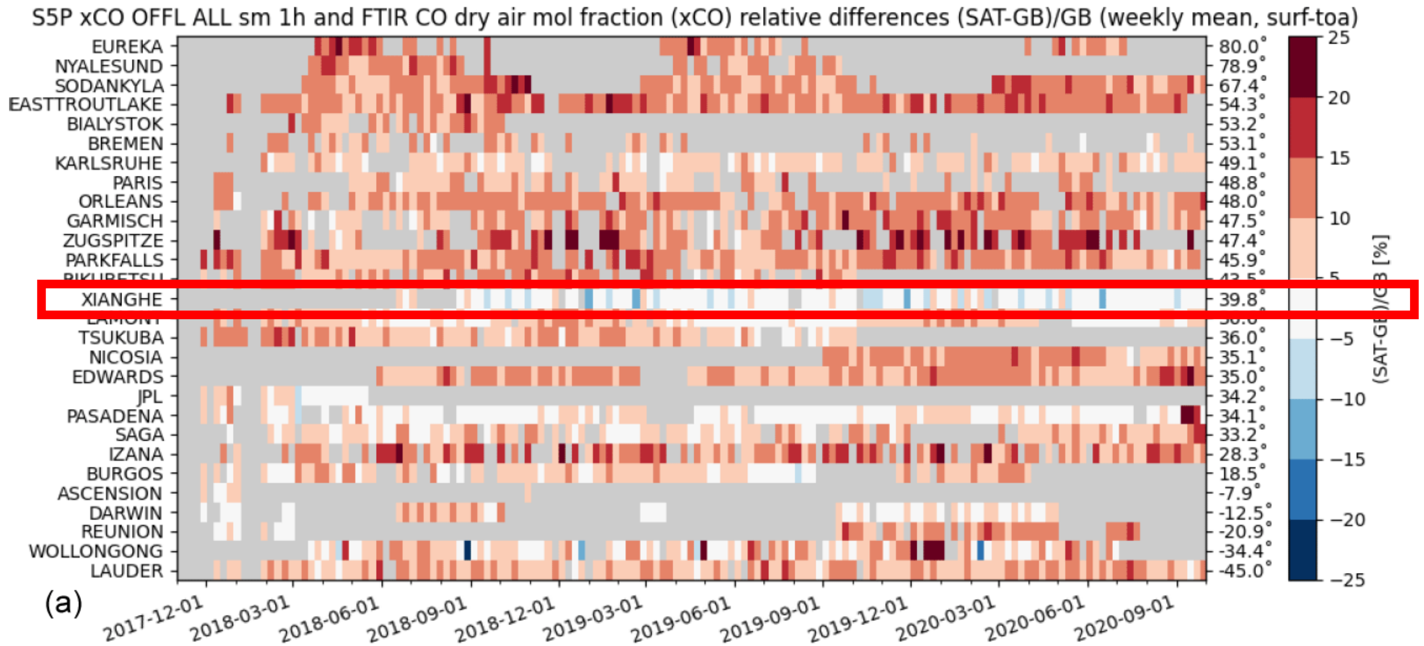
FTIR - NDACC – TROPOMI/OMPS-NPP/N20

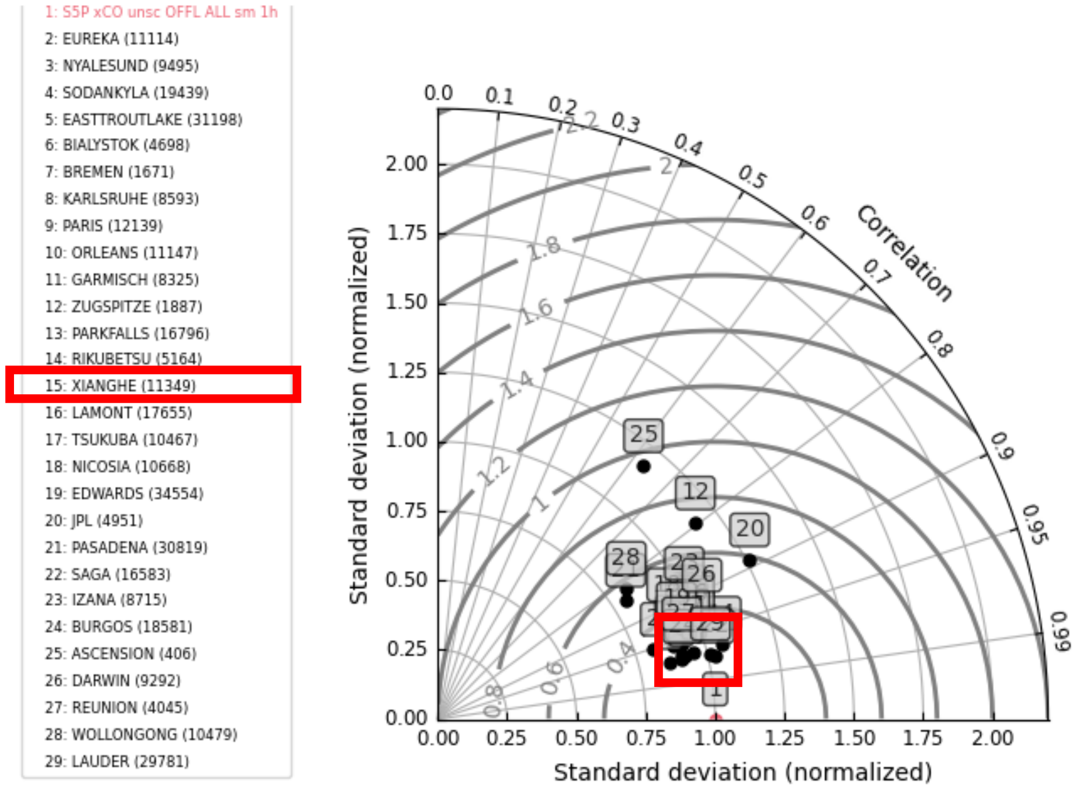
- HCHO (Vigouroux et al., 2020; Kwon et al., 2023)

DOAS - NDACC – TROPOMI/OMI

- HCHO (De Smedt et al., 2021)
- CHOCHO (Lerot et al., 2021)
- NO2 , SO2 (Wang et al., 2022)

TROPOMI-FTIR – CO validation



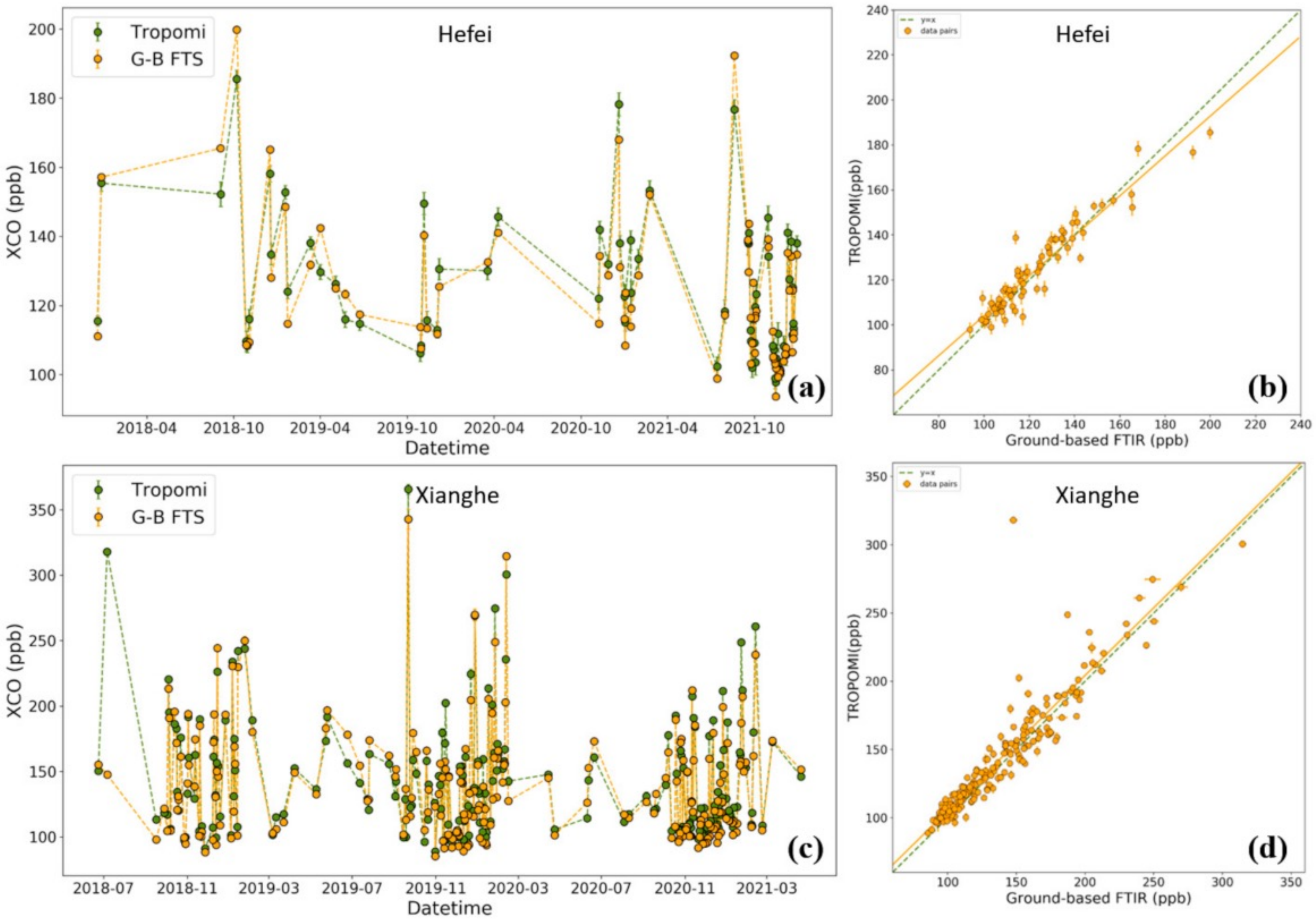


Overall:

- Xianghe site show very bias
- Consistent: no seasonal variation in bias
- Good correlation R>0.95

(Sha et al., 2021)

TROPOMI-FTIR – CO validation

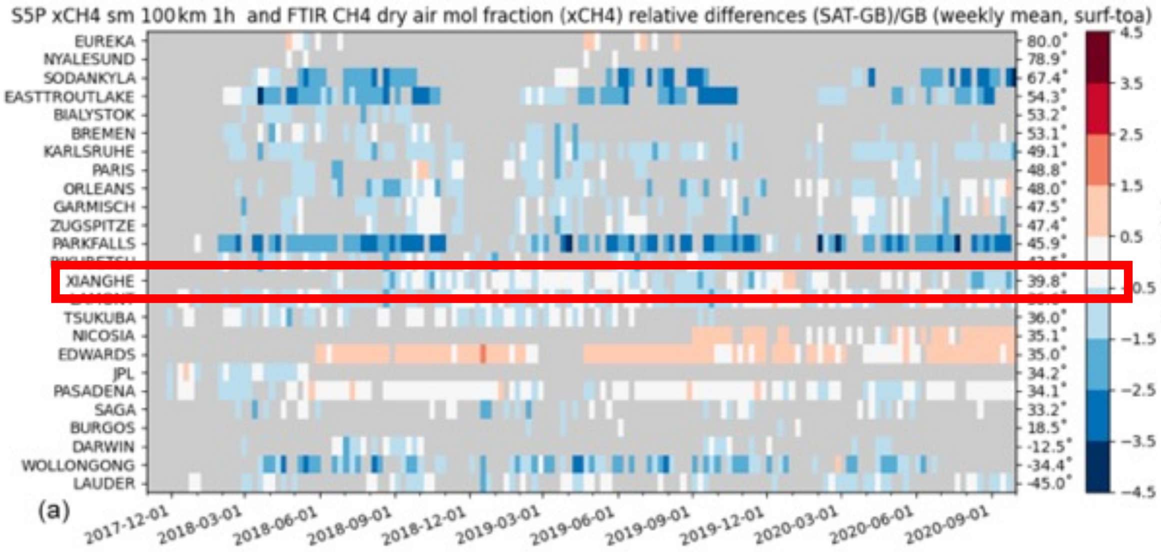


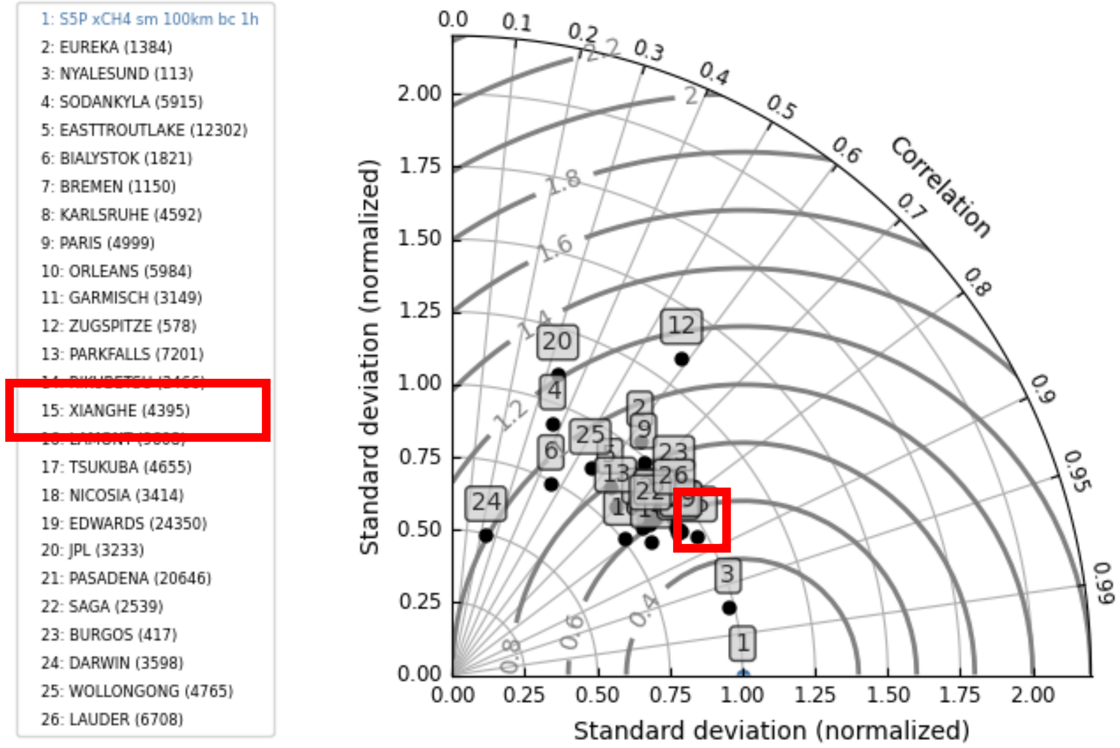
Overall:

- Xianghe (TROPOMI–FTIR): 5.33 ± 14.24 ppb or 3.85 ± 10.30%
- Good correlation R=0.99
- The TROPOMI observations over the polluted region can well reproduce the day-to-day and seasonal variabilities of CO observed by the FTIR

(Tian et al., 2022)

TROPOMI-FTIR – CH_4 validation



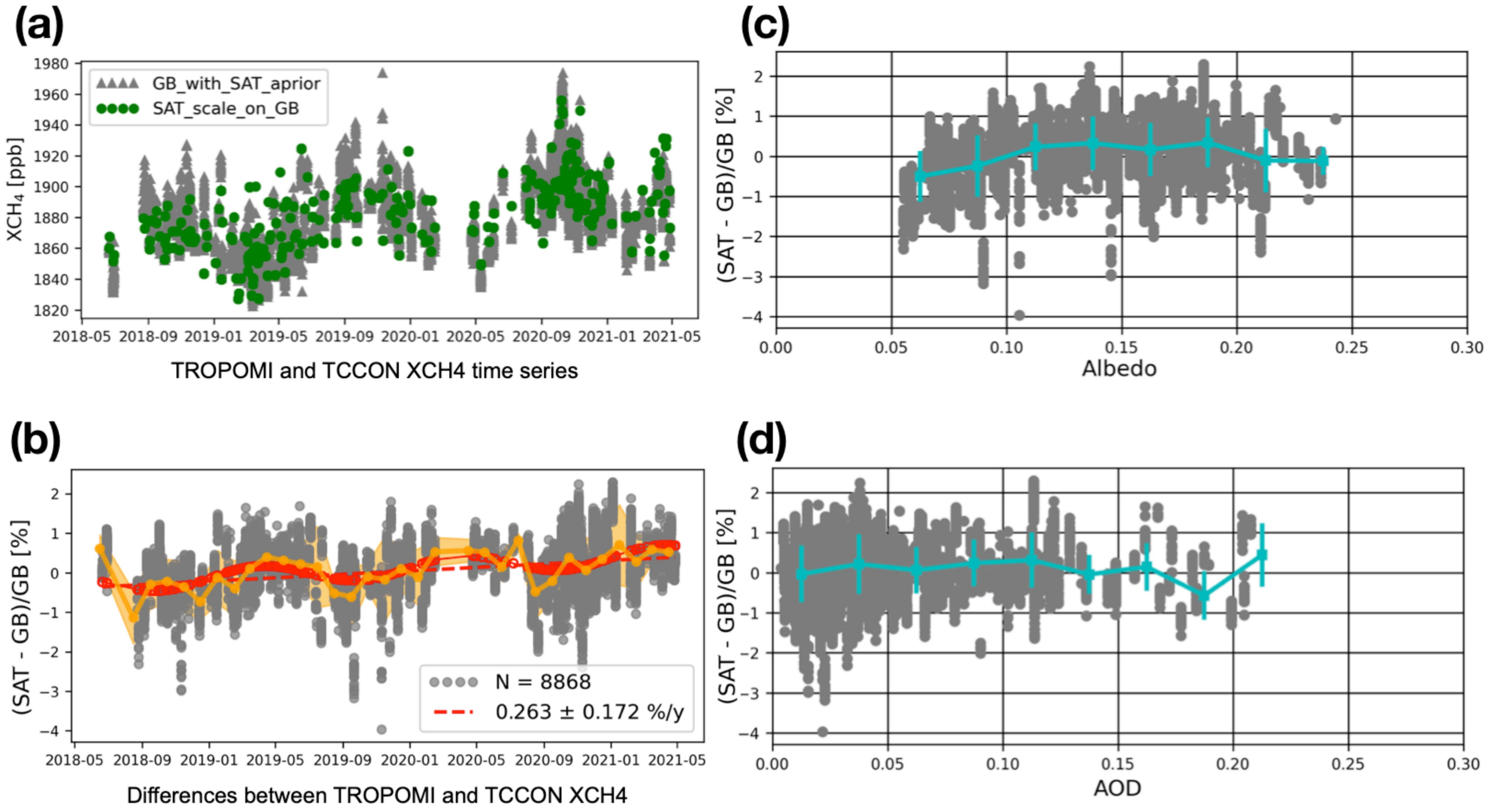


Overall:

- Small mean bias < 0.5%
- Consistent: no seasonal variation in bias
- Good correlation R>0.8

(Sha et al., 2021)

TROPOMI-FTIR – CH_4 validation

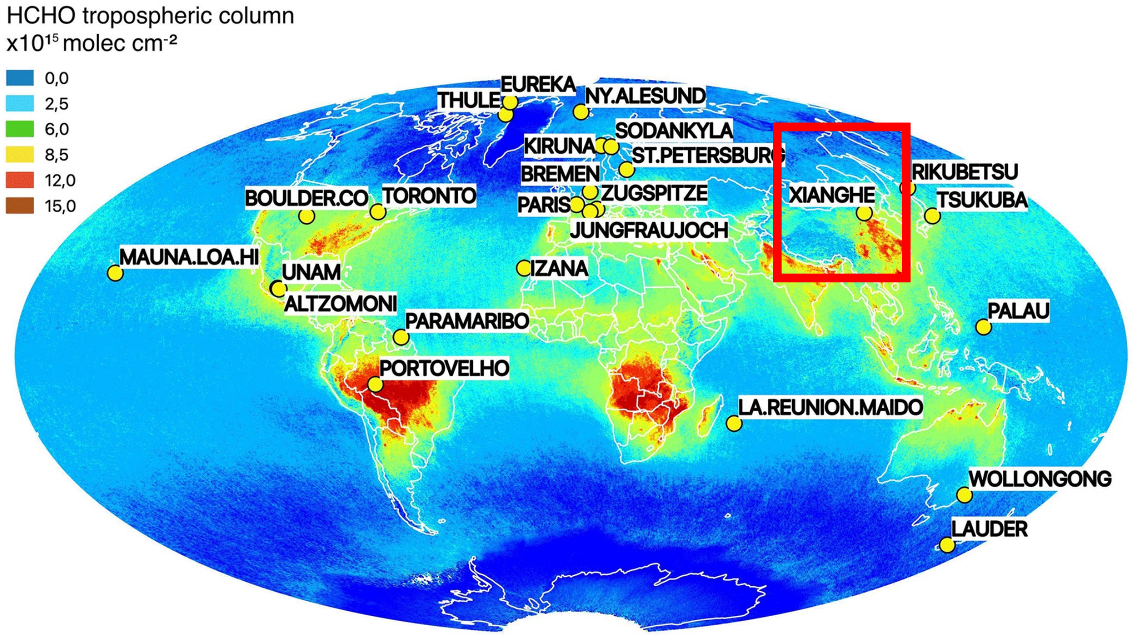


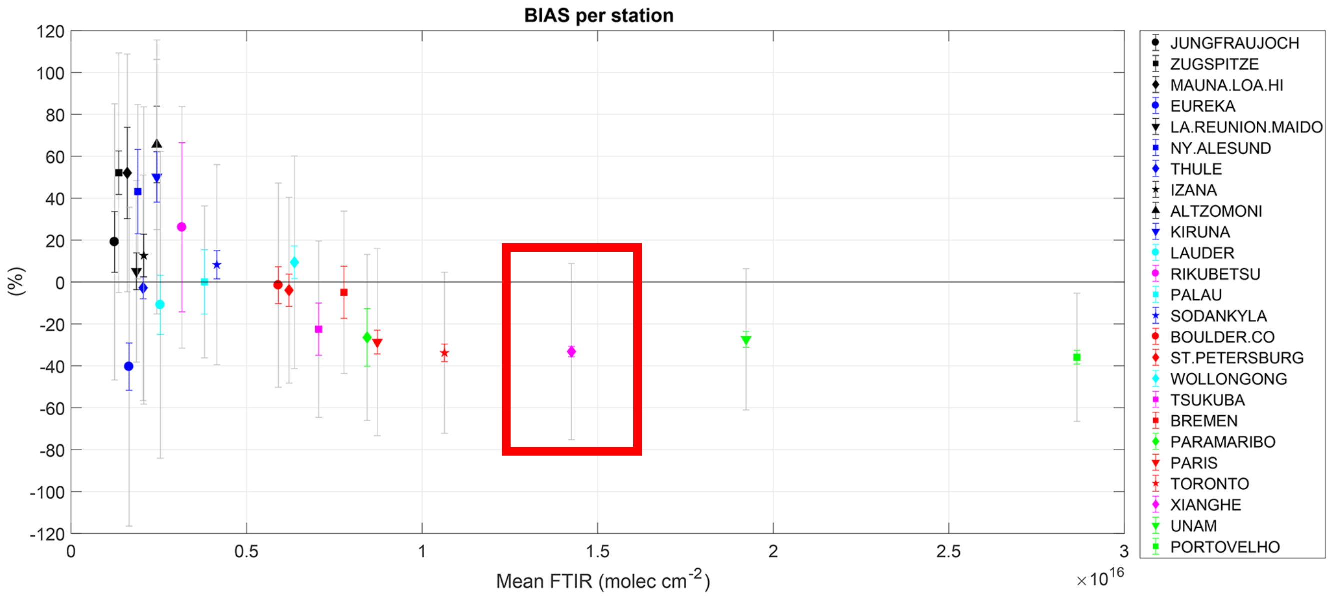
Overall:

- TROPOMI: an underestimation of seasonal oscillations.
- the XCH_4 growth rate observed by TROPOMI was higher than that observed by FTIR
- the observed value of TROPOMI is smaller than that of FTIR (Albedo less than 0.1),
- the difference is basically not affected by the change of AOD (AOD < 0.22)

(Zhou et al., 2023)

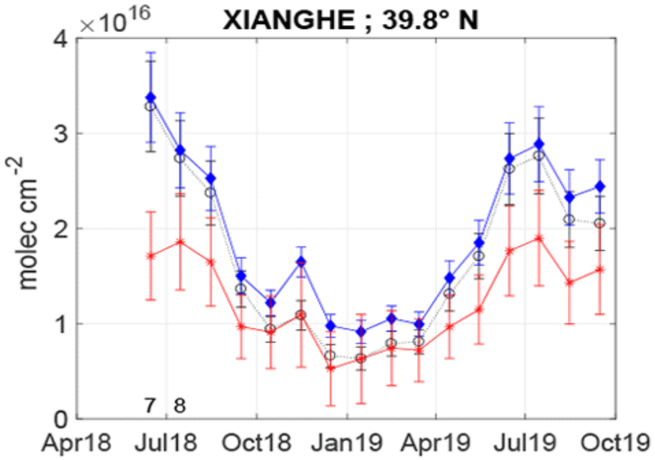
TROPOMI-FTIR – HCHO validation





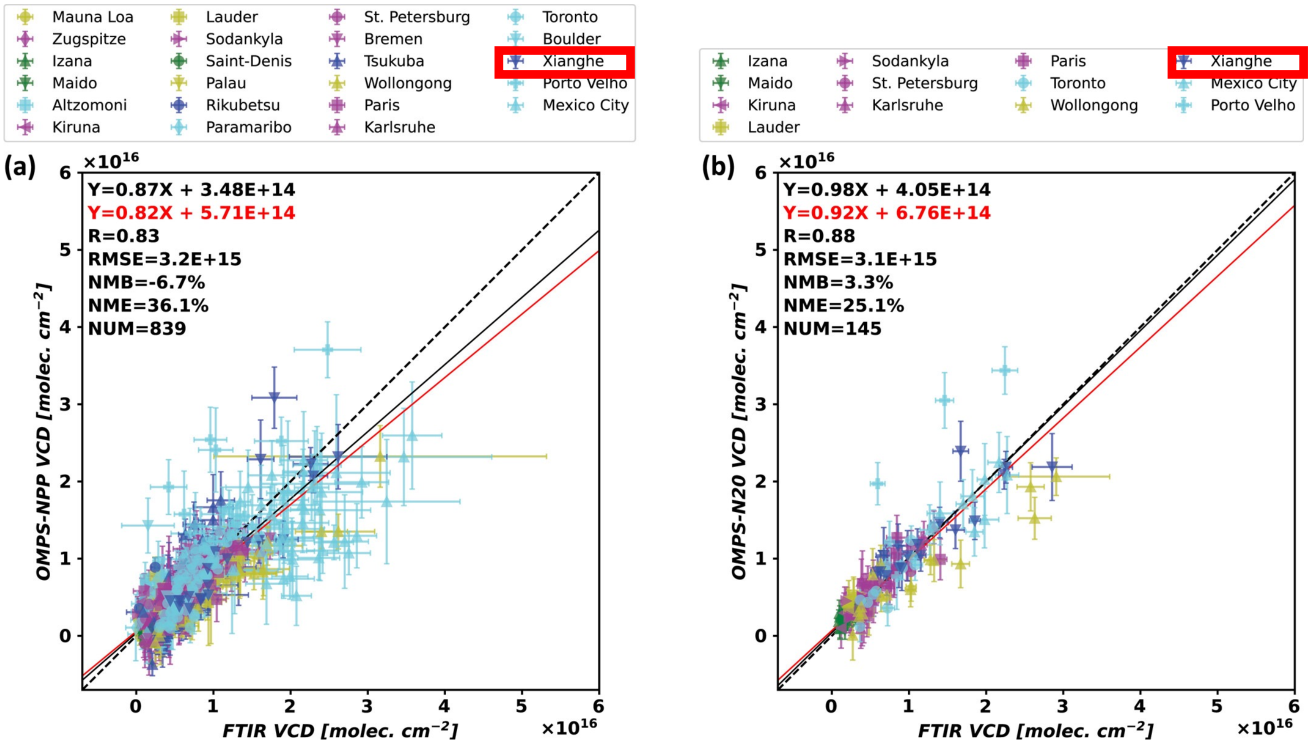
Overall:

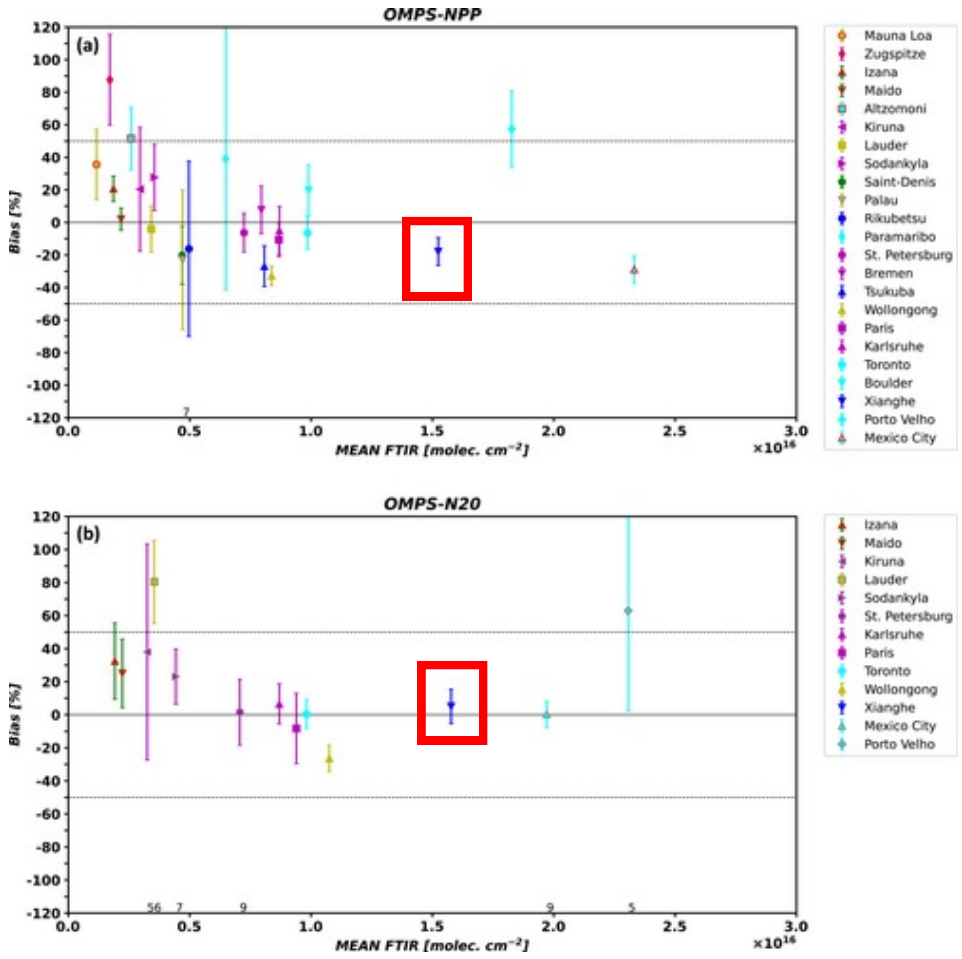
- Typical urban high HCHO site
- Xianghe shows that TROPOMI has a underestimation when HCHO is high
- Good correlation R>0.9
- Same seasonal variation



(Vigouroux et al., AMT, 2020)

OMPS-NPP/N20-FTIR – HCHO validation



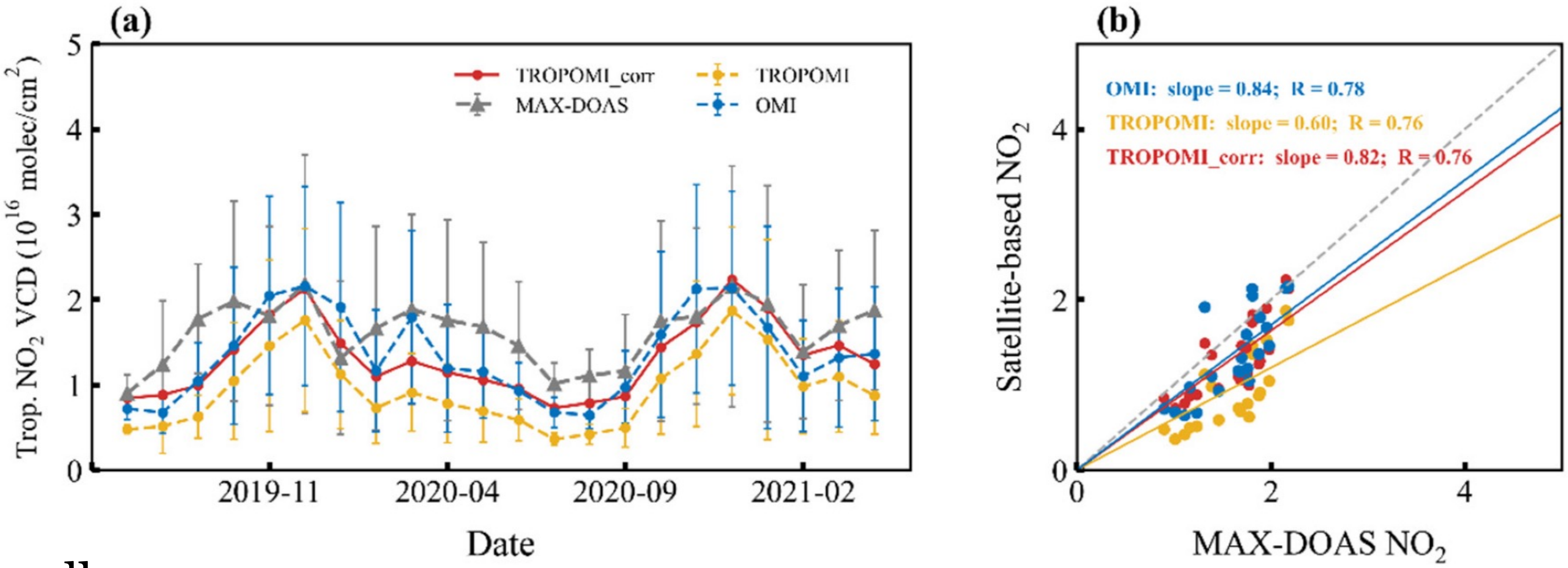


Overall:

- Typical urban high HCHO site
- Relatively low bias (OMPS-NPP: -18±9%, OMPS-N20: 5±10%)
- Good correlation (OMPS-NPP: R=0.86, OMPS-N20: R=0.89)

(Kwon et al., 2023)

TROPOMI-OMI-MAXDOAS – NO_2 validation

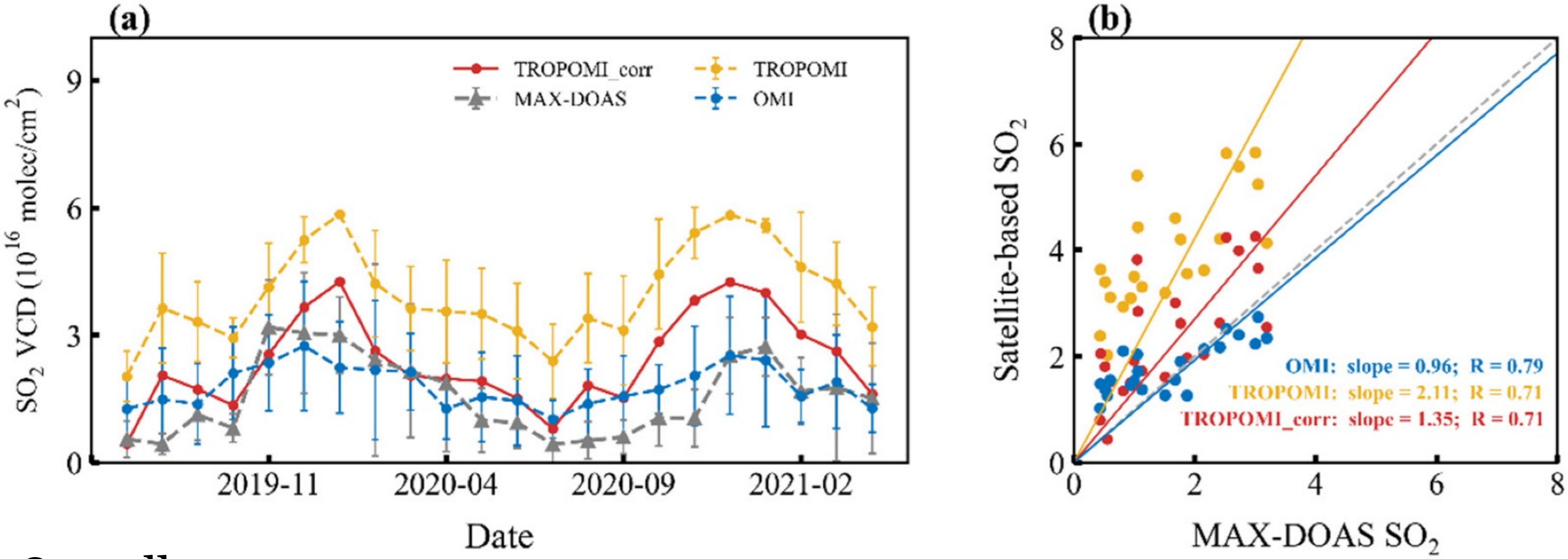


Overall:

- Similar seasonal variation observed by MAX-DOAS, OMI, TROPOMI
- MAX-DOAS is close to OMI, but TROPOMI NO_2 is underestimated

(Wang et al., 2022)

TROPOMI-OMI-MAXDOAS – SO_2 validation



Overall:

- Similar seasonal variation observed by MAX-DOAS, OMI, TROPOMI
- MAX-DOAS is close to OMI, but TROPOMI SO2 is overestimated

(Wang et al., 2022)

Outline

1. **Brussels-Xianghe collaboration**

2. **Atmospheric remote sensing activities at Xianghe**

3. **Validation activities at Xianghe**

4. **Intercomparison of CH_4 products in China from GOSAT, TROPOMI, IASI and AIRS satellites**

5. **Future plans**

Background

- Given the increased interest in CH_4 emission reduction in recent years and the widespread use of satellite measurements in CH_4 research
- For the research of CH_4 satellite products in China, the previous work mainly focused on a single instrument

- This work：

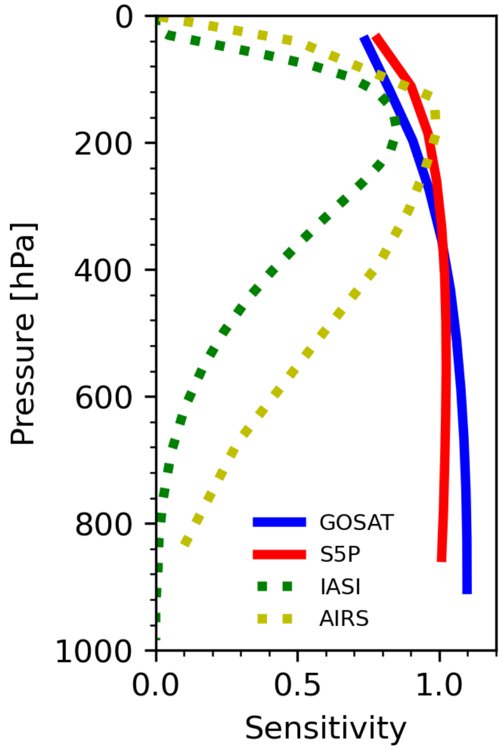
➢ The temporal and spatial distribution of CH_4 in China was analyzed using CH_4 observation data from four satellites (GOSAT, TROPOMI, IASI, AIRS)

➢ Focus on the differences between CH_4 products from different satellites

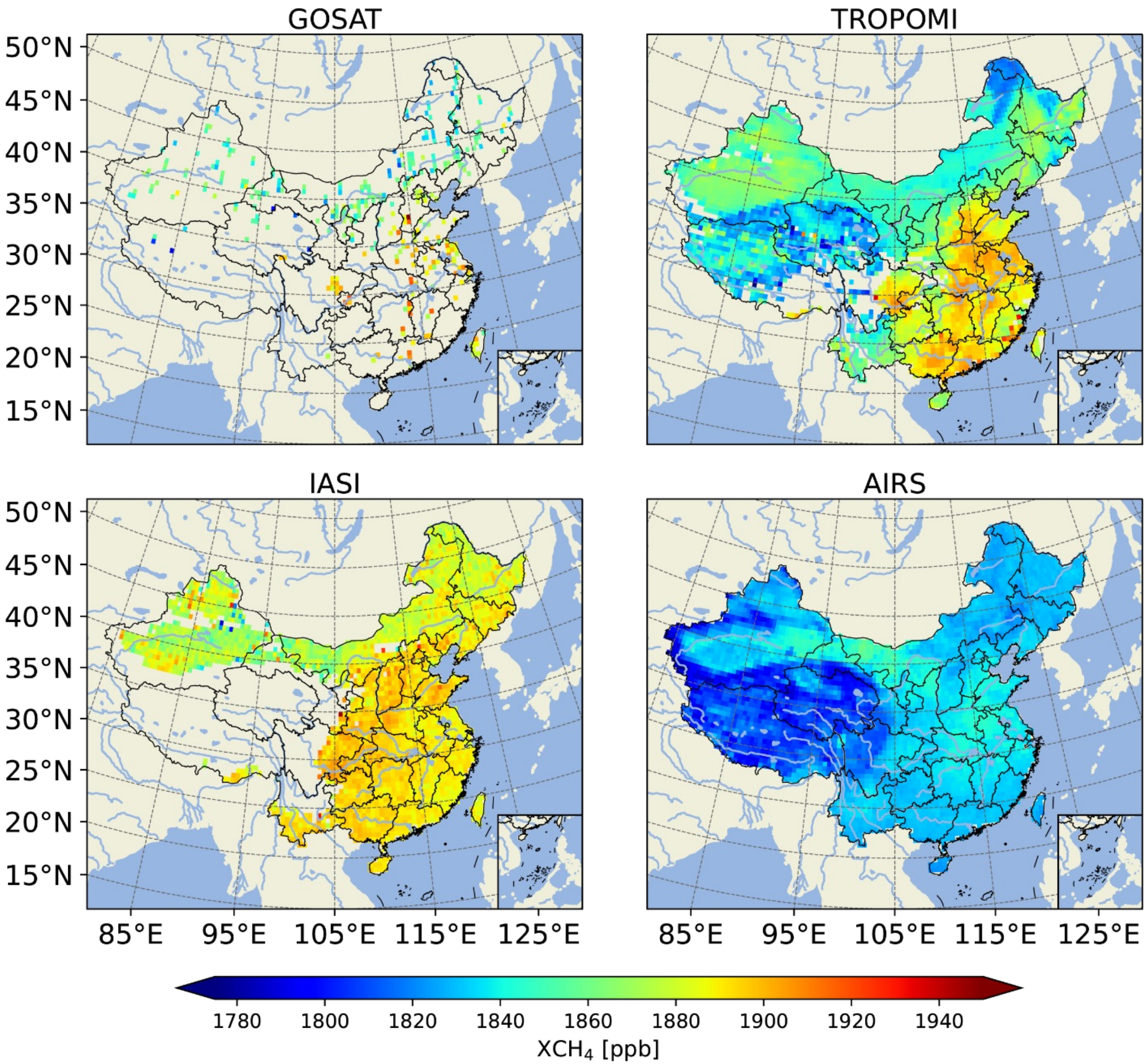
GOSAT vs TROPOMI （SWIR）, IASI vs AIRS (TIR) ,TROPOMI vs AIRS （SWIR vs TIR)

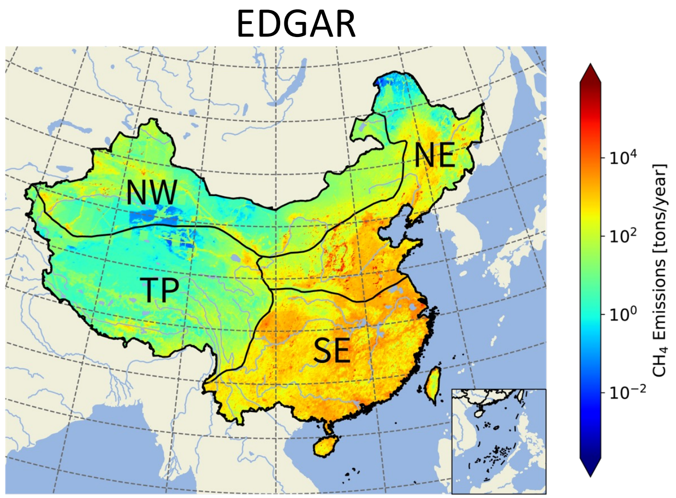
Satellite instruments for measuring atmospheric CH4

Instruments	TANSO-FTS	TROPOMI	IASI	AIRS
Satellite	GOSAT	S5P	MetOp-A	Aqua
Agency	JAXA	ESA, NSO	EUMETSAT	NASA
Data period	2009-now	2017-now	2007-now	2002-now
Overpass time [local time]	01:00/13:00	01:30/13:30	09:30/21:30	01:30/13:30
Fitting window [nm] Spectral resolution	1560-1720 0.27 cm^{-1}	2310-2390 0.25 nm	7100-8300 0.5 cm^{-1}	6200-8200 0.5 cm^{-1}
Pixel size	10.5 km	5.5×7.0 km^2	12 km	13.5 km
Swath [km]	Discrete, 1-9 points	2600	2200	1650
Retrieval algorithm	SRFP	RemoTeC	Neural network	OEM
Product type	column-averaged dry-air mole fraction of CH_4 (XCH_4)	column-averaged dry-air mole fraction of CH_4 (XCH_4)	mid-to-upper tropospheric columns of CH_4	total column/profile
Reference	Kuze et al. (2009)	Lorente et al. (2021)	Crevoisier et al. (2009)	Xiong et al. (2008)



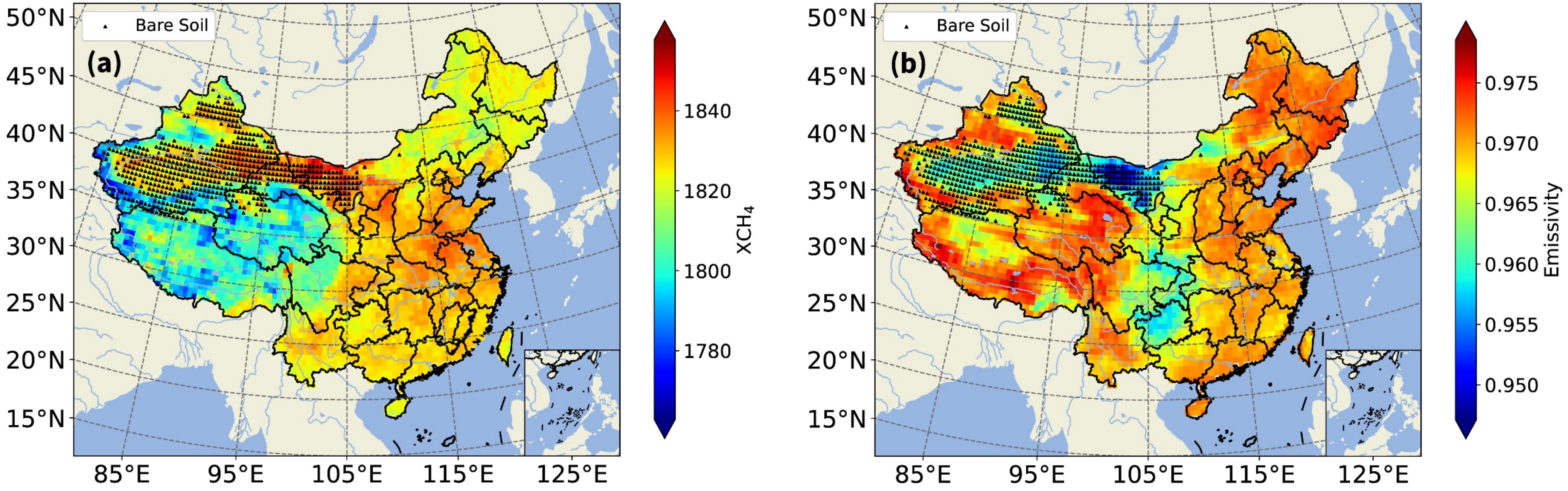
CH_4 products map of 4 satellites





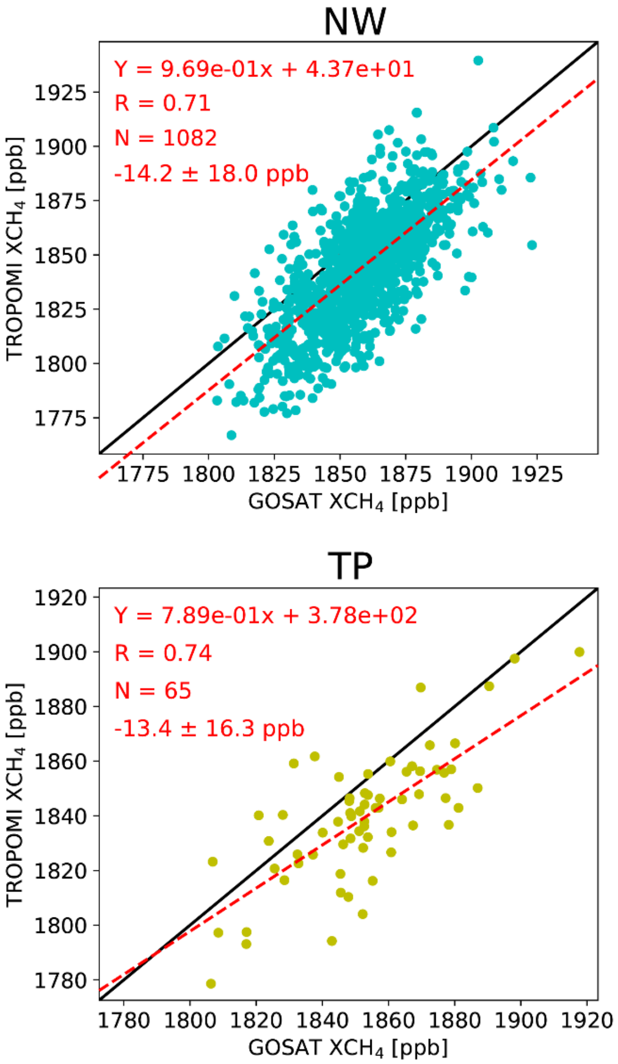
- GOSAT and TROPOMI XCH_4 are very consistent with EDGAR
- IASI XCH_4 is relatively uniform compared to that of the TROPOMI
- AIRS XCH_4 is abnormally high in the NW region

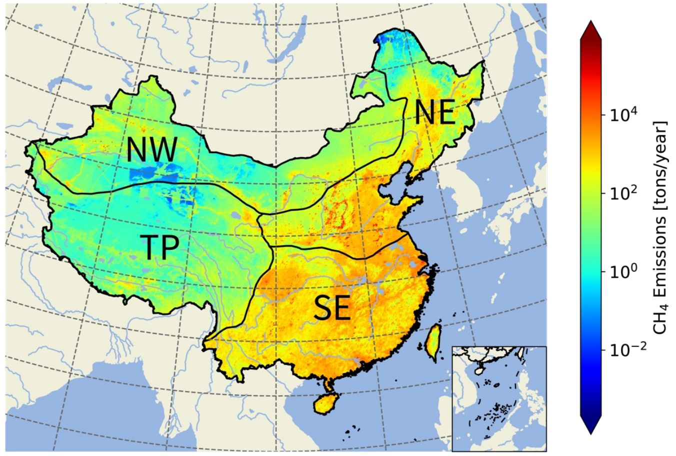
AIRS abnormity



The low surface emissivity leads to a low signal-to-noise ratio of the infrared spectrum, and the AIRS CH_4 retrieval maybe affected by it.

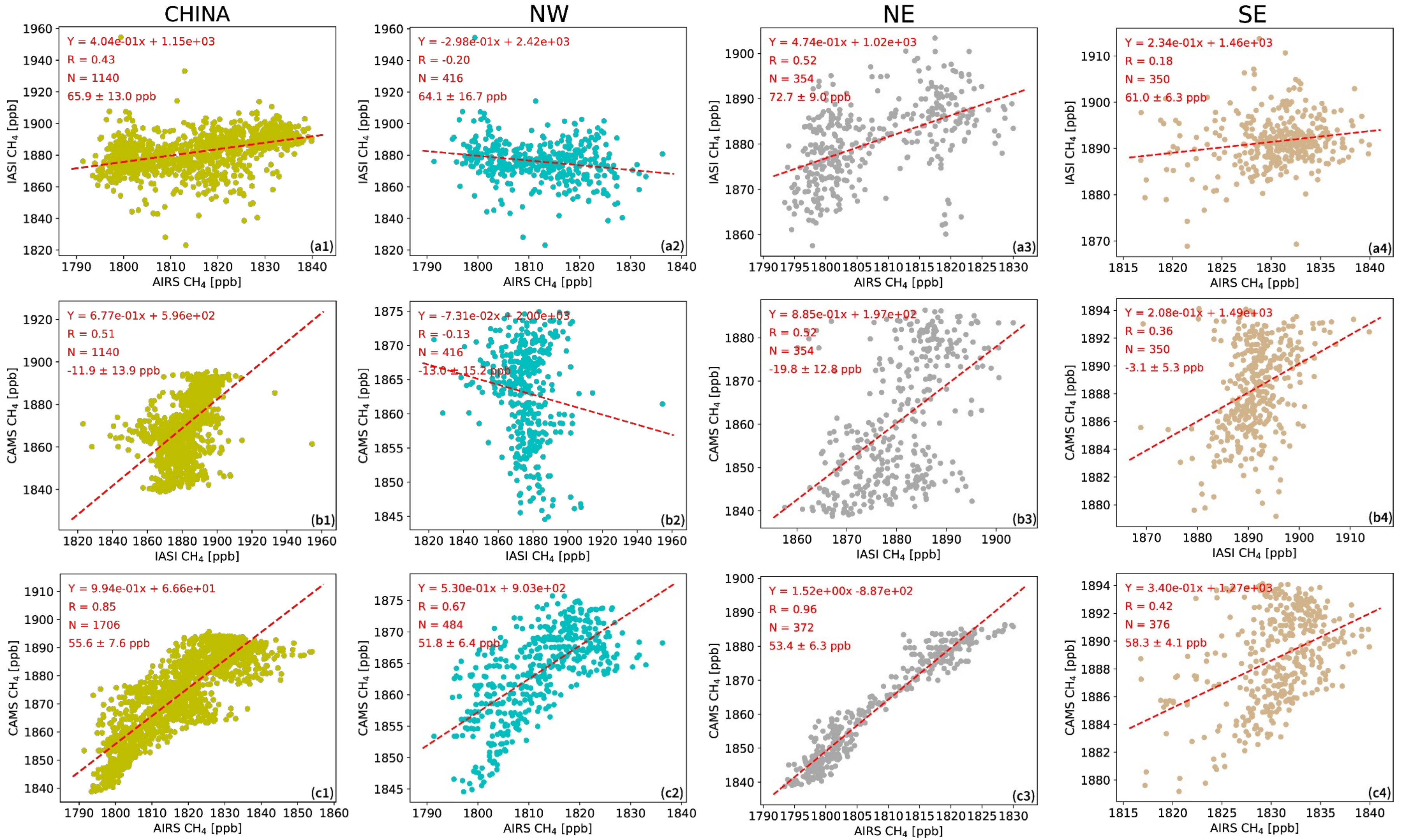
GOSAT vs TROPOMI

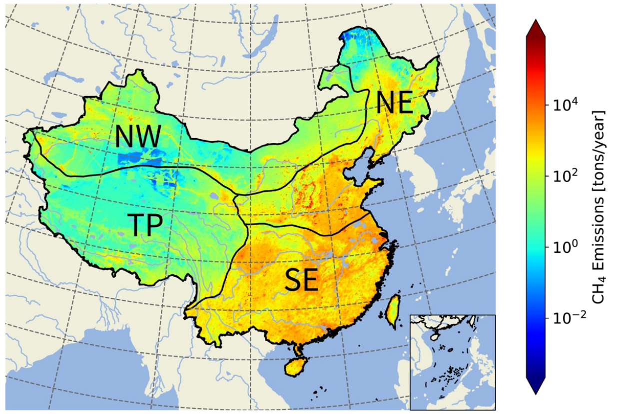




- TROPOMI and GOSAT show good consistency in all 4 regions, especially in SE.
- The bias in the NW, NE and TP regions is approximately 85% higher than that in SE. (higher snow cover)

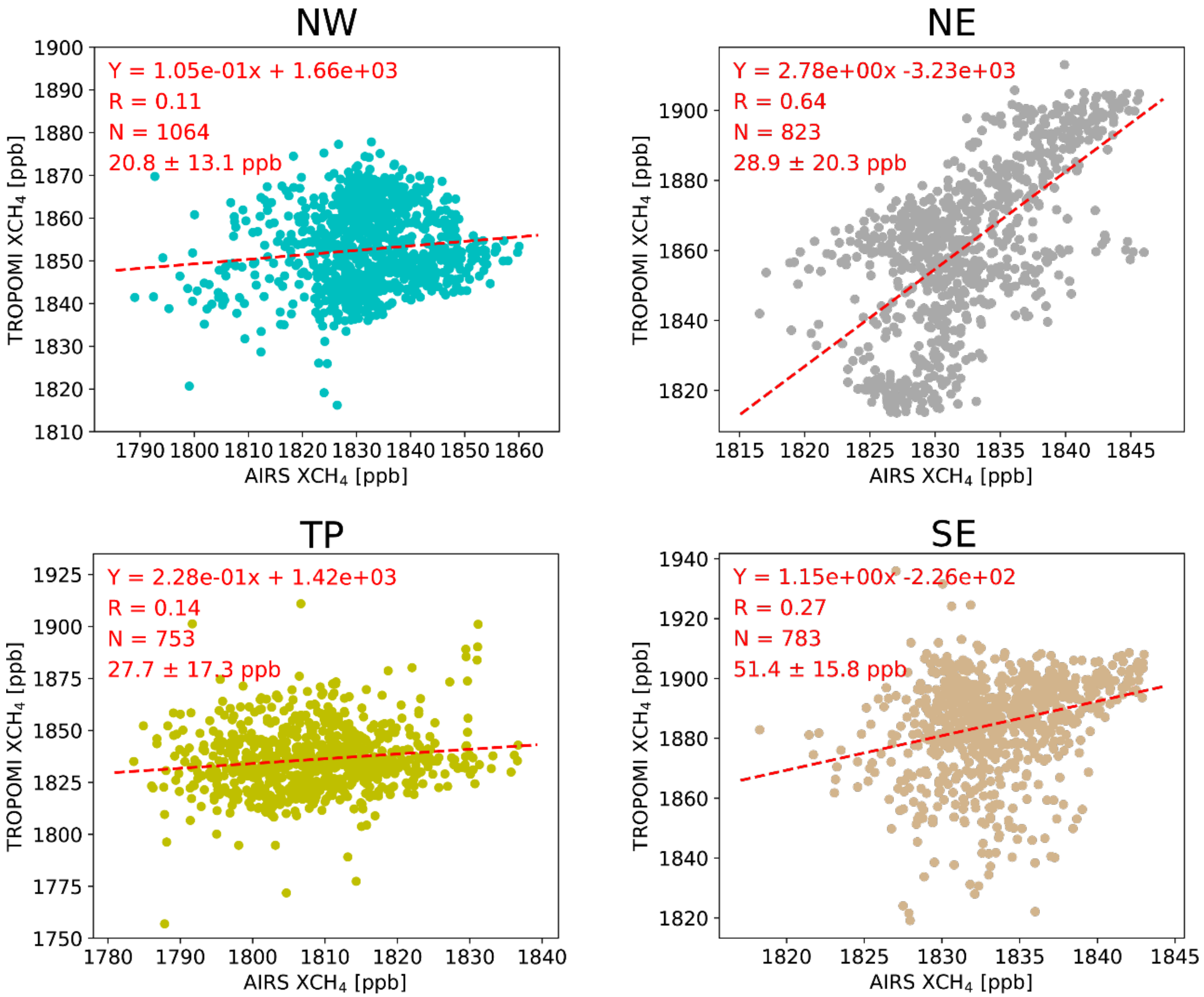
IASI vs AIRS

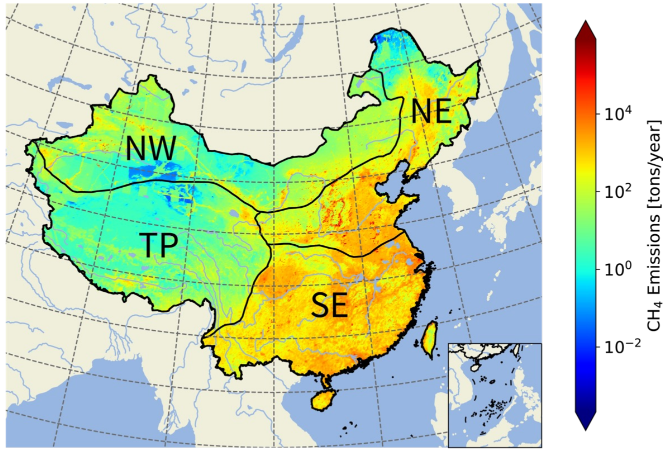




Comparison against the CAMS model, the AIRS measurements could better present the CH_4 variation in the mid-upper troposphere as compared to the IASI measurements.

TROPOMI vs AIRS

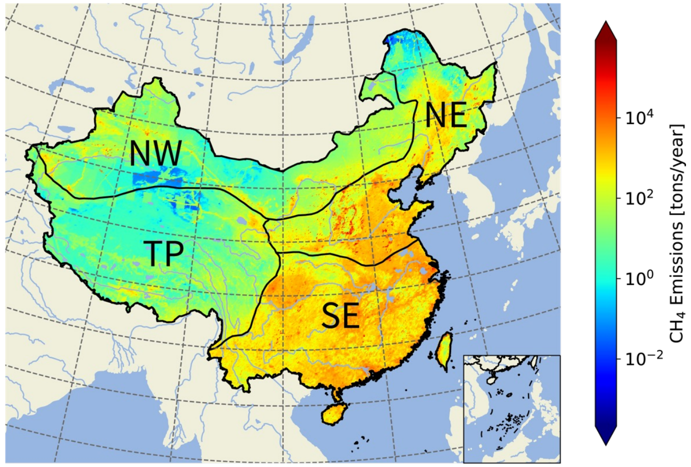


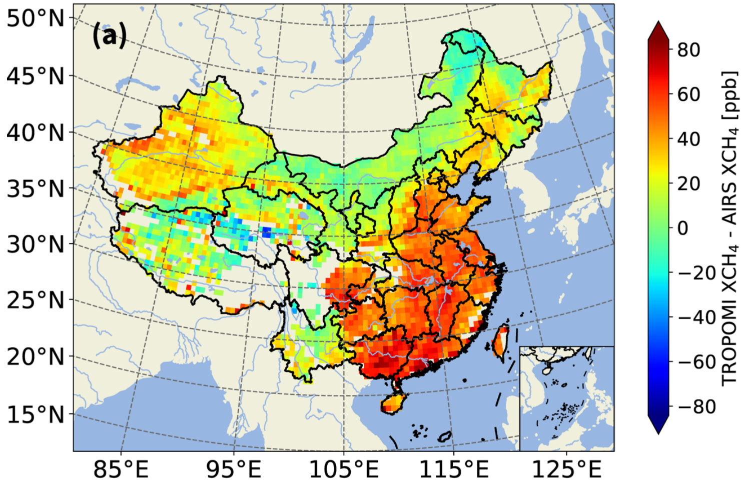


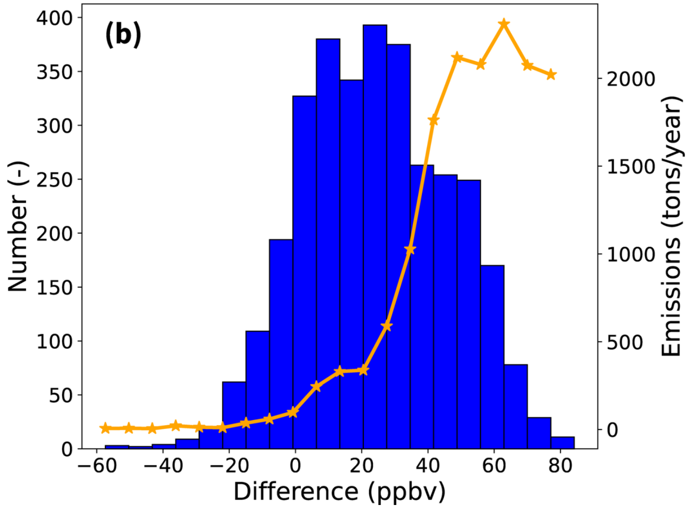
- AIRS XCH_4 is systematically underestimated.
- The correlation is poor, especially in NW, TP and SE.
- different retrieval band and sensitivity

TROPOMI vs AIRS

EDGAR







$$x_{r,T} = x_{a,T} + A_T(x_t - x_{a,T})$$

$$x_{r,A} = x_{a,R} + A_R(x_t - x_{a,R}),$$

$$x_{r,T} - x_{r,A} = x_{a,T} - x_{a,R} + A_R(x_t - x_{a,T}) - A_R(x_t - x_{a,R}),$$

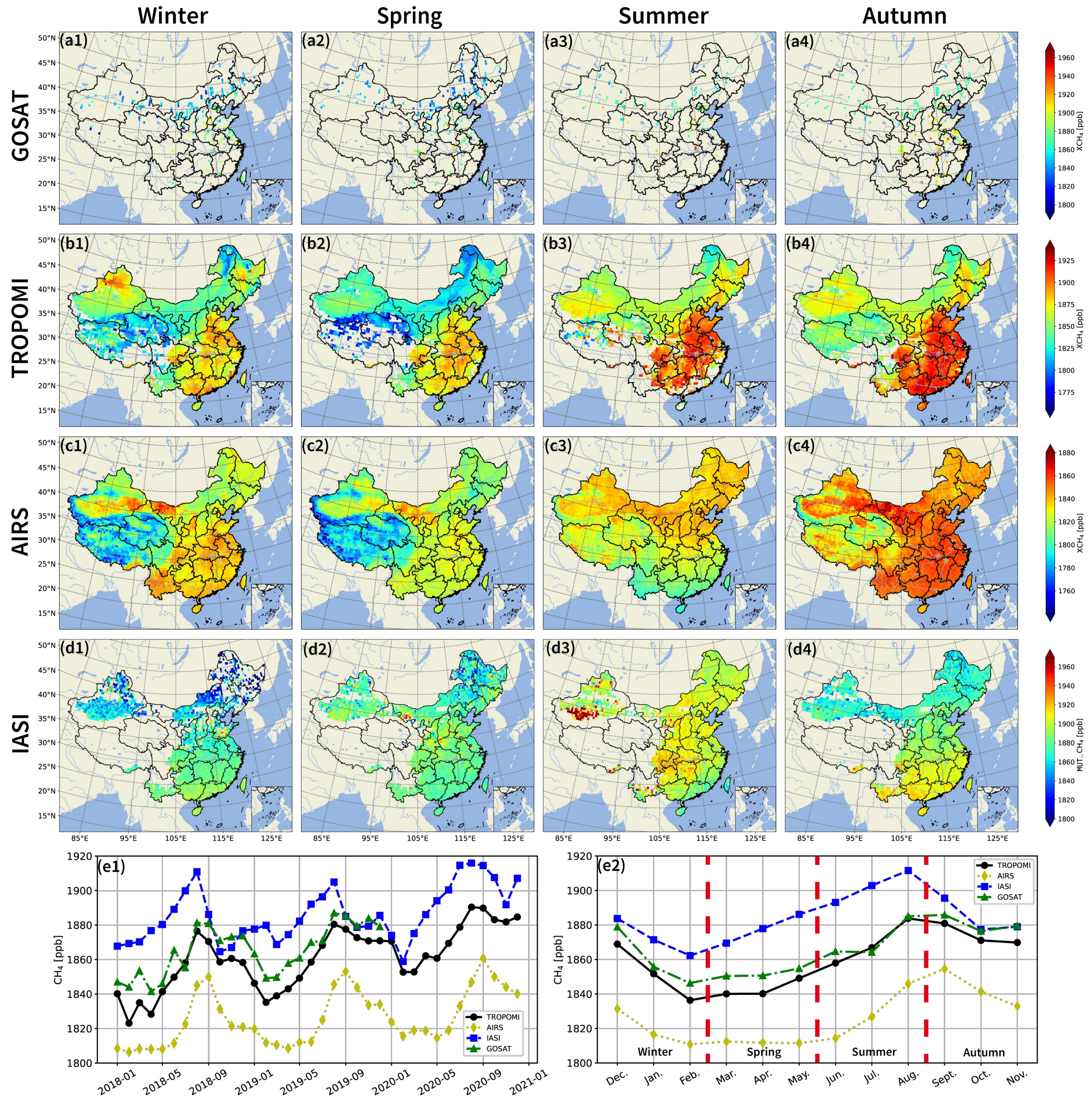
Assuming $x_{a,T}$ is close to x_t,

$$x_{r,T} - x_{r,A} = x_{a,T} - x_{a,R} - A_R(x_t - x_{a,R}) = (I - A_R)(x_t - x_{a,R}),$$

where, subscripts T and R represent TROPOMI and AIRS, respectively, x_t, x_a and x_r are the true, a priori and retrieved CH_4, A is the averaging kernel.

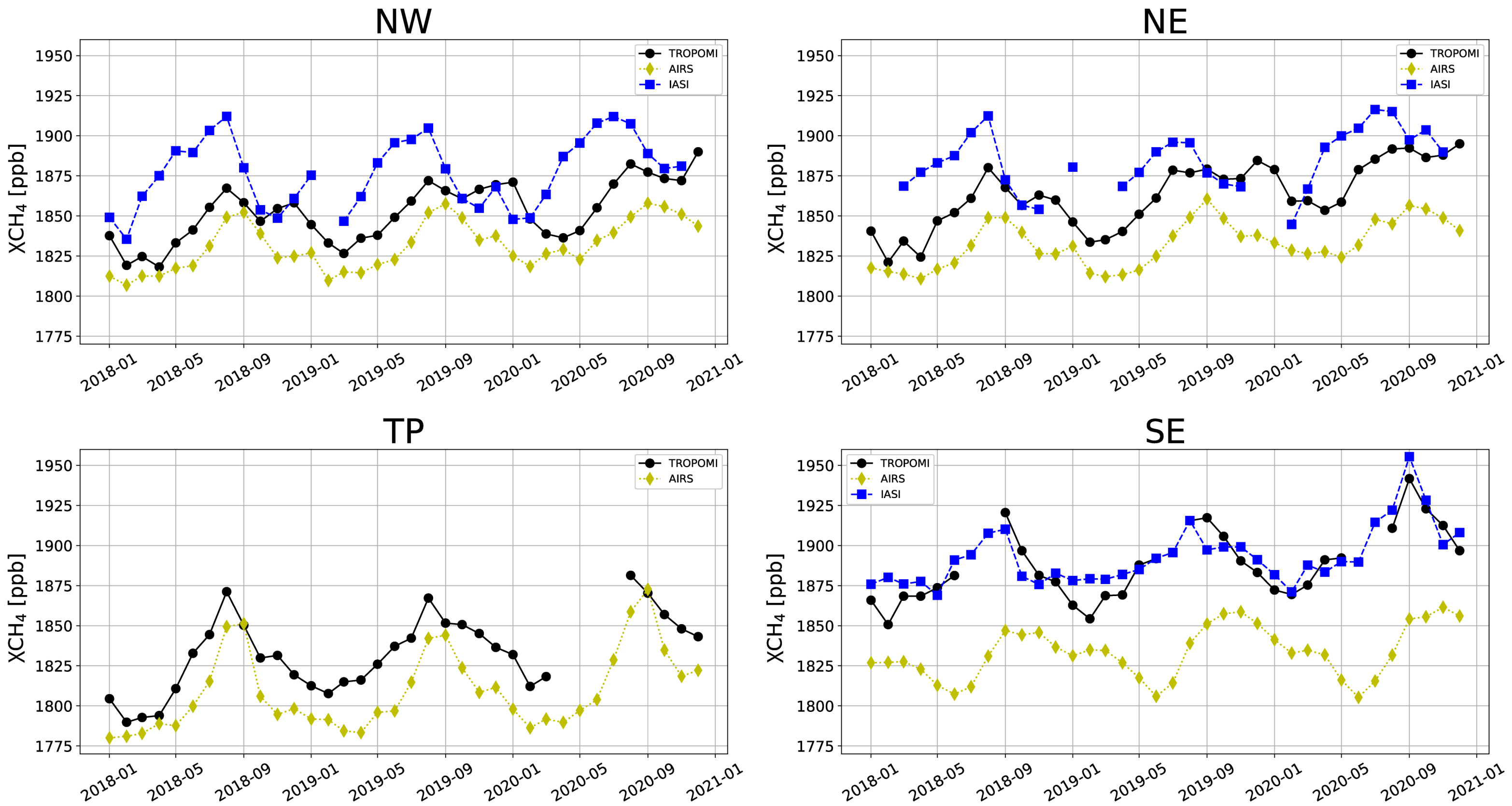
- a similar pattern to the CH_4 anthropogenic emission
- the difference is up to 80 ppb in SE, where the largest CH_4 emission exists
- significant deviations between the a priori profiles and the actual conditions

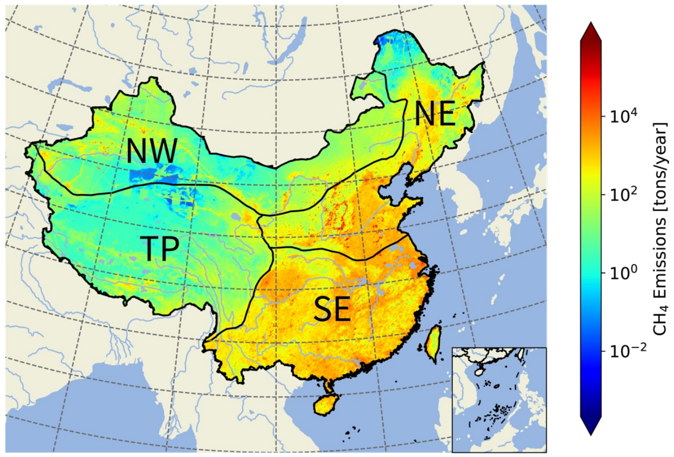
Temporal Variation



- high CH_4 concentrations in summer and autumn, and low in winter and spring
- The spatial pattern of TROPOMI XCH_4 remains consistent.
- AIRS XCH_4 vary significantly with time, relatively high value in Inner Mongolia
- IASI CH_4 measurements are systematically higher

Temporal Variation





- NW is similar to NE, TROPOMI measurements have a bimodal peak
- TP: TROPOMI and AIRS XCH4 have a similar seasonal variation
- SE: IASI and S5P XCH4 are very close in absolute value and trend, while AIRS is systematically low and has phase difference

Summary and Prospect

- GOSAT and TROPOMI (SWIR): a good correlation
- IASI and AIRS (TIR) : relatively weak correlation, different retrieval algorithm
- TROPOMI and AIRS: the differences between them are highly related to the CH_4 emissions (~80 ppb in high CH_4 emissions regions)
- Cautions must be taken when using these satellite products in China

- It is better to compare aircraft or AirCore profile measurements with IASI/AIRS CH_4 products

Outline

1. **Brussels-Xianghe collaboration**

2. **Atmospheric remote sensing activities at Xianghe**

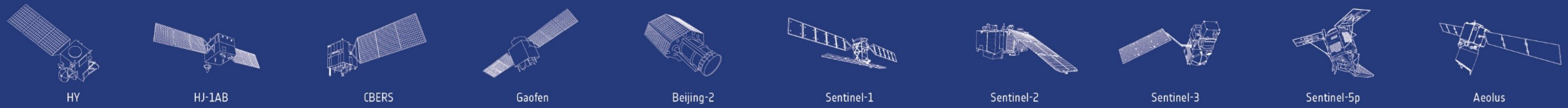
3. **Validation activities at Xianghe**

4. **Intercomparison of CH_4 products in China from GOSAT, TROPOMI, IASI and AIRS satellites**

5. **Future plans**

FUTURE PLANS

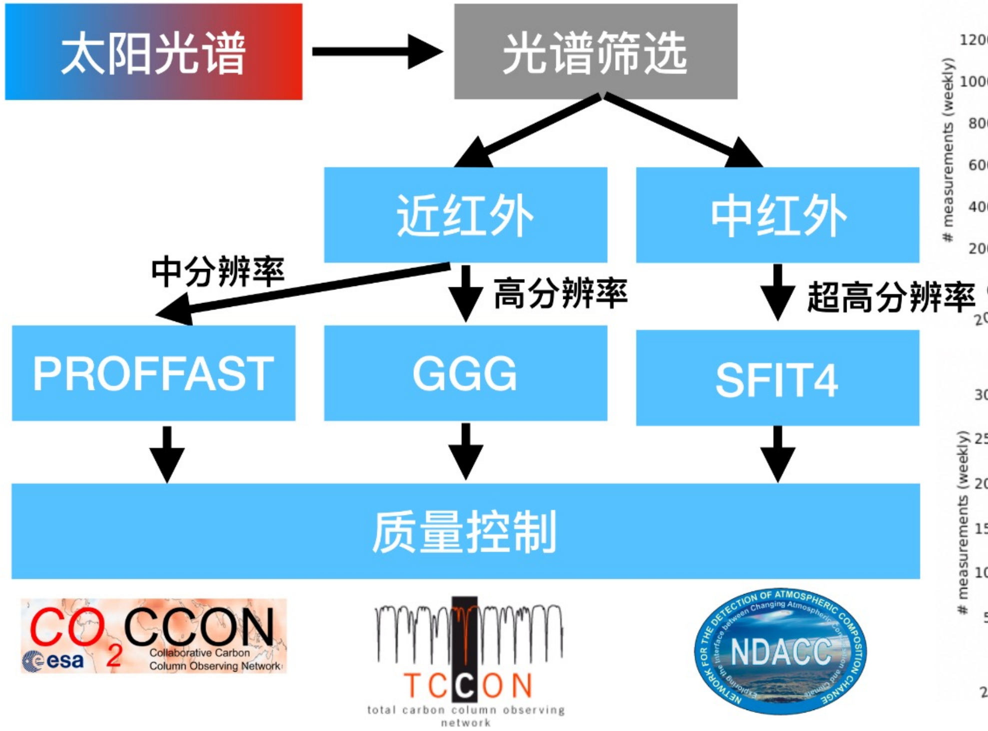
- Replace the MAX-DOAS instrument at Xianghe
- Continue providing high quality data to TCCON
- Continue performing NDACC type FTIR measurements
- Xianghe's official TCCON status, clears it for use in validation studies within projects such as CCI-GHG+, CAMS etc.

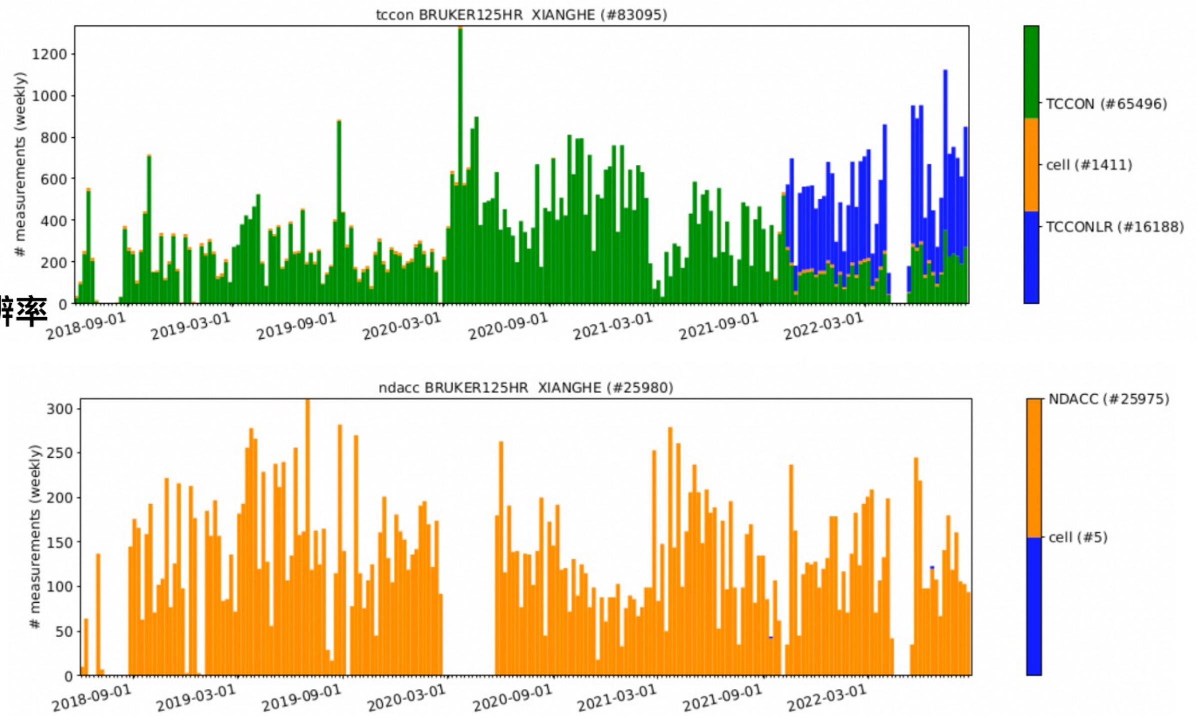


Thanks for your attention!

特性	TCCON	NDACC-IRWG	COCCON
主要FTIR	Bruker IFS 125HR	Bruker IFS 120/125HR Bruker IFS 120/125M ABB Bomen DA8	Bruker EM27/SUN
探测器	1个硅 (Si)和1个铟镓砷 (InGaAs)	1个锑化铟 (InSb) 和1个碲化镉 (MCT)	2个铟镓砷 (InGaAs)
主要监测气体	CO_2, CH_4, H_2O, O_2, HDO, HF, CO, N_2O	O_3, HNO_3, HF, HCl, CO, CH_4, N_2O, $ClONO_2$, HCN, C_2H_6	CO_2, CH_4, H_2O, O_2, CO
反演算法	GGG2020	SFIT4/PROFFIT	PROFFAST
先验廓线	GEOS-FPIT	WACCM	GEOS-FPIT
CH_4反演波段(cm^{-1})	5872.0~5988.0 5996.45~6007.55 6007.0~6145.0	2611.6~2613.35 2613.7~2615.4 2835.55~2835.8 2903.82~2903.925 2941.51~2942.22	5897.0~6145.0
光谱分辨率(cm^{-1})	0.02	0.0035	0.5
产品类型	柱总量	垂直廓线和柱总量	柱总量
CH_4柱总量观测误差	系统误差 <0.1% 随机误差 <0.5%	系统误差 <0.2% 随机误差 <1.0%	系统误差 <0.1% 随机误差 <0.5%
备注	CH_4的地基遥感观测标准；与WMO的温室气体观测精度对接；对大气整层的CH_4浓度变化敏感	具有一定的垂直信息层，在对流层中上层有最佳的敏感信息。也能提供高精度的CH_4柱浓度信息	对TCCON的全球观测具有很好的补充，可以获得与TCCON精度相当的CH_4柱浓度，能进行组网观测
参考文献	Wunch等，2011	De Mazière等，2018	Frey等，2019

观测设备	125HR			EM27/SUN
观测模式	TCCON	COCCON	NDACC	COCCON
光谱分辨率 (cm^{-1})	0.02	0.5	0.0035	0.5
反演算法	GGG2020	PROFFAST	SFIT4	PROFFAST
CH_4产品	柱平均浓度	柱平均浓度	垂直廓线和柱总量	柱平均浓度
观测时间	2018.06 -今	2021.11 -今	2018.06 -今	2021.09 -今


太阳光谱
光谱筛选
近红外
中红外
中分辨率
高分辨率
超高分辨率
PROFFAST
GGG
SFIT4
质量控制
CO2CCON
esa
Collaborative Carbon Column Observing Network
TCCON
total carbon column observing network
NDACC


tccon BRUKER125HR XIANGHE (#83095)
measurements (weekly)
TCCON (#65496)
cell (#1411)
TCCONLR (#16188)
ndacc BRUKER125HR XIANGHE (#25980)
NDACC (#25975)
cell (#5)