WRF-Chem simulations of CO_2 over Western Europe assessed by ground-based measurements

Jiaxin Wang, Sieglinde Callewaert, Minqiang Zhou, Filip Desmet, Sébastien Conil, Michel Ramonet, Martine De Mazière

Institute of Atmospheric Physics, Chinese Academy of Sciences, China

Royal Belgian Institute for Space Aeronomy (BIRA-IASB), Belgium

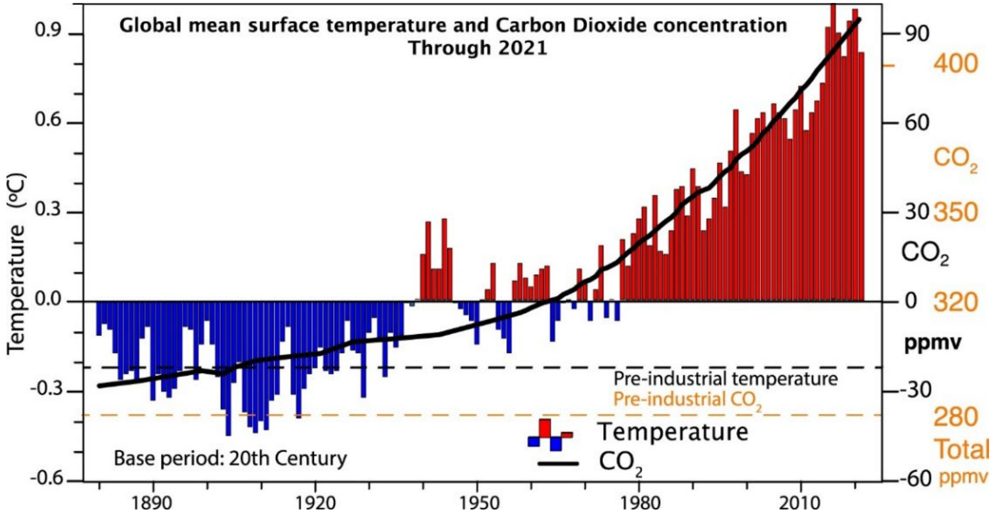
12 Nov 2025, Ghent

CONTENTS

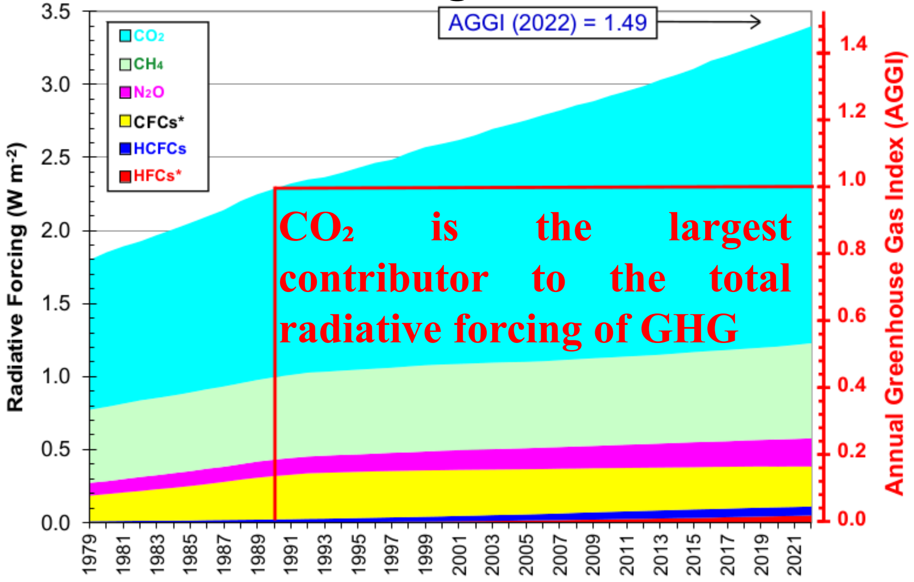
- Research background
- Model and data
- Results
- Conclusion and acknowledgement

Research Background

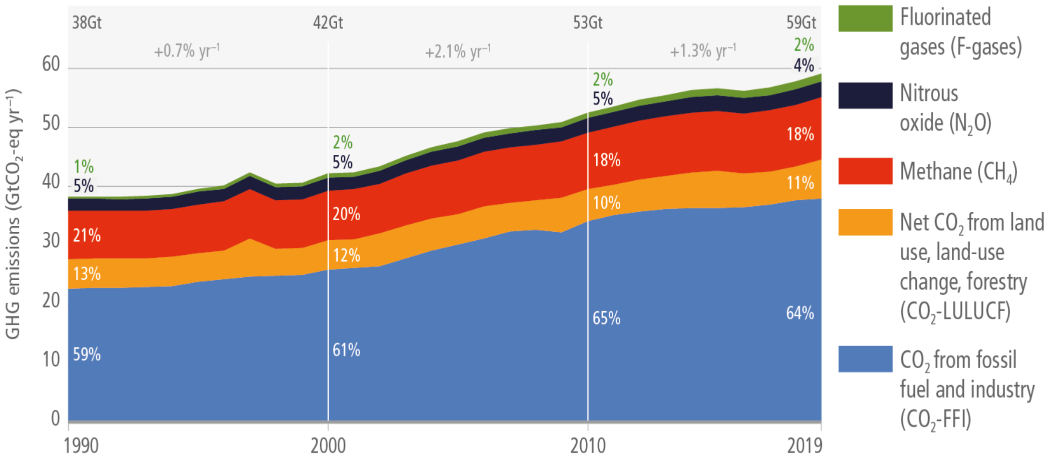
Mean surface temperature



Radiative forcing



Anthropogenic emissions

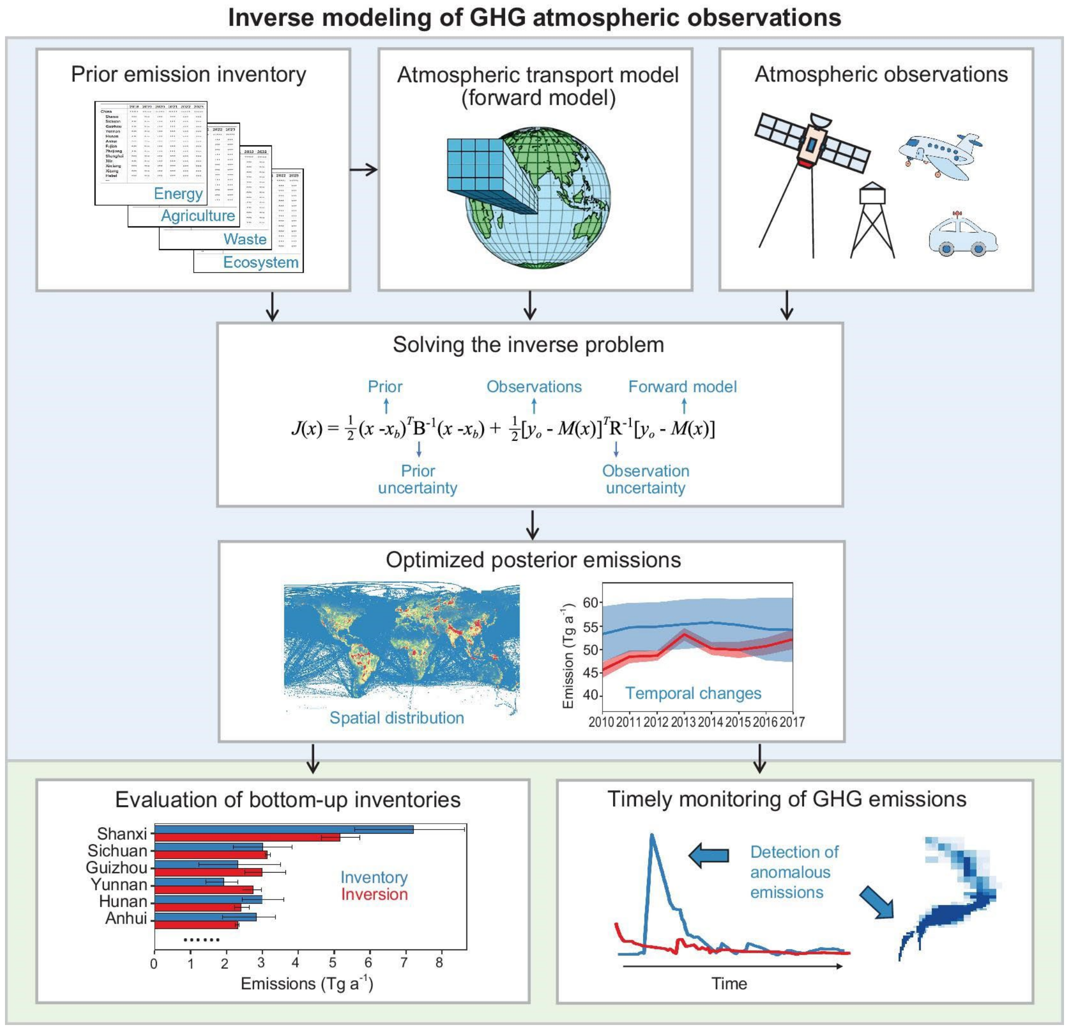


In the context of the Paris Agreement,

the **VERBE** project aims to establish an independent, **top-down**, temporally and spatially resolved **Monitoring and Verification Support (MVS)** capacity for greenhouse gas (GHG) emissions in Belgium.

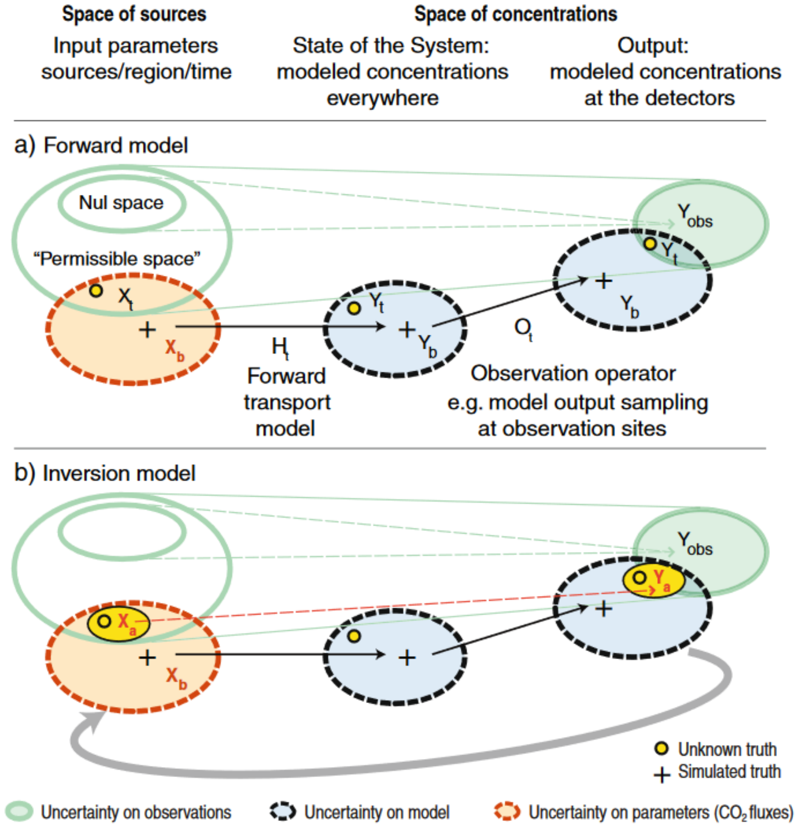
Trenberth et al., 2022, IPCC AR6

Research Background



Framework of atmospheric inversions

(Wang et al., 2025)



How to reduce the uncertainty?

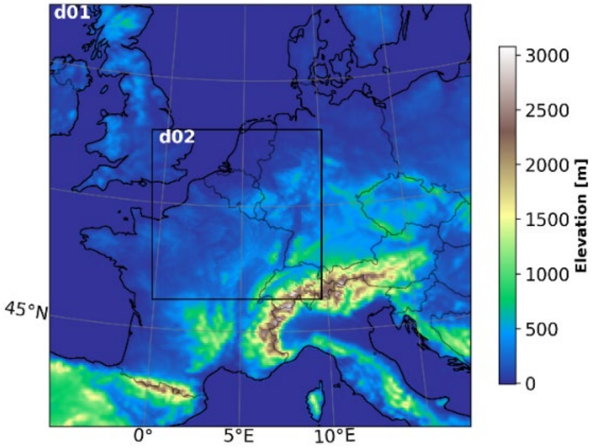
Uncertainties in

- ***Model***
- *Observations*
- *Prior emissions*

(Ciais et al., 2010)

Model and Data —— WRF-GHG model

WRF-GHG: Weather Research and Forecast model coupled with Chemistry in its passive tracer option



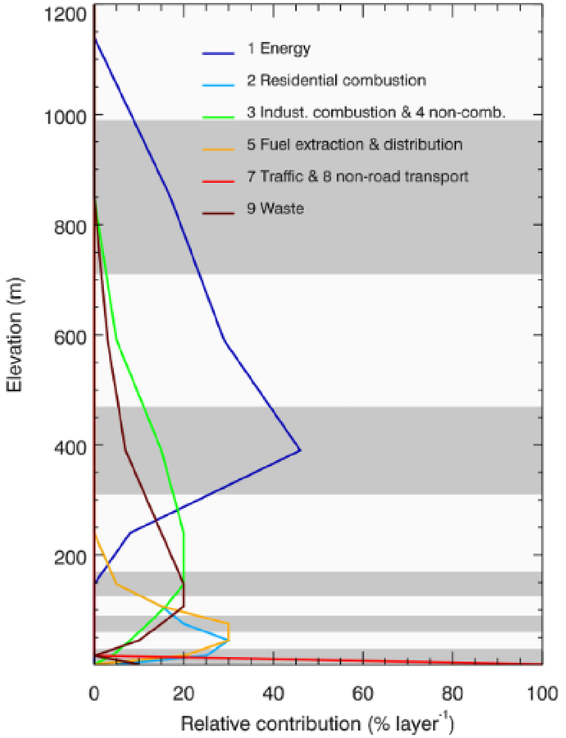
- Simulated period: 2018.6.1-2018.8.31
- Horizontal Res: 9km (d01), 3km (d02)
- Vertical Res： 60 hybrid levels from surface to 50hpa
- Physical parameterizations *(Poraicu et al., 2023)*

Anthropogenic emissions：

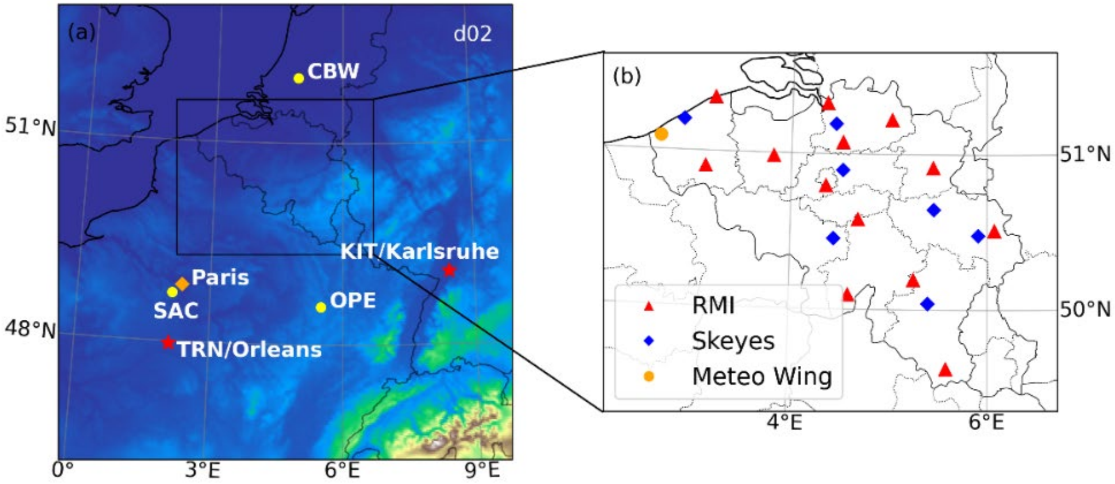
	Test	*Type*	*Inventory*	*Resolution*	*Temporal variation*
1	EDGAR_S	S	EDGAR v2024 (sector-specific)	Monthly 0.1°×0.1°	constant hourly values within each month
2	EDGAR_P	P			
3	CAMS_S	S	CAMS-REG-ANT v8.0 (sector-specific)	Yearly 0.1°×0.05°	sector-specific factors from CAMS-REG-TEMPO
4	CAMS_P	P			
5	TNO_CAMS	S	TNO_GHGco_v4.1 + CAMS-REG-ANT v8.0	Yearly 1/60°× 1/120° (for TNO)	temporal profile factors from Nassar et al. (2013)

S: all emissions released at the surface. P: emissions released according to source-specific vertical profiles

(Brunner et al., 2019)



Model and Data —— Observations



- 21 synoptic stations in Belgium
- 3 ICOS sites (yellow dots)
- 1 TCCON site (orange diamond)
- 2 co-located sites (red stars)

ICOS Stations		*Location*	*Altitude (m a.s.l.)*	*Observation Height (m a.g.l.)*
Karlsruhe	KIT	49.0915°N 8.4249°E	110	30/60/100/200
Trainou	TRN	47.9647°N 2.1125°E	131	50/100/180
Saclay	SAC	48.7227°N 2.142°E	16	60/100
Observatoire Pérenne de l'Environnement	OPE	48.5619°N 5.5036°E	390	50/120
Cabauw	CBW	51.9703°N 4.9264°E	0	207

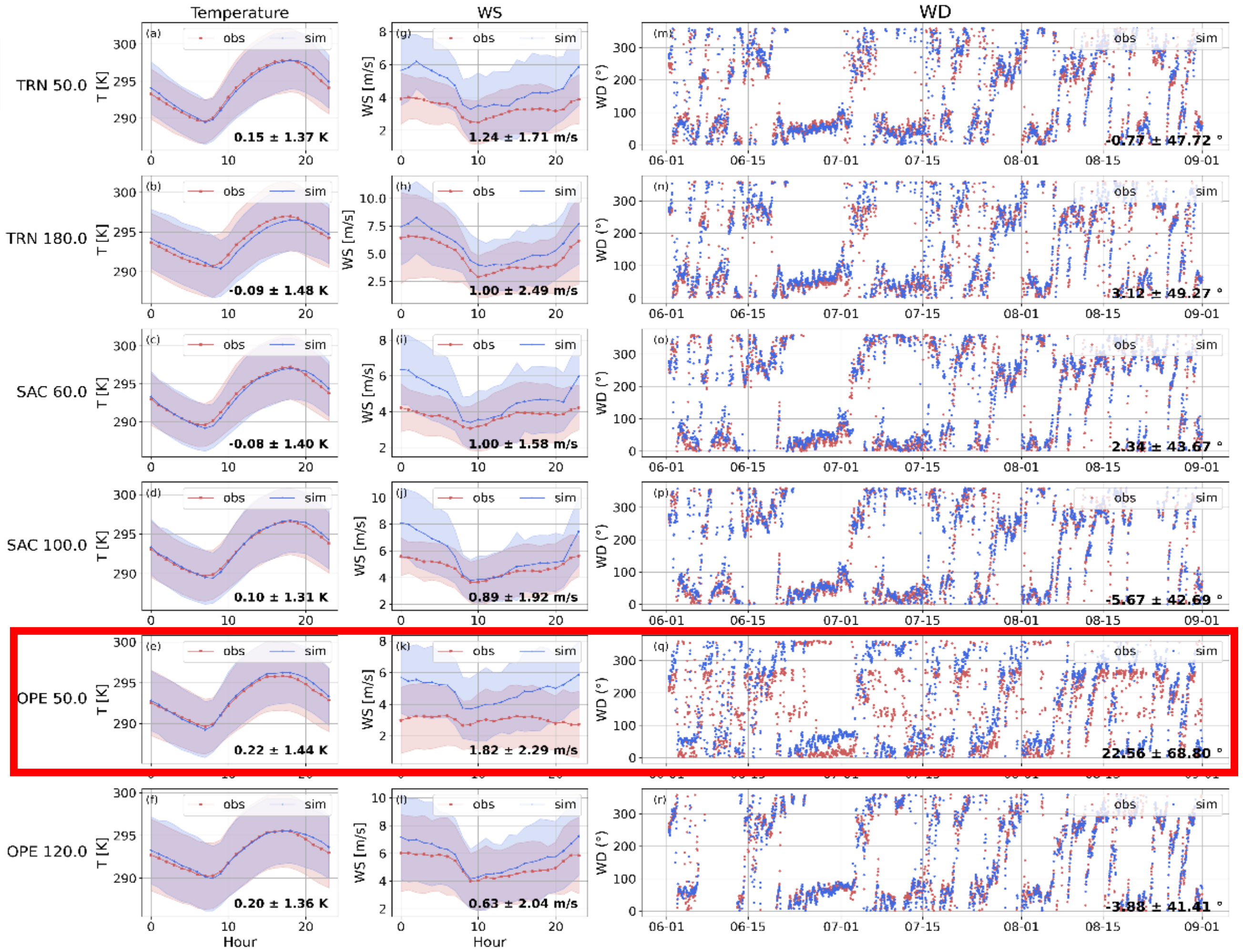
Results —— Meteorological fields

synoptic obs

	N	MBE	STD	RMSE	R
Temperature (K)	44426	0.06	1.61	1.61	0.95
Wind Speed (m/s)	43843	0.20	1.45	1.47	0.63
Wind Direction (°)	41983	-3.31	43.16	43.29	0.57

across all 21 stations

ICOS



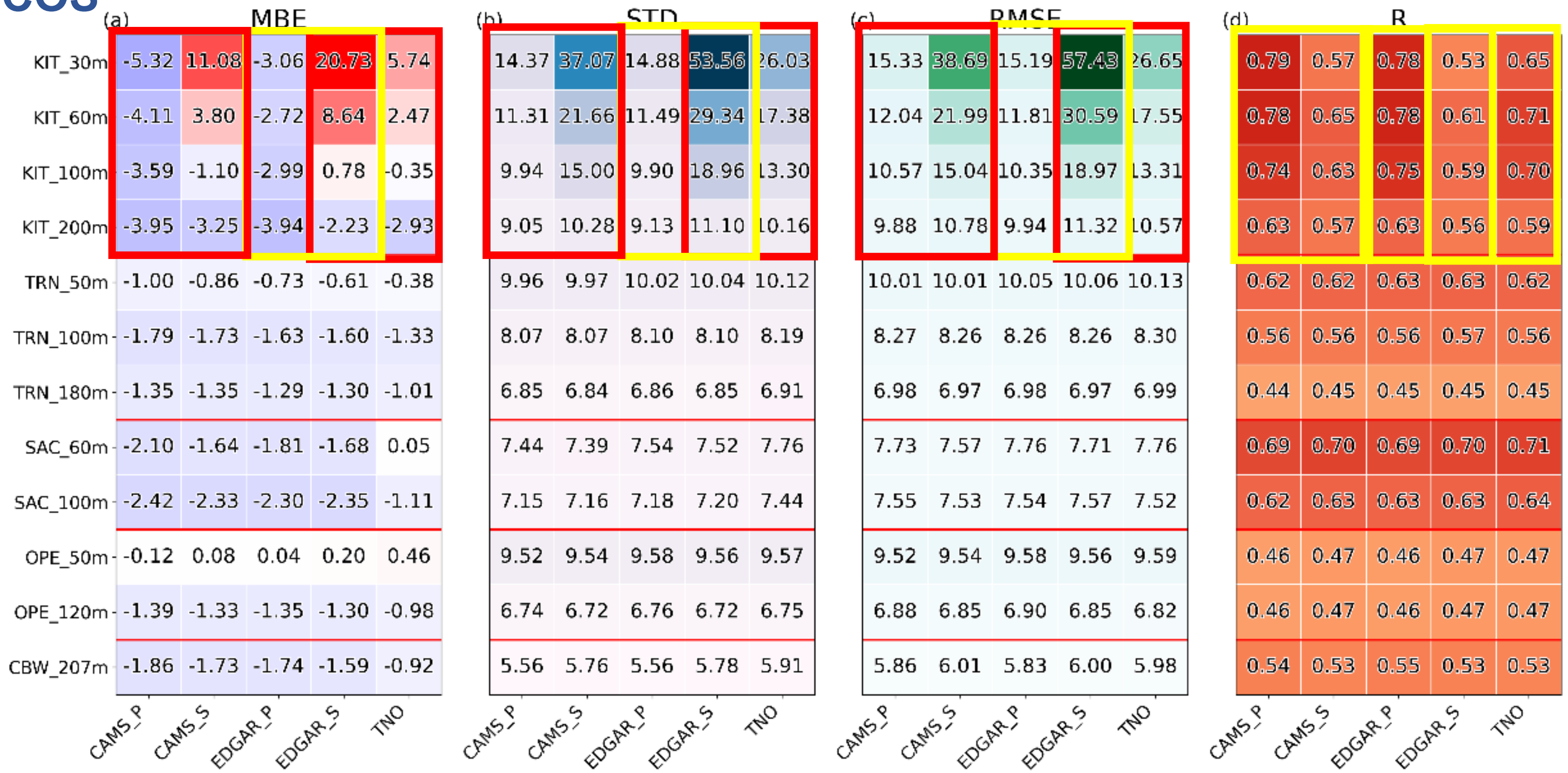
The model captures the near-surface variations in meteorological fields well, and exhibits high accuracy in the vertical profiles.

Uncertainties or measurement errors in the wind data from the ICOS anemometer,

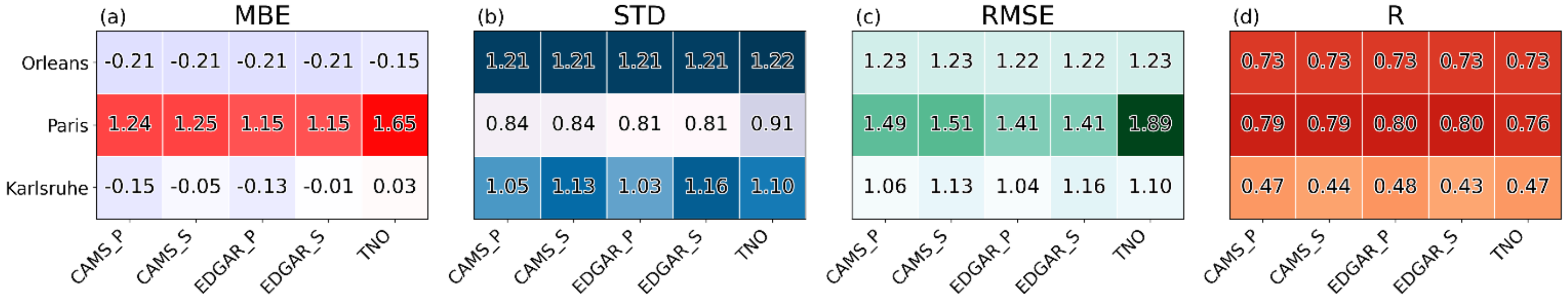
- **from the sensor itself**
- **relate to its setup, possibly affected by disturbances from the tower structure**

Results —— Chemical fields

ICOS



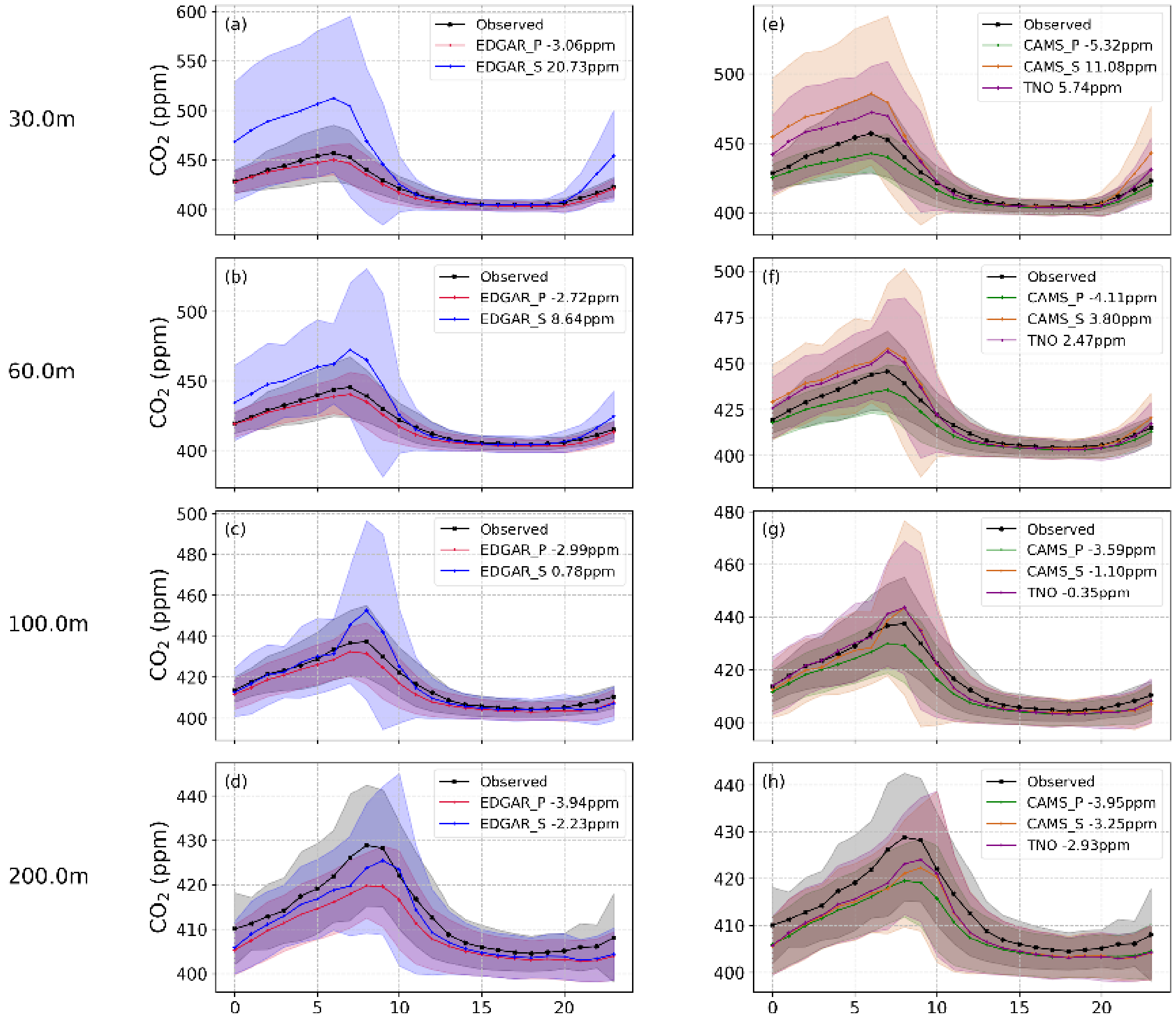
TCCON



At KIT site

- ✓ The difference of using different inventories can up to -14.99±31.98 ppm (between EDGAR and TNO)
- ✓ Considering the source-specific vertical profiles notably improves accuracy, increasing the correlation coefficient from 0.53 to 0.78 when using EDGAR.
- ✓ XCO_2 is less sensitive to the choice of anthropogenic emission inventory than near-surface concentrations, but the influence is still present.

Results —— Chemical fields



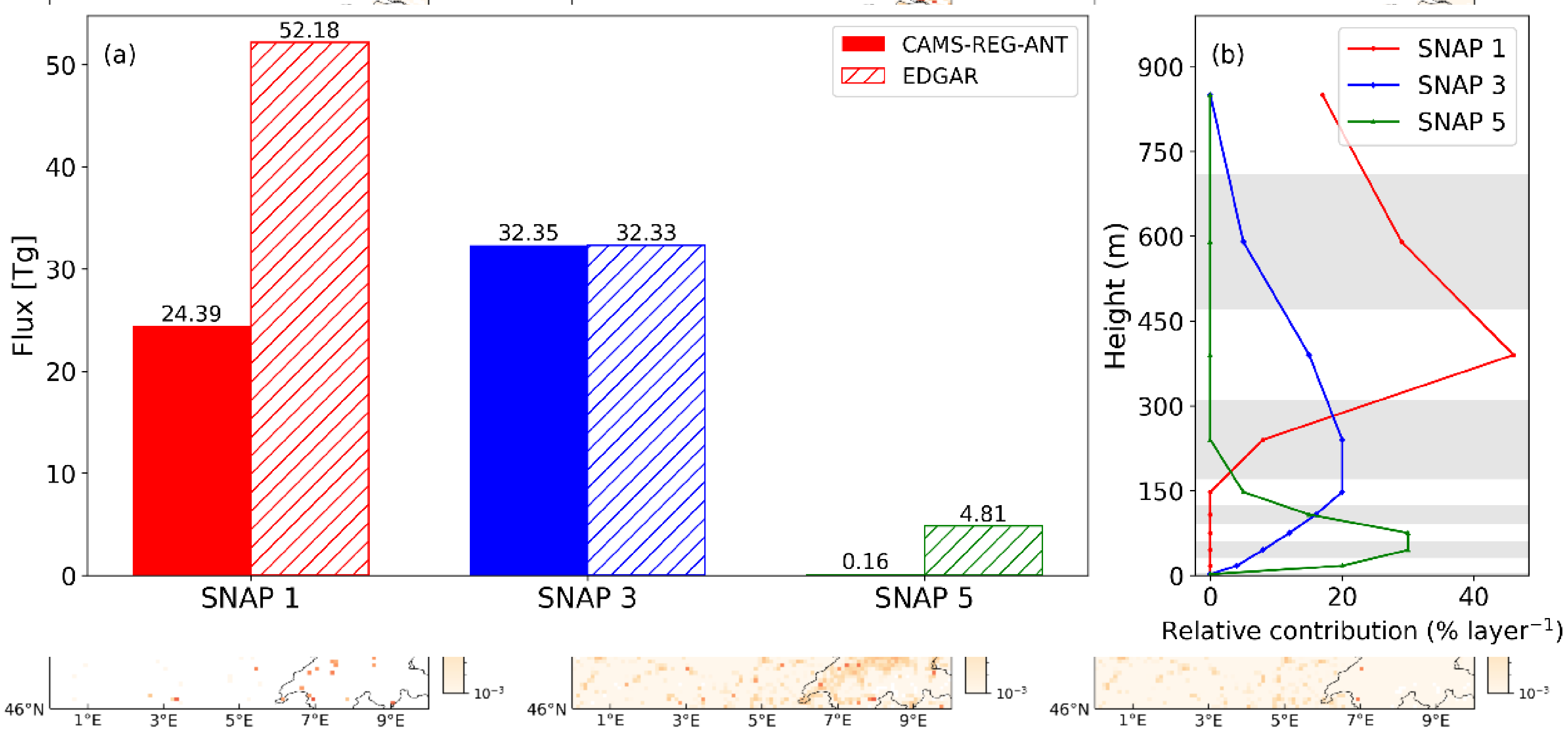
The diurnal cycle of observed and simulated near surface CO_2 concentrations at KIT site

- ✓ Model can capture the diurnal variation of CO_2
- ✓ At lower height, the simulations considering only surface emissions significantly **overestimate** higher CO_2 mole fractions in the morning, leading to large discrepancies with the observations.

Why does the configuration of anthropogenic emission inventory only have a significant impact on the results at the KIT site?

Results —— Chemical fields

Emission fluxes from different sectors within 47.6°N-50.6°N, 6.94°E-9.94°E



Emission distribution of major contributing sectors in 2018

- There are strong emission sources near the KIT site, while no significant high-emission sources are found near the other sites.
- Approximately 6.5 km southwest of the KIT station is the largest oil refinery in Germany, and about 45 km to the north there is a gas-fired combined heat and power (CHP) plant.
- Emissions from SNAP 1 and SNAP 3 are mainly concentrated at higher altitudes, with SNAP 1 emissions starting at around 150 meters above the ground.

Conclusion and Acknowledgement

Conclusion

- The WRF-GHG model reproduces the meteorological fields well, especially for temperature.
- The diurnal variation of near-surface CO_2 mole fractions at different heights across the five ICOS observation sites was well captured.
- Near large anthropogenic emission sources, the simulated near-surface CO_2 mole fractions are highly sensitive to the configuration of anthropogenic emission, considering the source-specific vertical profiles notably improves accuracy.
- Regarding XCO_2, the model is less sensitive to the choice of emission inventories and anthropogenic emission heights, but certain effects are still evident.

Next step

- Based on the results, use the WRF-GHG-CTDAS system to verify the CO_2 emission inventory of Belgium.

Acknowledgement

We acknowledge the providers of emission inventories. We thank all members of the Synoptic observations, TCCON, and ICOS Atmosphere Monitoring Station Assembly for providing the long-term and high-quality data on meteorological and greenhouse gas observations.

RMI BELGIAN CLIMATE CENTRE ICOS Integrated Carbon Observation System TCCON total carbon column observing network

Thank you for your attention!

WRF-Chem simulations of CO_2 over Western Europe assessed by ground-based measurements

Co-authors: Sieglinde Callewaert, Minqiang Zhou, Filip Desmet, Sébastien Conil, Michel Ramonet, Martine De Mazière

Institute of Atmospheric Physics, Chinese Academy of Sciences, China

Royal Belgian Institute for Space Aeronomy (BIRA-IASB), Belgium

Wang, J., Callewaert, S., Zhou, M., Desmet, F., Conil, S., Ramonet, M., Wang, P., and De Mazière, M.: WRF-Chem simulations of CO_2 over Western Europe assessed by ground-based measurements, EGUsphere [preprint], https://doi.org/10.5194/egusphere-2025-4537, 2025.