TOAR-2 chemical reanalysis WG report

Advancing understanding of tropospheric ozone through integration of satellite and in-situ observations in chemical reanalysis

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Chemical reanalysis Focus Working Group

Co-leads: Kazuyuki Miyazaki, Dylan Jones, Helen Worden

- Evaluate current chemical reanalysis products to assess their potential (Jones et al.).
- Assesses the relative importance of individual observations (e.g., ozone vs precursor) to improve ozone analyses and help to design observing systems (Sekiya et al.)
- Evaluate representativeness of FT ground-based ozone measurements (Miyazaki et al.).
- Human health impact assessment (Wang et al)
- ML downscaling and bias correction (Miyazaki et al)

Satellite ozone assessment paper

Co-leads: Daan Hubert, Kazuyuki Miyazaki

- Provide present day maps, long-term changes, and attributions of tropospheric ozone
- Evaluate agreements between satellite records and harmonized data products.

A·RIP

APARC Reanalysis Intercomparison (A-RIP)

INTERNATIONAL GLOBAL ATMOSPHERIC CHEMISTRY IGAC

TOAR tropospheric ozone assessment report Phase II

Overview and Goals in support of TOAR-II

- **Publication 1:** Evaluated chemical reanalyses with TOAR-II observations and other data to assess the potential of using reanalysis data for studying spatial gradients and trends at regional/global scales. **Lead: Dylan Jones**
- **Publication 2:** The relative importance of individual observations to improve surface ozone analyses were assessed to help design observing systems that better capture the distribution in surface and FT ozone. **Lead: Takashi Sekiya**

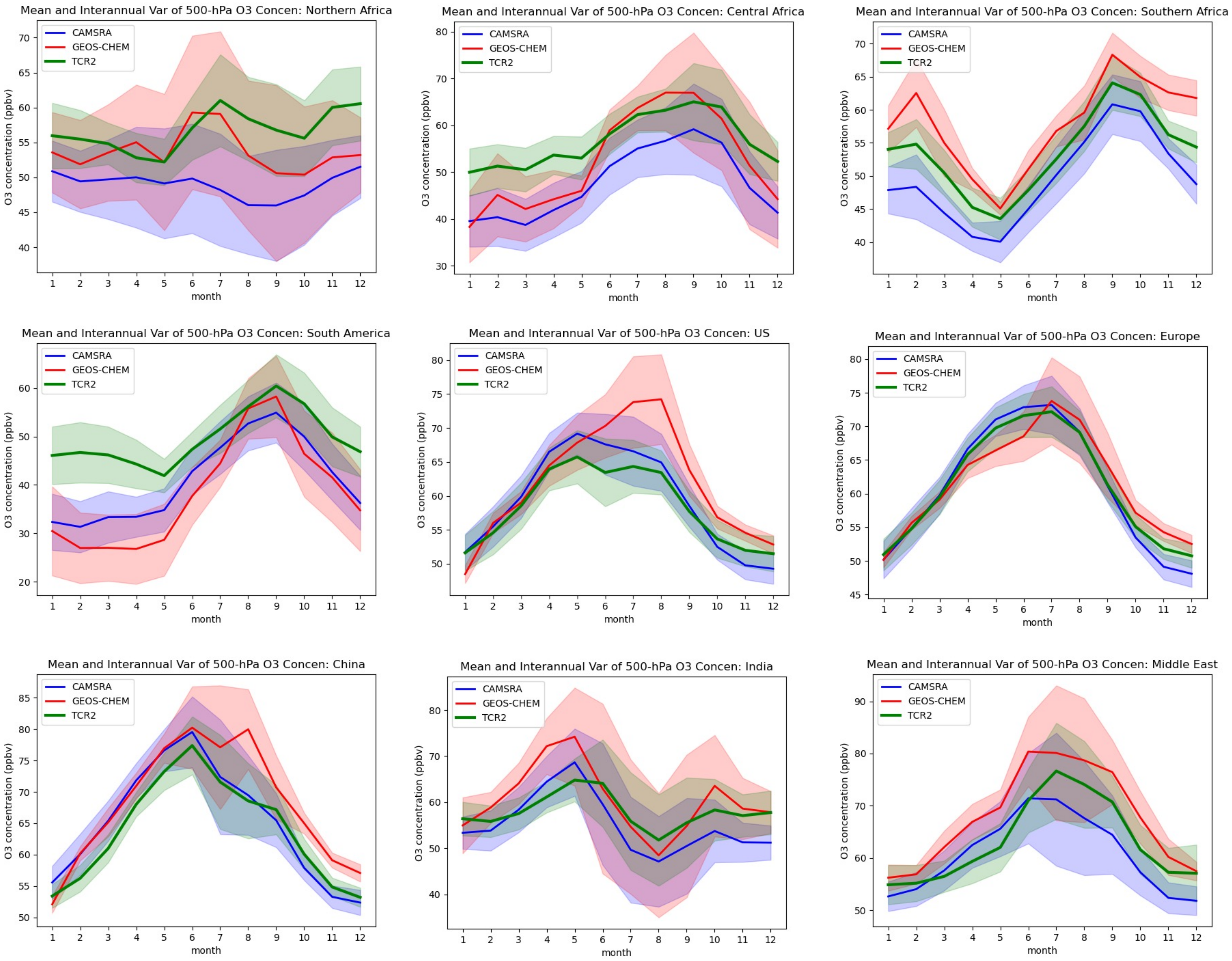
Next talk by Takashi Sekiya

- **Publication 3:** Well-validated chemical reanalysis ozone fields are used to improve the TOAR-II observation quality control processes and representativeness by providing a first guess information. **Lead: Kazuyuki Miyazaki**
- **Publication 4:** Machine learning application to identify the drivers of surface ozone bias in chemical reanalysis. **Lead: Kazuyuki Miyazaki**

Participating reanalysis systems

			Assimilated measurements				
Reanalysis system	**Domain**	**Resolution**	**Strato/Total O3**	**Tropo O3**	**Precursors**	**Surface**	**Scheme**
IASI-R (E. Emili)	GLOBAL, 0.1-1000 hPa	2° x 2°	MLS	IASI			3D-Var
CAMSRA (A. Inness)	GLOBAL	0.75° x 0.75°	SBUV, OMI, MLS, GOME2, SCIAMACHY, MIPAS, TROPOMI, OMPS		CO, NO2		4D-Var
RAQMS (B. Pierce)	GLOBAL, 0-60km	1° x 1°	OMI, MLS	OMI cloud cleared	CO, NO2 (offline NOx)		3D-Var
GEOS-CHEM (Z. Qu)	GLOBAL	2° x 2.5°			OMI NO2		4D-Var
TCR2 (K. Miyazaki)	GLOBAL, 70 - 1000 hPa	1.1° x 1.1°	MLS	TES, AIRS/ OMI	CO, NO2, SO2		EnKF
CAQRA (X. Tang)	REGIONAL (CHINA)	15 km x 15 km			CO, NO2	China surface observations	EnKF
CMAQ-GSI (R. Kumar)	REGIONAL (US)	12 km x 12 km			CO		3D-Var

Seasonal variations in regional mean ozone at 500 hPa

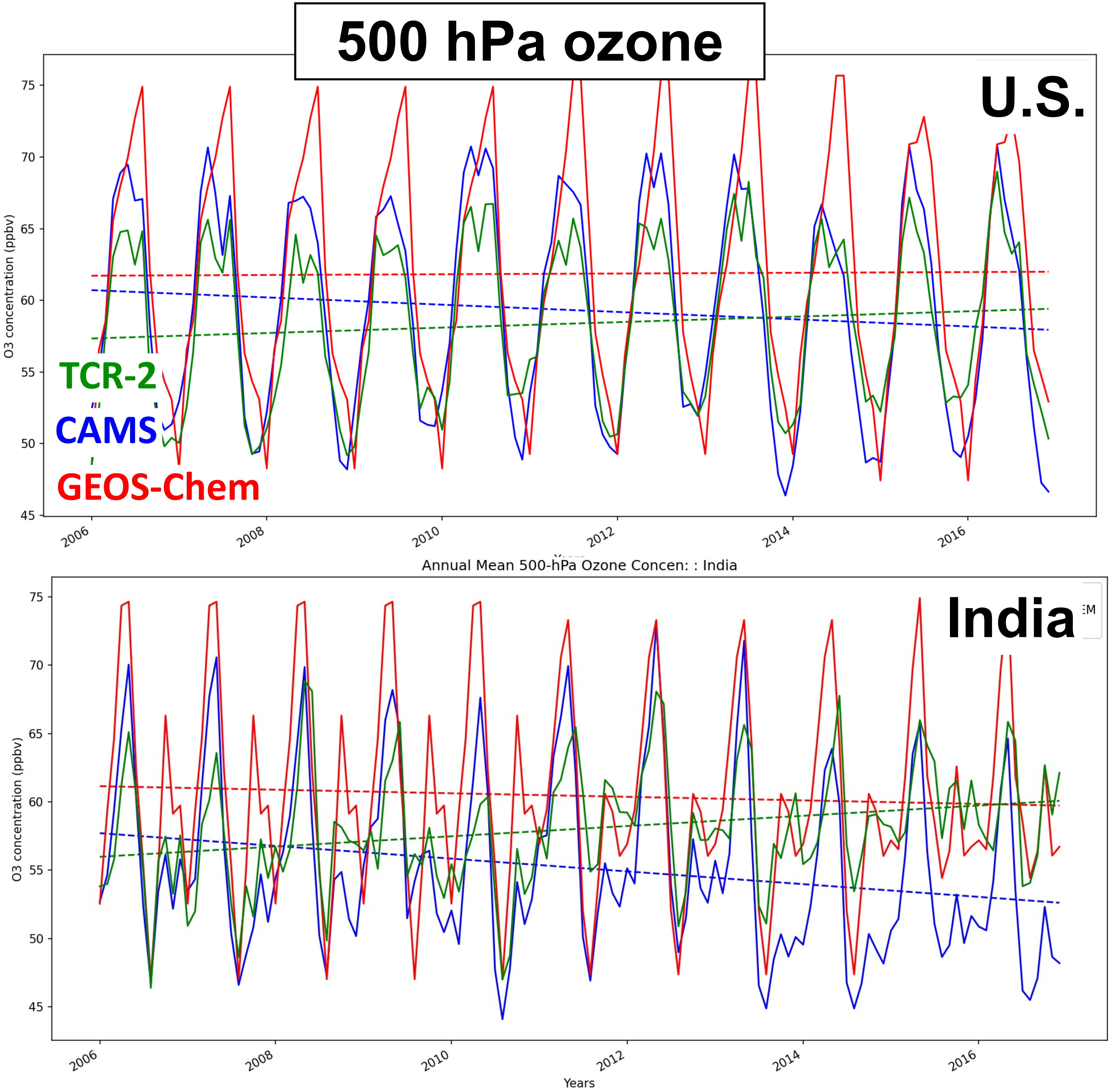


- In the middle troposphere, ozone concentrations are more consistent across all the reanalyses.
- Over South America and Central Africa, TRC-2 has higher ozone during Jan–May .
- Over the US, ozone in GEOS-Chem peaks 3 months later than in the other reanalyses.

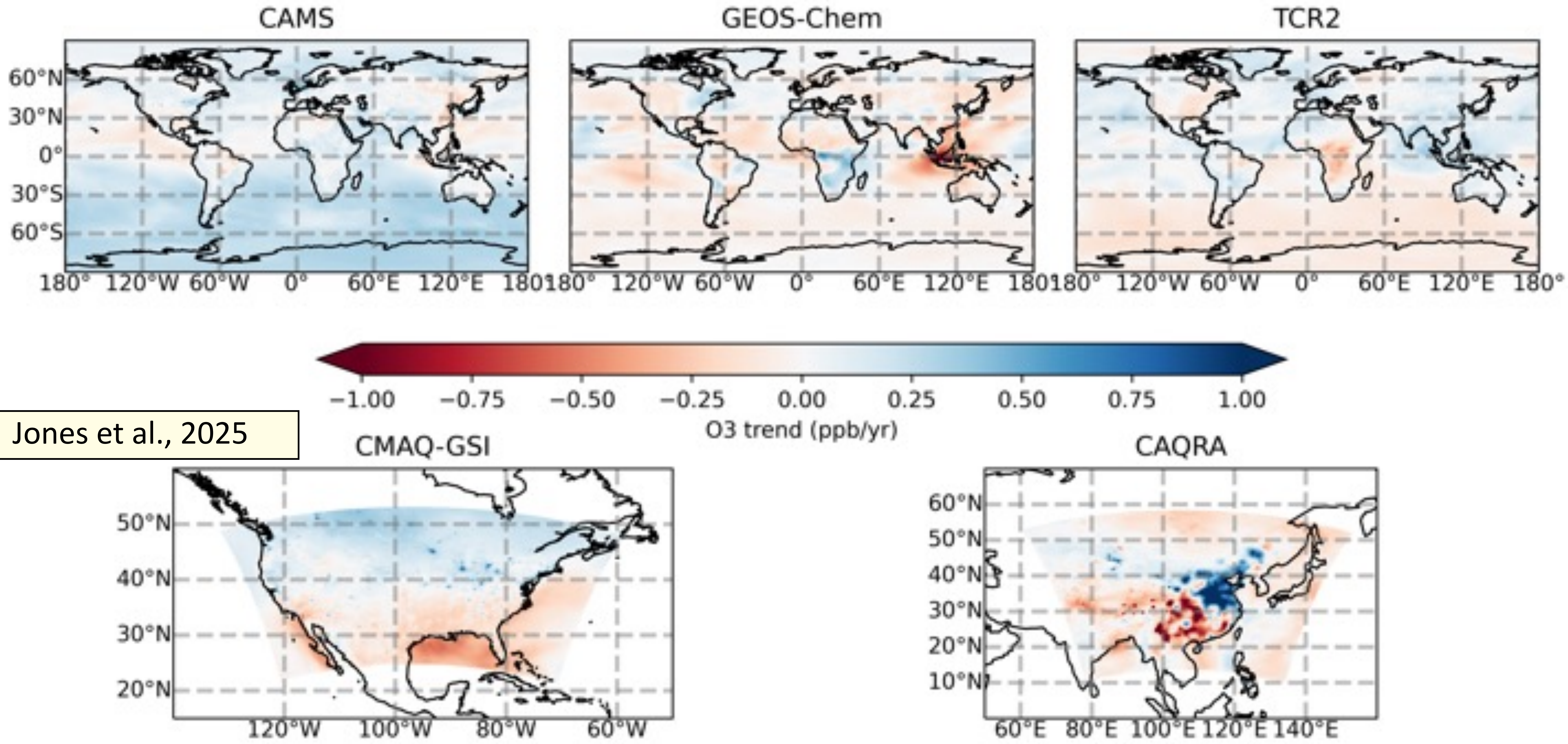
Chemical reanalysis intercomparisons

Challenges remain in capturing interannual variations, likely associated with uncertainties in precursor emissions

Jones et al., 2025



2005-2018 surface ozone linear trends



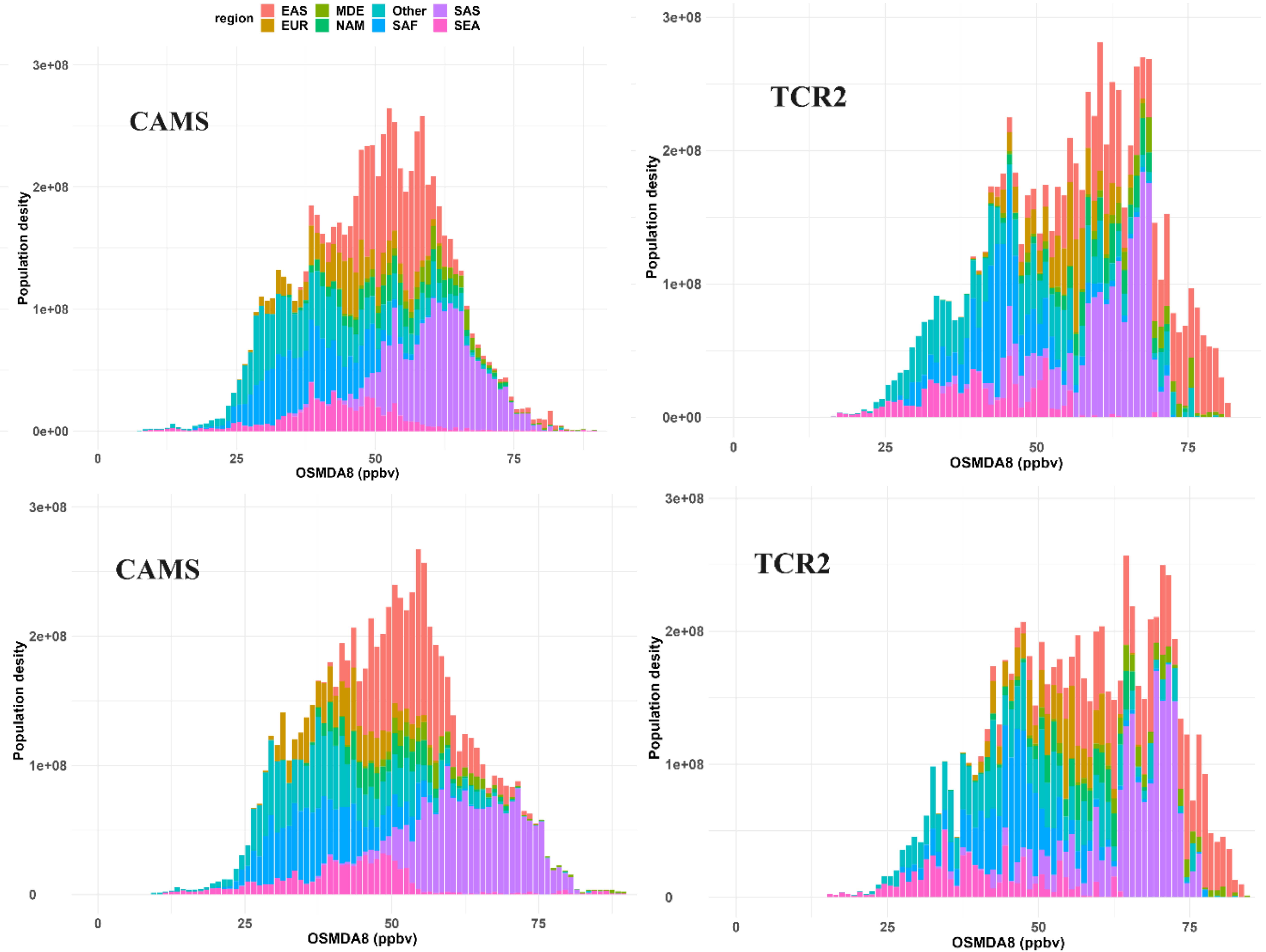
Jones et al., 2025

Further improvements using additional multi-scale observations with advanced DA techniques

Population exposed to average ozone (OSMDA8)

2006

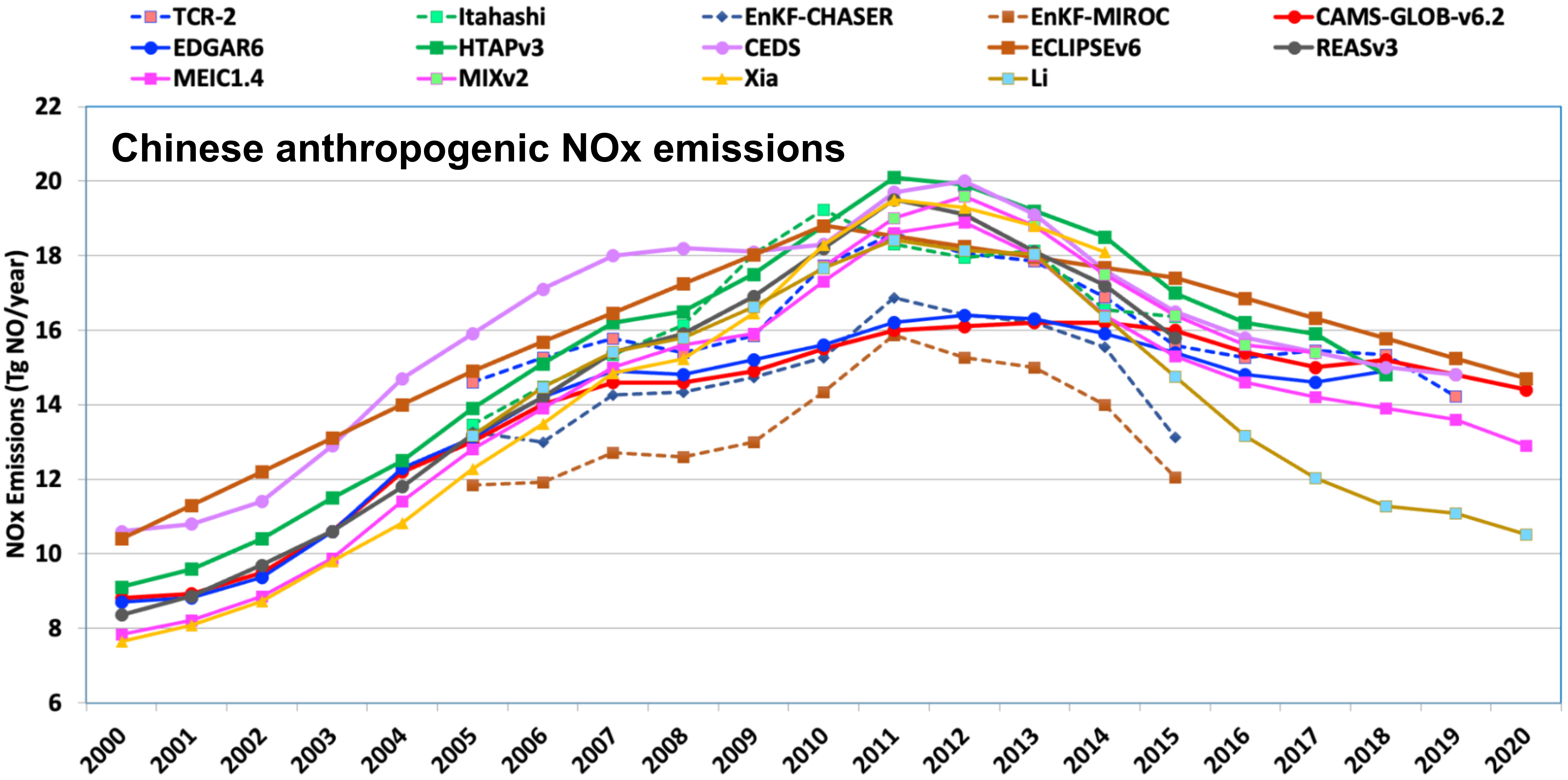
2016



Require better observational constraints, particularly in densely populated regions with limited monitoring

Wang et al., 2025

Importance of correcting emissions within chemical reanalysis



He et al., 2025 (BAMS)

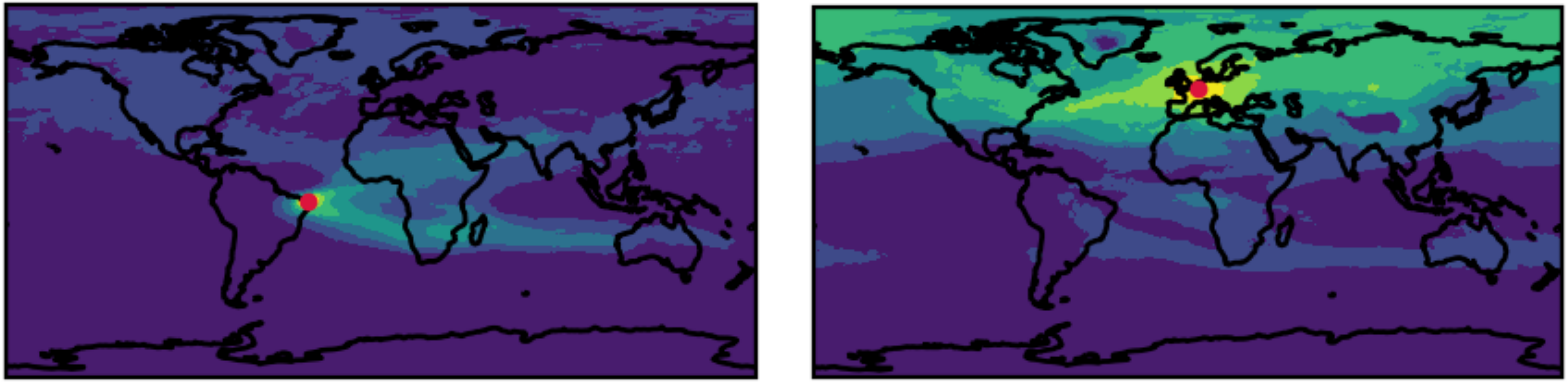

MLS
(Ozone, CO,HNO3)
TES, AIRS/OMI, CrIS
(Ozone)
Long-lived GHGs
Oxidation capacity (OH)
↓
CH4
AQ-GHG co-emissions
↓
CO2
MOMO-Chem Tropospheric Chemistry Reanalysis (TCR-3)
Secondary pollutants
Ozone, PAN,
Secondary aerosols
(nitrate, sulfate, ammonium)
Chemistry
Validation
CrIS (PAN)
CrIS (CO,NH3)
OMPS (SO2,NO2)
Primary pollutants
SO2, NOx, CO, VOCs, NH3,
Primary aerosols (dust, carbon)
Assimilation
OMI,TROPOMI
(SO2,NO2,CH2O)
MODIS, VIIRS
(AOD)
MOPITT, TROPOMI
(CO)

Representative errors of ground-based observations

REEs occur when the atmospheric state is not uniformly and frequently sampled and lead to spurious signals in trend analysis, which can be evaluated using the complete chemical reanalysis fields.

What are the spatial & temporal representative scales of individual ground-based stations and networks?

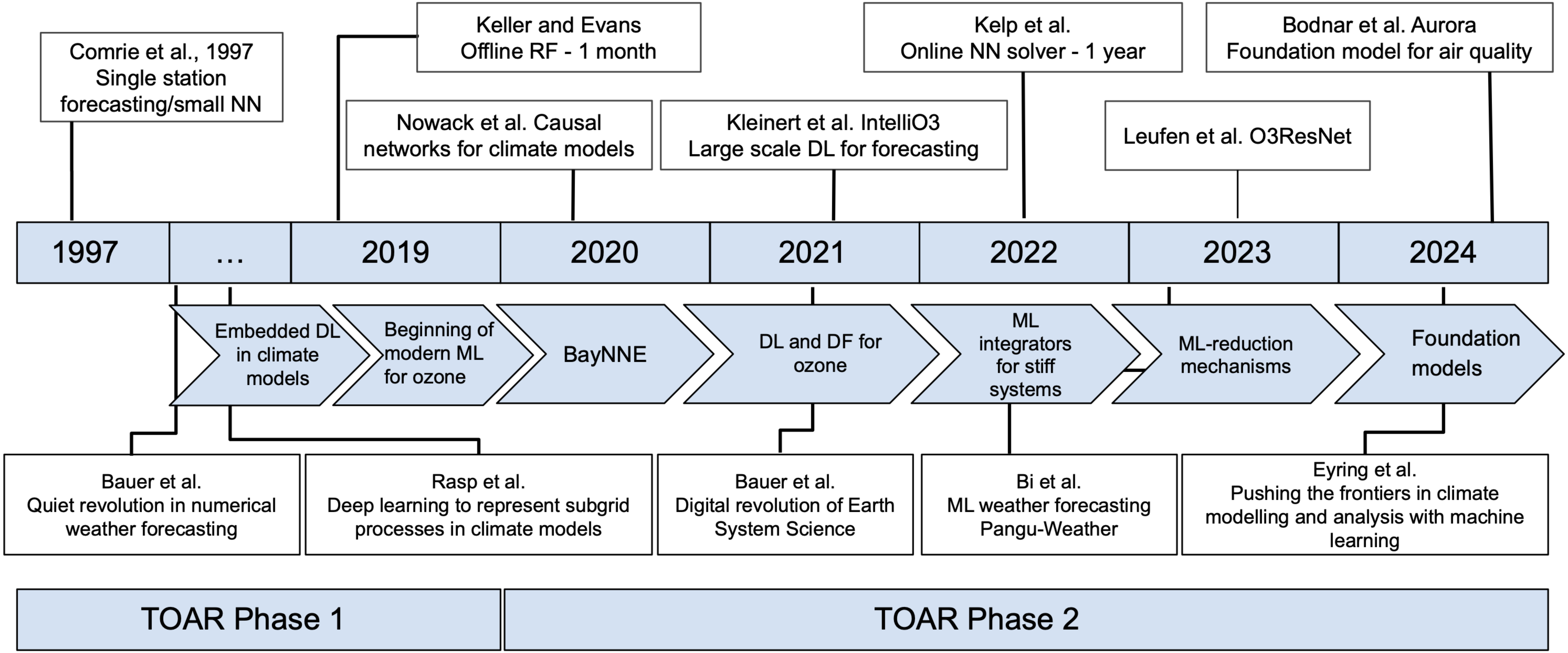
FTIR, ozonesode, IAGOS, Umkehr



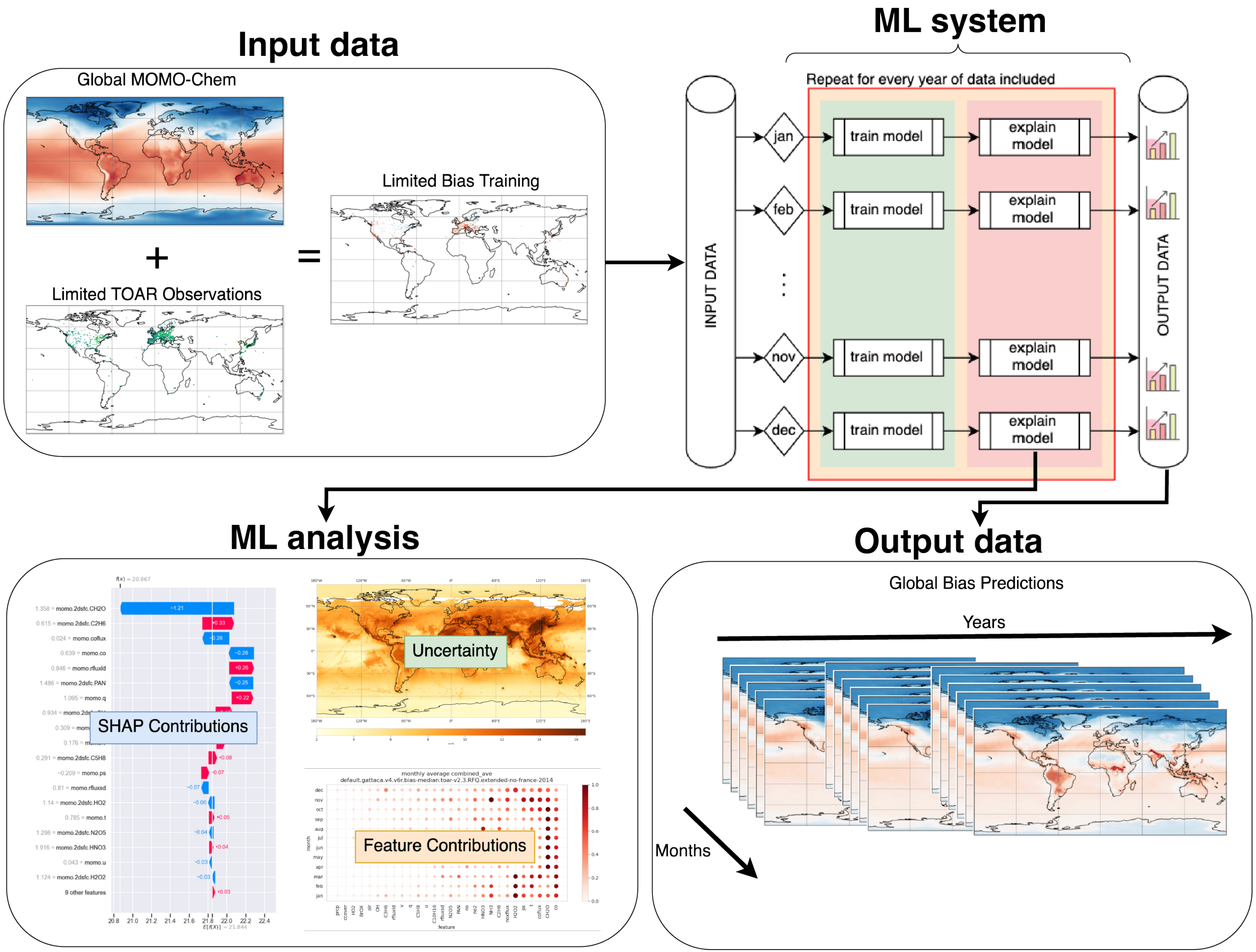
Toward effective observing system design to better capture regional-global scale ozone variations

Miyazaki et al. (in prep)

Integration with machine learning



Hickman et al., 2025



- **Global bias patters**
- **Downscalling**
- **Bias correction**
- **Underlying drivers**

↓

- Useful datasets for health impact assessment
- advancements in modeling, DA, observational system design

Miyazaki et al., 2025

Summary

- Chemical reanalysis data has been used to enhance our understanding of tropospheric ozone, and has been integrated into the broader TOAR-2 synthesis, including health & climate assessment, and satellite product evaluation.
- Intercomparison results reveal that regional differences persist across products, and ozone precursor fields exhibit substantial variability.
- Emerging techniques, such as machine learning and high resolution modelling, and new-generation satellite observations will be essential for further improving their accuracy and expanding their applicability across a wide range of domains.

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