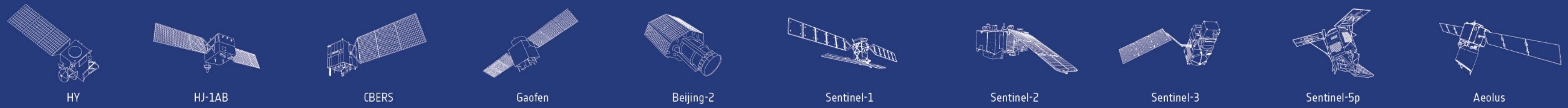
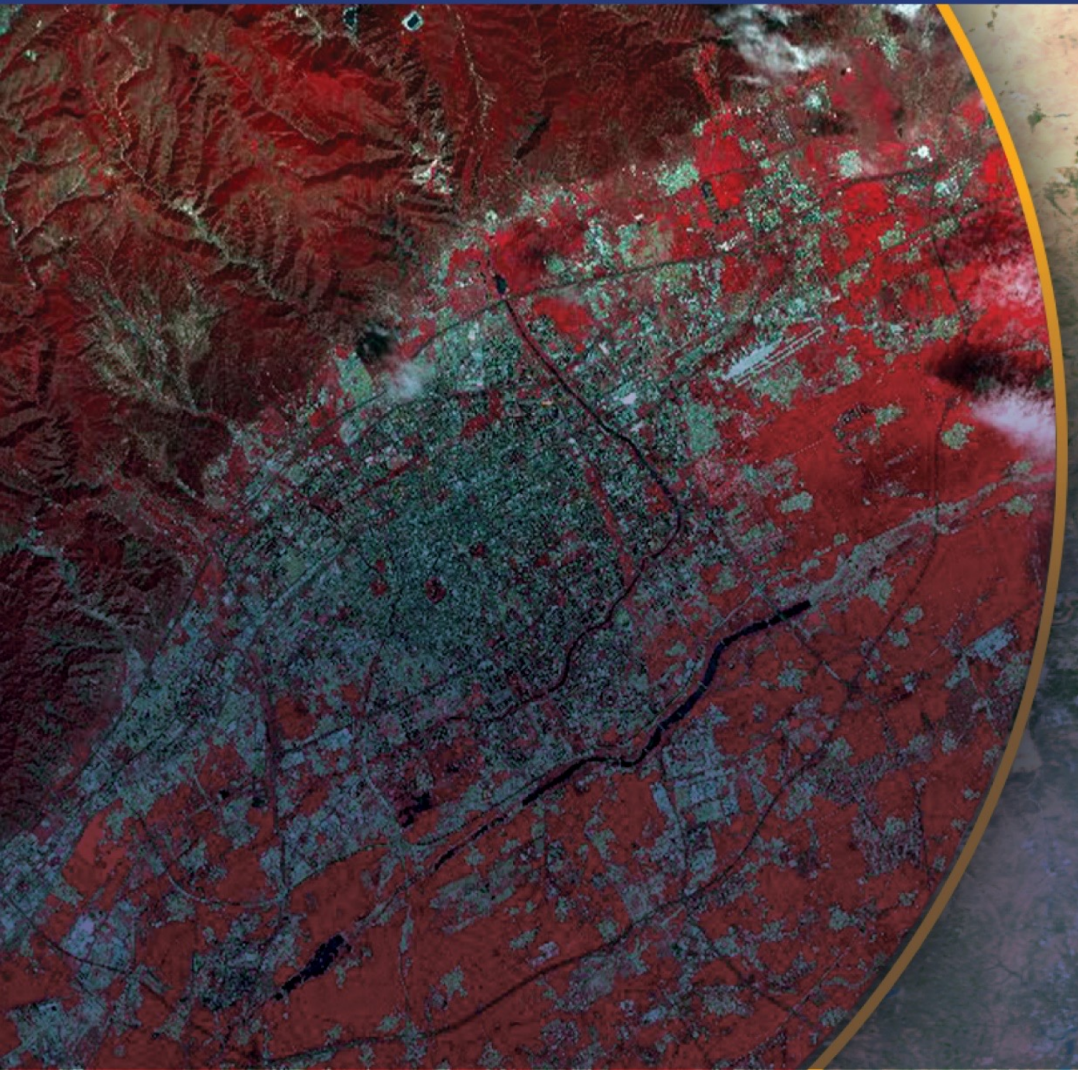




Monitoring ghg from space：TanSat-2 city monitoring and validation

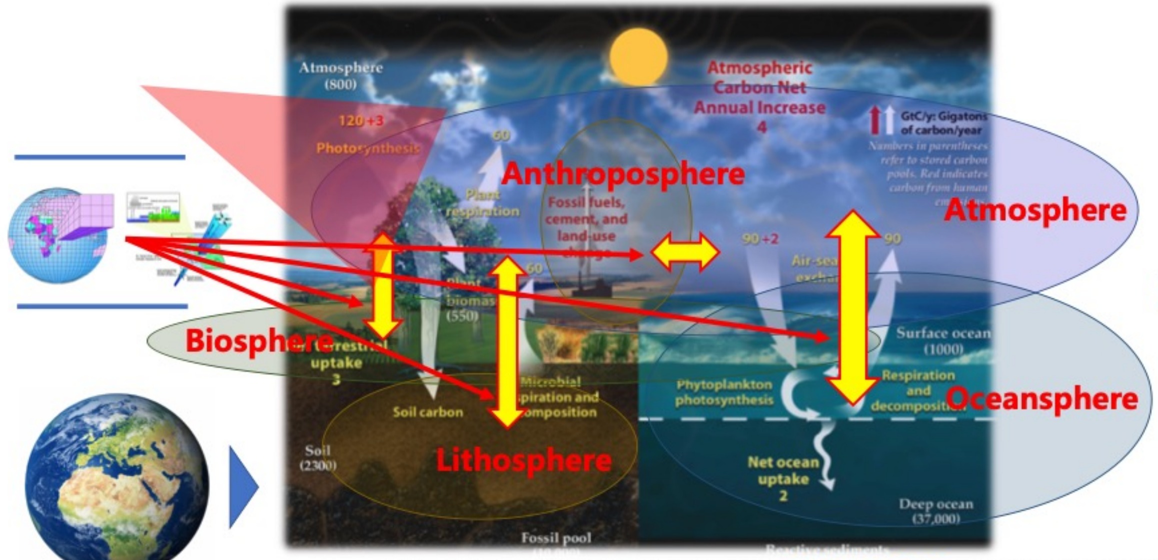
Yi Liu、Dongxu Yang et al.

Content

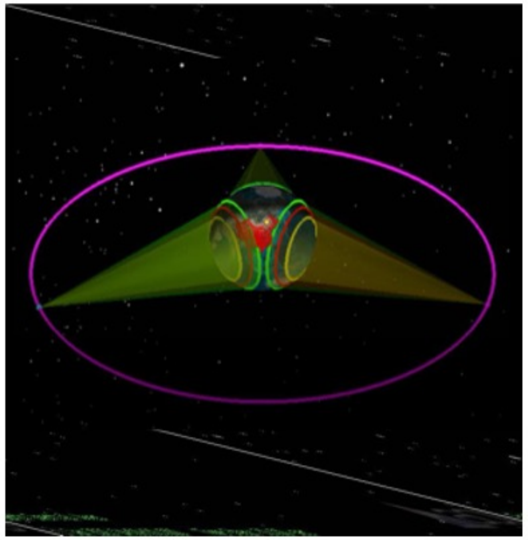
1. TanSat-2 city monitoring simulation

2. GHGs surface measurement and Validation

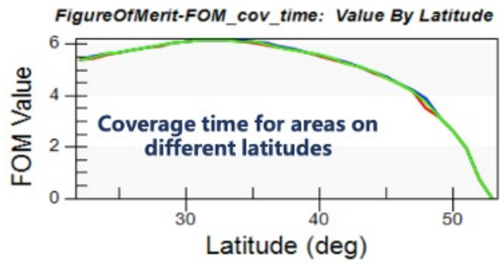
TanSat-2 mission



Background figure: Riebeek, Holli (16 June 2011). "The Carbon Cycle". Earth Observatory. NASA

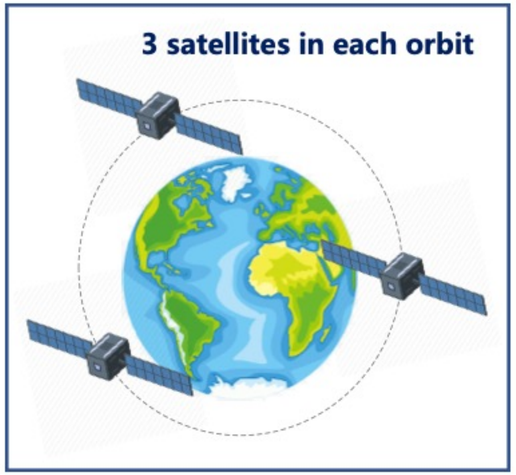


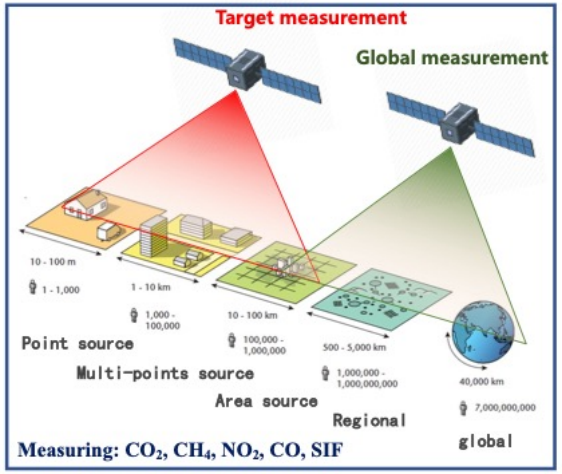
MEO satellites option advantages in global coverage and revisit period



LEO satellites option

Multiple satellites

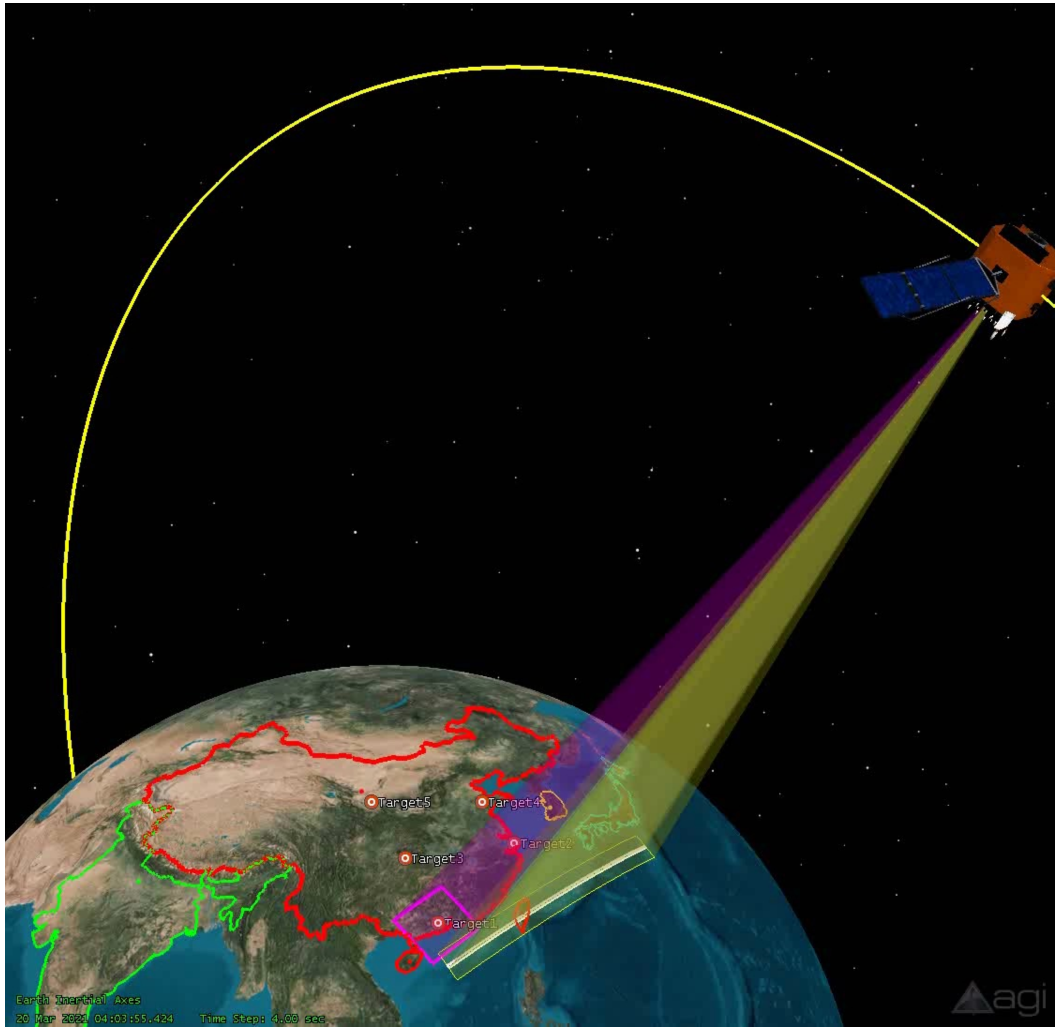


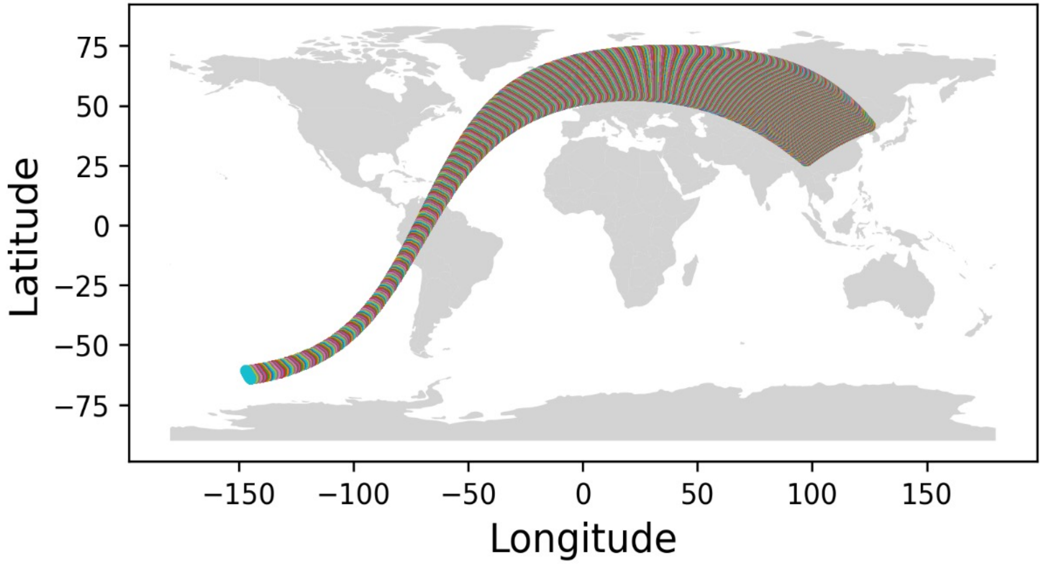


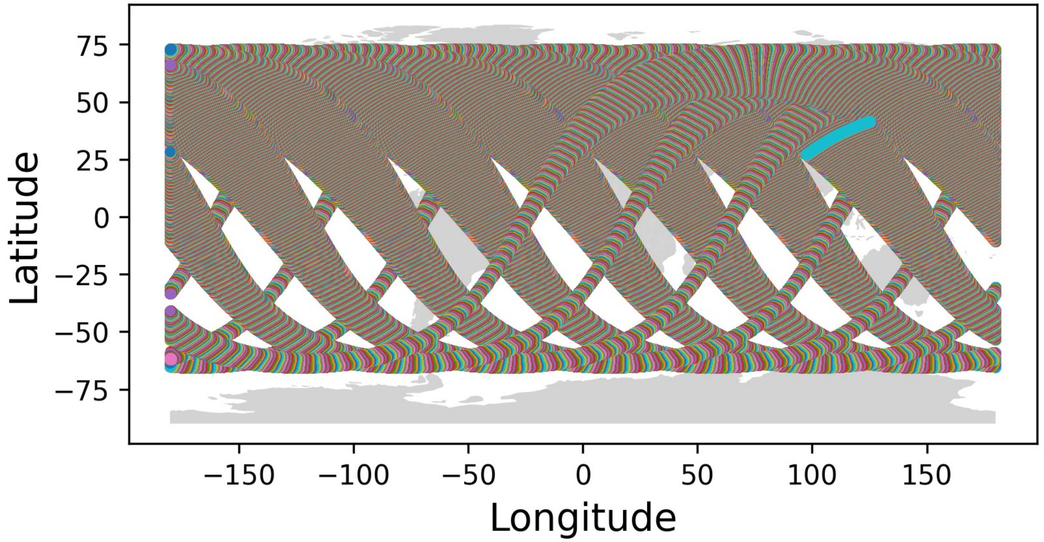
- **XCO_2: 1 ppm precision**
- **XCH_4: 8 ppb precision**

Bands	NO_2 Band	O_2A Band	Weak CO_2	Strong CO_2	CH_4 Band
Geophysical P.	NO2	O_2、SIF	CO_2、CH_4	CO_2	CH_4、CO
Range /μm	0.4-0.49	0.747-0.773	1.590-1.675	1.990-2.095	2.305-2.385
Width /nm	90	26	85	105	80
SR /nm	0.6	0.12	0.3	0.35	0.25
SSI	3	3	3	3	3
TanSat SNR@Lref (photons/s/nm/cm2/sr)	800@2.4E13	620@6.4E12	520@2.1E12	480@1.8E12	150@8.5E11
CO2@Lref (photons/s/nm/cm2/sr)	500@1.3E13	330@6.4E12	400@2.1E12	400@1.8E12	

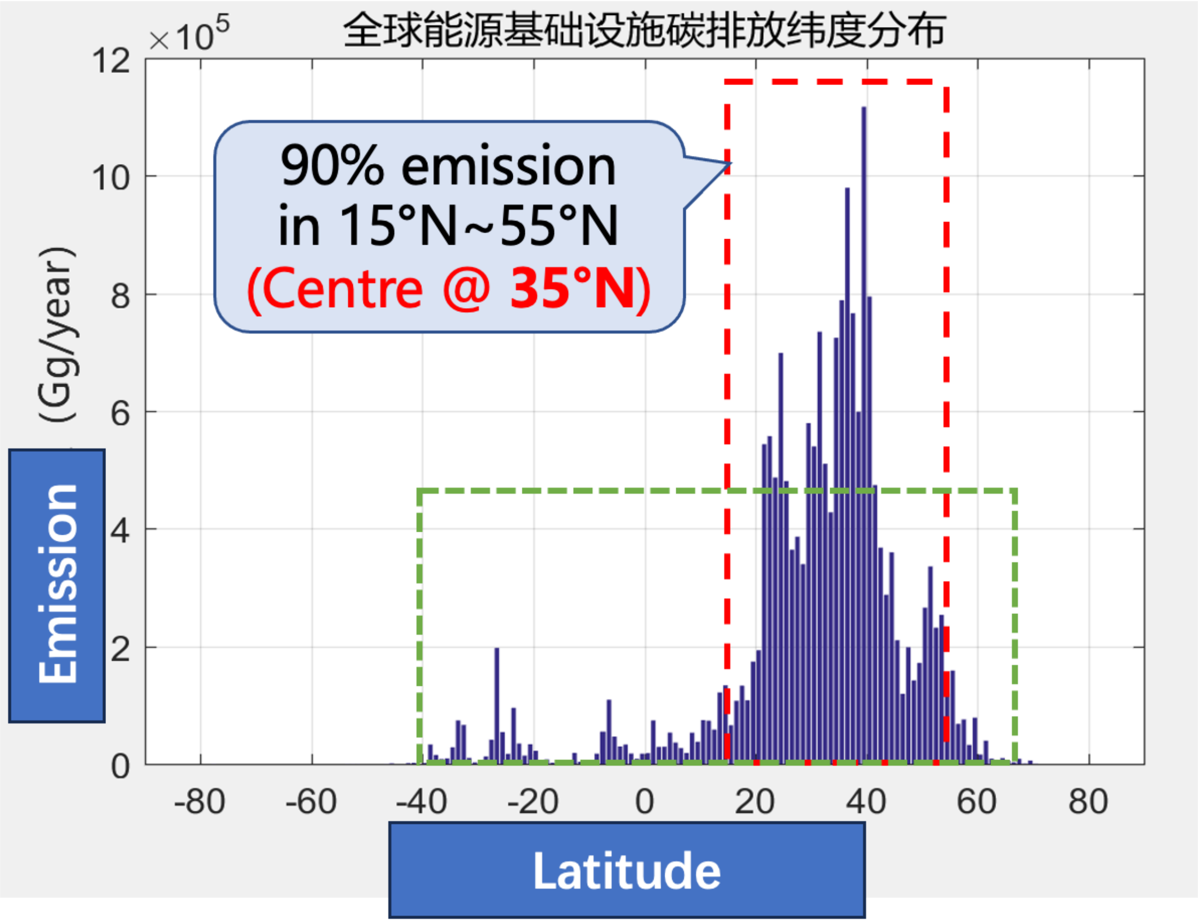
MEO satellite design







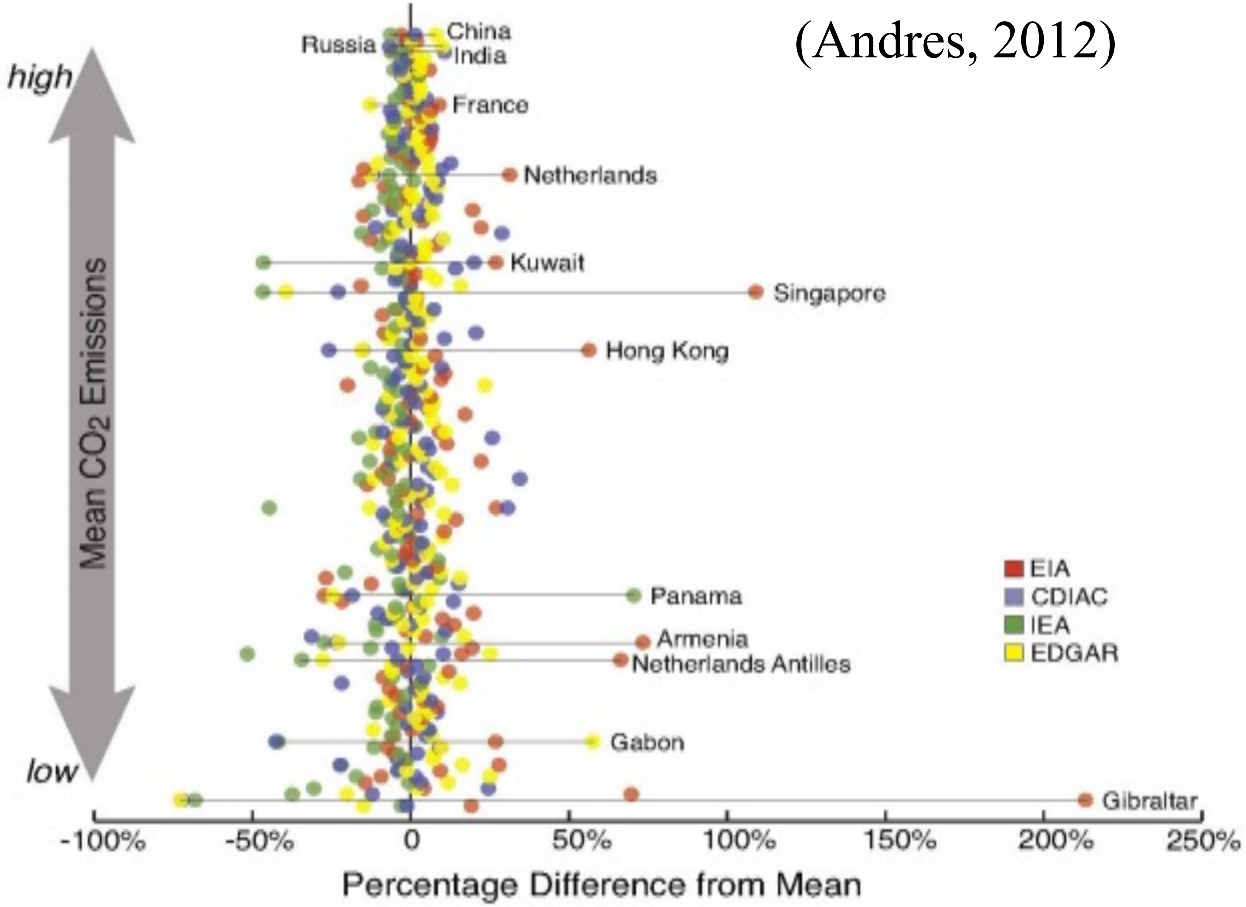
Foucs on the FF emssions



Orbit characters	Value
Perigee	522km
Apogee	7840km
Inclination	116.565°
Lat @ Apogee	35°N
repeat cycle	1day
delta Resolution	0.87km
Swath	2900km
OZA	<30°

Motivation

Inventory: small-scale flux estimates are aggregated together to form a total emission inventory using activity data (energy consumption, population density, traffic data and local air pollution reporting) and simulation tools

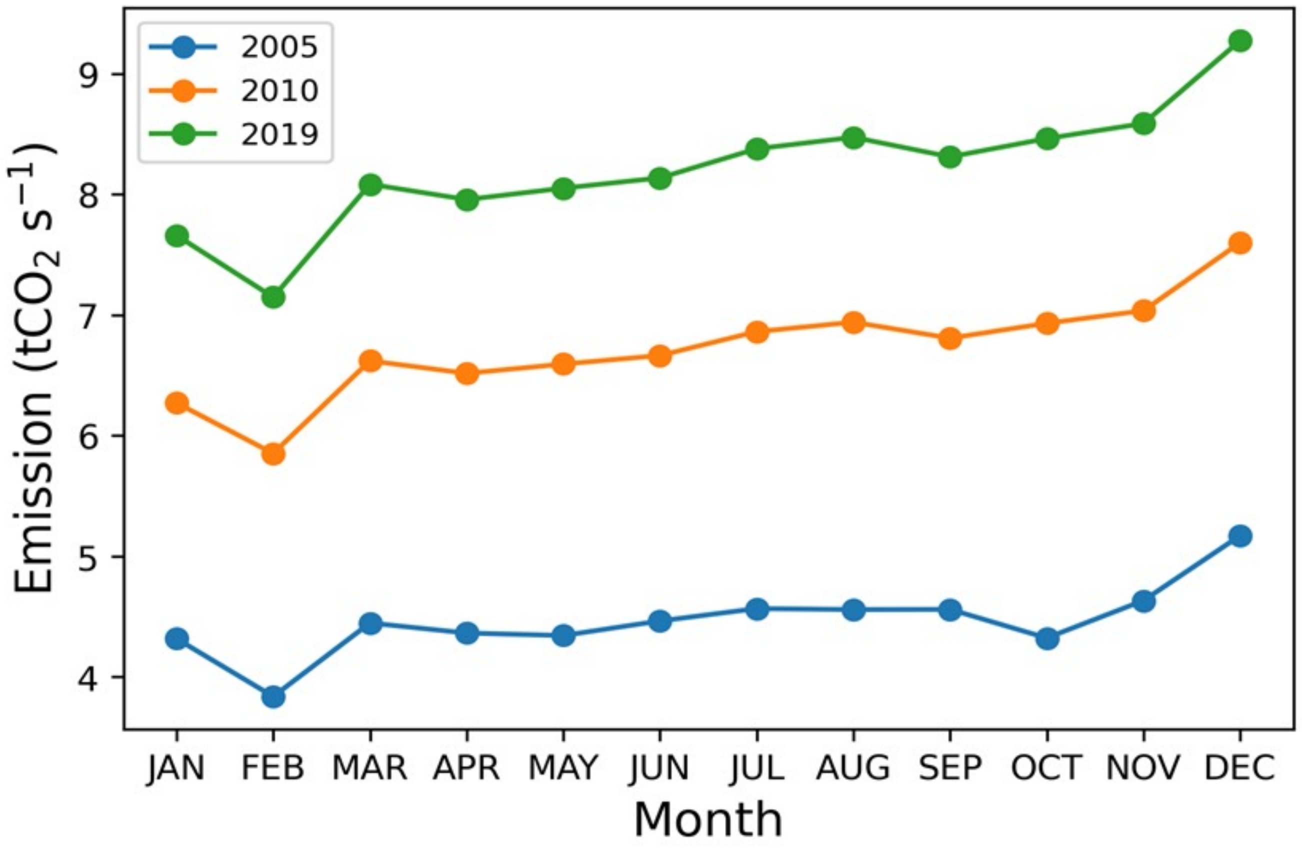


(Andres, 2012)

Inventories are prone to systematic errors and their uncertainties are not well known

Motivation

Seasonality of ODIAC CO_2ff emissions in Beijing



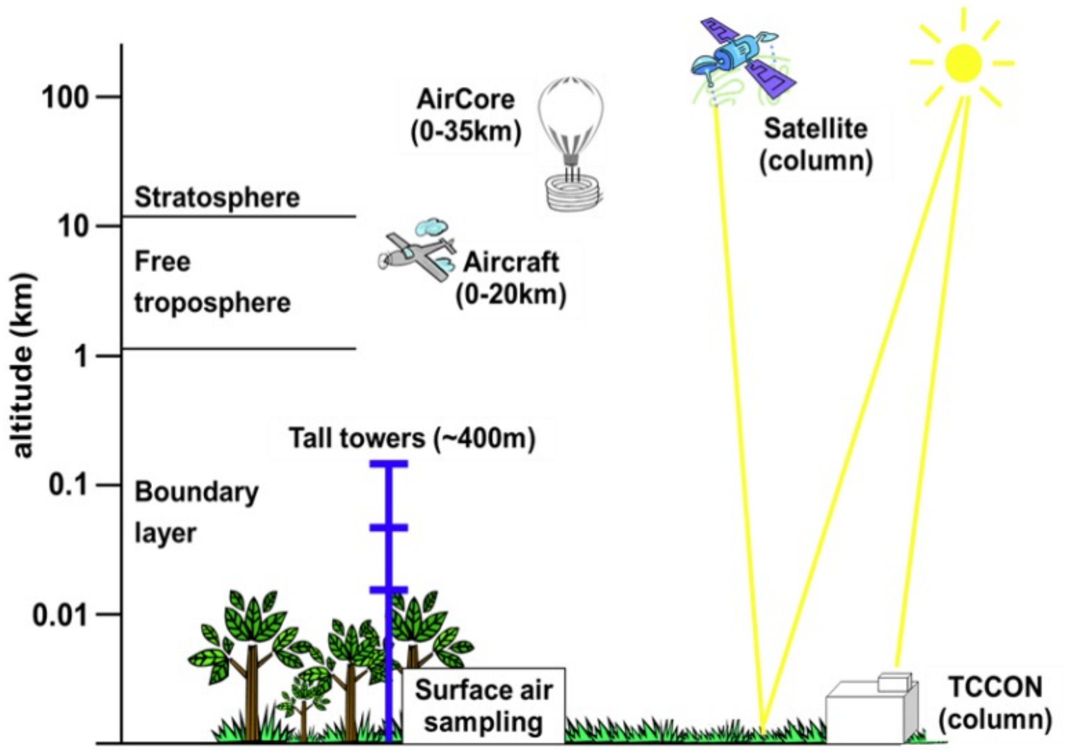


Figure 1: Observations of atmospheric greenhouse gases

Image courtesy of the ICOS report

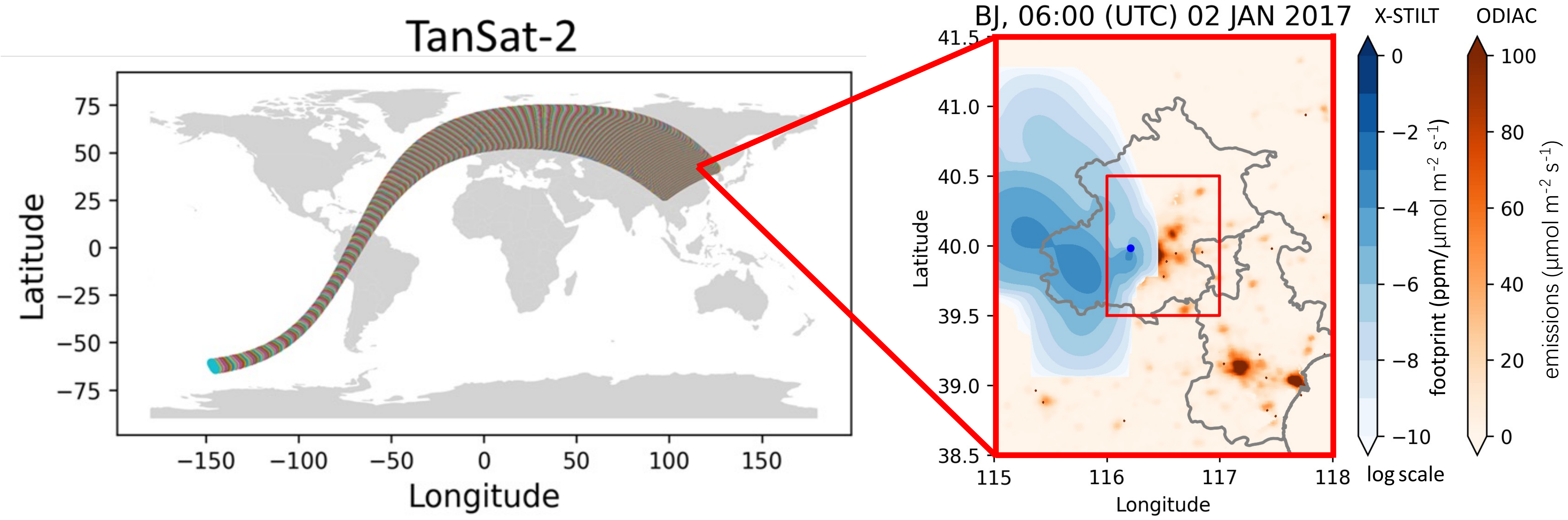
- ➢ Limited ability of inventory for assessing the seasonality of anthropogenic CO_2 emissions
- ➢ Atmospheric CO_2 measurements are valuable to verify emissions inventories

Motivation

TanSat-2 is planned to be launched in 2025 to measure column-averaged CO_2 (XCO_2) at 3000 km wide across-track swaths, with a pixel size of 2 km × 2 km.

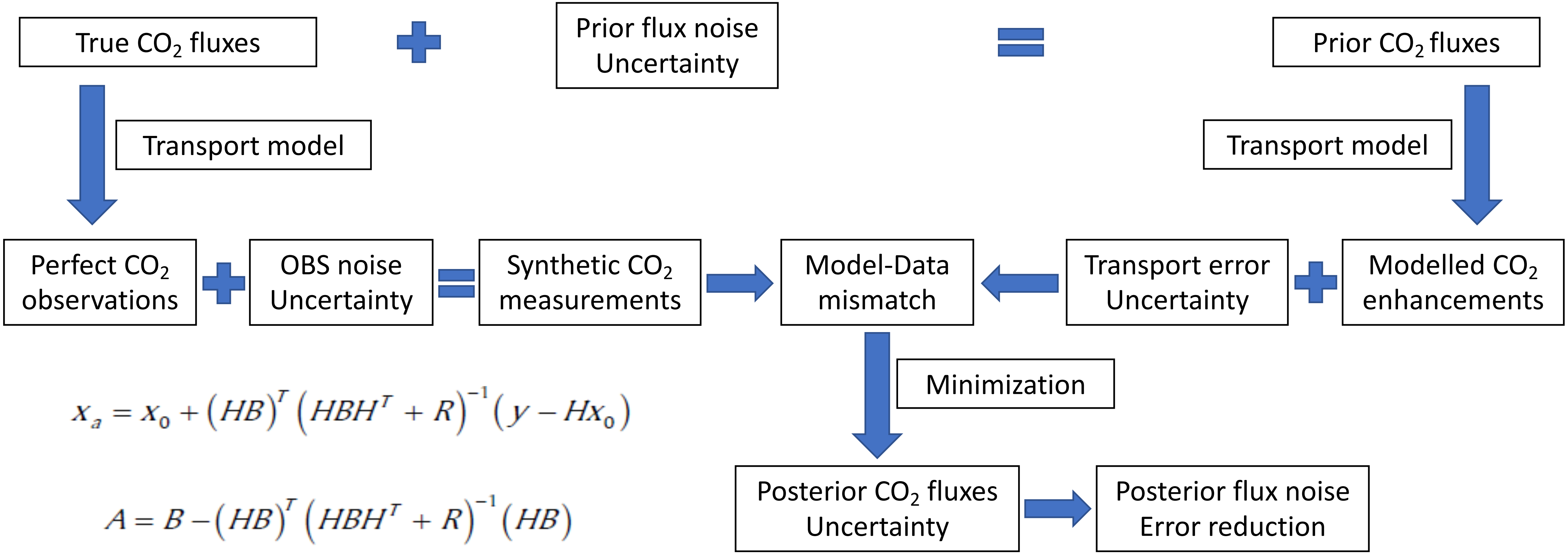
The precision of satellite sampling is expected to be less than 1 ppm.

X-STILT and ODIAC at 1 km resolution are used to simulate synthetic data and develop an urban CO_2 inversion system.



Methods: Observing System Simulation Experiment (OSSE)

To minimize the mismatch between observed and modeled [CO_2] by optimizing the prior fluxes

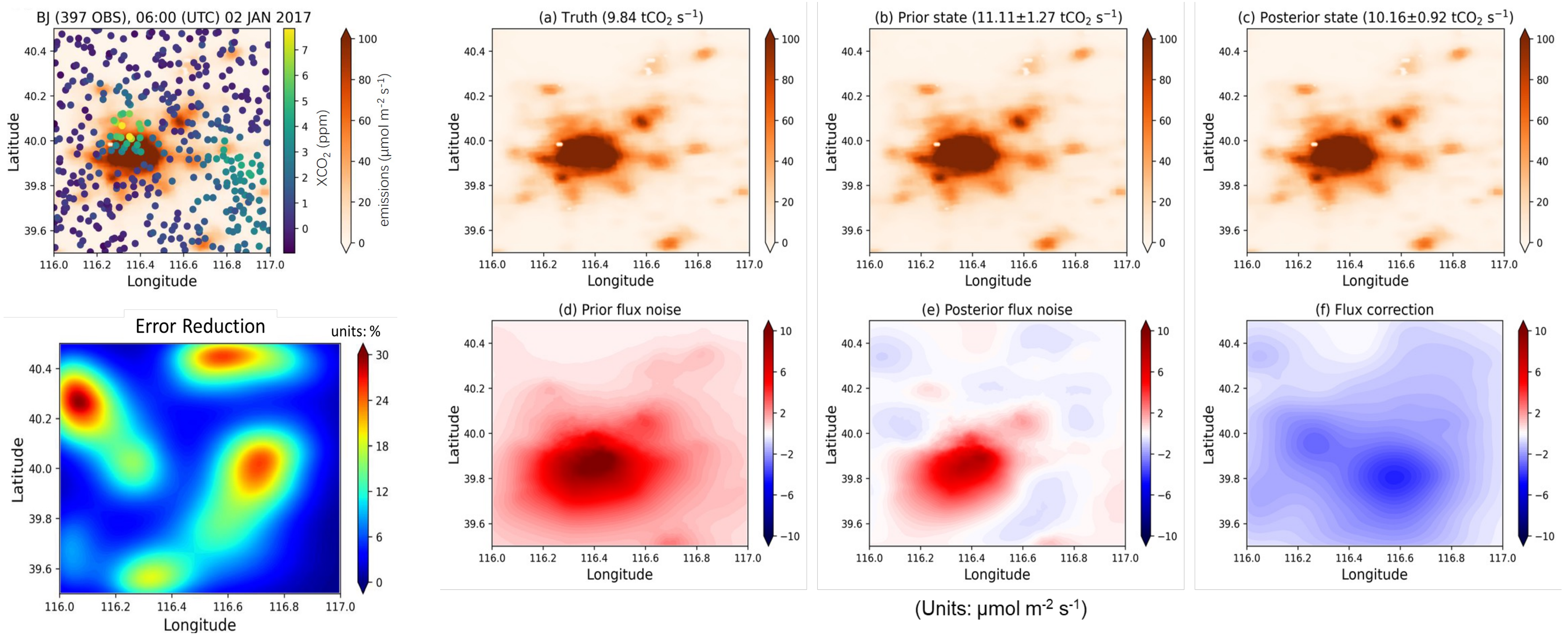


$$x_a = x_0 + (HB)^T \left(HBH^T + R\right)^{-1} (y - Hx_0)$$

$$A = B - (HB)^T \left(HBH^T + R\right)^{-1} (HB)$$

Results: a case study in Beijing

- ERA5 total cloud cover data are used to identify cloud-free samples of TanSat-2.
- Outside the growing season, assimilating cloud-free TanSat-2 data can have a 20-30% reduction in prior flux errors.

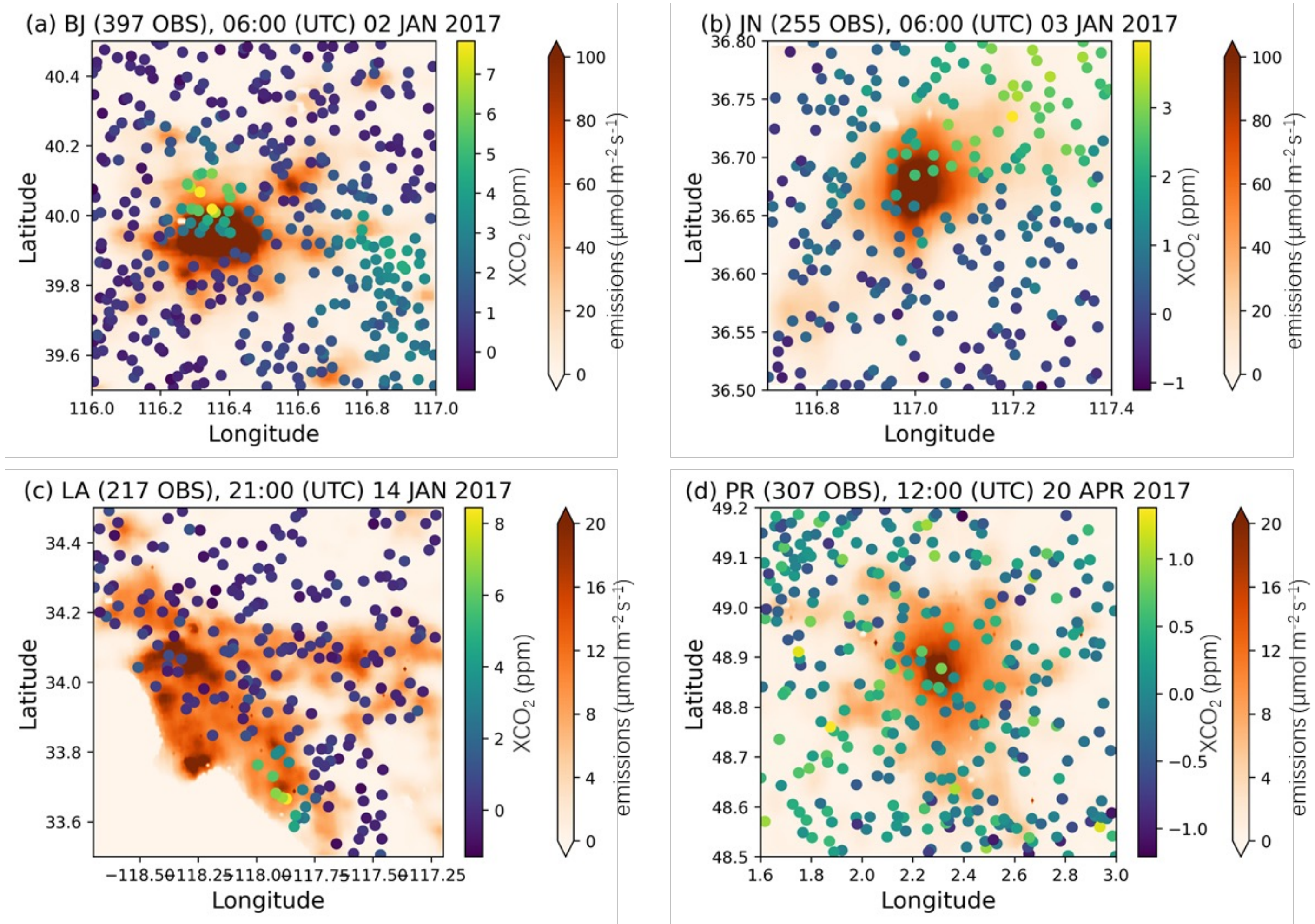


(Units: μmol m^{-2} s^{-1})

Results: comparison of flux inversion in different cities

- Test the impacts of sampling patterns and XCO_2 retrieval errors on reducing prior flux errors.

- Correction in systematic flux errors is sizable, subject to unbiased satellite sampling and favorable meteorological conditions (less cloud cover and low wind speed).



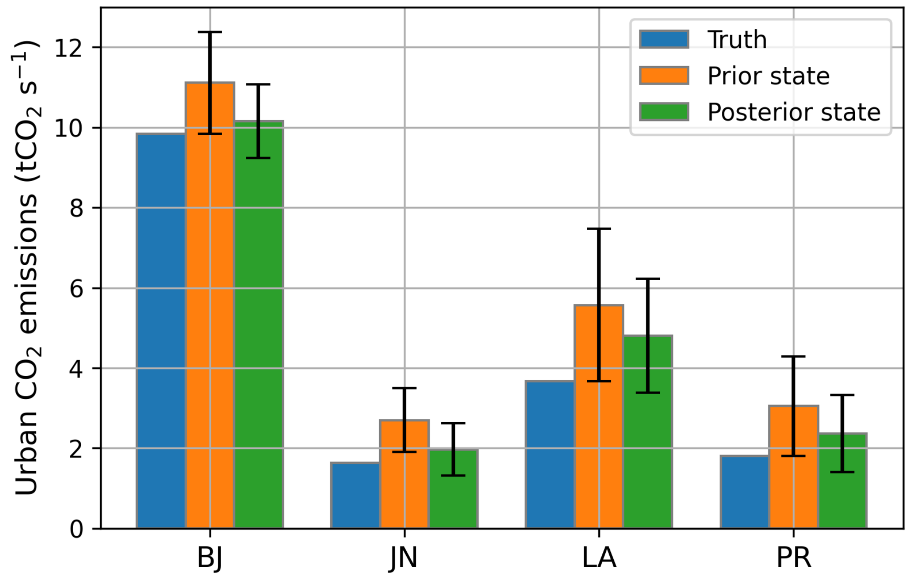


Table 1. Reduction of flux bias and random error (RE) and overall correction (OC) of integrated urban CO_2 emissions in Beijing (BJ), Jinan (JN), Los Angeles (LA), and Paris (PR). Units are %.

City	Bias	RE	OC
BJ	75	28	46
JN	68	19	45
LA	40	25	32
PR	56	23	37

Results: comparison of flux inversion in different cities

- Reduction in systematic and random flux errors is correlated with the signal-to-noise ratio of satellite measurements, which is 2.8 (BJ), 2.1 (JN), 0.7 (LA), and 0.1 (PR), related to different magnitudes of error reduction.

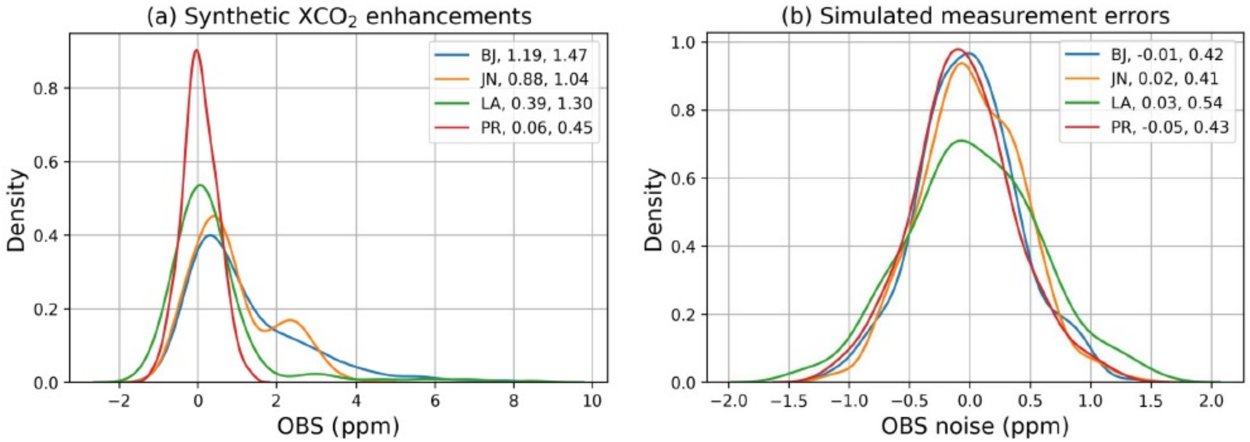


Figure 4. Probability density of synthetic X_{CO_2} enhancements over Beijing (BJ), Jinan (JN), Los Angeles (LA), and Paris (PR) (a) and the corresponding measurement errors (b). The values after the city name are the mean (first number) and standard deviation (second number), and units are ppm.

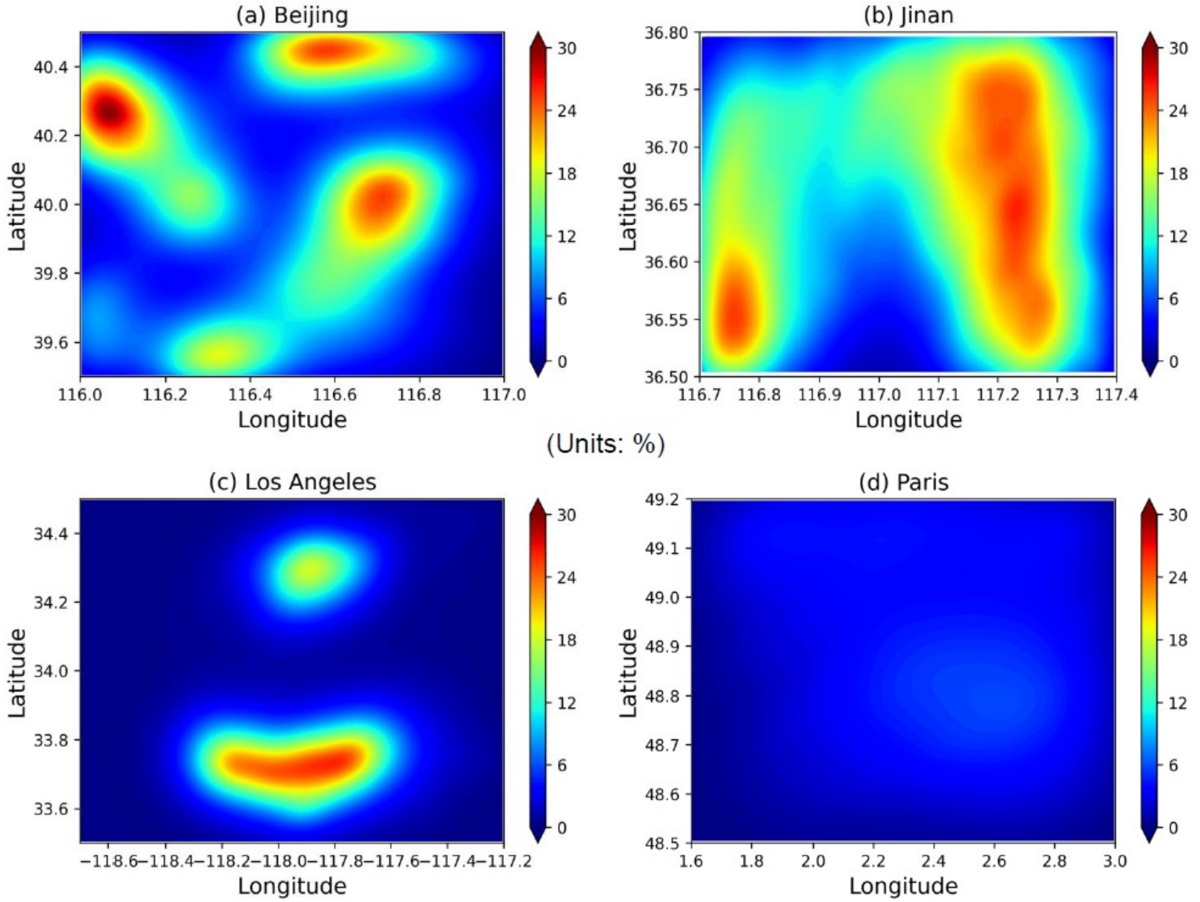


Figure 5. Flux error reduction in Beijing (a), Jinan (b), Los Angeles (c), and Paris (d).

Results: sensitivity to systematic and random measurement errors

- A systematic measurement error of 1 ppm would significantly degrade emission estimates inferred from satellite data

- The scenario of 4 km resolution (127 OBS) with 1 ppm uncertainty has similar error reduction to the scenario of 8 km (76 OBS) with 0.75 ppm random error, indicating better measurement precision can partially compensate for lower observation density.

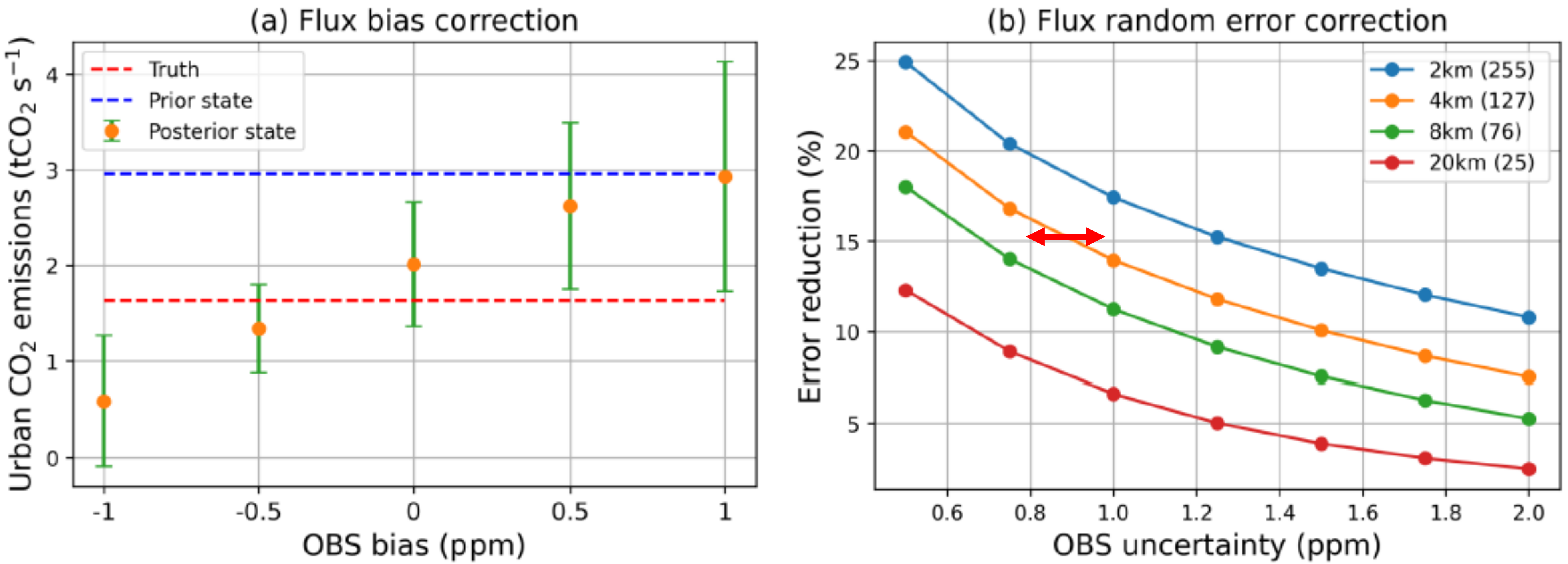


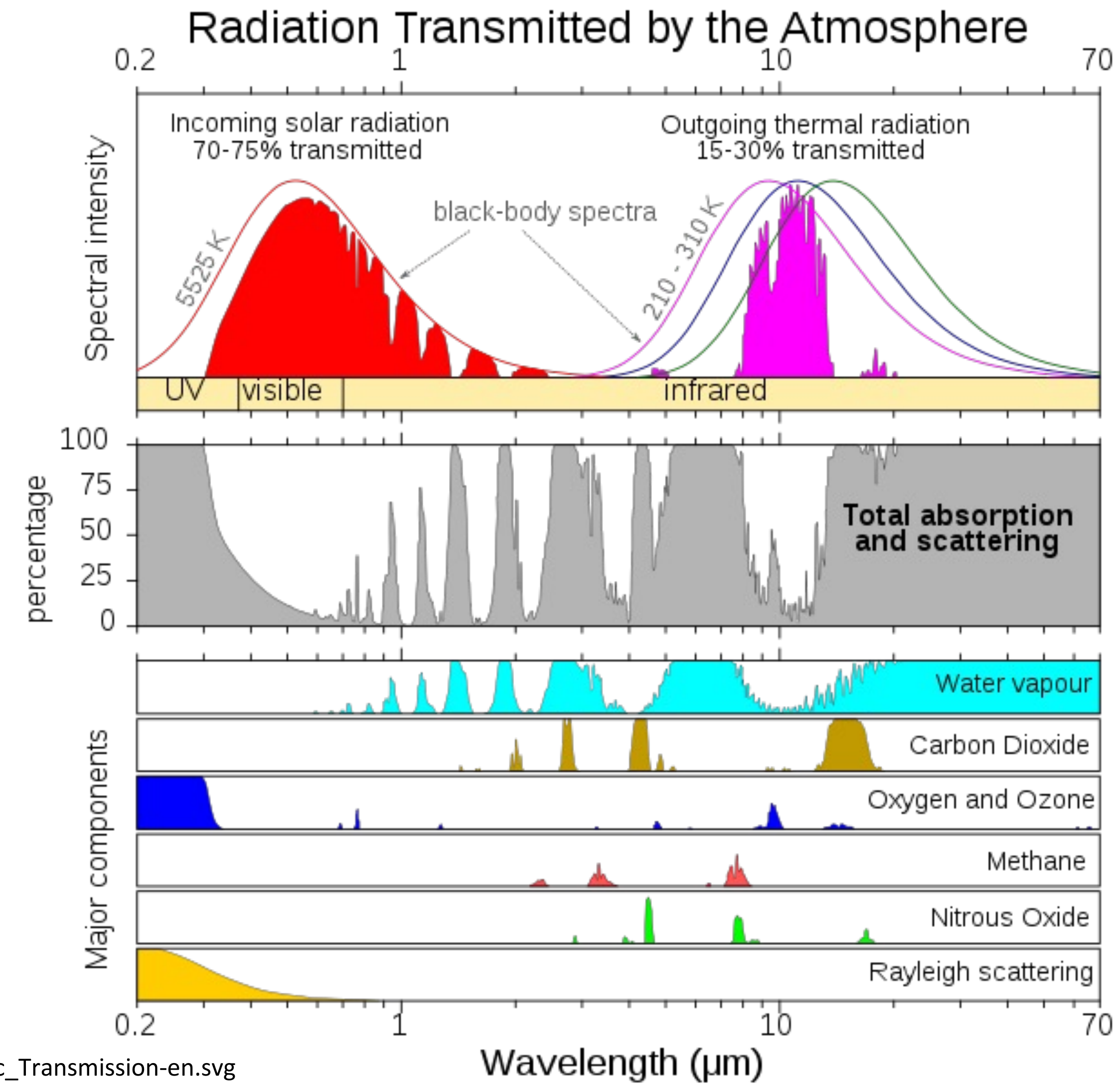
Figure 8. Correction of flux bias with the change of observation bias in Jinan (a) and reduction of spatially-averaged random flux error with the change of observation uncertainty under different sampling resolutions in Jinan (b). The numbers in parentheses are the number of observations.

1. TanSat-2 city monitoring simulation

2. GHGs surface measurement and Validation

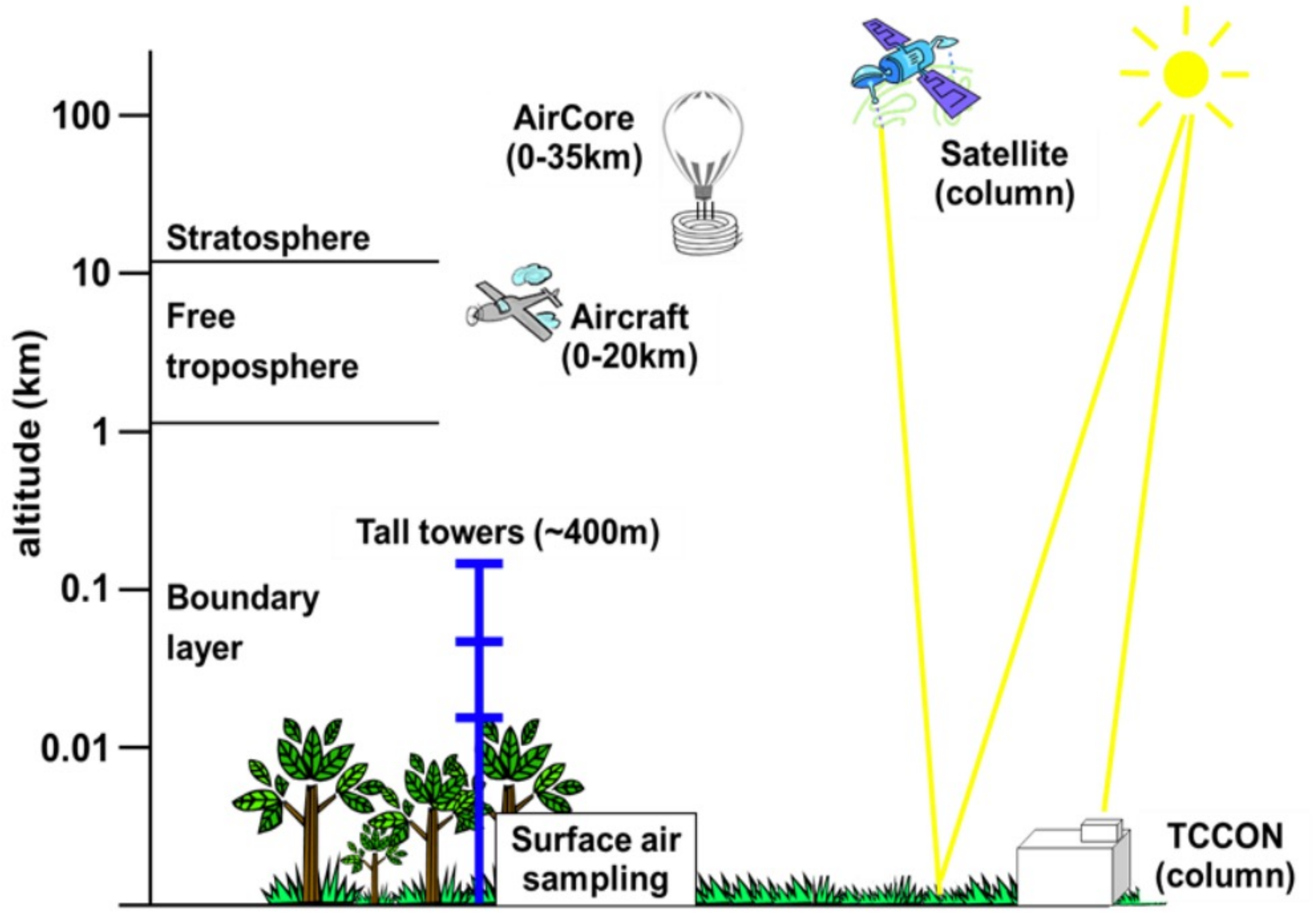
Background and significance of the research

- Greenhouse gases(GHG) （CO_2、CH_4、N_2O、CFC…）

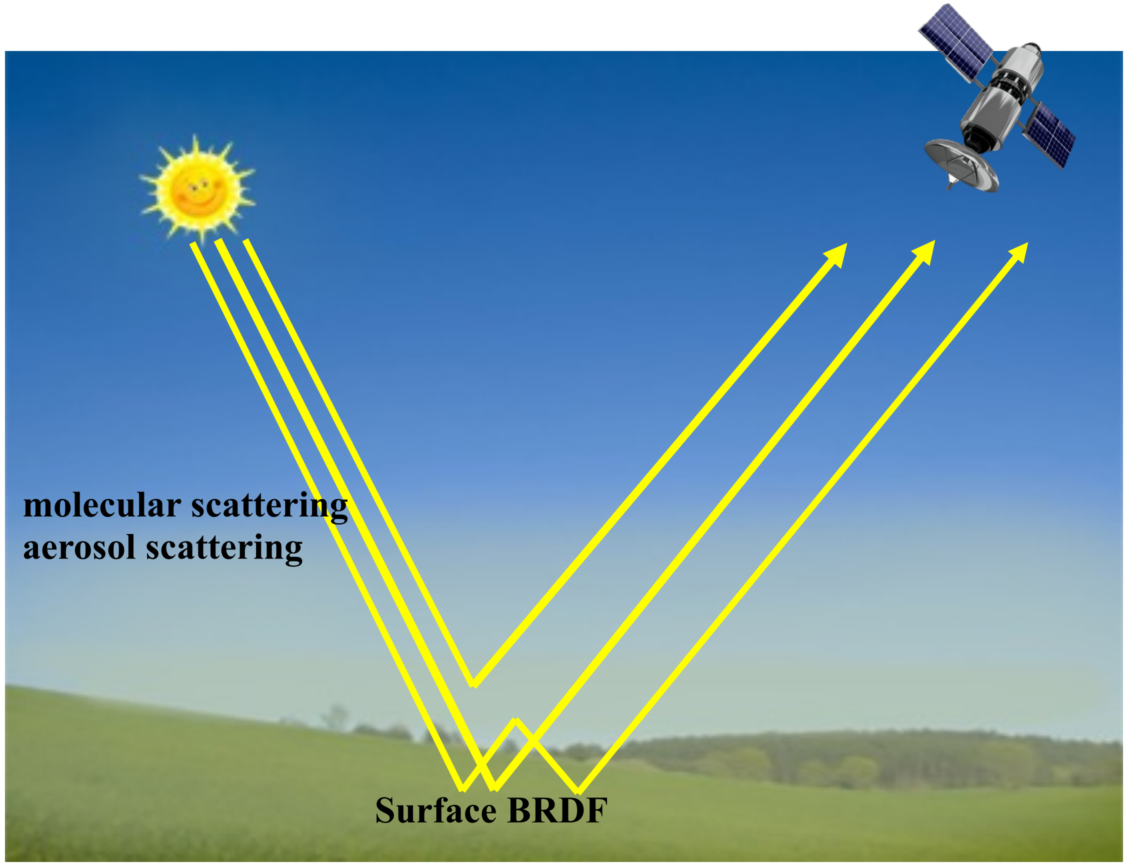


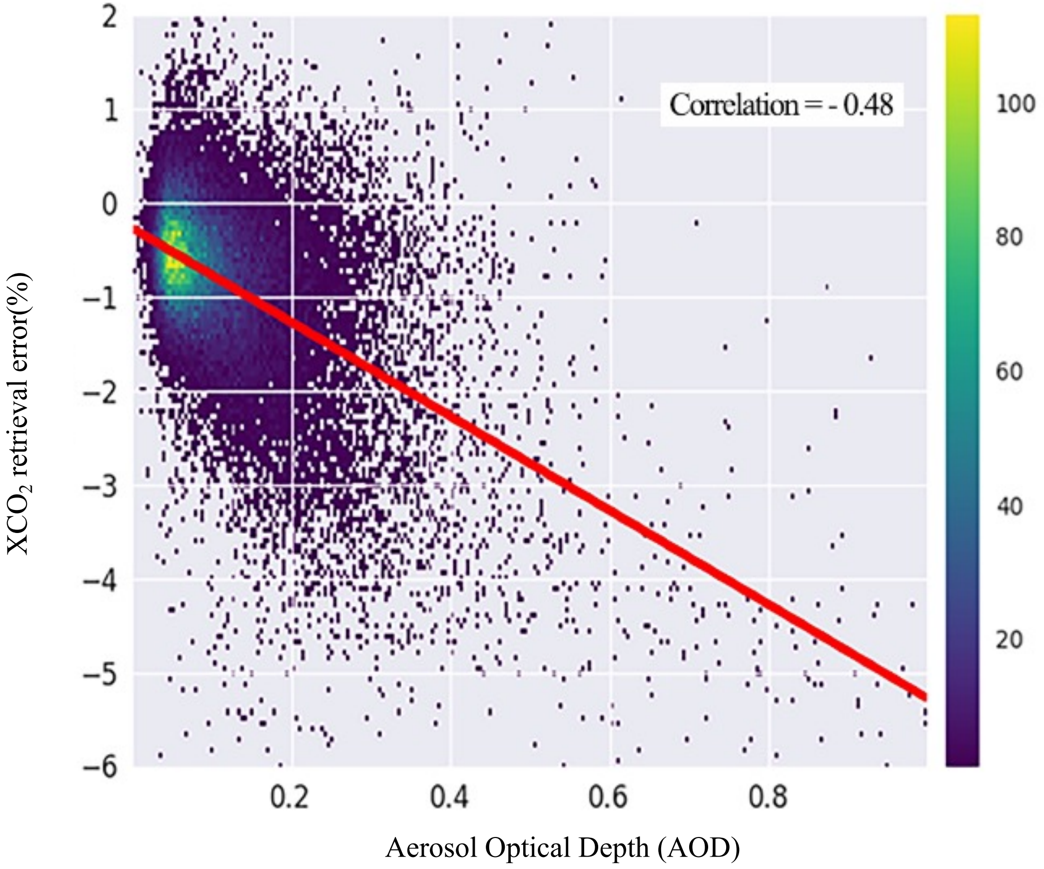
https://commons.wikimedia.org/wiki/File:Atmospheric_Transmission-en.svg

GHG concentration measurement techniques

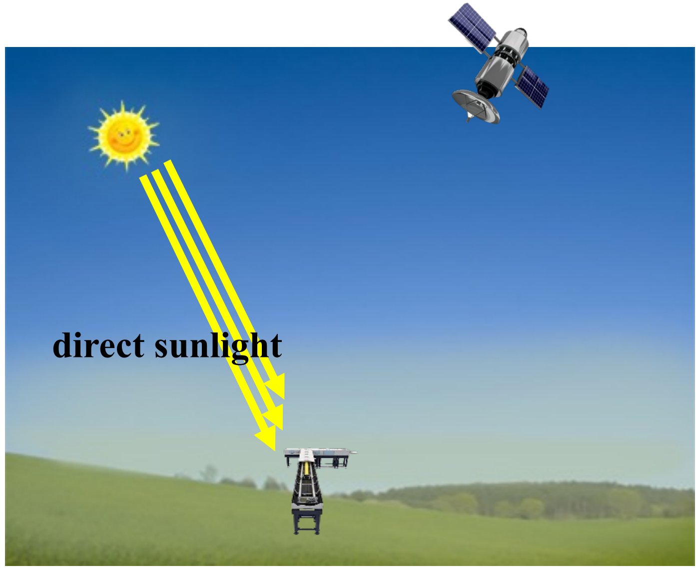


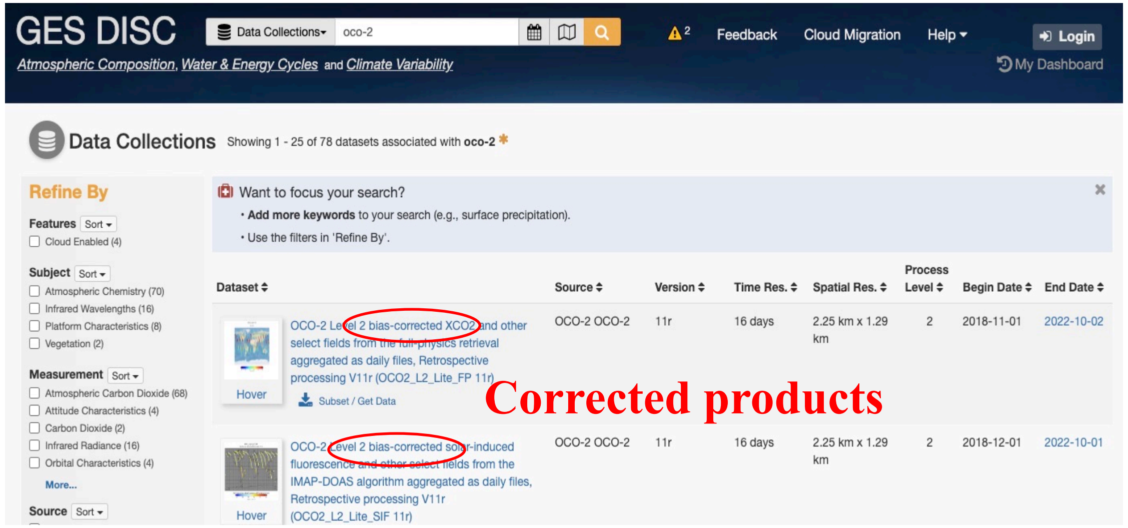
Challenges in satellite remote sensing

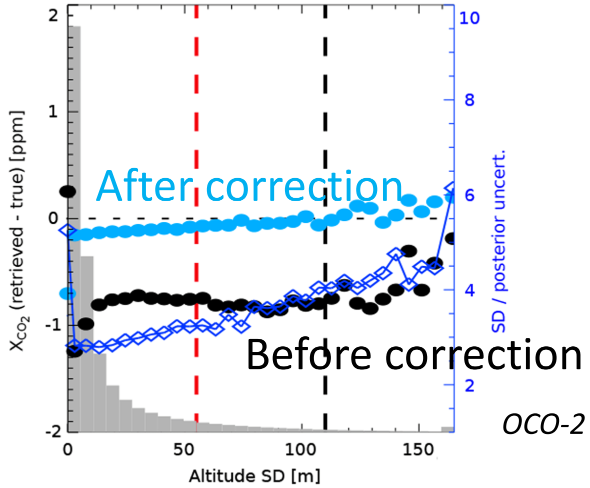




Bias correction of satellite data



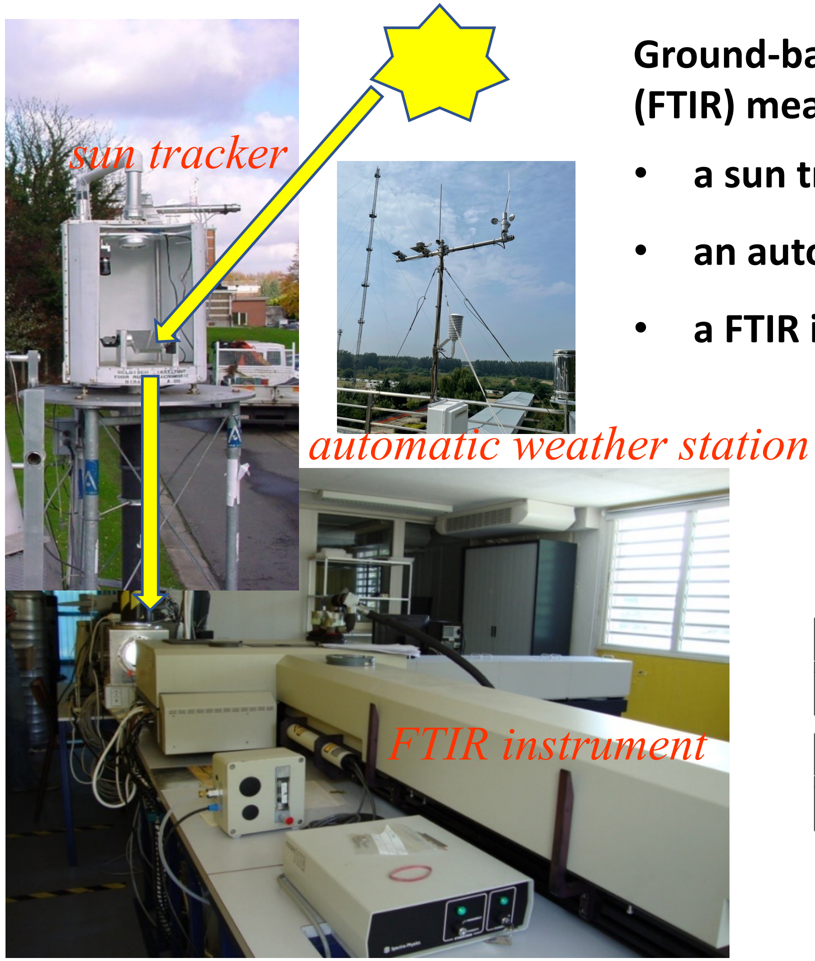




OCO-2 ATBD

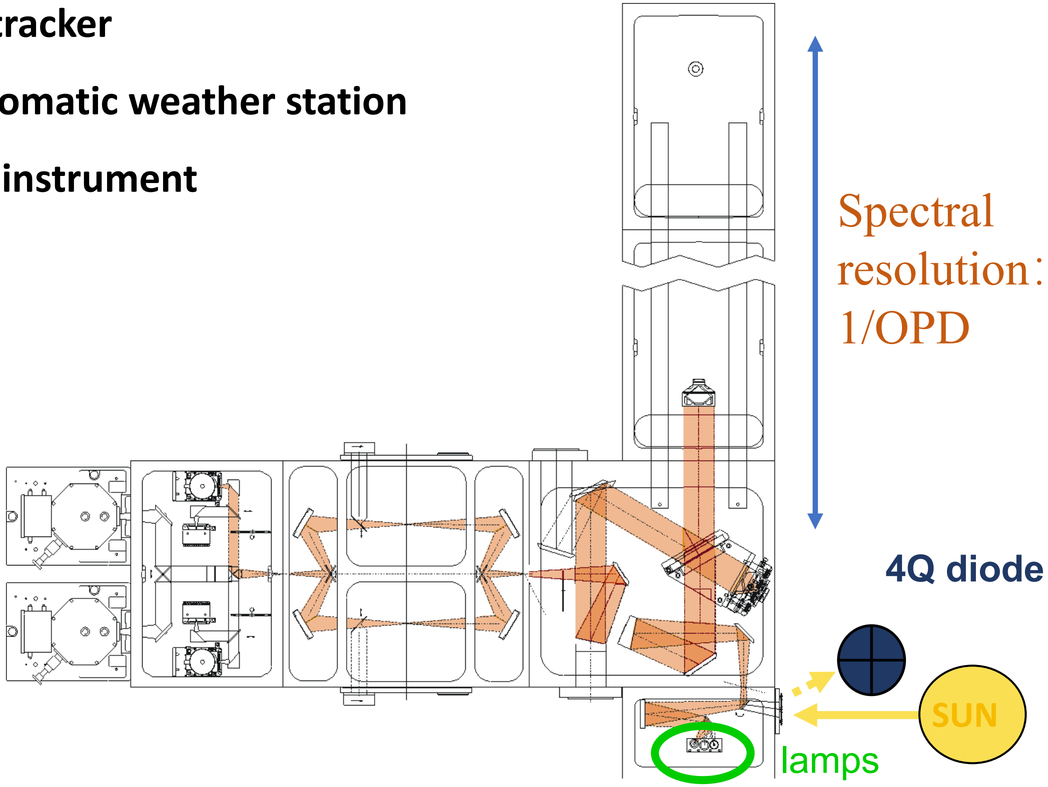
Principles of ground-based FTIR measurement

record direct solar radiation, the spectral resolution can up to 0.003-0.5 cm^{-1}
principle: Michelson Interference



Ground-based Fourier-transform infrared (FTIR) measurement system

- **a sun tracker**
- **an automatic weather station**
- **a FTIR instrument**



Introduction to the International Observation Networks

Detection of Atmospheric Composition Change – the Infrared Working Group

NDACC IRWG

- mainly Bruker IFS 120HR/125HR
- thermal infrared 800 - 4800 cm^{-1}
- 0.0036 – 0.005 cm^{-1}
- profile/column concentration
- single measurement time ~10 mins

Total Carbon Column Observing Network

TCCON

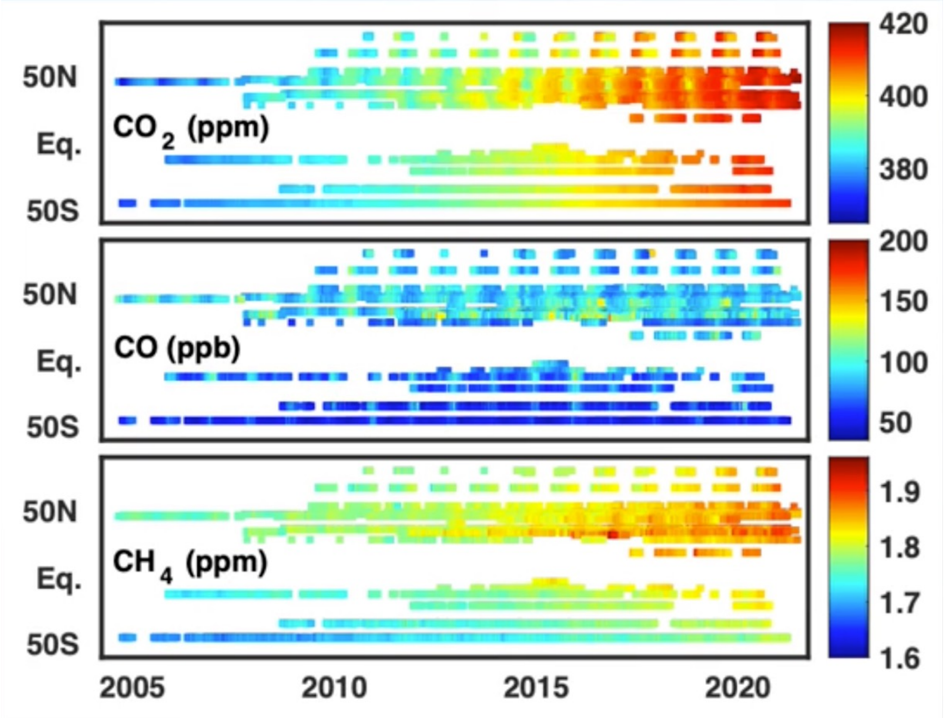
- Bruker IFS 125HR
- near infrared 4800 - 16000cm^{-1}
- 0.02cm^{-1}
- column concentration
- single measurement time - 3 mins

COllaborative Carbon Column Observing Network

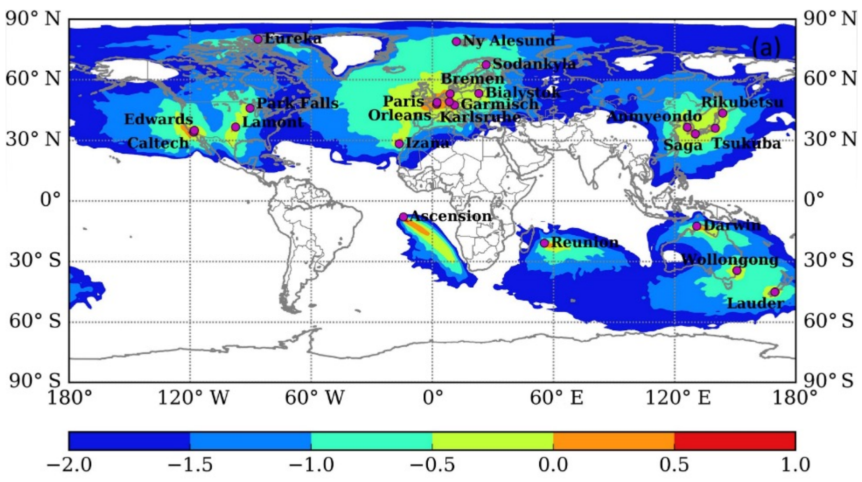
COCCON

- Bruker EM27/SUN
- near infrared 4800 - 12000cm^{-1}
- 0.5cm^{-1}
- column concentration
- single measurement time - 1 min

TCCON



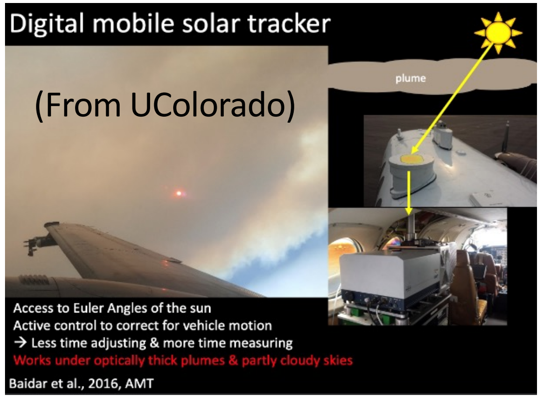
Time series of column-average dry-air mixing ratio of CO_2, CO, and CH_4 based on the TCCON network



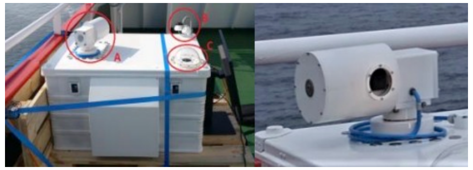
Belikov et al., ACP2017

- The concentrations of CO_2, CH_4 increase yearly.
- The concentration of CO shows a decreasing trend.
- Lack of observations in South America, Africa, South-Central Asia (Western China)

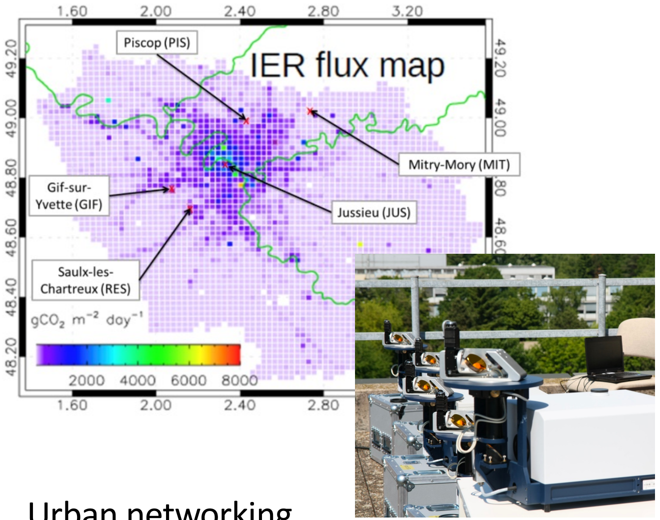
COCCON



Airborne



Shipborne

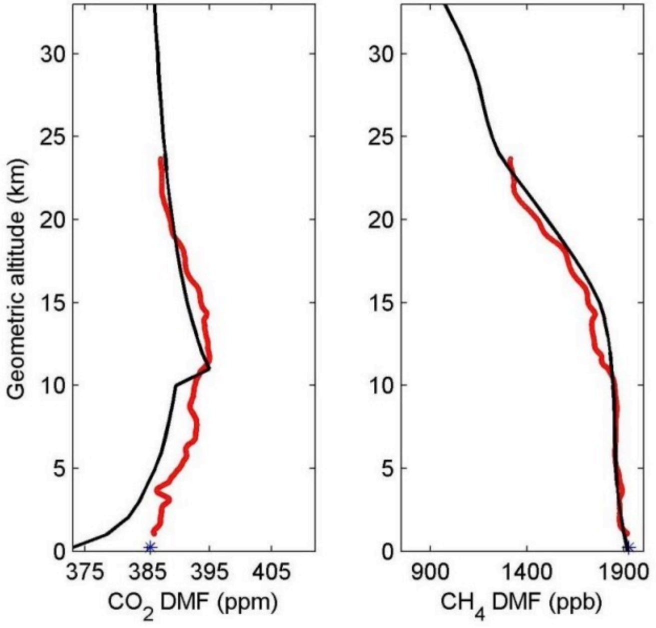


Urban networking observation experiment

Baidar et al., 2016; Butz et al., 2021; Vogel et al., 2019

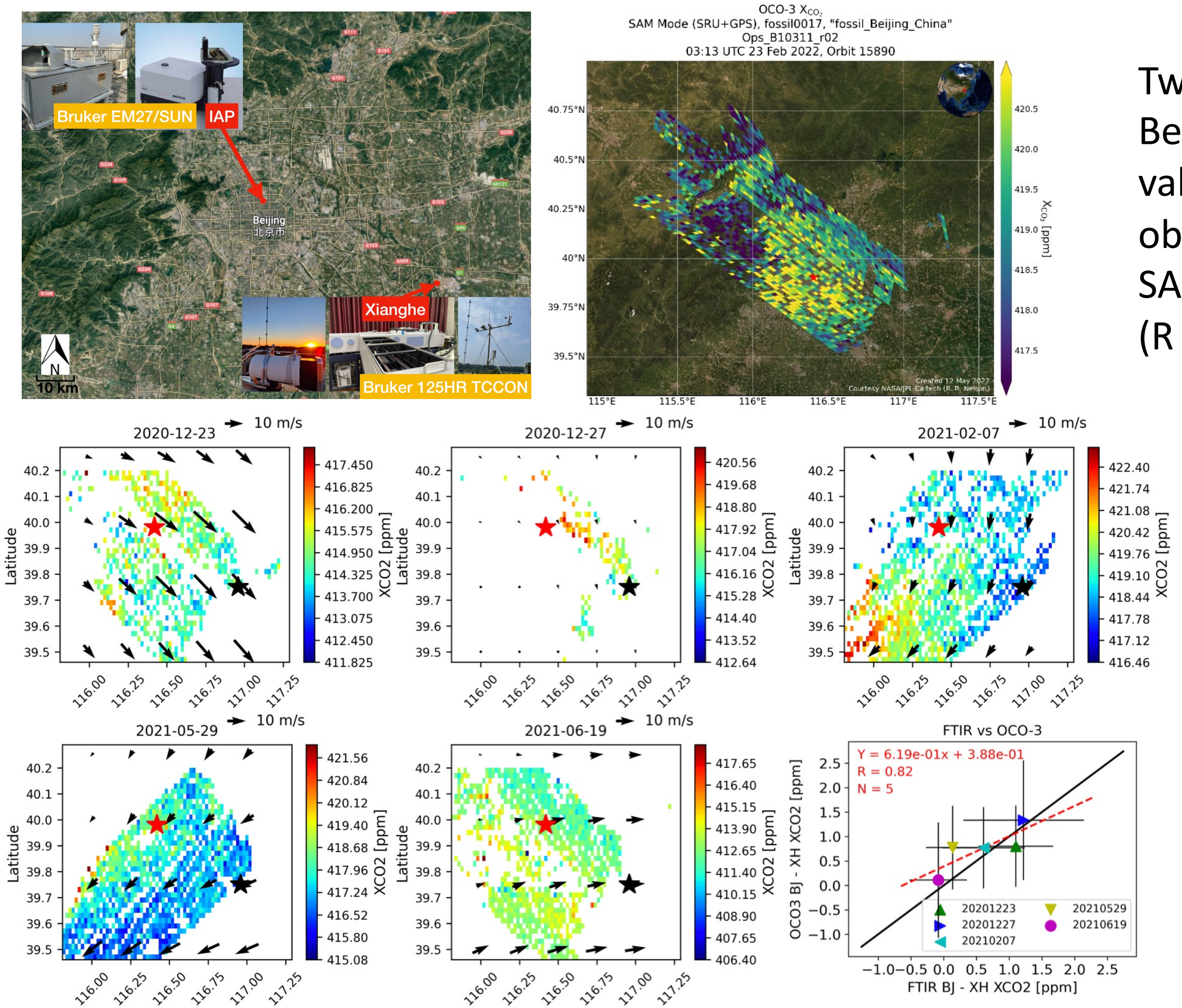
Calibration TCCON/COCCON to the WMO standard

FTIR and AirCore Campaign



red： AirCore measurements
black： TCCON initial values

Satellite validation regionally



Two FTIRs (Xianghe and Beijing) are applied to validate the spatial gradient observed by the OCO-3 SAMS XCO2 measurements (R =0.82)

Zhou et al., 2022

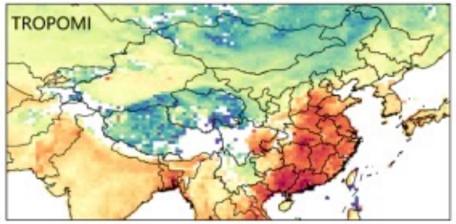
G-b FTIR measurements support model verification

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

Ruosi Liang[1,2,3], Yuzhong Zhang[2,3], Jingran Liu[1,2,3], Wei Chen[1,2,3], Peixuan Zhang[2,3,4], Cuihong Chen[5], Huiqin Mao[5], Guofeng Shen[6], Zhen Qu[7], Zichong Chen[7], Minqiang Zhou[8], Pucai Wang[8], Robert J. Parker[9,10], Hartmut Boesch[9,10], Alba Lorente[11], Joannes D. Maasakkers[11], and Ilse Aben[11]

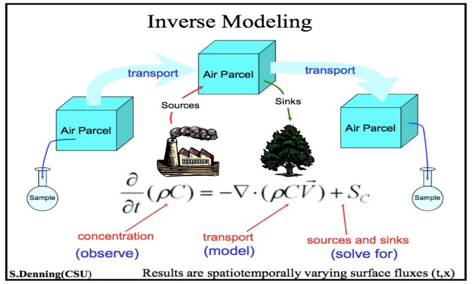
- The model column concentrations after assimilation with GOSAT are more close to TCCON measurements (Xianghe and Hefei) than TROPOMI.
- TROPOMI XCH_4 may still have a bias over China.

Satellite measurement



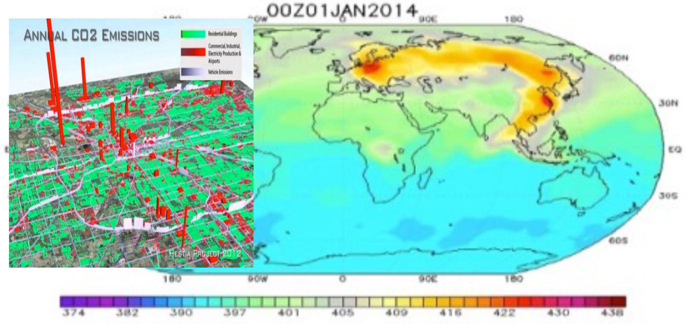
assimilation

Model inversion



validation

validation



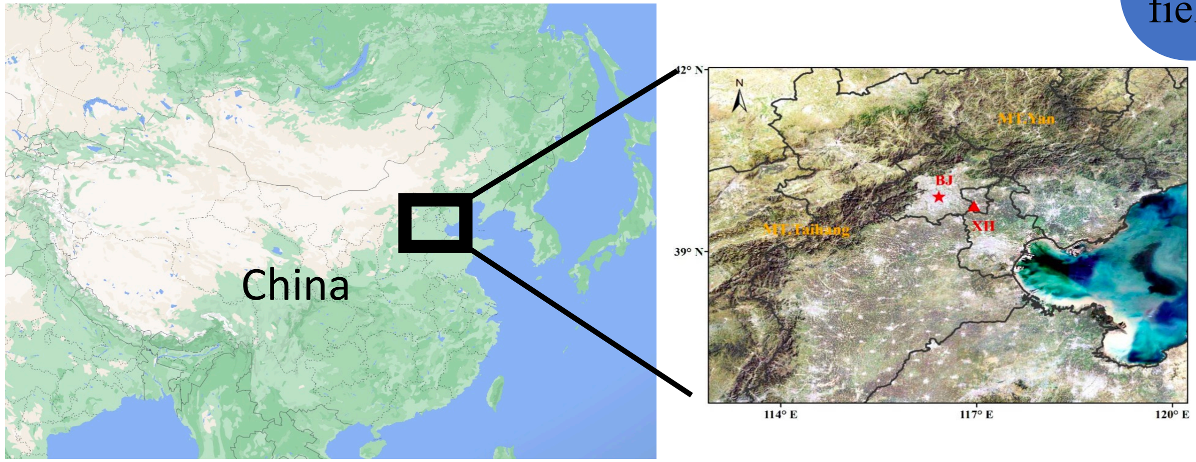
TCCON/COCCON
ground-based measurement

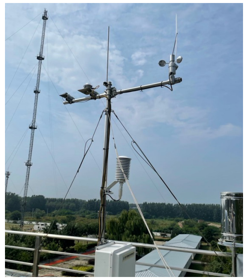
gridded concentration and flux products

FTIR instruments @ IAP

Instrument	Bruker 125HR	Bruker EM27/SUN
Location	Xianghe	Beijing Periphery
Observation mode	TCCON + partly NDACC (InSb)	COCCON
Operational state	normal	3 operational, 1 laboratory

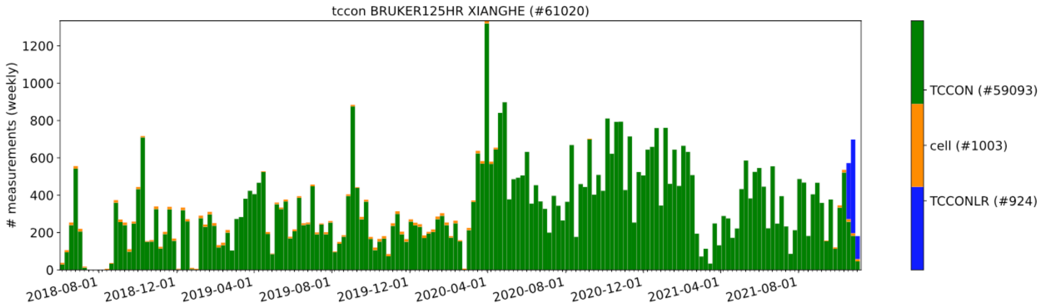
Currently, one Bruker 125HR and four Bruker EM27/SUN spectrometers are available.
Four EM27/SUN are mainly used for regional measurements in Beijing and surrounding areas and for organizing field observation experiments.





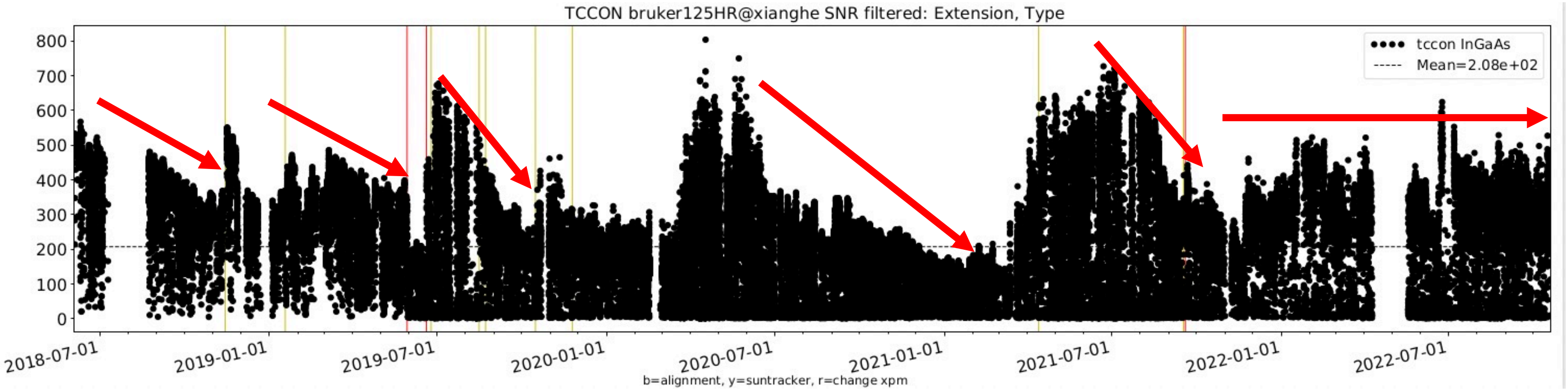
TCCON (Xianghe site)

The number of observed spectra per week - 400



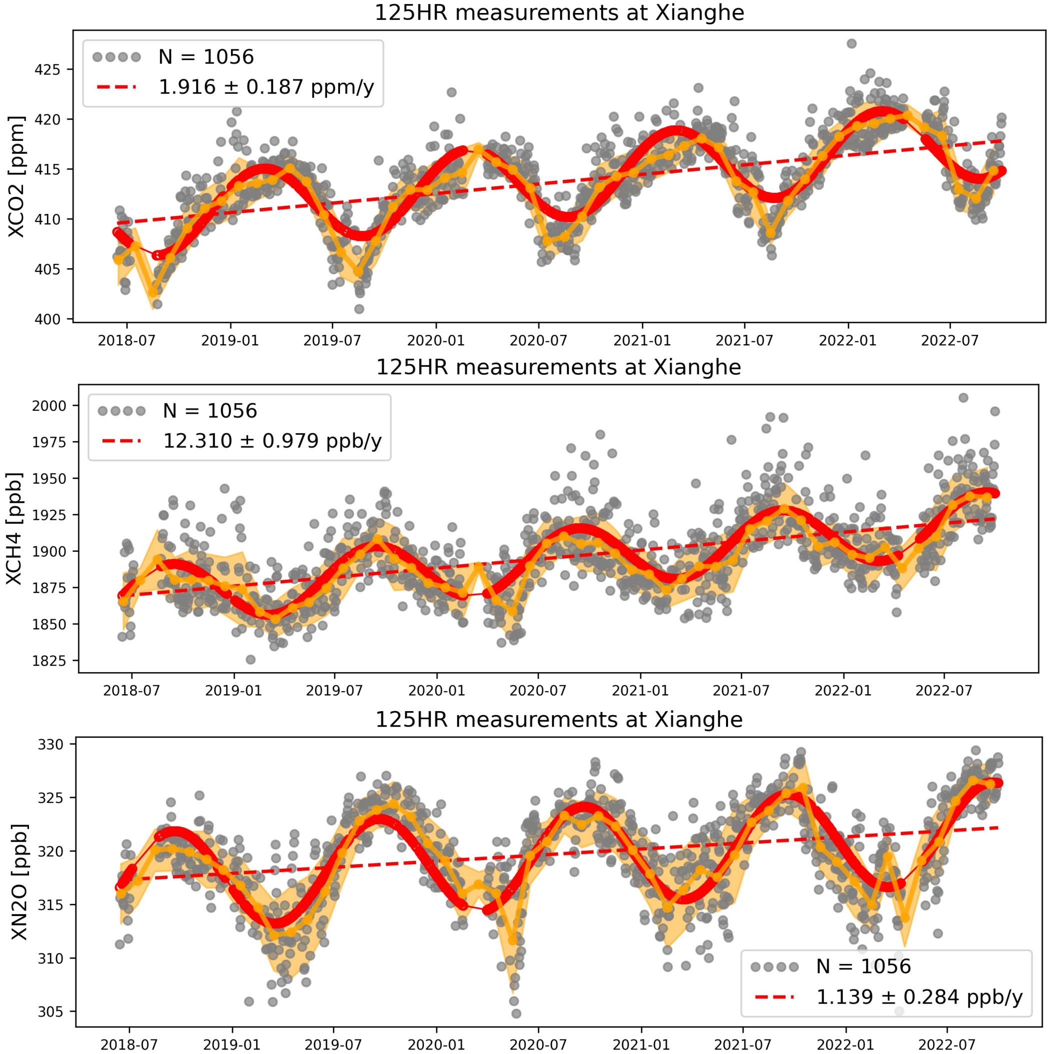
become a TCCON standard station in September 2021

- TCCON established harmonized standards for ground-based GHG remote sensing measurements (spectral signal-to-noise ratio, observation precision of meteorological parameters, retrieval algorithm, data quality control, etc.)



TCCON Xianghe site - Time Series

Time series of column-average dry-air mixing ratio of carbon dioxide, methane, and nitrous oxide (XCO_2, XCH_4, XN_2O)



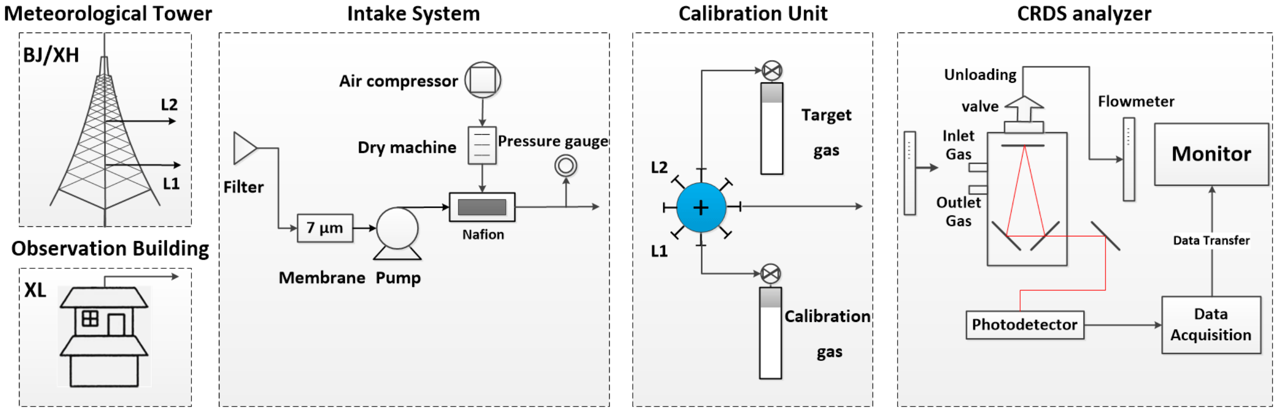
- The concentrations of XCO_2, XCH_4, XN_2O keep increasing.

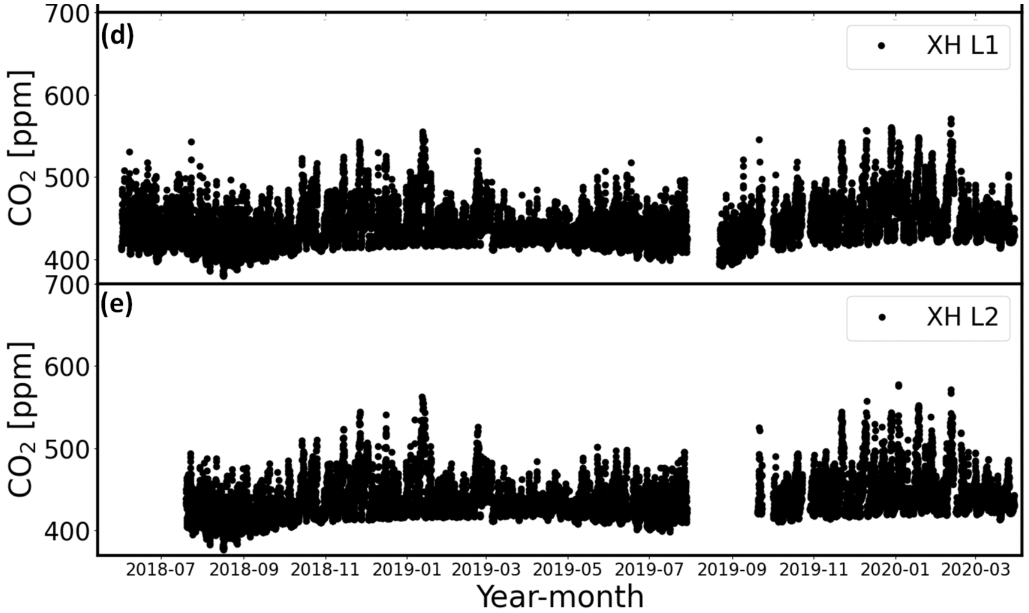
	Xianghe TCCON	Mauna Loa
CO_2	1.916ppm/year	2.38ppm/year
CH_4	12.31ppb/year	14.37ppb/year
N_2O	1.139ppb/year	1.178ppb/year

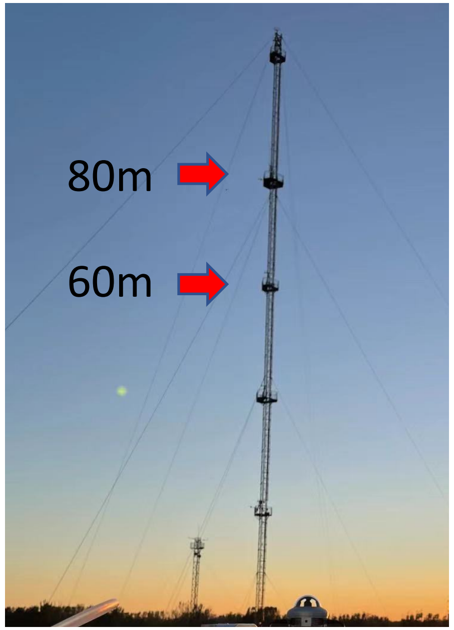
Yang, Zhou et al., 2020 ESSD;*
Zhou et al., 2022, RS
Zhou et al., in preparation

Comparison between TCCON XCO2 and near-surface CO2

PICARRO observation system

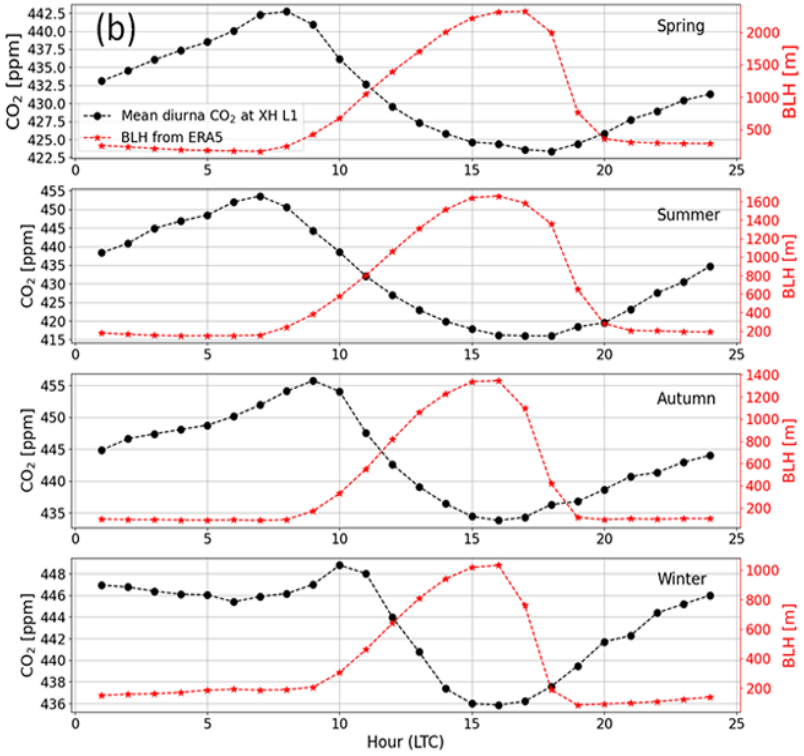




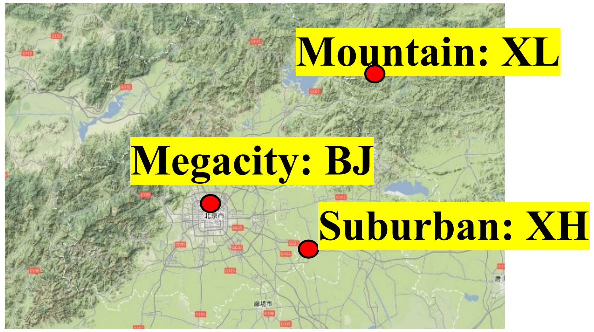


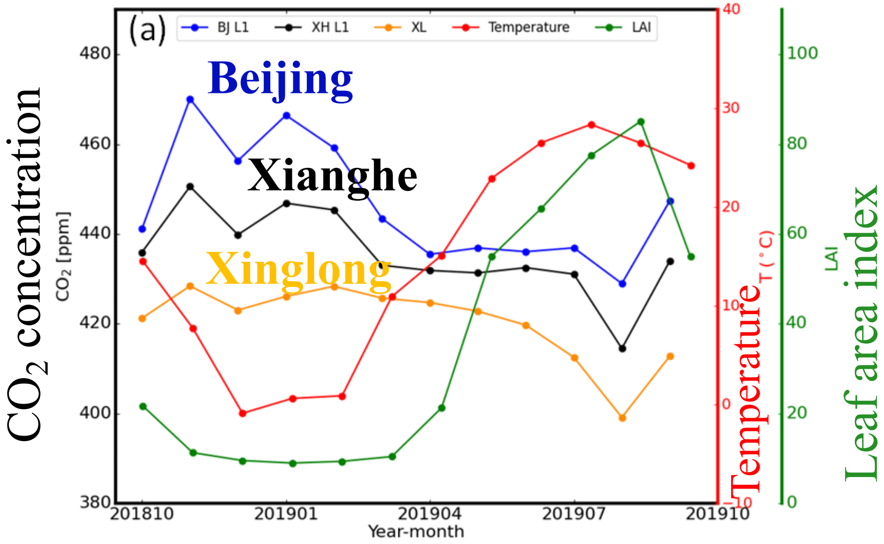
Yang, Zhou et al., 2021 ACP;*

Daily and seasonal variations in near-surface CO2



high at night and low at day;
associated with boundary layer changes



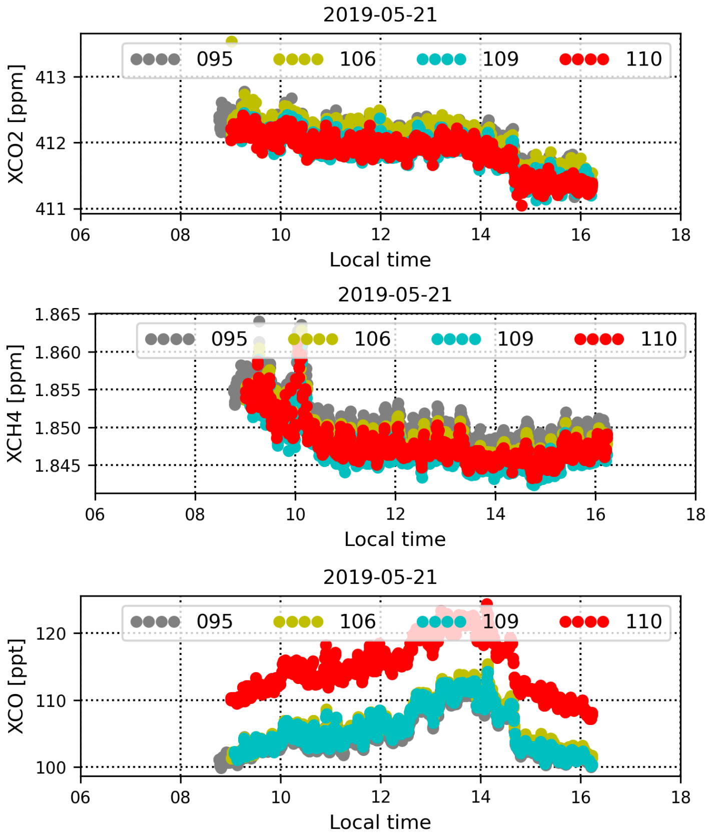


high in winter and low in summer;
associated with vegetation growth status

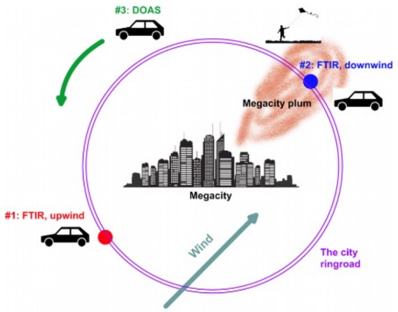
Yang, Zhou et al., 2021 ACP*

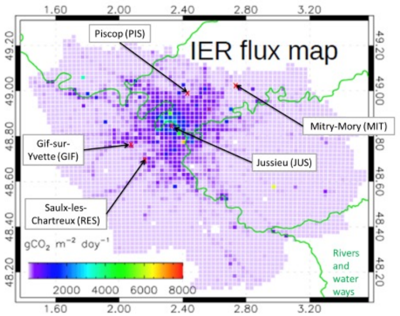
EM27/SUN– inter-comparison

4 EM27/SUN (SN #095/#106/#109/#110) operated on the top floor of IAP-CAS



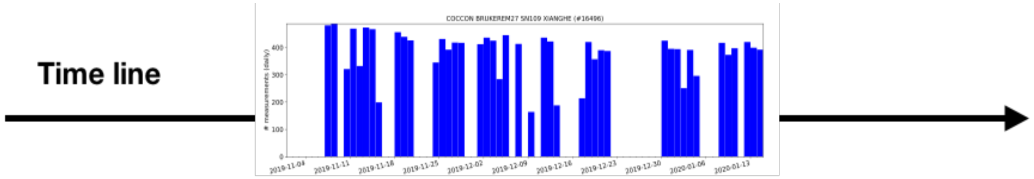
XCO$_2$, XCH$_4$, and XCO observed by four EM27/SUN measurements on 21 May 2019



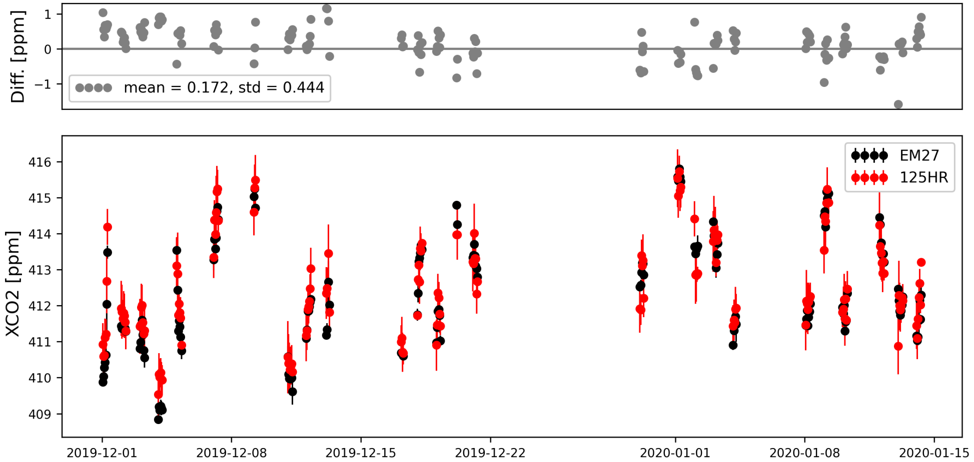


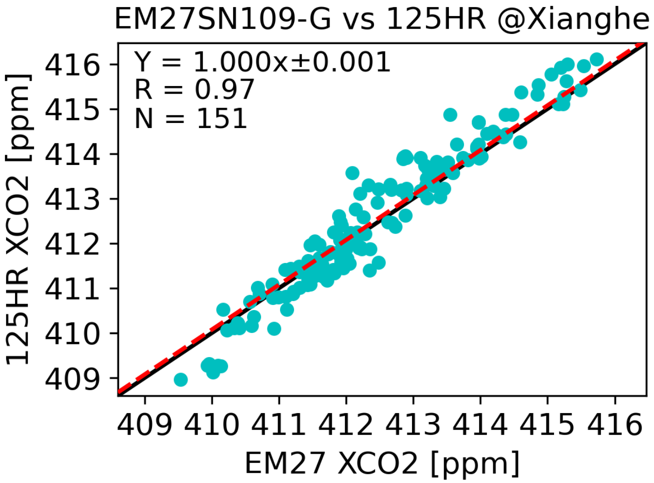
- There are discrepancies between EM27/SUN measurements, especially for XCO.
- Inter-instrument error should be corrected before organizing regional observation experiments.

EM27/SUN-125HR parallel comparison



Bruker EM27/SUN SN109
201911 - 202001



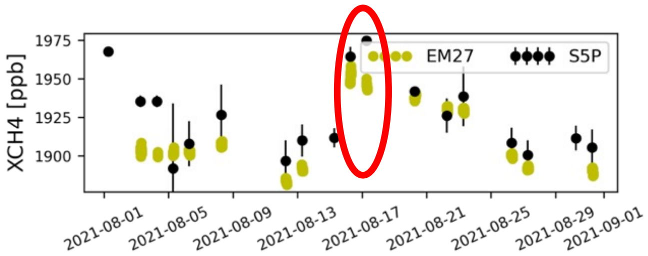


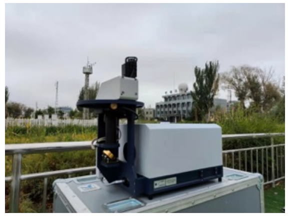
❖ high correlation between EM27 and TCCON （R=0.97）

EM27/SUN– Observational experiments

- In August 2021, the observation experiment of EM27/SUN at Golmud, Qinghai was organized;
- Aims of the experiment: validate satellite measurement errors; analyze variations of column concentrations of CO_2/CH_4/CO at Golmud

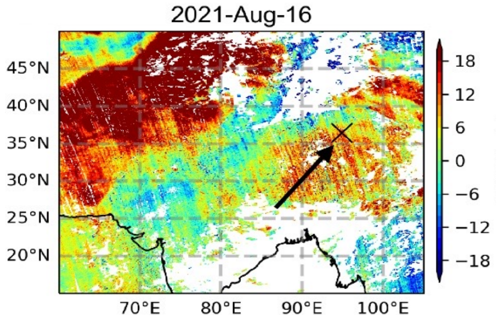
CH_4 high values observed in ground-based and satellite measurements

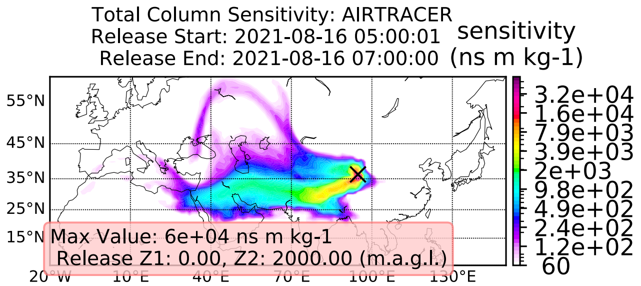




EM27/SUN GHG remote sensing observational experiment at Golmud

Analysis of the transport pathway of CH_4 high values





Combining remote sensing measurements and atmospheric transport models, the transport of CH_4 high values from India was observed in Qinghai.

Zhou et al., 2022,AAS

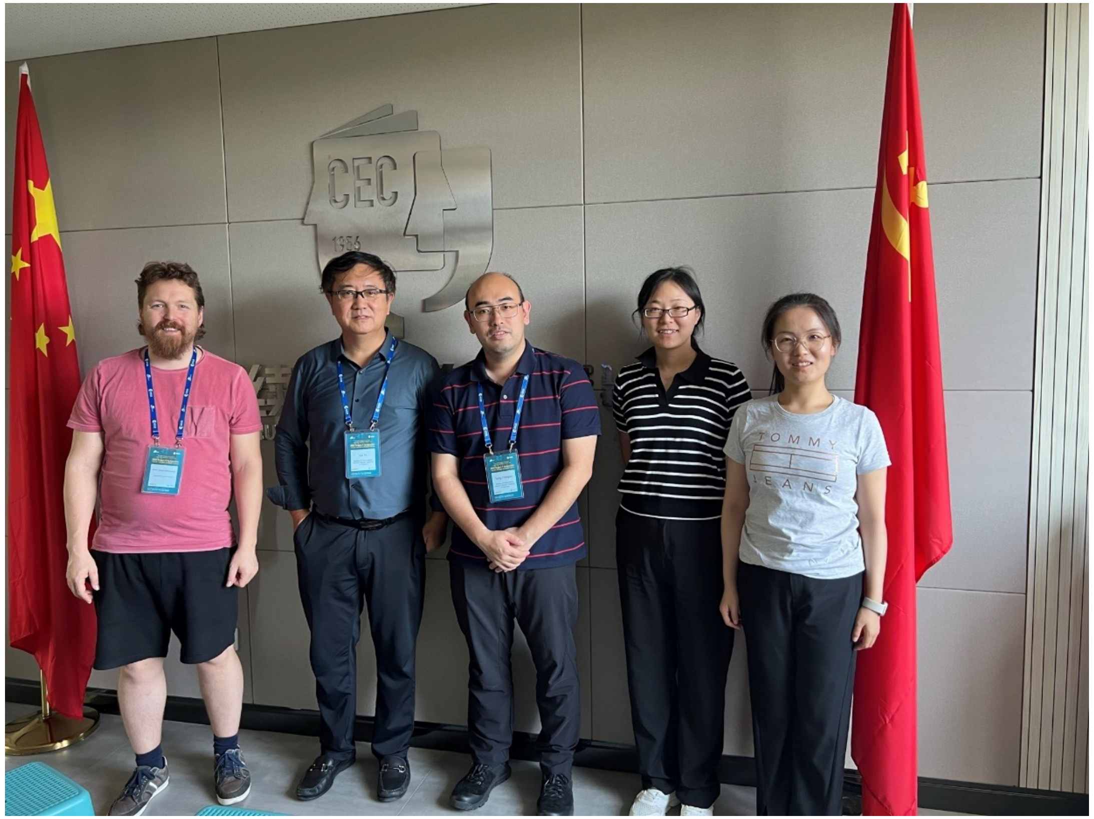
Remote sensing instruments at Xianghe (IAP)

- Band: cover UV, VIS, IR
- pollutant gases, greenhouse gases, aerosols,
- near-surface, troposphere, stratosphere
- Strong international collaboration, e.g., TCCON, GAW, COCCON, AERONET…

Exchange and visiting

ID. 59355

- Dr. Yang and Dr. Wang visiting University of Edinburgh (April- July 2023)
- Dr. Hakkarainen visiting Institute of Atmospheric Physics, CAS (Septemper 2023)
- Group meet at IMNU (Septemper 2023)

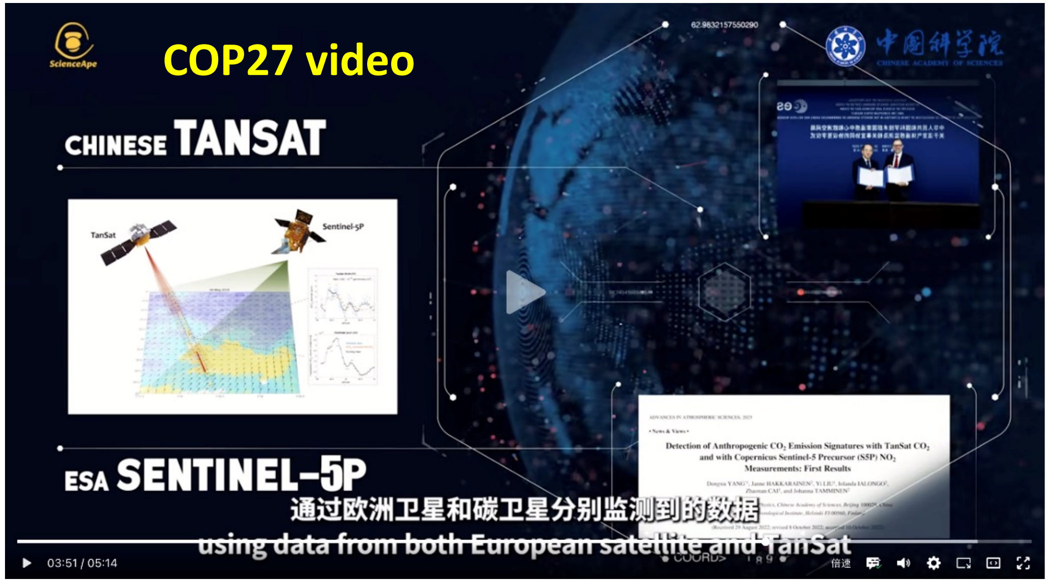


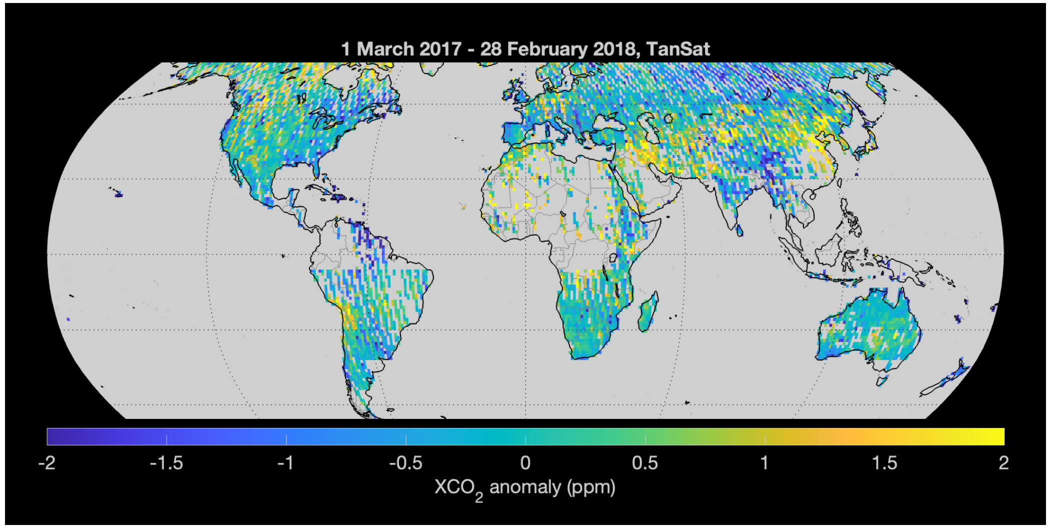
Outcomes of cooperation

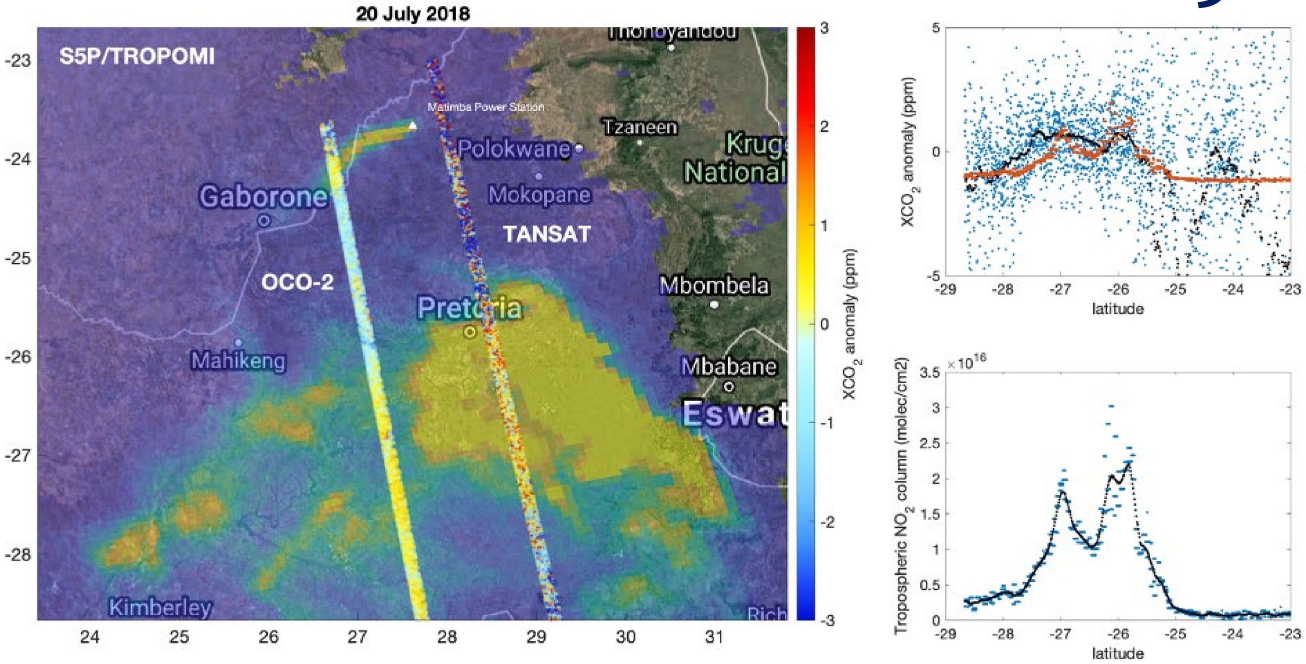
ID. 59355

TanSat city and hotspot emissions

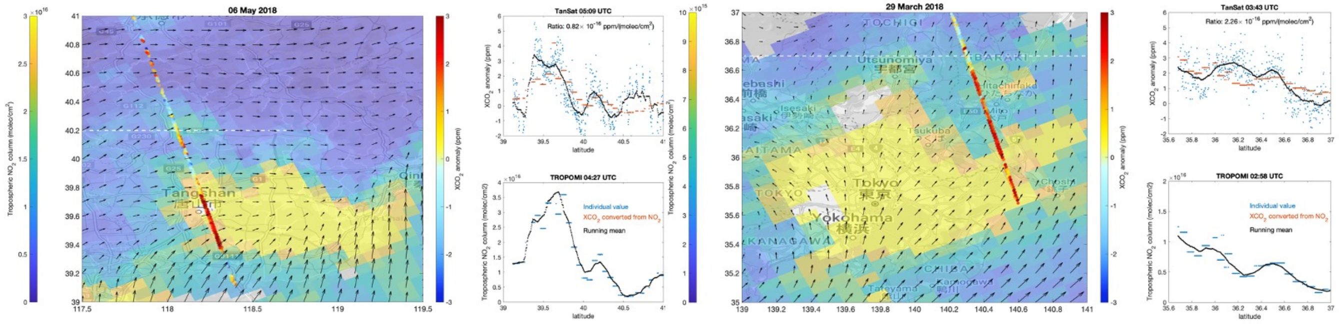
TanSat coordinated with Sentinel-5P







Yang D., Hakkarainen J., Liu Y., et al., 2023

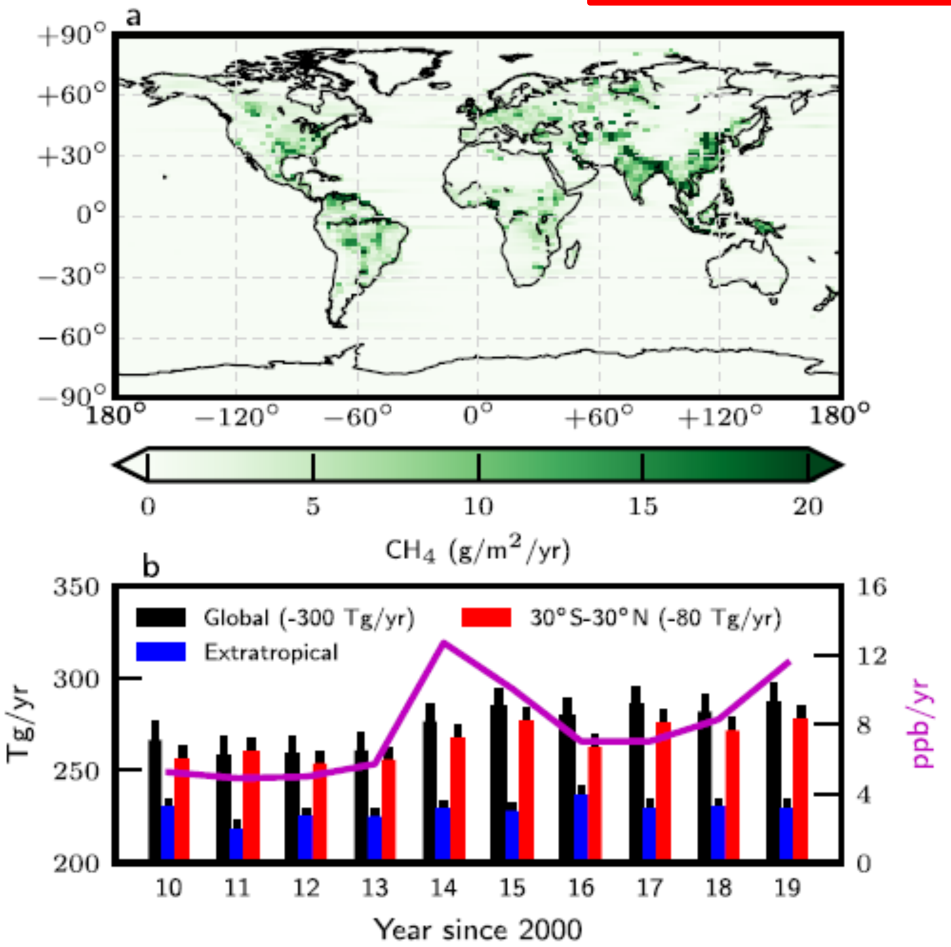


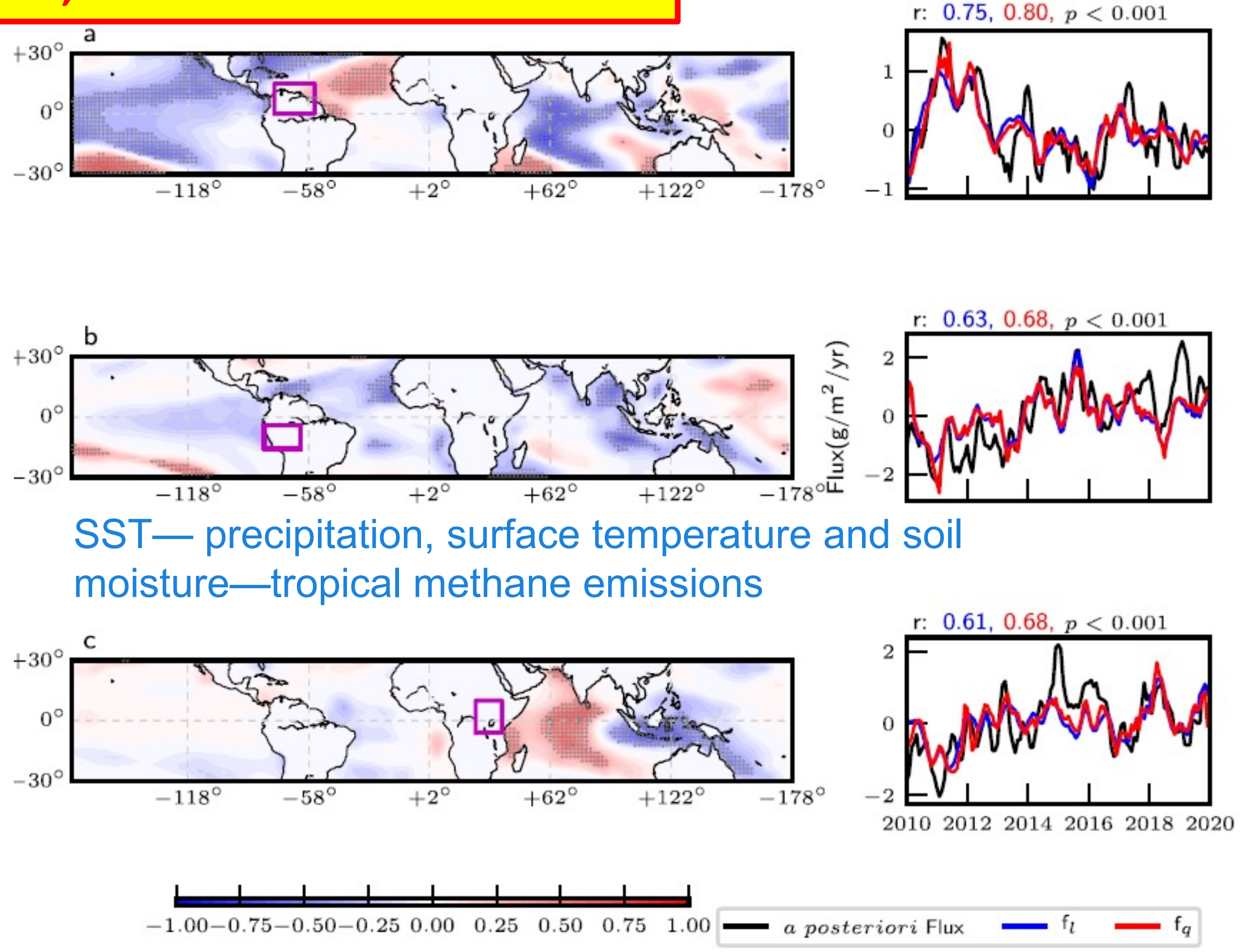
Outcomes of cooperation

ID. 59355

- Tropical methane emissions, nearly 60% of global totals, explain 84% of global atmospheric methane growth rate
- Sea surface temperature (SST) variations could be used to help forecast variations in global atmospheric methane

Feng L., et al, 2022, Nature communication





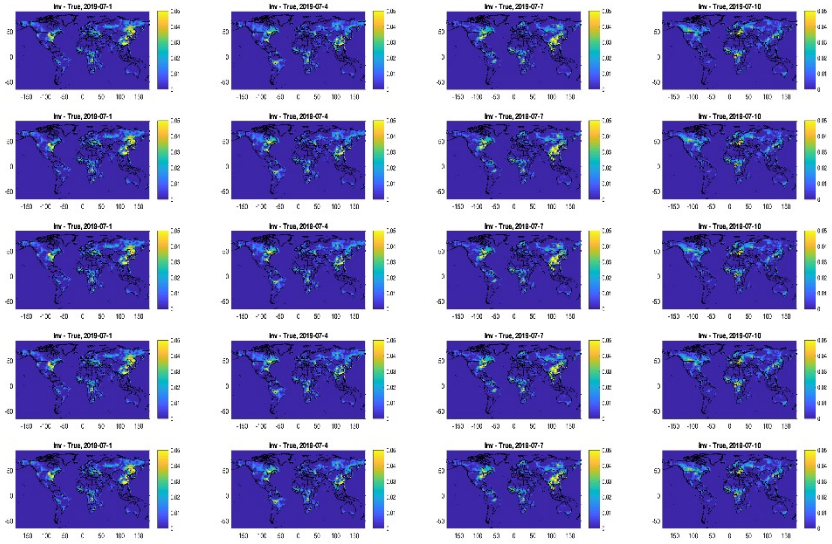
SST— precipitation, surface temperature and soil moisture—tropical methane emissions

On going and future cooperation

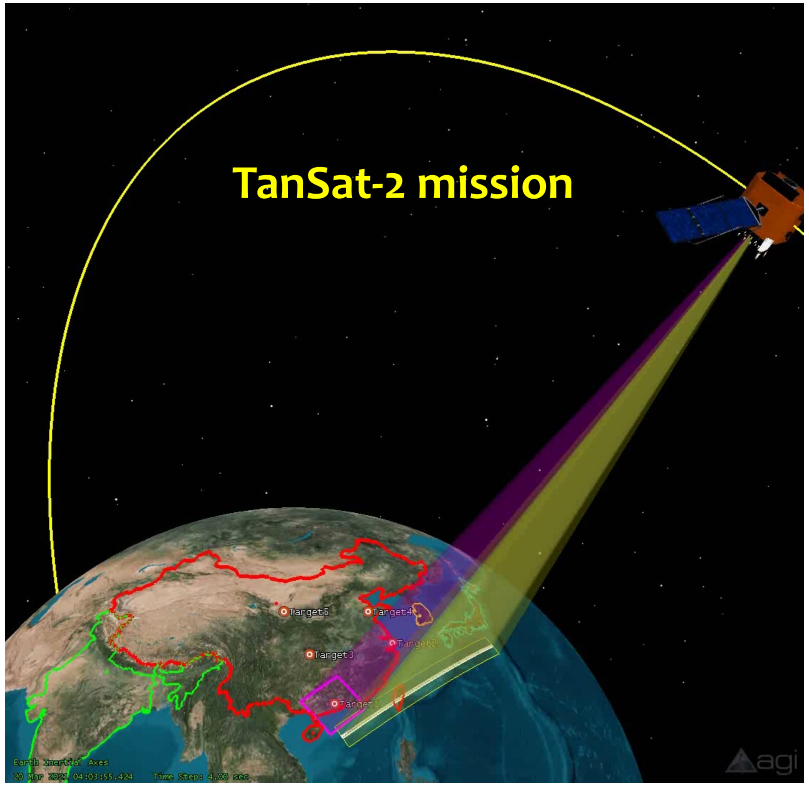
ID. 59355

- TanSat-2 and CO2M cooperation and coordination in future
- New CO_2 and CH_4 retrieval algorithm development
- New methods for emission estimation from plume obsveration measurement
- Atmospheric inversion of CO_2 and CH_4 for contribute Global Stocktake

GHG MOST-ESA meeting



TanSat-2 OSSE and design



Thank you!