Inverse modelling of Austrian CH4 fluxes

University of Vienna

USER & STAKEHOLDER CONFERENCE
CLOSURE MEETING

26. – 27.02.2025

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FFG project || GHG-KIT
[contract #FO999893432]

INTRODUCTION

OBJECTIVES

Improve estimates of CH_4 fluxes using inverse modelling

Reduce uncertainty on emissions in Austria

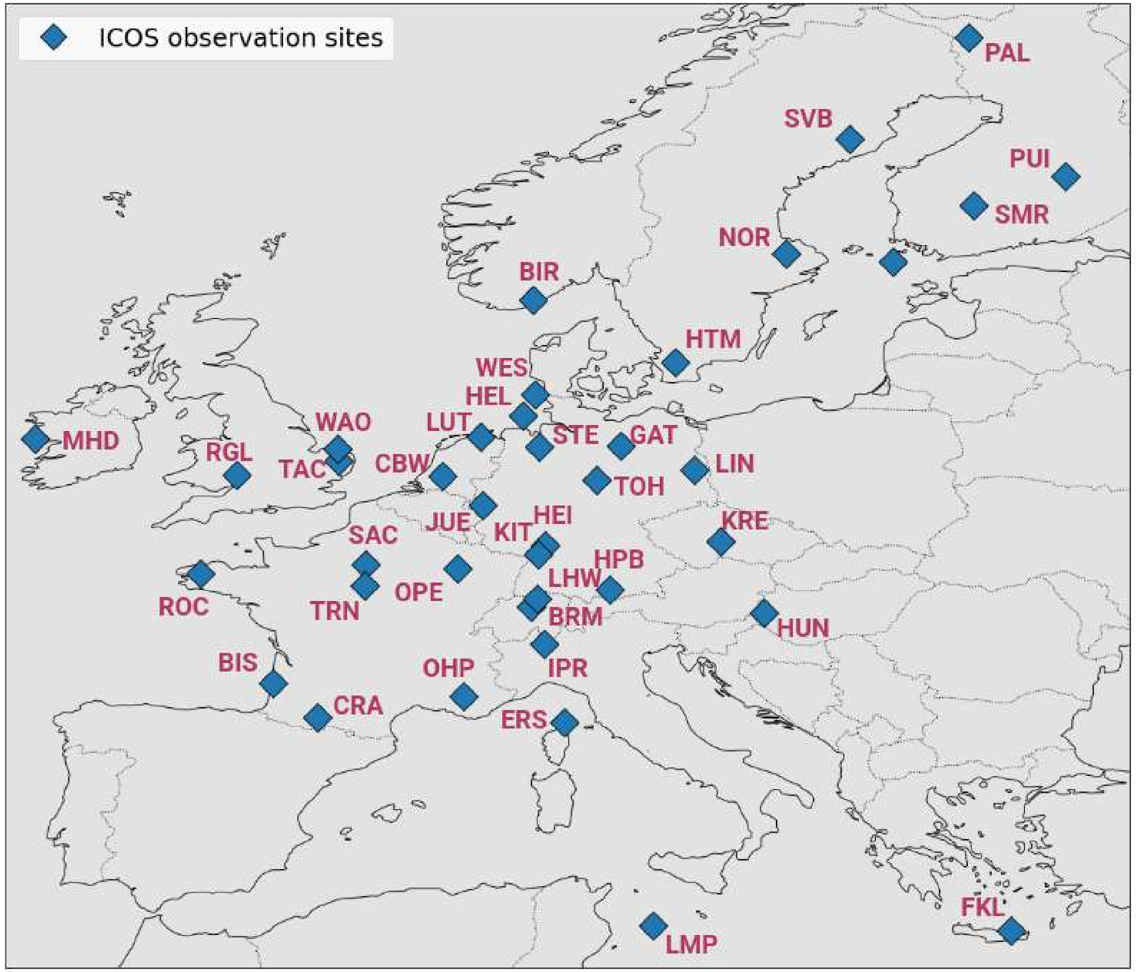
CHALLENGES

Limited stationary observation network
→ Austria not part of ICOS

Limited quality of observations from current satellite missions

IN SITU OBSERVATION NETWORK

- **51** observation **sites for 2022** (48 ICOS sites + 3 in Austria)
- Austrian observation sites:
  - → SNB (mountain site)
  - → IAO and VUCL (urban sites)
- **39** observation sites for **final inversion**, all outside of Austria
  - → Mountain sites not well represented by transport model
  - → Urban sites would require higher resolution to capture local influences
- **5** stations in **vicinity of Austria**



European in situ observation network, 2022

PRIOR CH_4 FLUXES

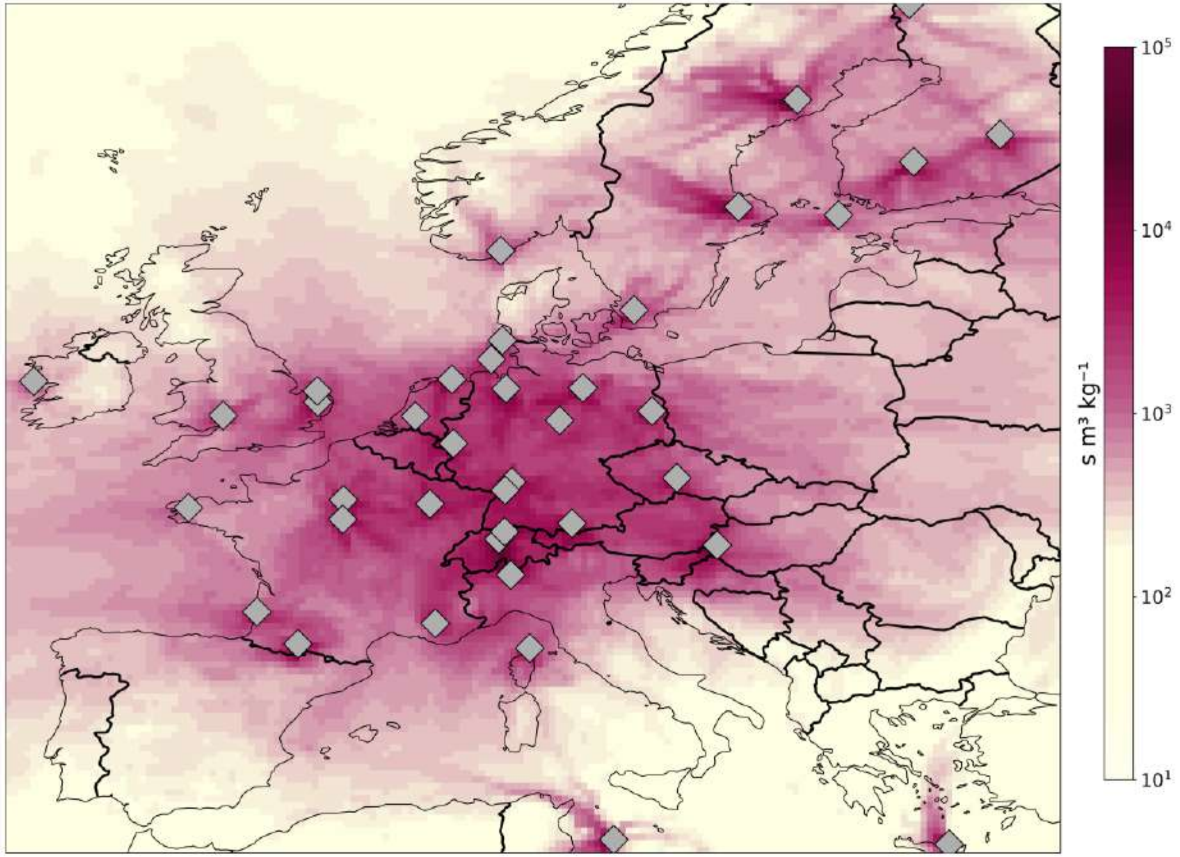
- All data sets: **monthly** temporal resolution
- Different spatial resolutions

  → Re-gridded to 0.25° x 0.25° and 1.0° x 1.0°

Type	Source/Sink	Reference
Anthropogenic	All combined	GeoSphere, based on CAMS
Natural	Wetlands	WetCHART v1.3.1 (2019)
	Wildfires	GFED v4.1 beta (2022)
	Geological	Based on Etiope et al. (2019), scaled to 15.4 Tg/yr
	Termites	Saunois et al. (2020) (GCP-CH4)
	Ocean	Weber et al. (2019)
	Soil Sink	Ridgwell et al. (1999)

FLEXPART AND FLEXINVERT SET-UP

- **Global output** at 1° x 1° spatial resolution
- **Nested output** at 0.25° x 0.25° over European domain
  - → Longitudes: 15° W to 35° E
  - → Latitudes: 35° N to 72° N
- **Trajectories** of particles calculated **50 days** backwards in time
- Inversion domain: **Europe**
- CH_4 fluxes optimized at **monthly temporal resolution**
- **Initial mixing ratios** based on concentration fields (**FLEXPART CTM**, provided by NILU)
  - → Optimized over latitude bands

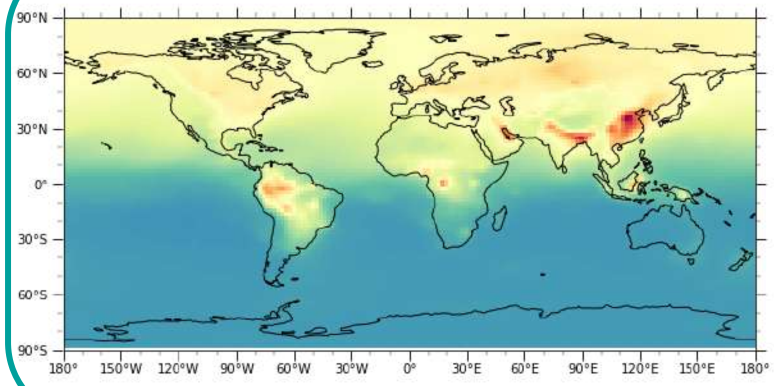


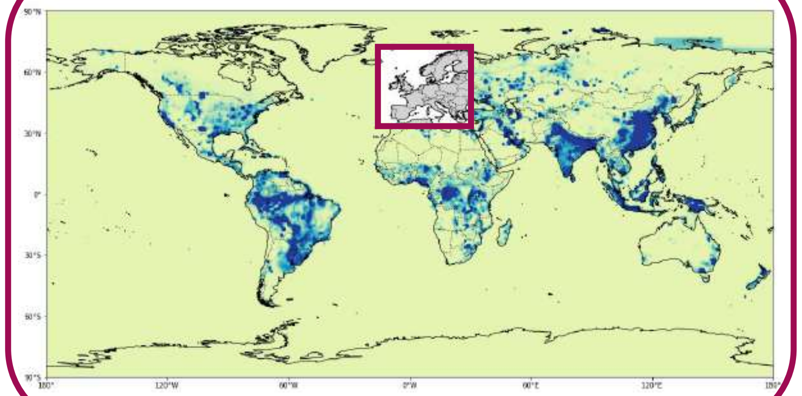
FLEXPART Footprint for inversion network, annual average 2022

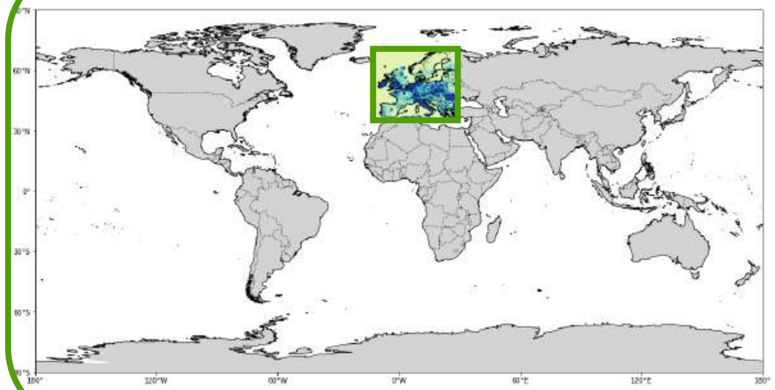
CALCULATION OF A PRIORI CH_4 CONCENTRATIONS

$$y^{pri} = y^{cini} + y^{bkg} + y^{ghg} + y^{pri}$$

$$y^{pri} = 0$$



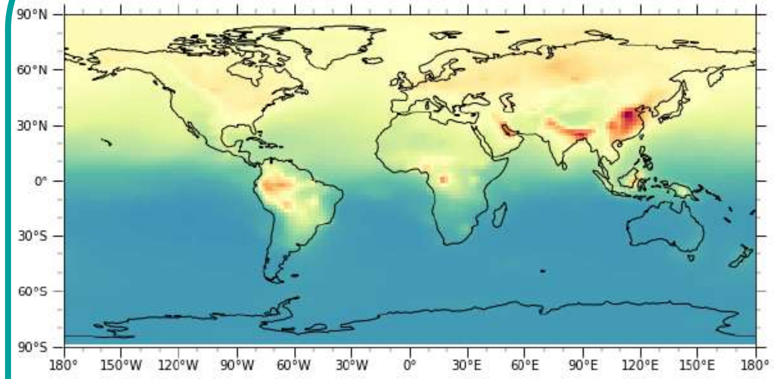




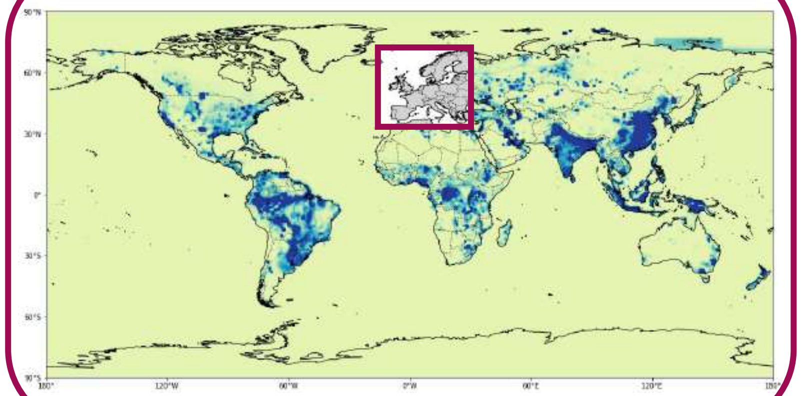
CALCULATION OF A POSTERIORI CH_4 CONCENTRATIONS

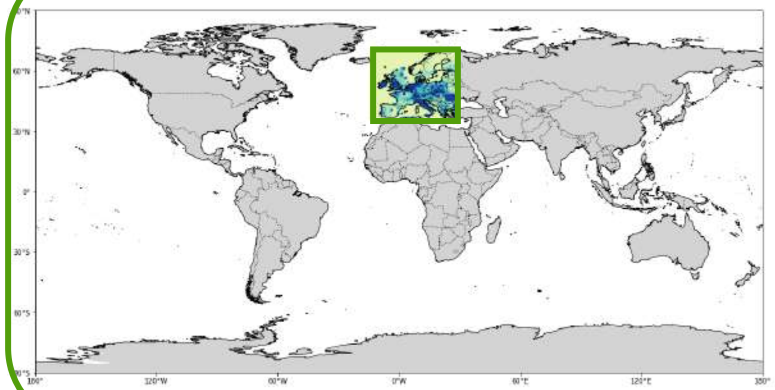
$$y^{pos} = y^{cinipos} + y^{bkg} + y^{ghg} + y^{post}$$

Contribution from the posterior state vector

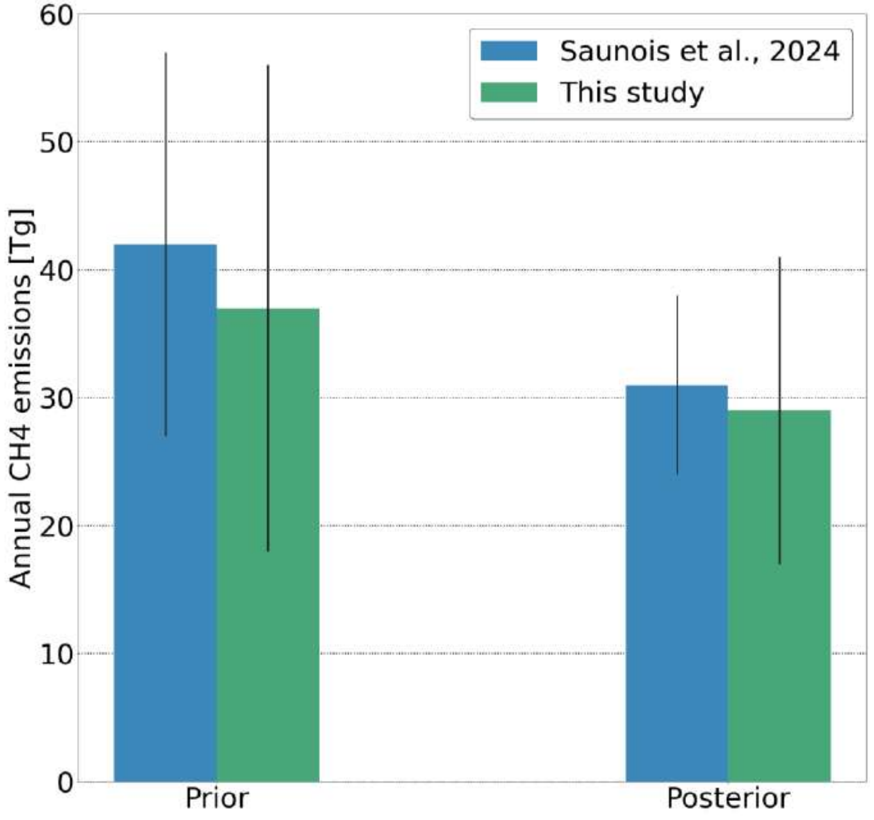


+ Optimization factor





ANNUAL CH_4 FLUXES IN EUROPE

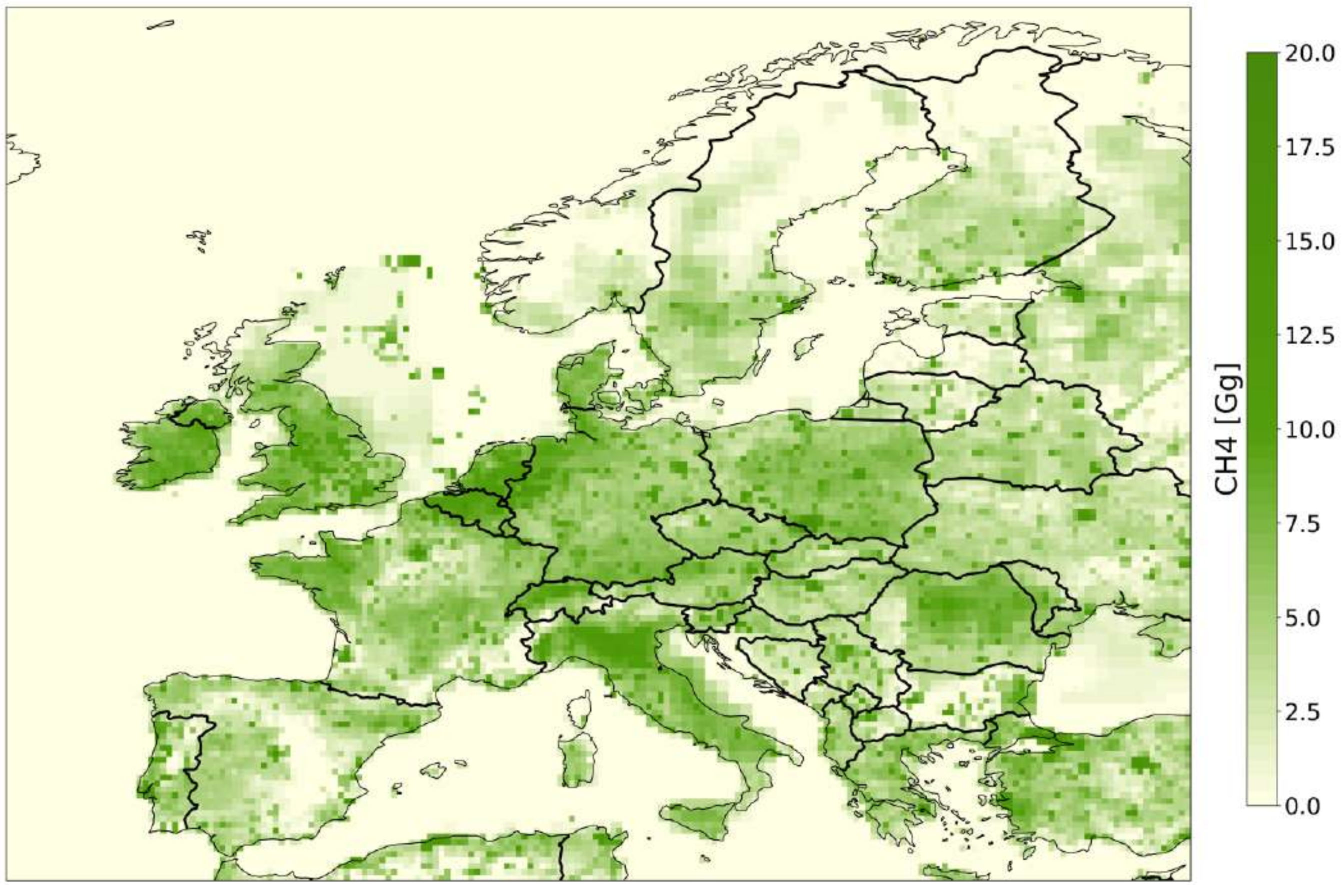


Total prior Europe: **37 Tg** [18 Tg – 56 Tg]

- Saunois et al., 2024: ~42 Tg [29 Tg – 57 Tg]

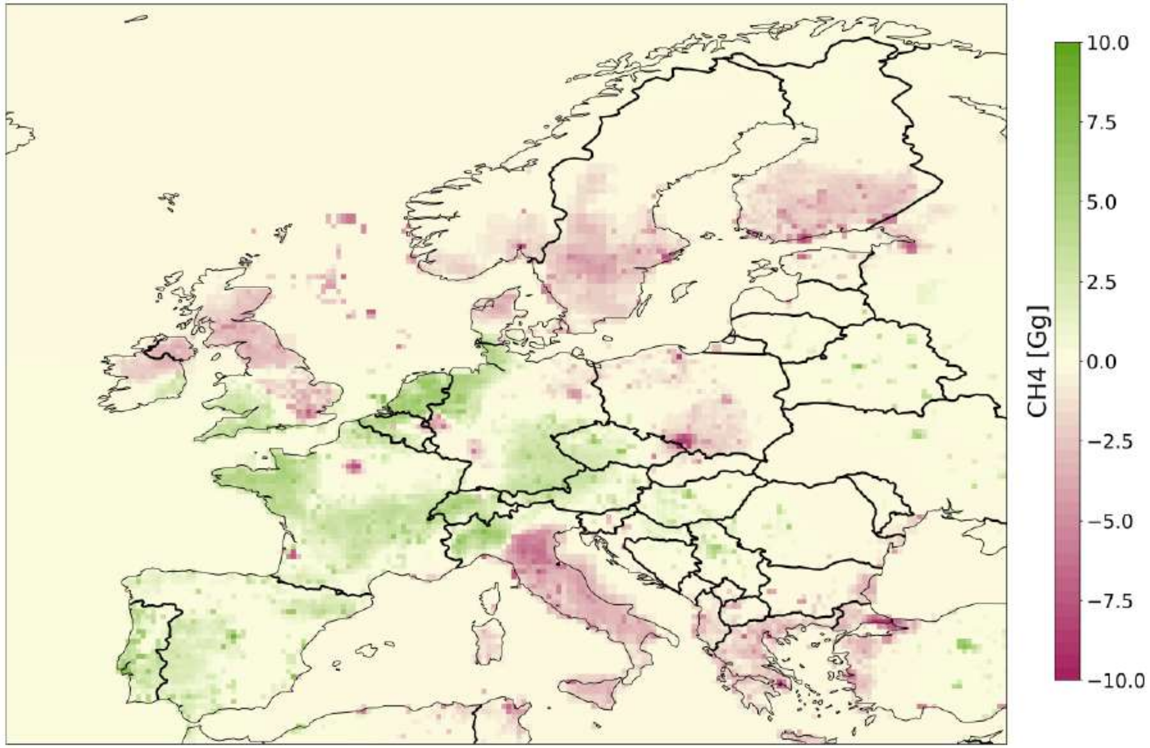
Total posterior Europe: **29 Tg** [17 Tg – 41 Tg]

- Saunois et al., 2024: ~31 Tg [24 Tg – 36 Tg]

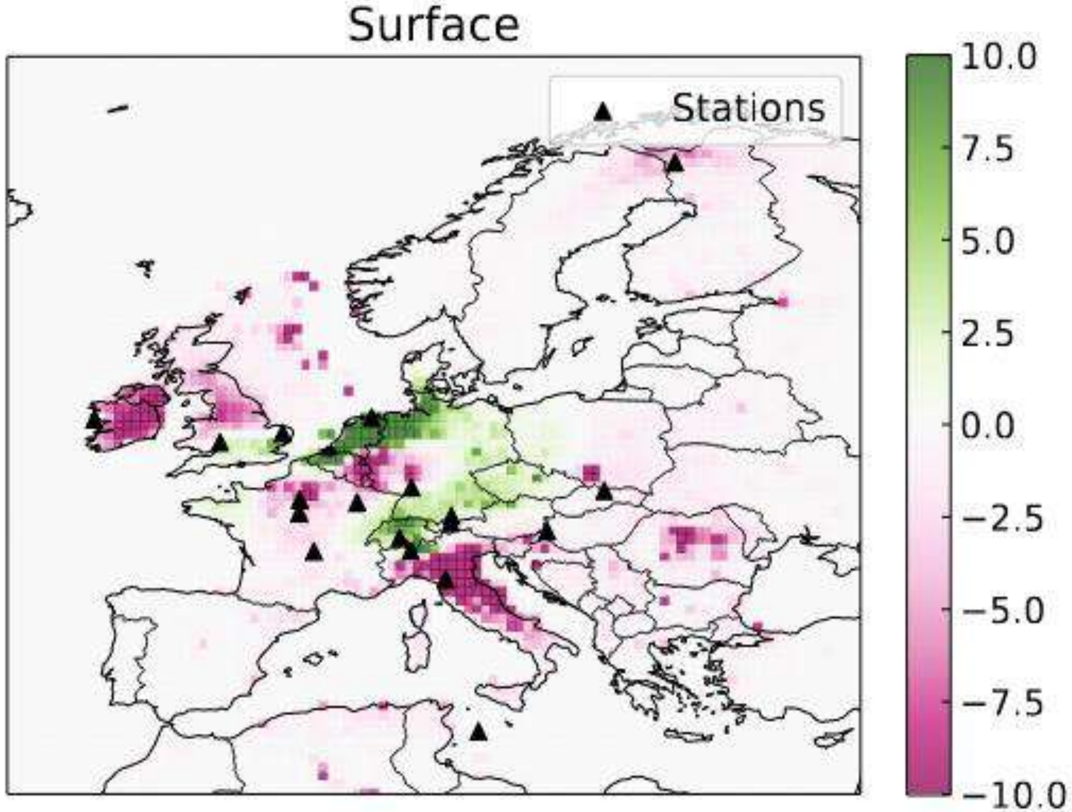


Prior CH_4 fluxes in Europe, monthly average 2022

CH_4 FLUX INCREMENT IN EUROPE



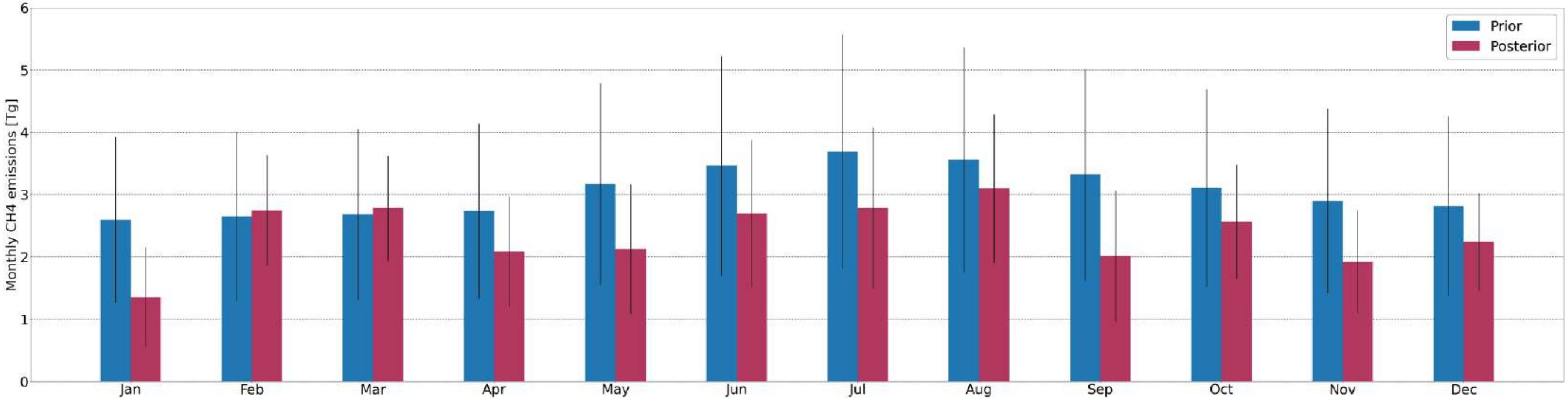
Increment of CH_4 fluxes in Europe, monthly average 2022



Increment of CH_4 fluxes in Europe, 2019 (CIF-CHIMERE)
Figure: A. Sicsik-Paré (ESA SMART-CH4), personal communication

- **Posterior** fluxes predominantly **increased** in **western, south-western and central Europe**
- **Posterior** fluxes predominantly **decreased** in **Scandinavia, Italy, the UK and south-eastern Europe**

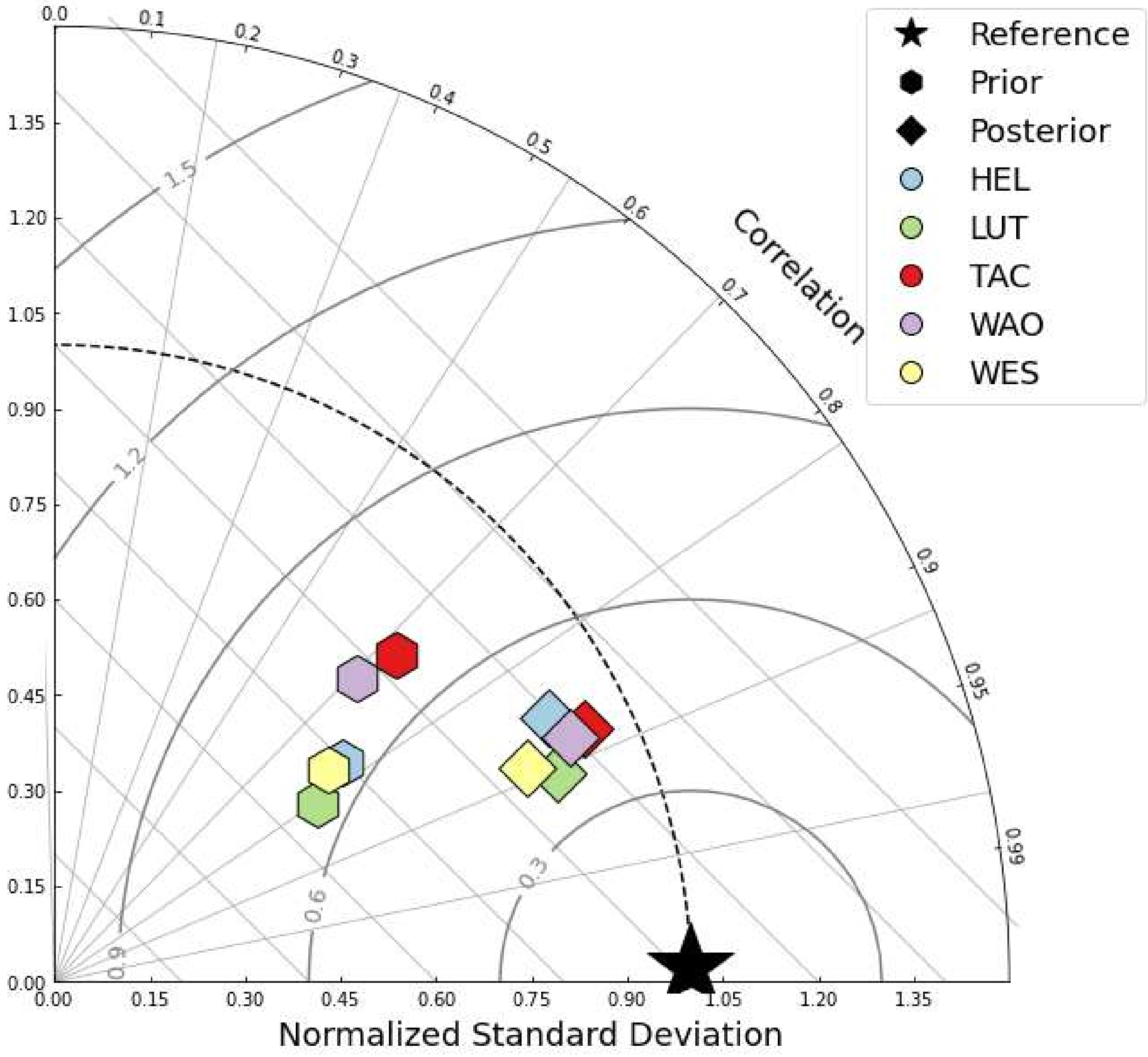
MONTHLY CH_4 FLUXES IN EUROPE



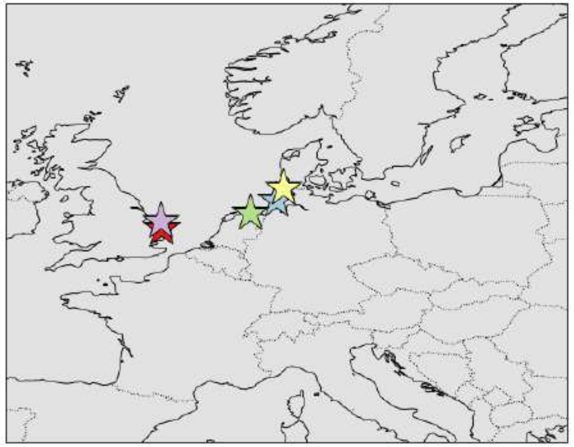
Comparison of prior and posterior CH_4 fluxes in Europe, monthly total 2022

- **Prior** CH_4 fluxes:
  → **Higher during summer** months due to influence of **natural CH_4 sources**
  → Maximum in July (3.7 Tg), minimum in January (2.6 Tg)
- **Posterior** CH_4 fluxes:
  → **Lower than prior** for most months
  → Highest discrepancies in January and September (~1.3 Tg lower)
  → Posterior only slightly higher than prior in February and March (~0.1 Tg higher)

Evaluation of Inversion Performance



Taylor diagram for sites close to North Sea



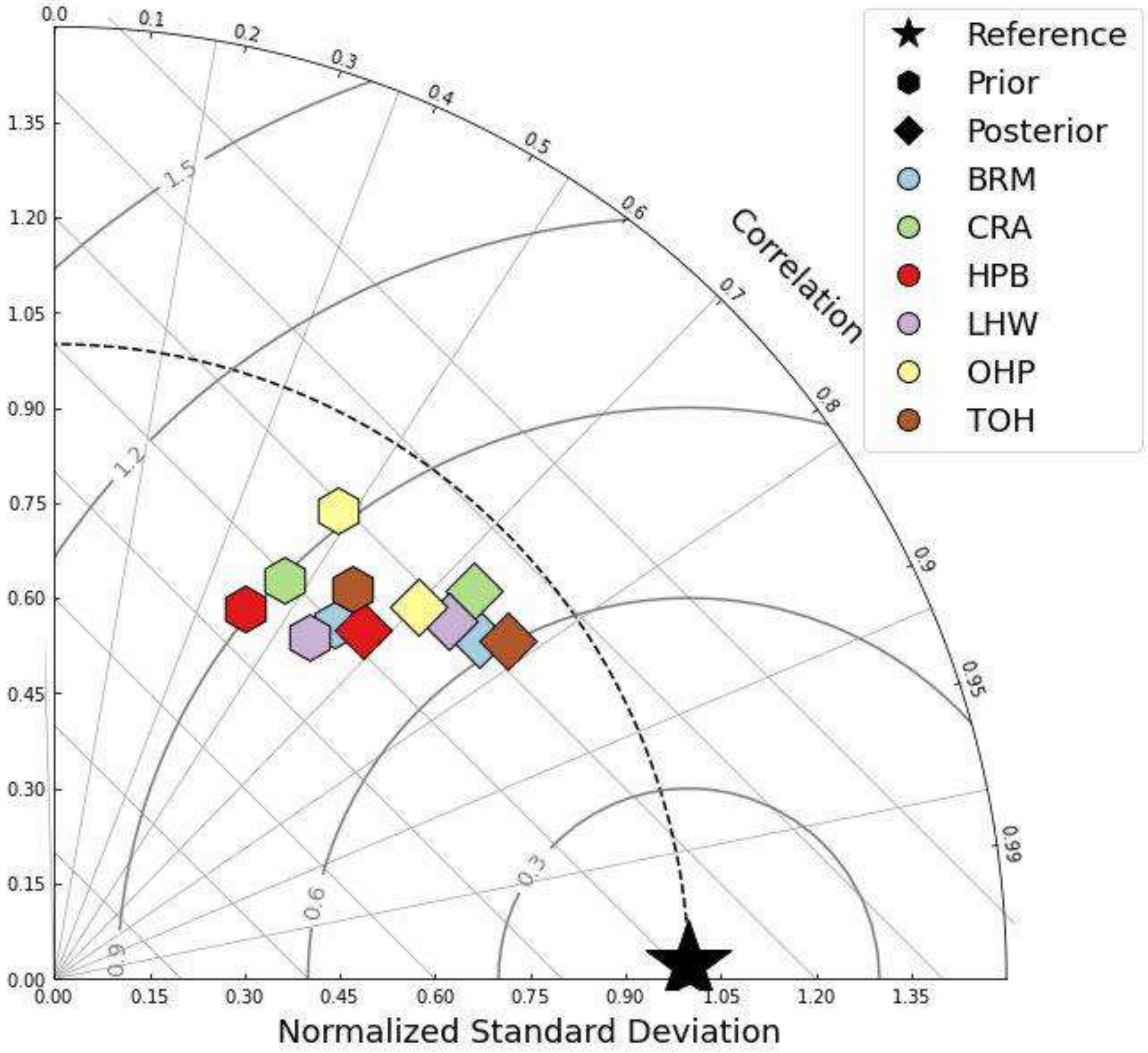
- Taylor diagram shows how well modelled patterns match observations
- **Improvement** most evident at stations **close to North Sea**:

  → Prior concentrations already match observations well

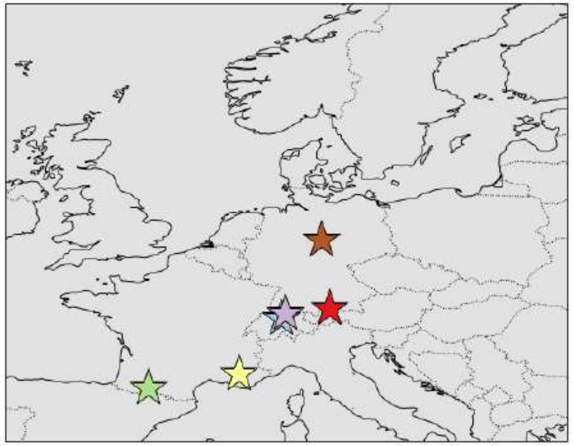
  → **Underestimation of the variability** in prior CH_4 concentrations

  → **Posterior** concentrations show **better agreement** with amplitude and pattern of observations

EVALUATION OF INVERSION PERFORMANCE



Taylor diagram for sites at high altitudes



- **Least improvement** at observation sites at **high altitudes** (600 – 1000 masl):

  → **Little difference between** prior and posterior CH_4 concentrations

  → **Posterior** CH_4 concentrations show **slight improvement** in variability

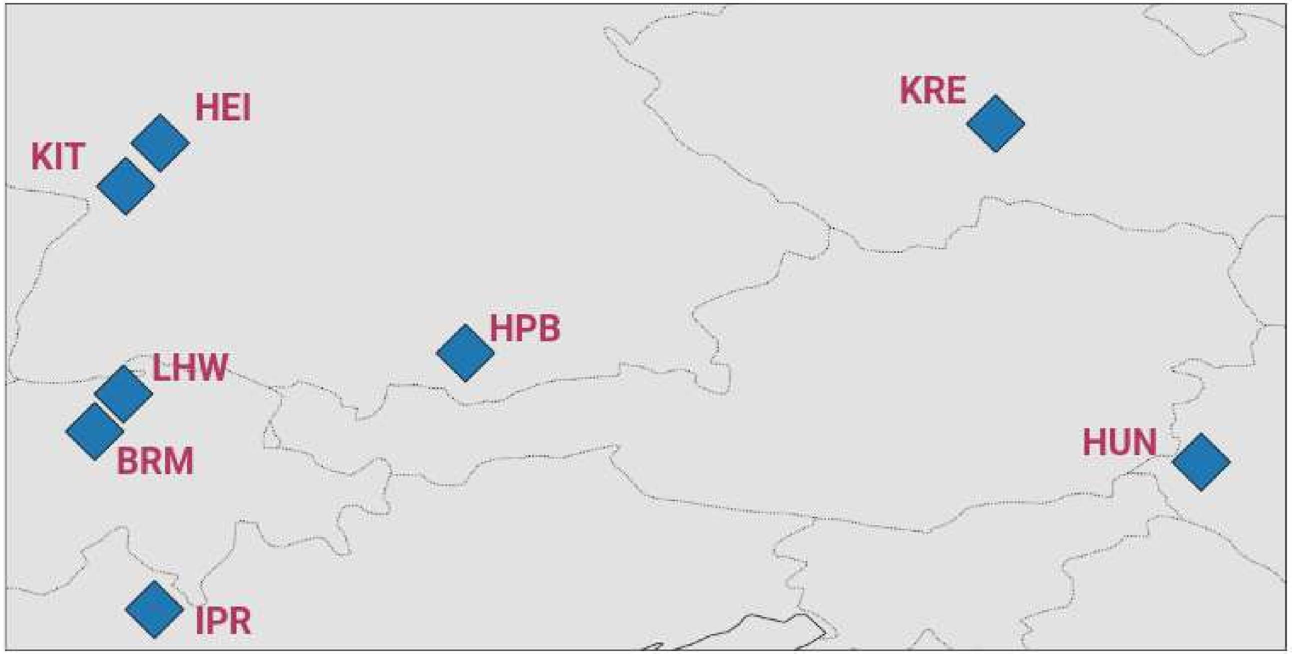
  → Mountainous terrain more challenging to model and stations far from emission sources

OBSERVATIONS IN AND AROUND AUSTRIA

- In 2022: **3 observation** sites measuring CH_4 concentrations **in Austria**
  - → Sonnblick (SNB): mountain site in the Alps
  - → Innsbruck Atmospheric Observatory (IAO): measurements on rooftop in city centre of Innsbruck
  - → Vienna Urban Carbon Laboratory (VUCL): measurements at Arsenal tower since May 2022

- **Mountain sites** (above 1000 masl) **excluded** from inversion
  - → **Observations lower** than **modelled background** concentrations led to high negative CH_4 fluxes
  - → **Exclusion** of **SNB** and **5 ICOS sites** in vicinity of Austria

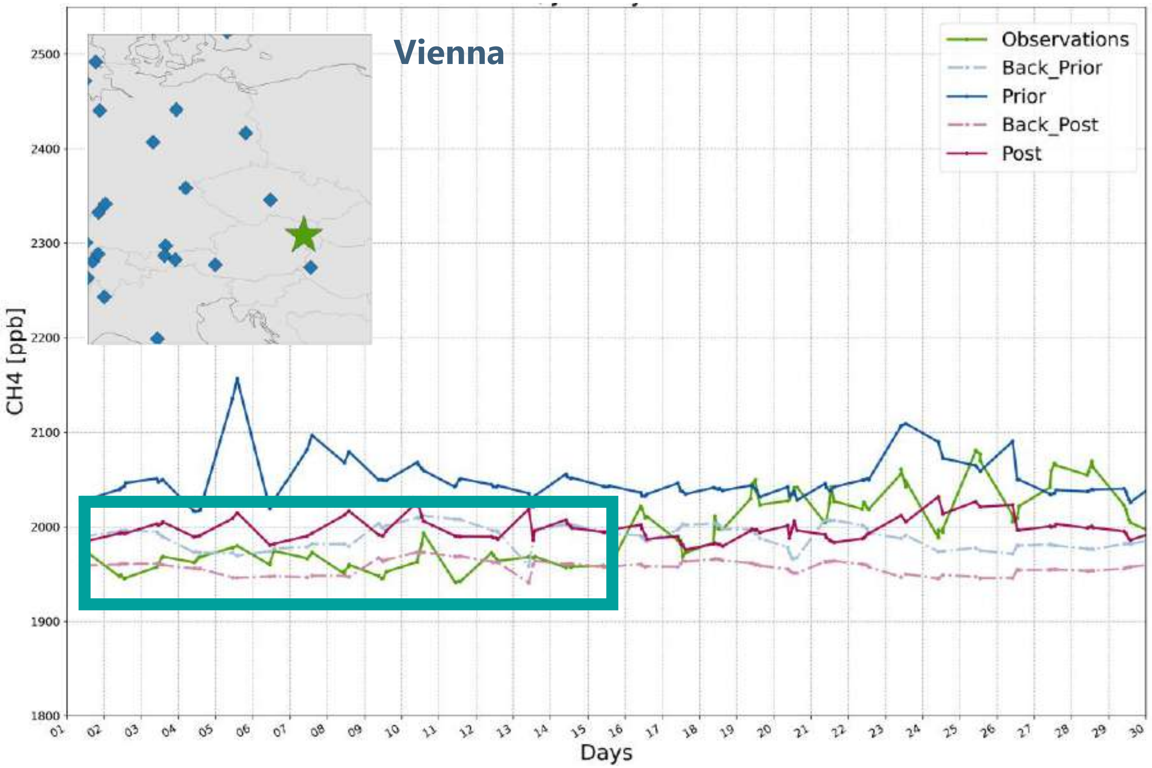
- 5 ICOS sites remaining in vicinity of Austria
  - → 3 of them at high altitudes



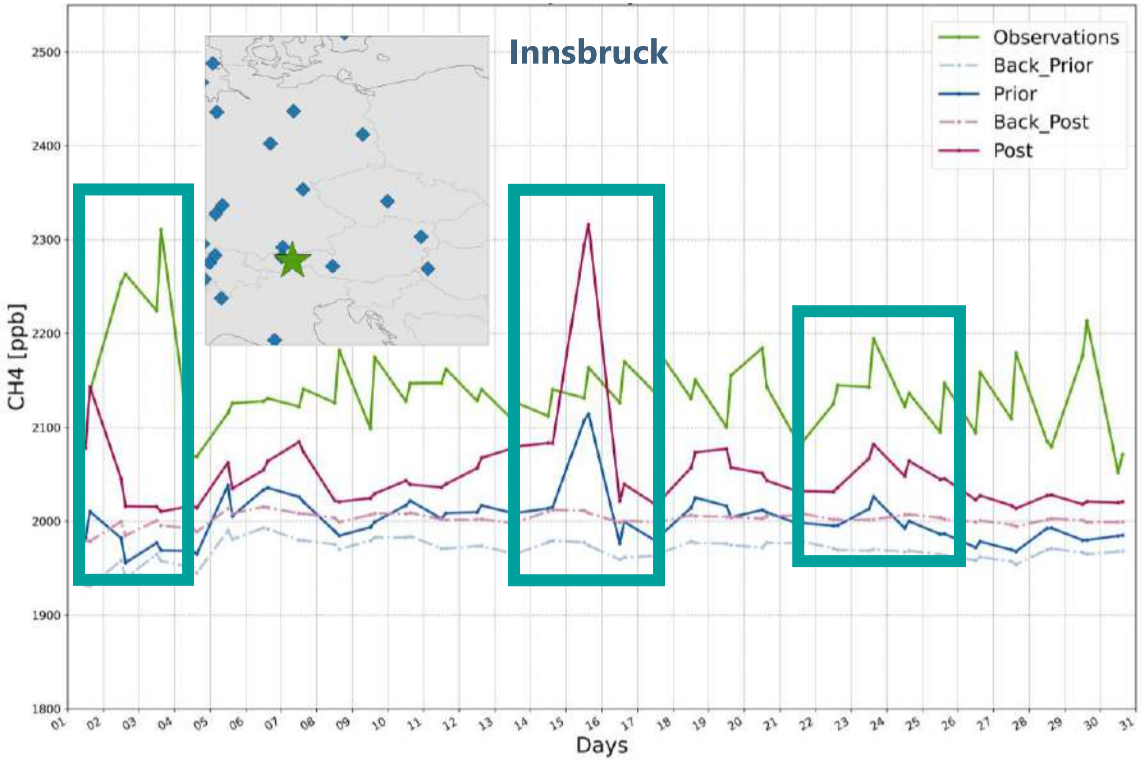
In situ observation sites in and around Austria

CH_4 CONCENTRATIONS IN AUSTRIAN CITIES

June 2022



January 2022



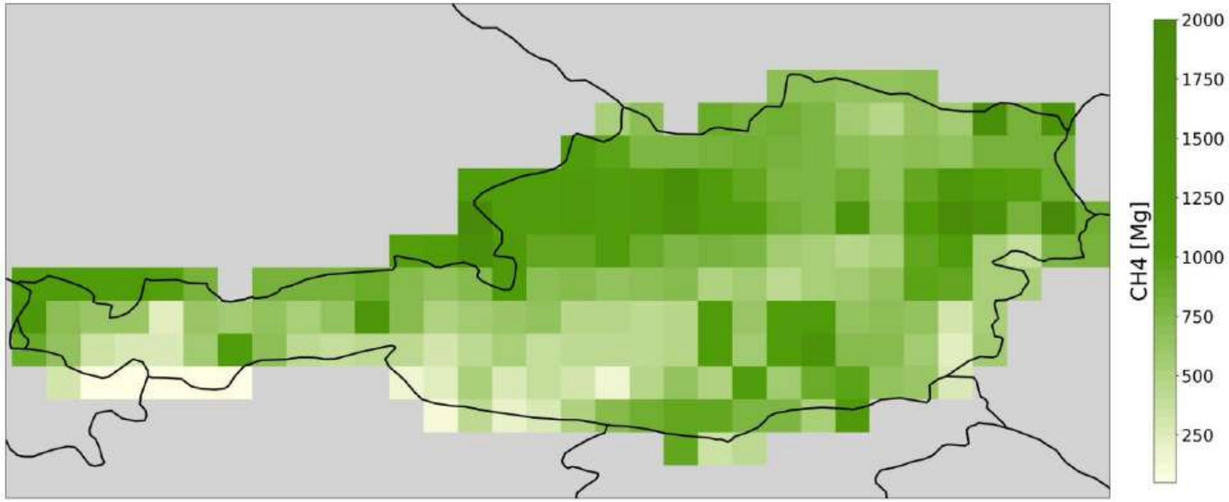
Vienna

- **Observations lower** than modelled concentrations
- **Background** concentrations partly **too high**
  → Especially during summer months
- Measurement peaks not well captured

Innsbruck

- **Observations much higher** than modelled concentrations
  → Both prior and posterior
- Measurement peaks not well captured

ANNUAL CH_4 FLUXES

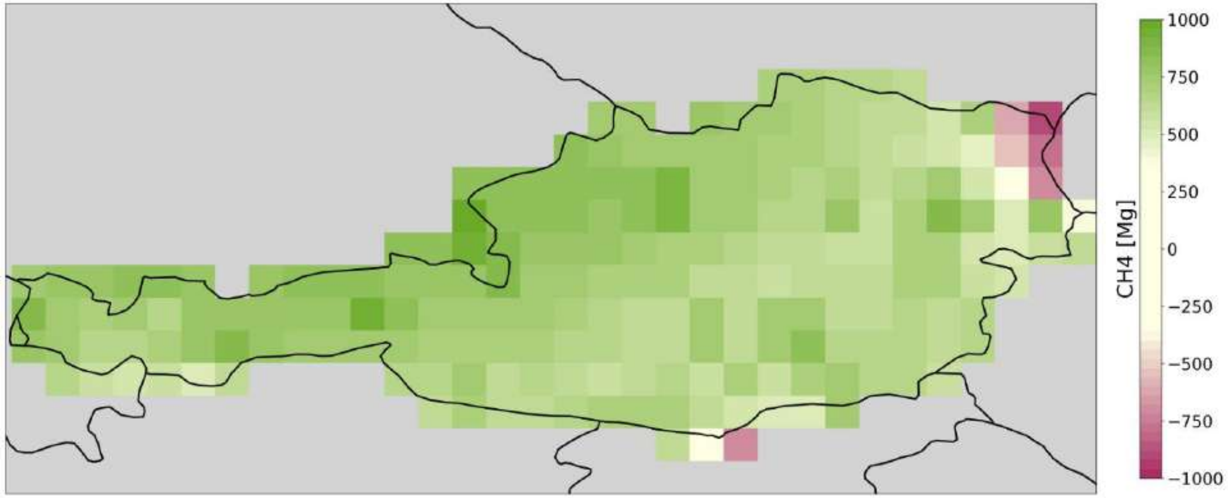


Prior CH_4 fluxes in Austria, monthly average 2022

- **Total prior**: **700 Gg** [350 Gg – 1050 Gg]
- **Anthropogenic** prior: **475 Gg** [237.5 Gg – 712.5 Gg]

  → **Reported** CH_4 emissions in Austria 2022: ~**260 Gg** (NIR Austria, 2024)

  → Lower than estimated prior, but within uncertainty ranges



Increment of CH_4 fluxes in Austria, monthly average 2022

- **Posterior CH_4 fluxes increased** all over Austria
- Slight reduction in north-east and south of Austria
- **Total posterior**: **910 Gg** [752 Gg – 1068 Gg]

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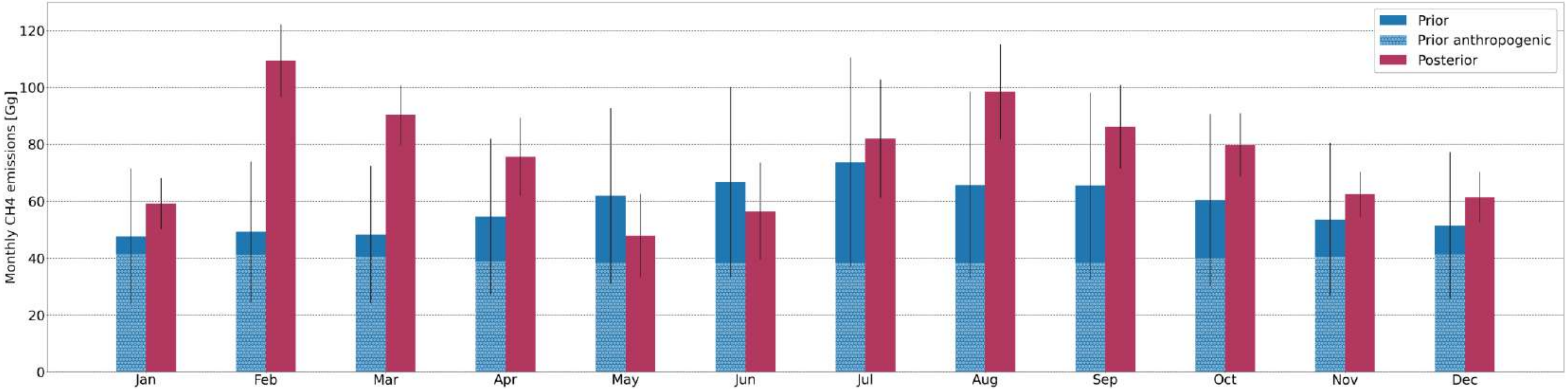
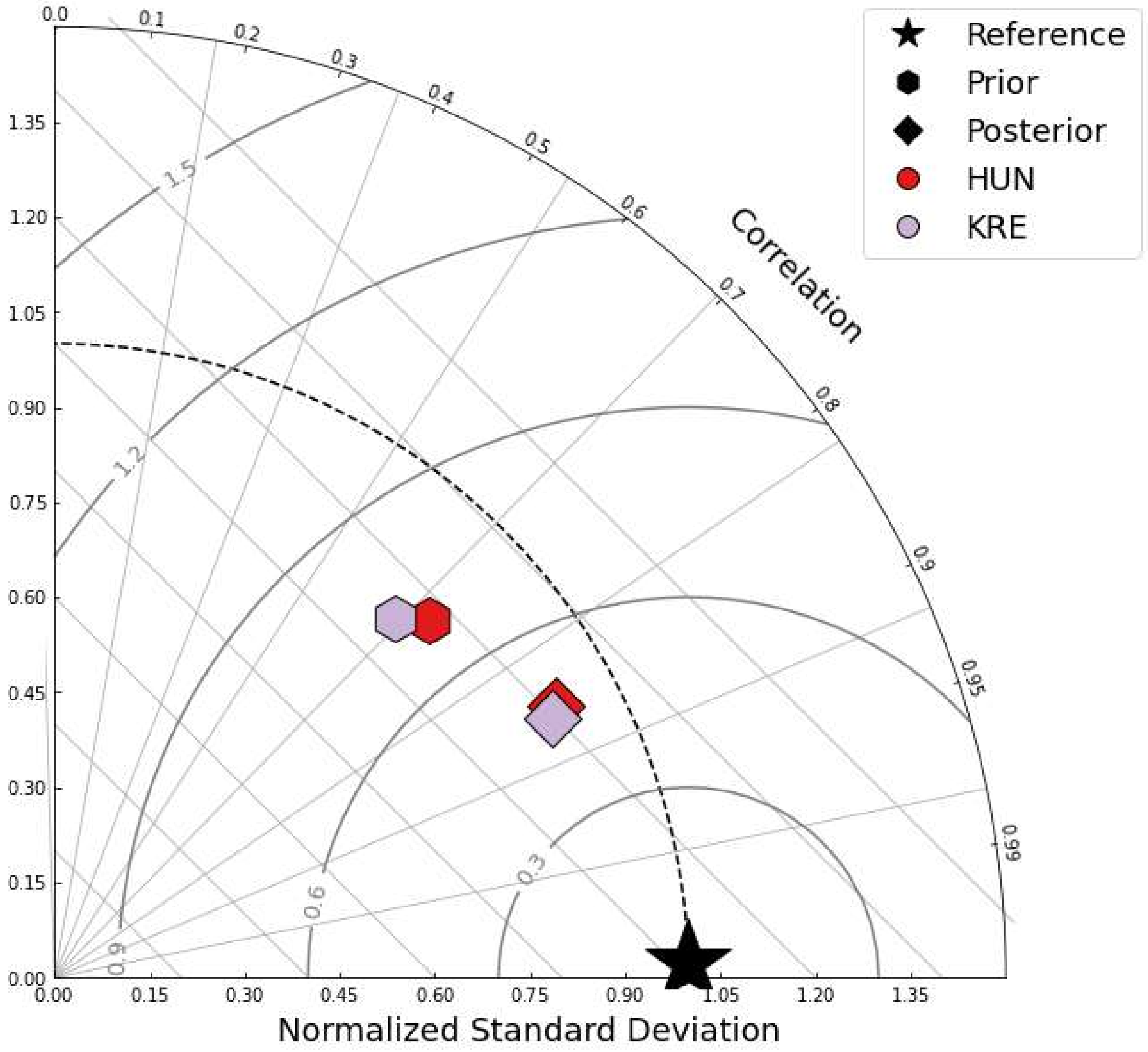
Monthly CH_4 fluxes in Austria



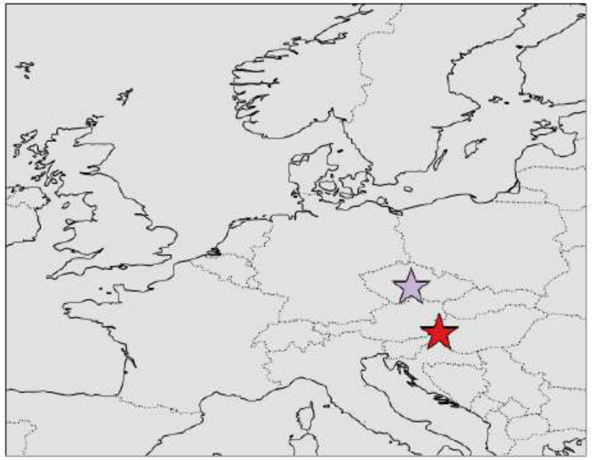
Comparison of prior and posterior CH_4 fluxes in Austria, monthly total 2022

- **Prior** CH_4 fluxes:
  - → **Higher during summer** months due to influence of natural CH_4 sources
  - → **Anthropogenic** CH_4 emissions **nearly constant** (between 38.1 Gg and 41.3 Gg)
- **Posterior** CH_4 fluxes:
  - → **Higher than prior** for most months
  - → Minimum in May (47.9 Gg)
  - → Posterior CH_4 fluxes **significantly higher** than prior in **February** (~60 Gg) and **March** (~42 Gg)
  - → Except February and March: posterior CH_4 fluxes within uncertainty ranges of prior

EVALUATION OF INVERSION PERFORMANCE



Taylor diagram for sites close to Austria



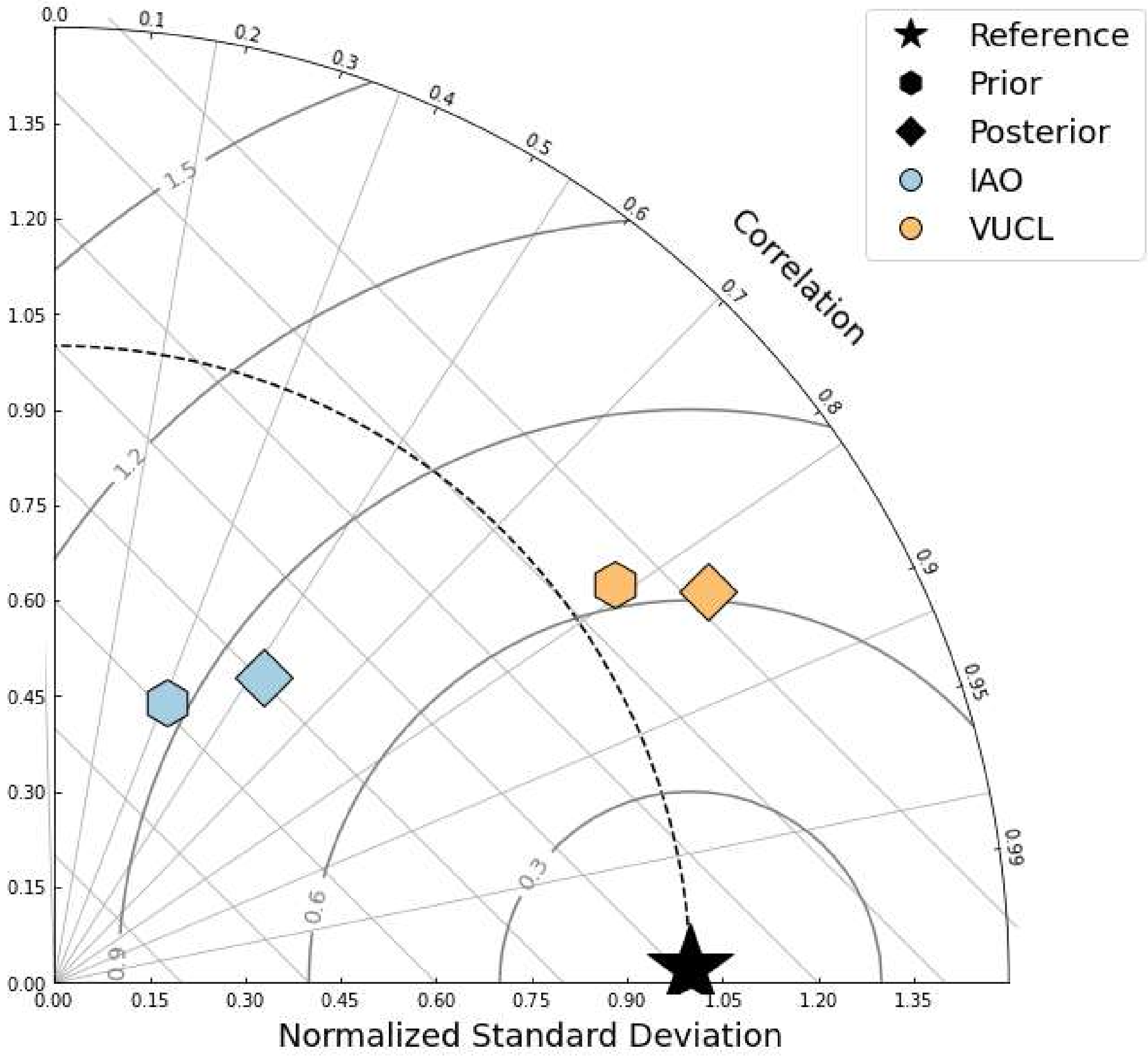
- **3 stations** close to Austria at **high altitudes**

  → **Posterior** CH_4 concentrations show **slight improvement** in variability

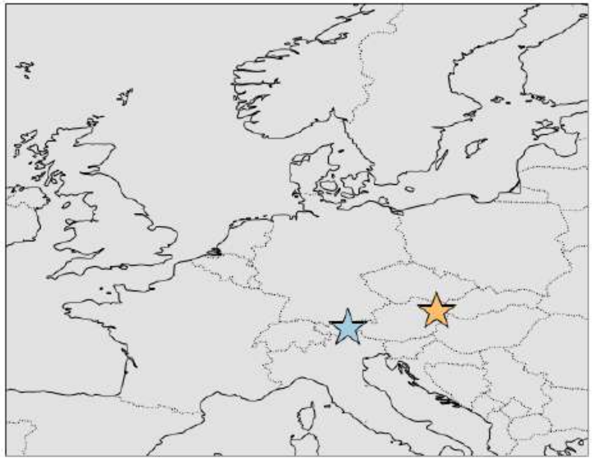
- **2 stations** close to Austria in **rural areas**

  → **Posterior** CH_4 concentrations show **significantly better agreement** with observations

EVALUATION OF INVERSION PERFORMANCE



Taylor diagram for sites in Austria



- **2 urban sites** in Austria excluded from inversion

  → **Innsbruck**: **slight improvement** in posterior CH_4 concentrations but still not good match with observation

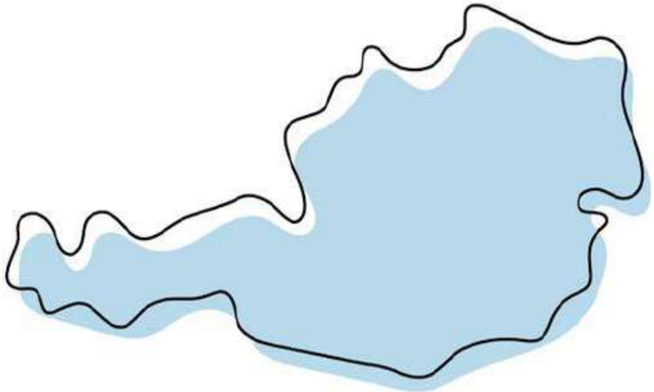
  → **Vienna**: modelled CH_4 concentrations overestimate variability, **prior better than posterior**

  → Data not suitable to verify inversion

CONCLUSION FOR IN SITU INVERSION

Europe

- Prior fluxes possibly overestimated for 2022
- Good agreement with other studies
- Improvement of posterior CH_4 fluxes especially in regions well constrained by observations (e.g. north-west Europe)

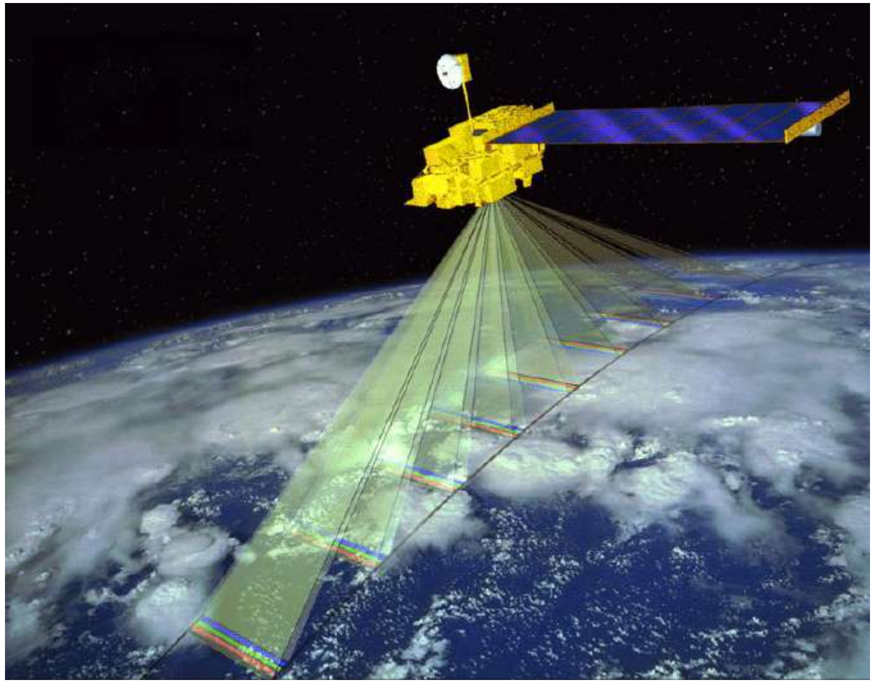


Austria

- Prior fluxes possibly underestimated for 2022
- Lack of observation sites in and around Austria
- No suitable data for verification of posterior CH_4 fluxes

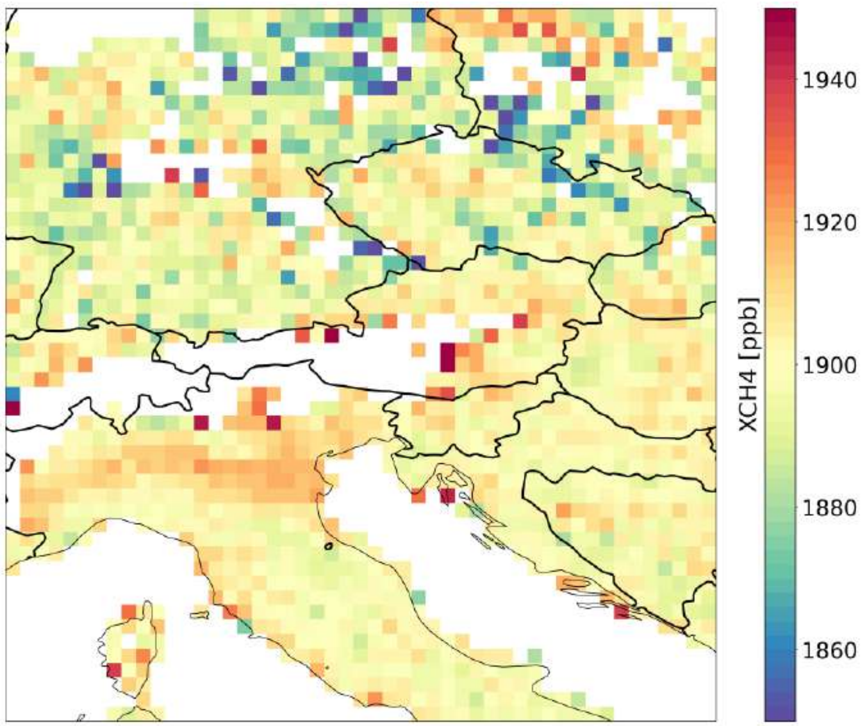
SATELLITE INVERSION SET UP

- Observation from **TROPOMI** instrument, data product from University of Bremen
- **Global output** at 1° x 1° spatial resolution
- **Nested output** at 0.25° x 0.25° over Austrian domain
  - → Longitudes: 7° E to 19° E
  - → Latitudes: 41° N to 53° N
- **Trajectories** of particles calculated **10 days** backwards in time
- Two months of 2022: **January** and **July**

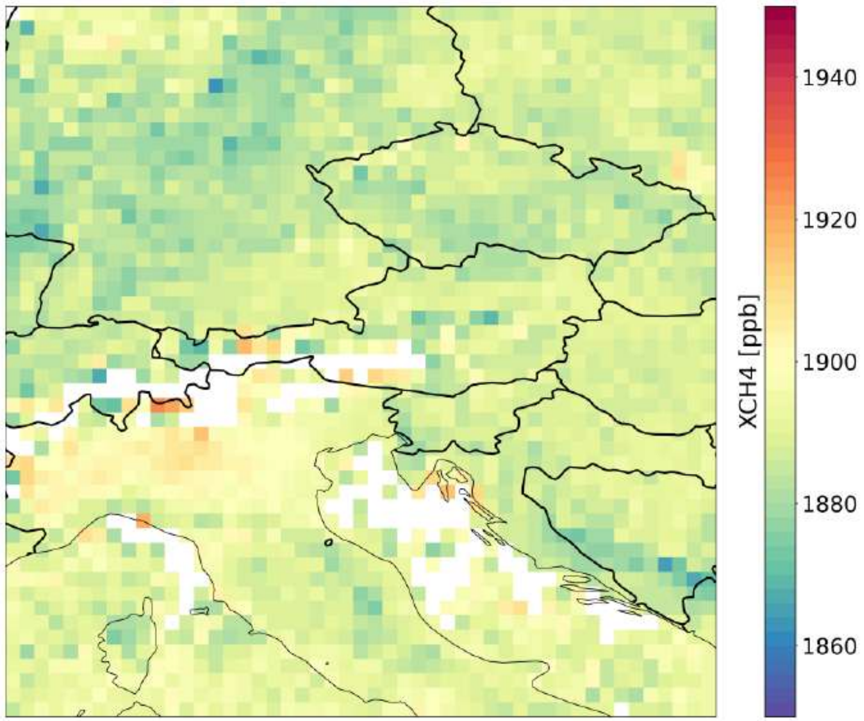


- Inversion domain: **Austrian domain**
- CH_4 fluxes optimized at **monthly temporal resolution**
- **Initial mixing ratios** based on concentration fields (**FLEXPART CTM**)

TROPOMI DATA OVER INVERSION DOMAIN



TROPOMI observations, monthly average January 2022



TROPOMI observations, monthly average July 2022

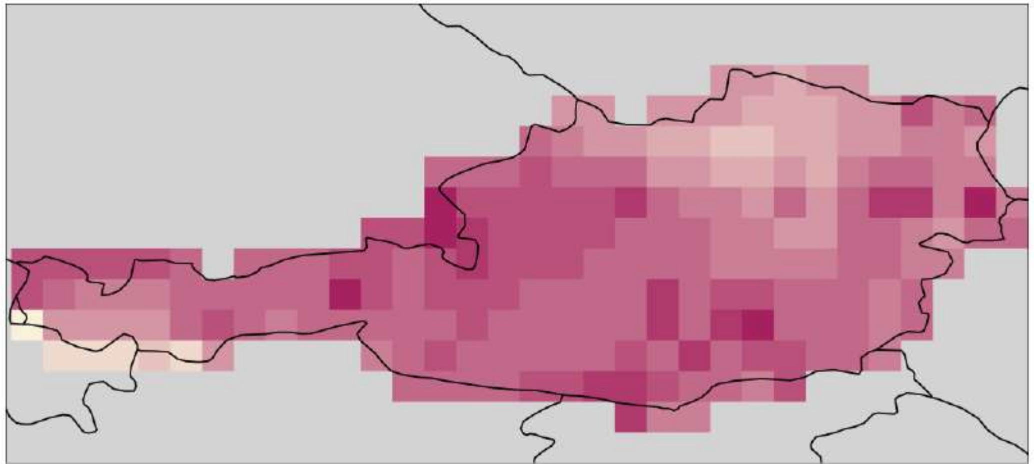
January:

- **High heterogeneity** of observations
- **Outliers** in observations, e.g. **surrounding the Alps**
- Possibly **influenced** by **albedo**, cloud coverage, solar zenith angle and/or less sunlight in northern hemisphere

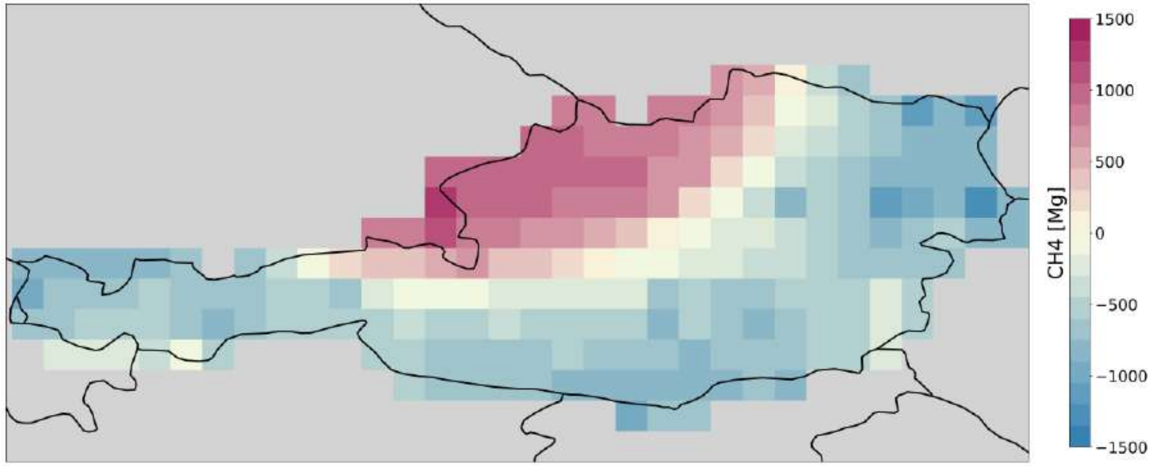
July:

- **Observations homogeneous**
- Slightly higher concentrations surrounding the Alps

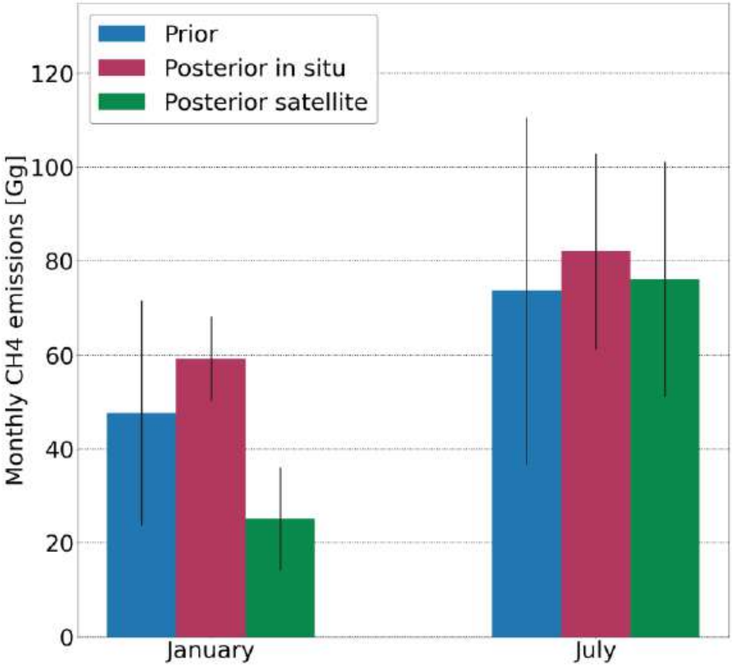
COMPARISON IN SITU AND SATELLITE INVERSION



Difference in situ and satellite inversion, January 2022



Difference in situ and satellite inversion, July 2022



January:

- **Satellite inversion** shows **poor agreement** with in situ inversion
- **In situ** inversion **far higher** in all of Austria
- Satellite inversion (~25 Gg) lower than both in situ inversion (~59 Gg) and prior CH_4 fluxes (~48 Gg)

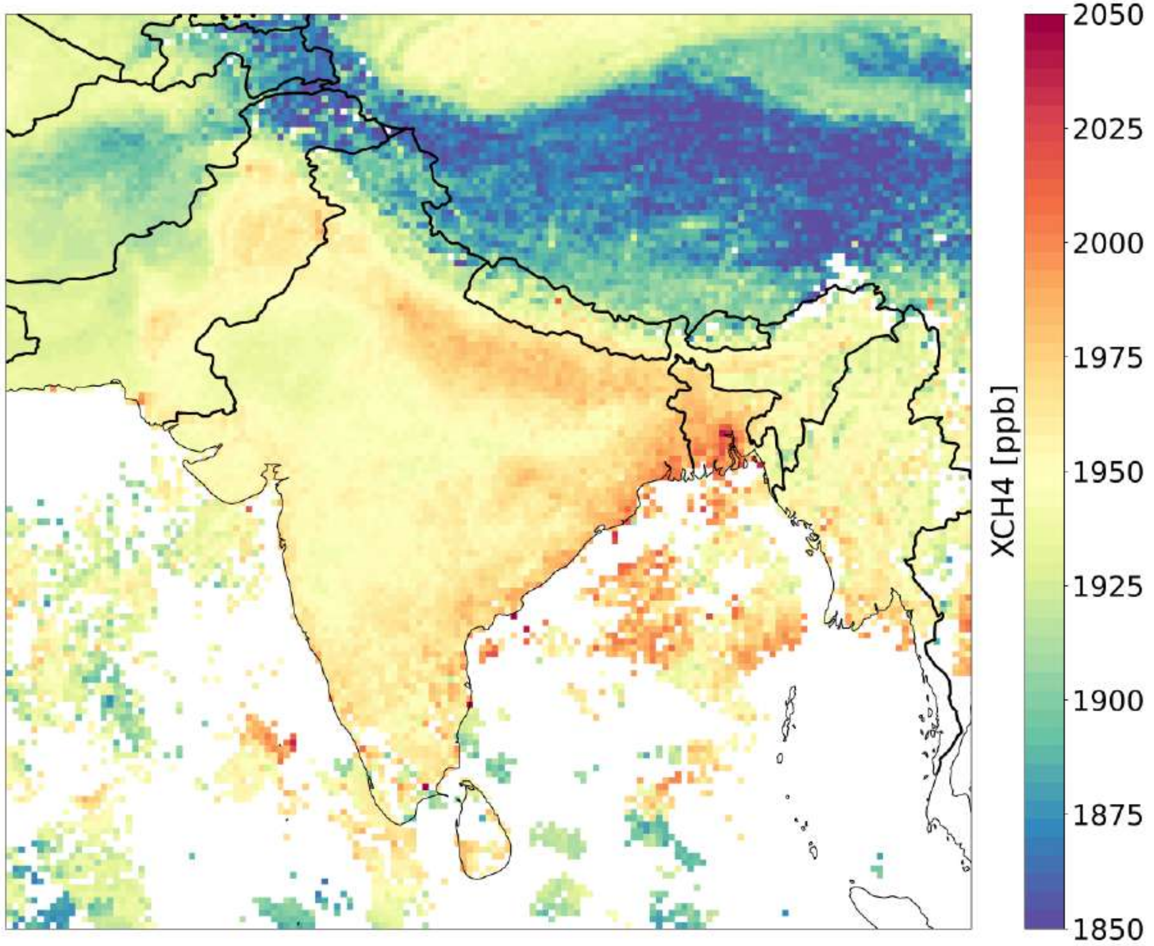
July:

- **In situ** inversion **higher** in the **north-west of Austria**
- Both in situ inversion (~82 Gg) and satellite inversion (~76 Gg) close to prior CH_4 fluxes (~74 Gg)

SATELLITE INVERSION OVER SOUTH ASIA

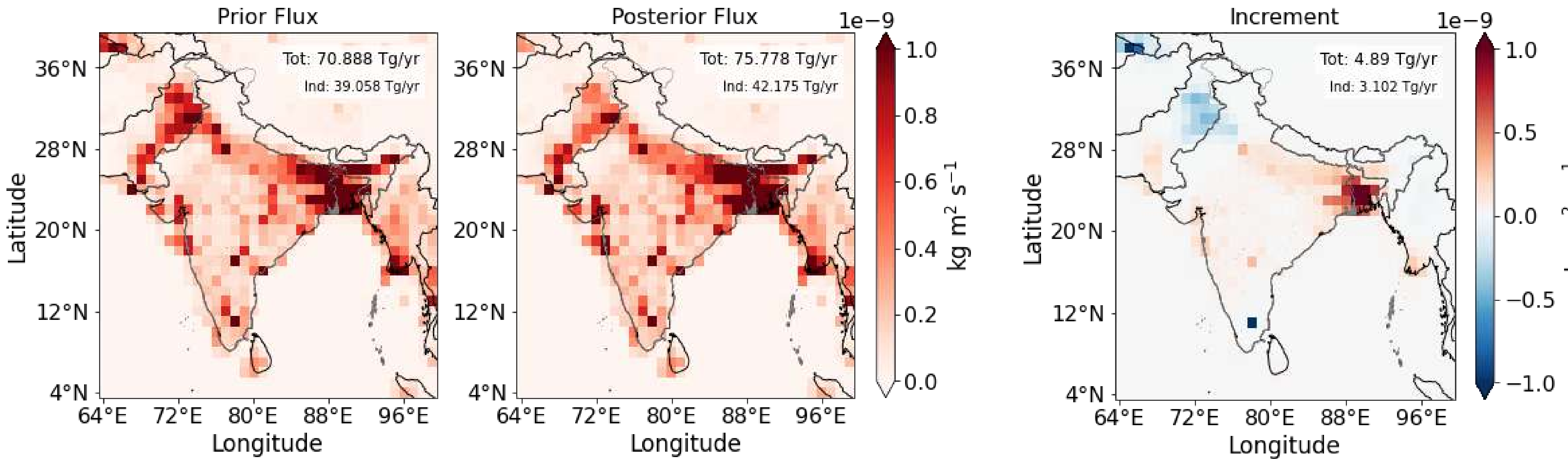
- Study over **South Asia** by Rakesh Subramanian for **year 2020**
- Particles followed **20 days backward** in time
- Spatial resolution: 1° x 1°

→ Regions where **high CH_4 emissions** occur can already be **recognized in TROPOMI observations** (e.g. Bangladesh and North India)



TROPOMI observations, monthly average September 2020

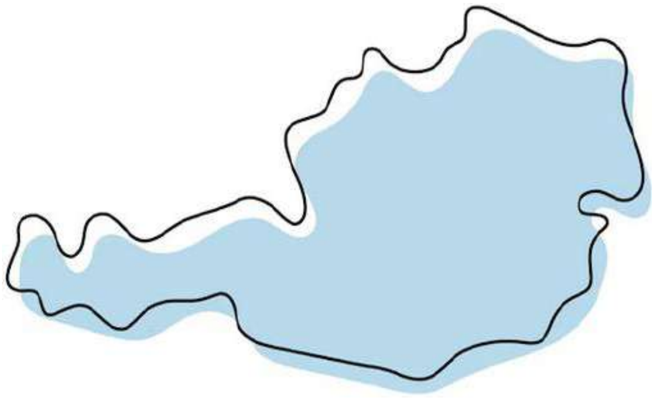
SATELLITE INVERSION OVER SOUTH ASIA



Prior and posterior CH_4 fluxes for 2020, Preliminary results from Rakesh Subramanian

- **Posterior** CH_4 fluxes ~76 Tg → **5 Tg higher** that prior fluxes
- Positive increments in the eastern and northeastern parts of India and Bangladesh, higher waste-related emissions in Delhi
- **Underestimated** sectors: **agriculture** and **wetlands**

Conclusion for satellite inversion



Austria

- Inversion shows good agreement with in situ inversion in summer but poor agreement during winter
- Limited quality of data throughout the year e.g. because of terrain in and around Austria
- Inversion results currently not reliable enough for Austrian domain

South Asia

- Better quality of data throughout the year
- Valuable for regions with limited accessibility of in situ observations and poor estimated of prior CH_4 fluxes

SUMMARY

Limited number of sites in and around Austria

Many mountain sites close to Austria → not optimal for inverse modelling

Urban sites in Austria could not improve constraints

Current satellite observations not reliable for Austria around the whole year

No suitable data for verification

FFG Forschung wirkt.
Bundesministerium Klimaschutz, Umwelt, Energie, Mobilität, Innovation und Technologie
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PERSPECTIVES

MODELLING

Improve spatial resolution over Austria (e.g. FLEXPART-WRF)
→ Better prior estimates especially of natural CH_4 emissions needed

Improve background estimates (e.g. FLEXPART-LCM)

OBSERVATIONS

Beneficial for Austria to become part of ICOS network
→ Austria more attractive for European projects

Possibly better satellite data in upcoming missions (e.g. MERLIN)

Support from mobile campaigns (e.g. for verification)

Thanks For Your Attention

University of Vienna Team

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Klimaschutz, Umwelt,
Energie, Mobilität,
Innovation und Technologie