Multi-model multi-constituent chemical (MOMO-Chem) data assimilation for city-to-global scale atmospheric composition and emission analysis

Kazuyuki Miyazaki

Longtao Wu, Jinkyul Choi, Jinhyeok Yu, Hyeonmin Kim, Joshua Laughner, Sina Hasheminassab, Vivienne Payne, Nathaniel Livesey, Kevin Bowman

NASA Jet Propulsion Laboratory, California Institute of Technology , USA

Takashi Sekiya (JAMSTEC), Henk Eskes (KNMI), Pieter Rijsdijk (KNMI), Laura Yang (Washington Univ) and more

Jet Propulsion Laboratory
California Institute of Technology

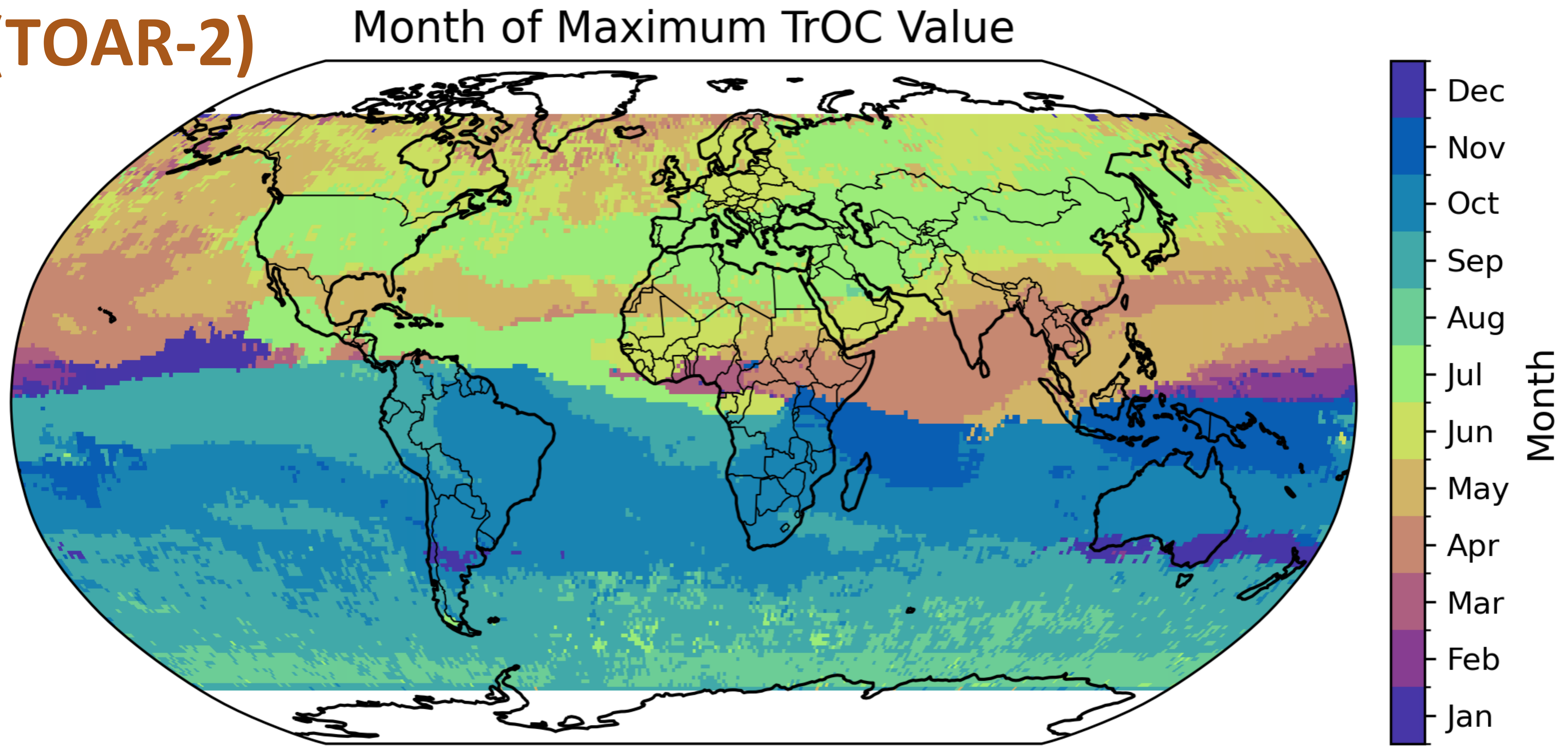
Tropospheric Ozone Assessment Report (TOAR-2)
Satellite Ozone Assessments

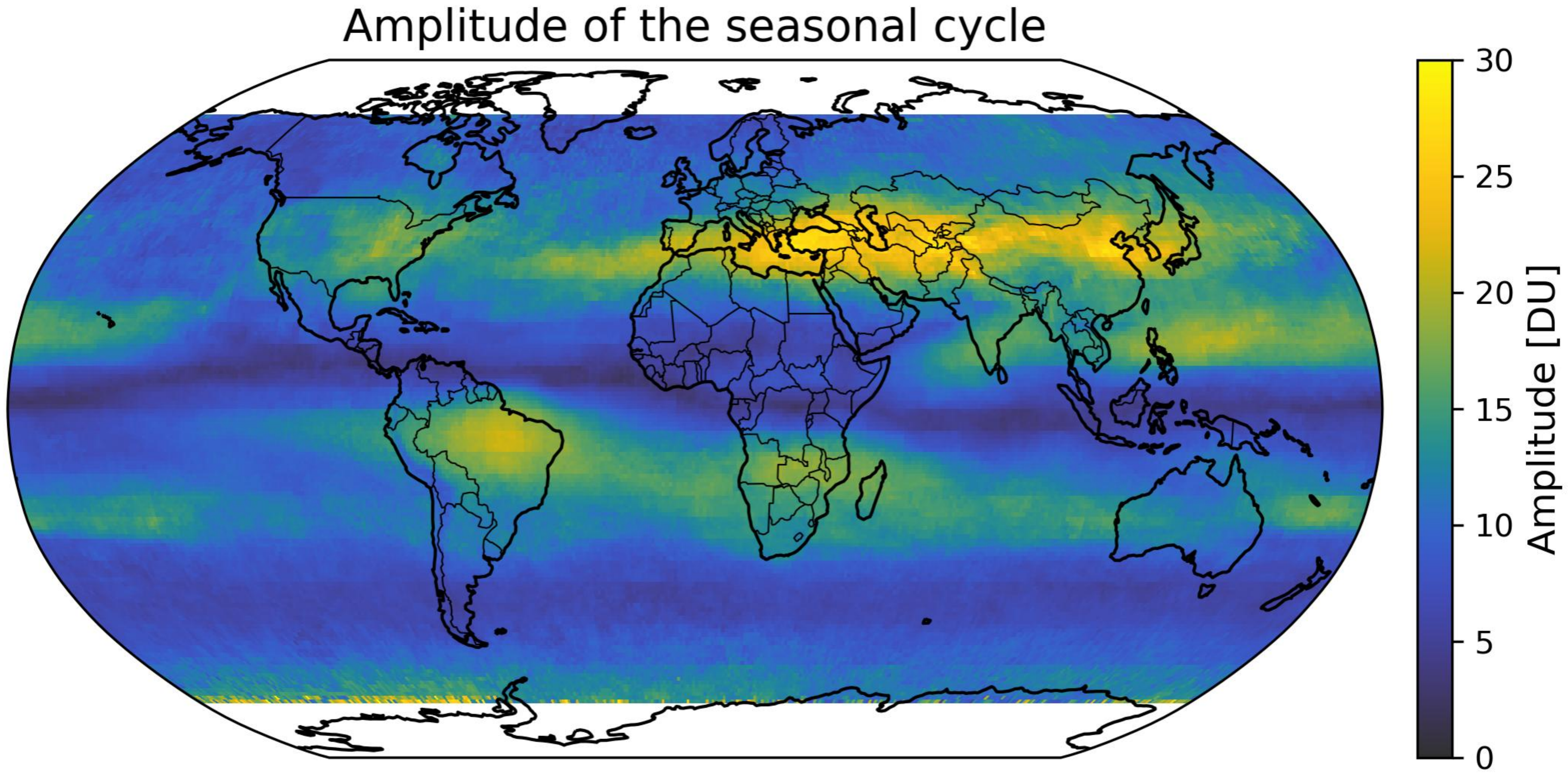
	TOAR-1 (2018)	TOAR-2 (2026)
Data sets	7	21
Harmonization	No	Yes
Spatial resolution	5°x5°	1°x1°
Temporal resolution	Seasonal	Monthly
Spatial coverage	60°S-60°N	90°S-90°N
Temporal coverage	~2016	~2022

↓

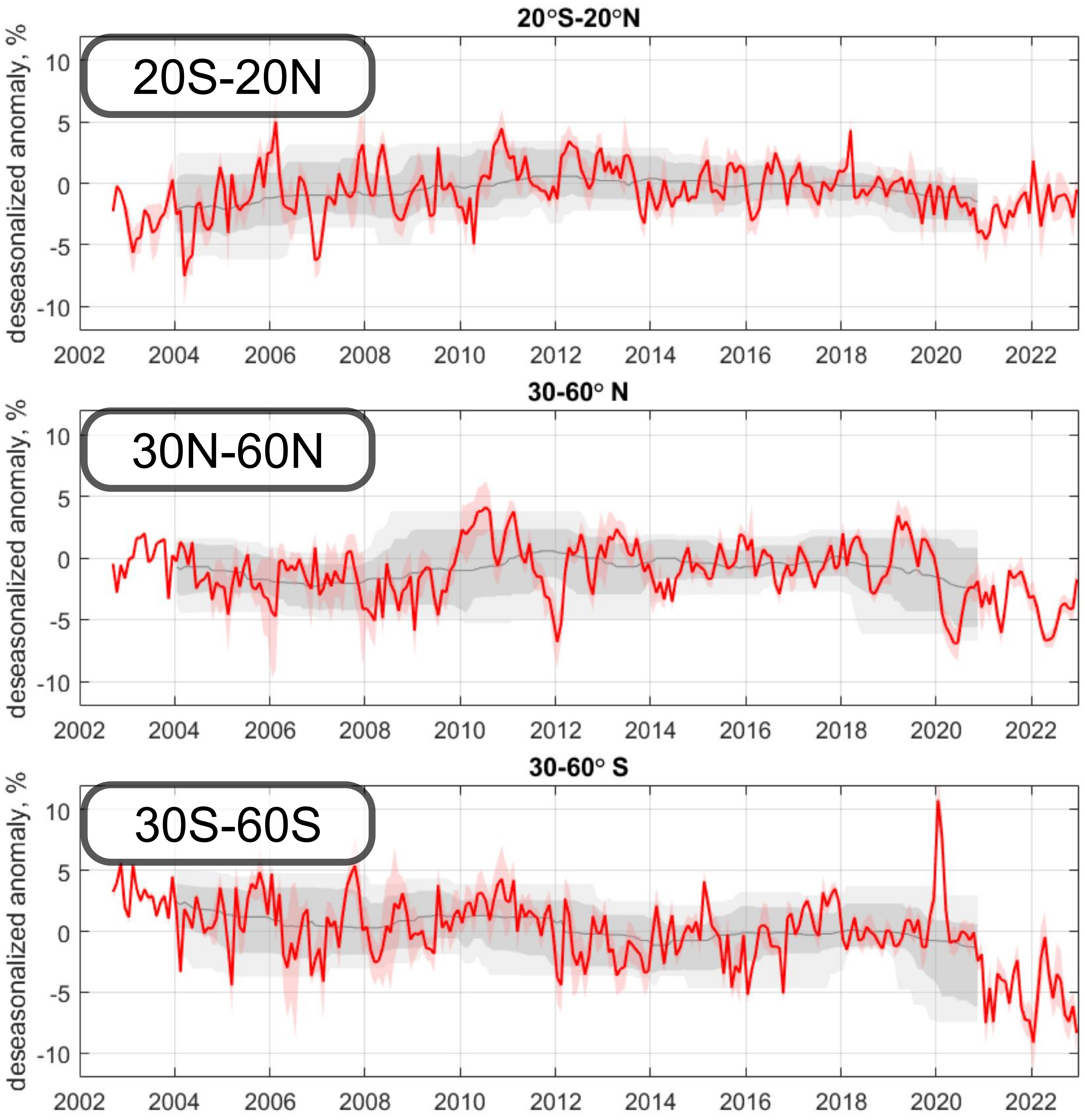
- Integrated into ensemble analyses with greater confidence
- Detect and attribute long-term changes

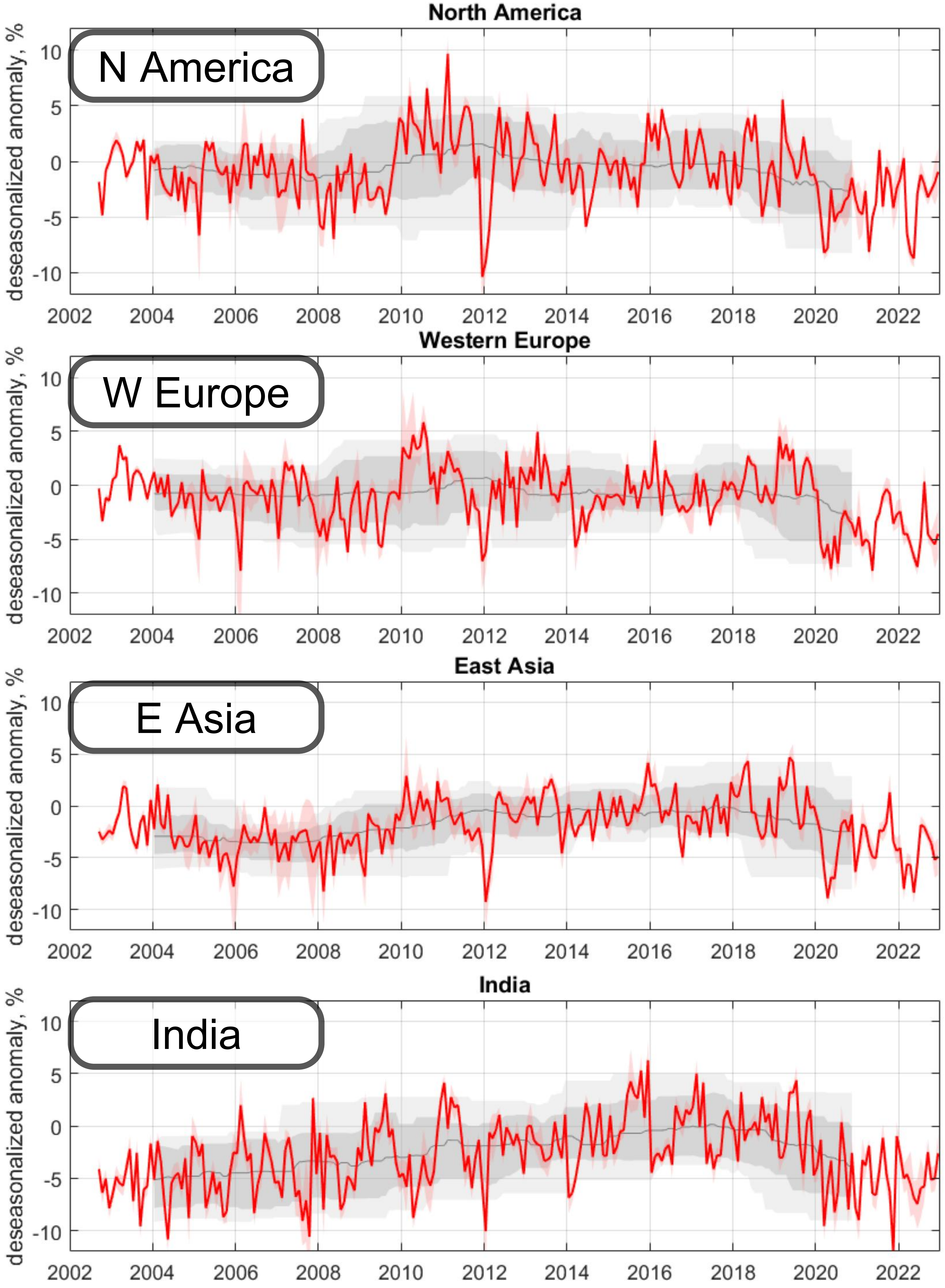
Hubert, Miyazaki et al., in press





TOAR
tropospheric ozone assessment report





Long-term changes (2005-2022)

- Highly non-linear, with clear increases over E Asia and India
- Dynamical drivers such as ENSO, extreme wildfires, and the COVID-19 lockdowns strongly influenced the variations.

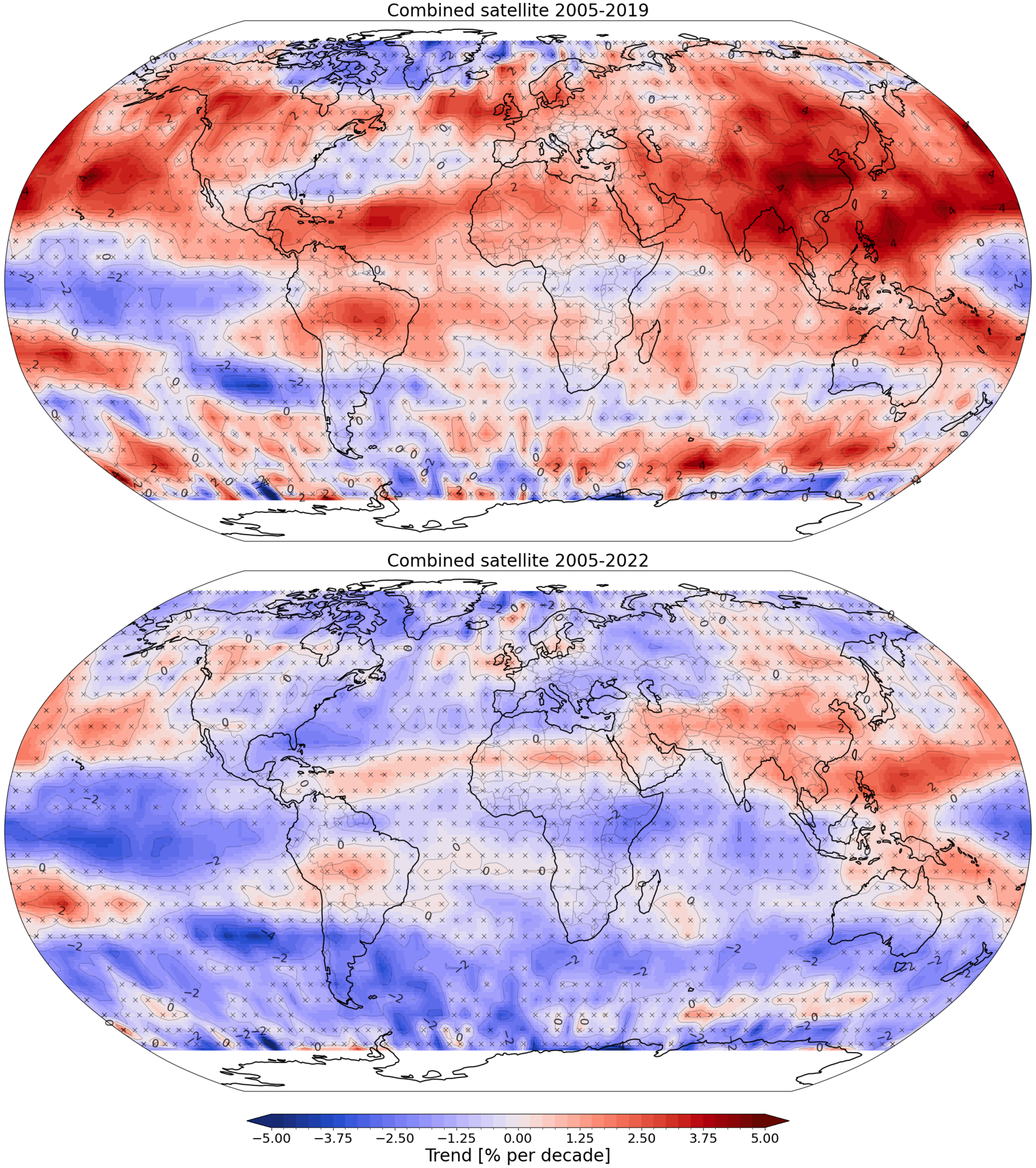
Liner trends of tropospheric ozone

2005-2019

Strongest increases (>3% per decade) in the NH and tropics.

2005-2022

Declines after 2020–2021, resulting in an overall decrease across two-thirds of the globe.



Episodic events

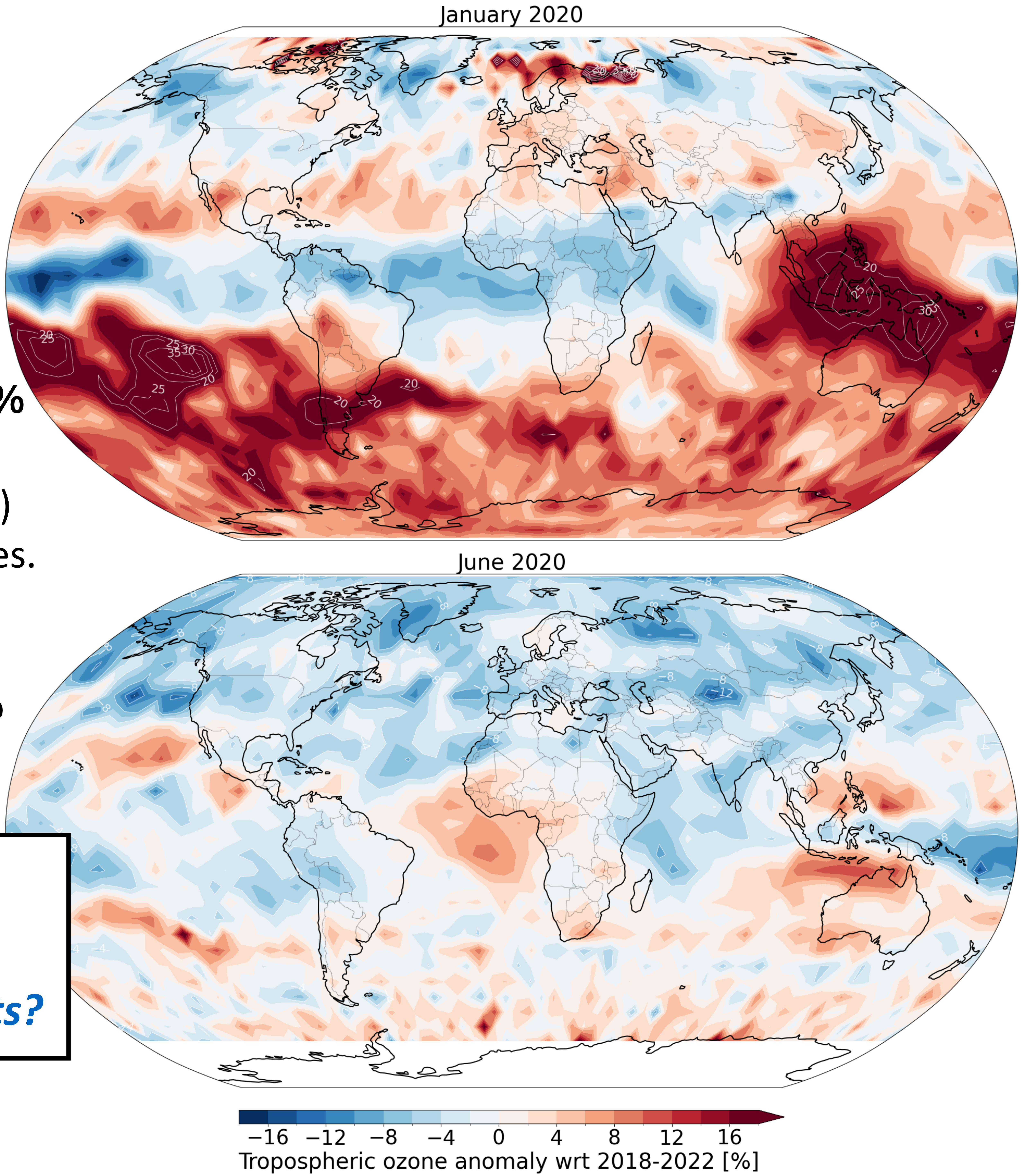
January 2020
Australian fire + other factors

+20 %

Extreme wildfires(e.g., Indonesia in 2015, Australian in 2020) produced increases of 10–20% at regional/hemispheric scales.

June 2020
COVID

-7 %



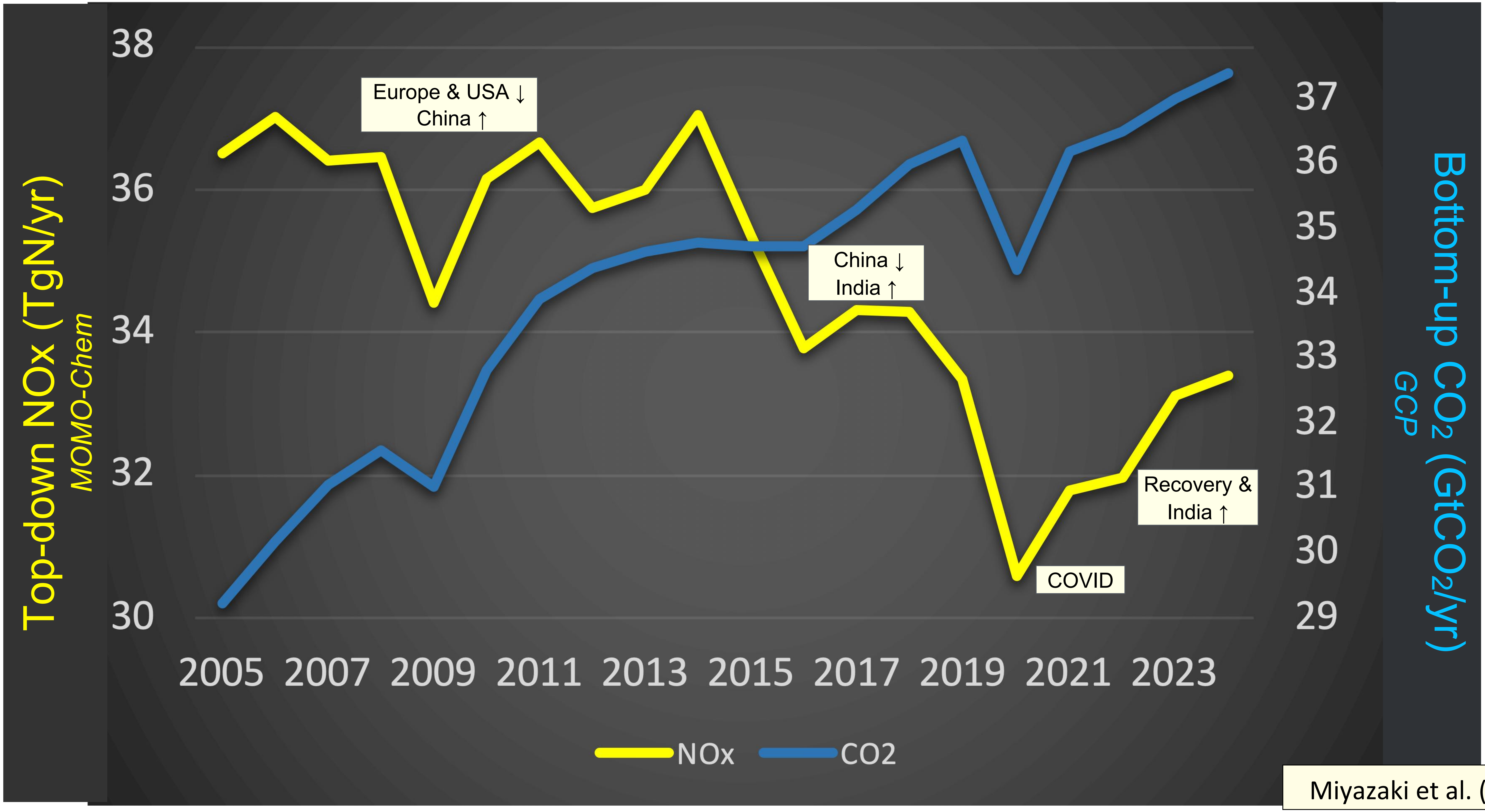
Key scientific questions:

What mechanisms drive these changes?

What are the resulting air quality and climate impacts?

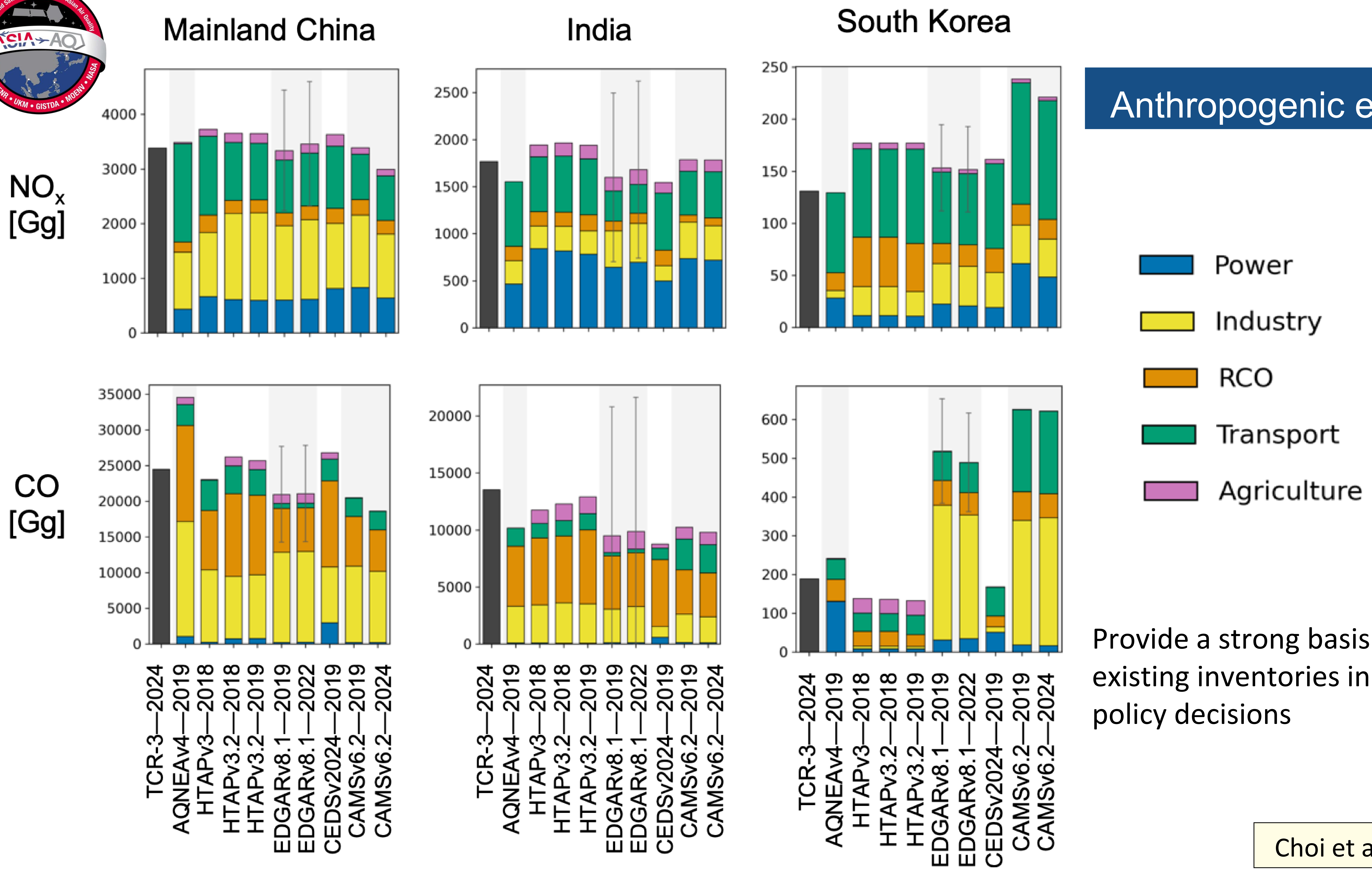

MLS
(Ozone, CO,HNO3)
TES, AIRS/OMI, CrIS
(Ozone)
Long-lived GHGs
Oxidation capacity (OH)
↓
CH4
AQ-GHG co-emissions
↓
CO2
Tropospheric Chemistry
Reanalysis (TCR-3)
Secondary pollutants
Ozone, PAN,
Secondary aerosols
(nitrate, sulfate, ammonium)
Chemistry
Validation
CrIS (PAN)
CrIS (CO,NH3)
OMPS (SO2,NO2)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

Global anthropogenic emissions over 20 years



Miyazaki et al. (in prep)

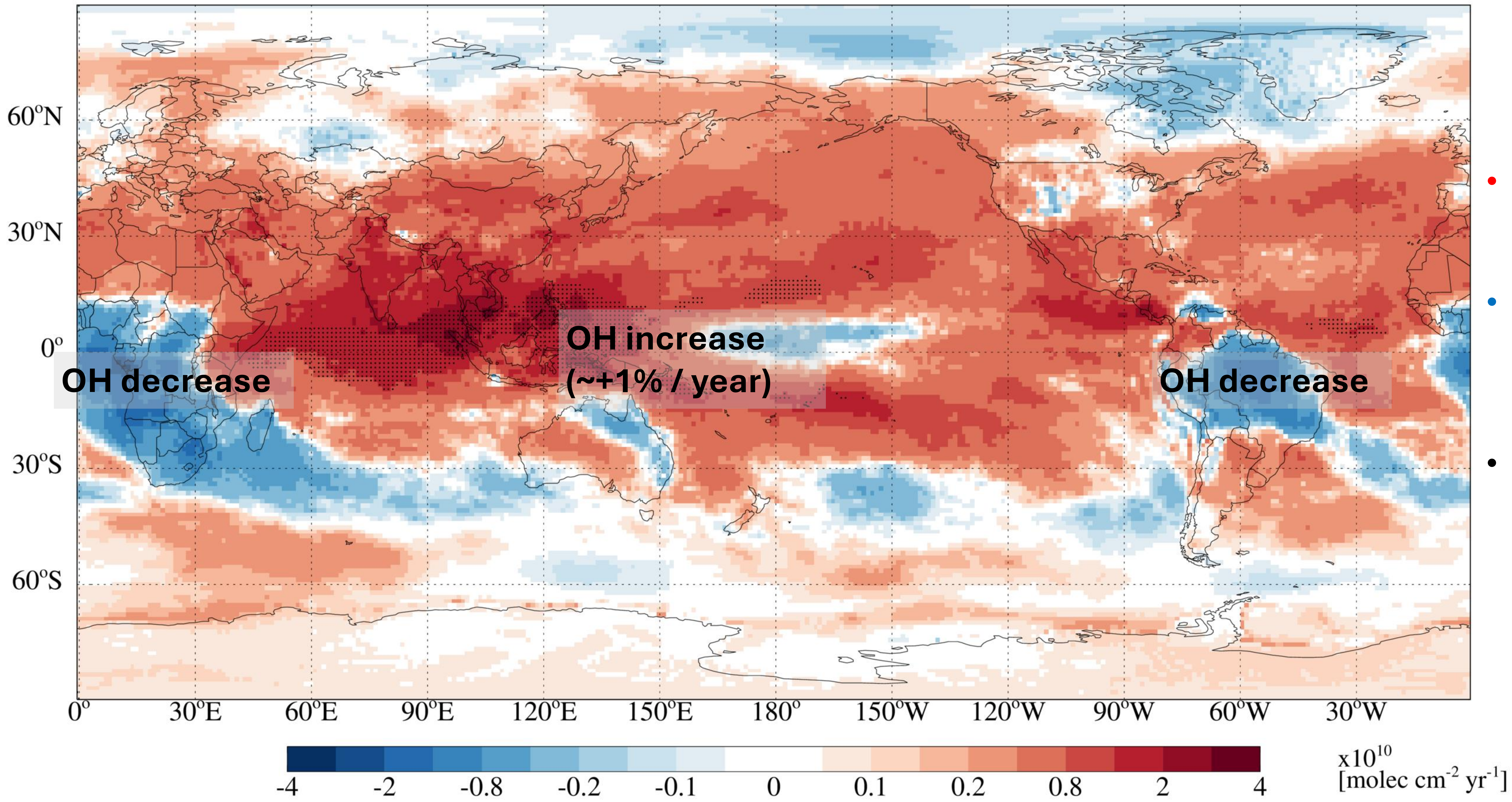
Anthropogenic emissions



Provide a strong basis to evaluate existing inventories in support of policy decisions

Choi et al. (in review)

Linear trend of tropospheric OH column (2005–2024)

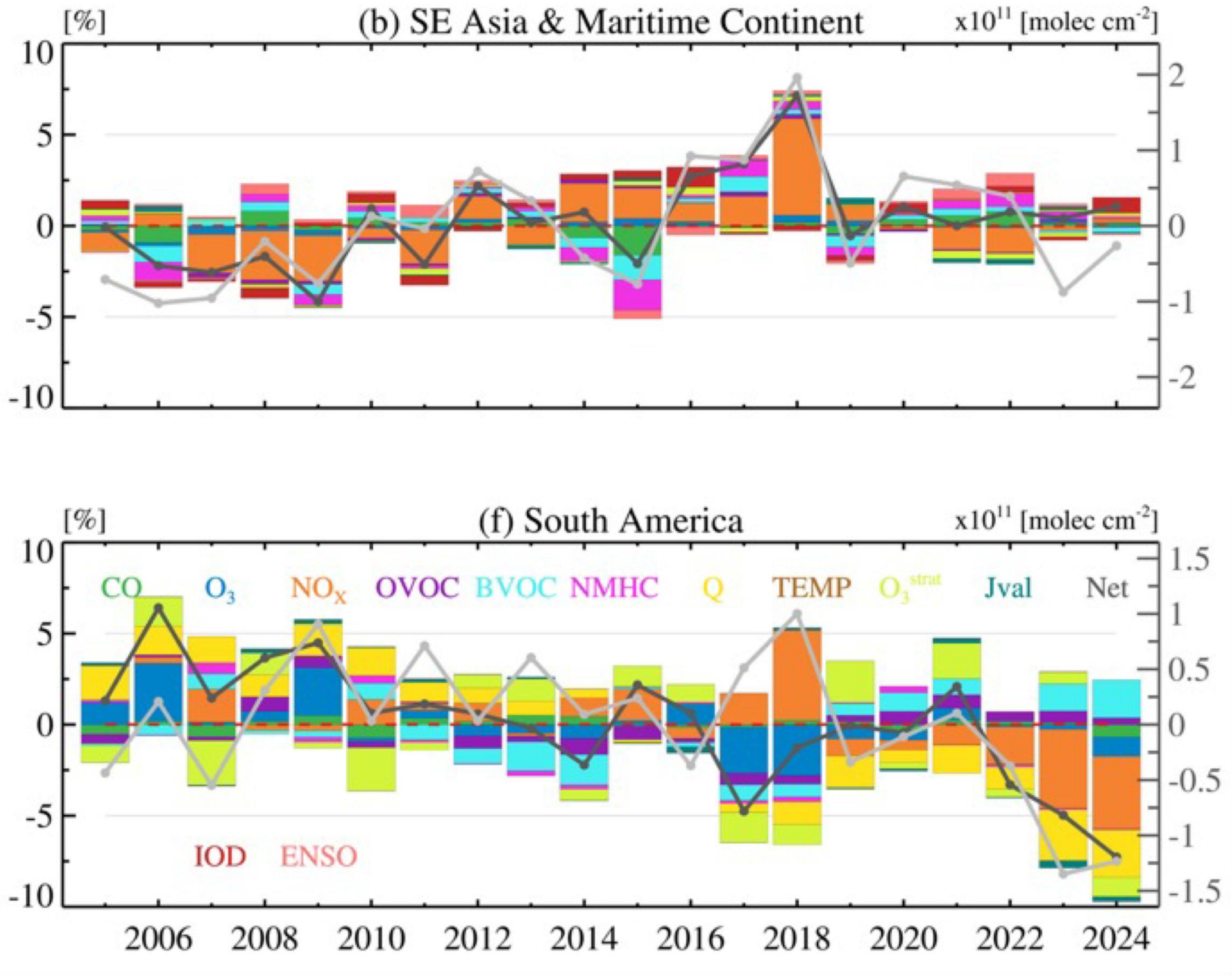


- OH increases (Maritime Continent)
- OH decreases (Sub-Saharan Africa, Central America)
- Goal: Identify key regional drivers of OH trends

Identify OH trend drivers for robust CH_4 budget analyses

Kim et al. (in prep)

Dominant drivers of OH trends (2005-2024)



Maritime Continent: Strongest OH increase
→ NOx (and O_3) CO dominate

Central Africa and South America: Robust OH decrease
→ Wate vapor, NOx, O_3, VOCs

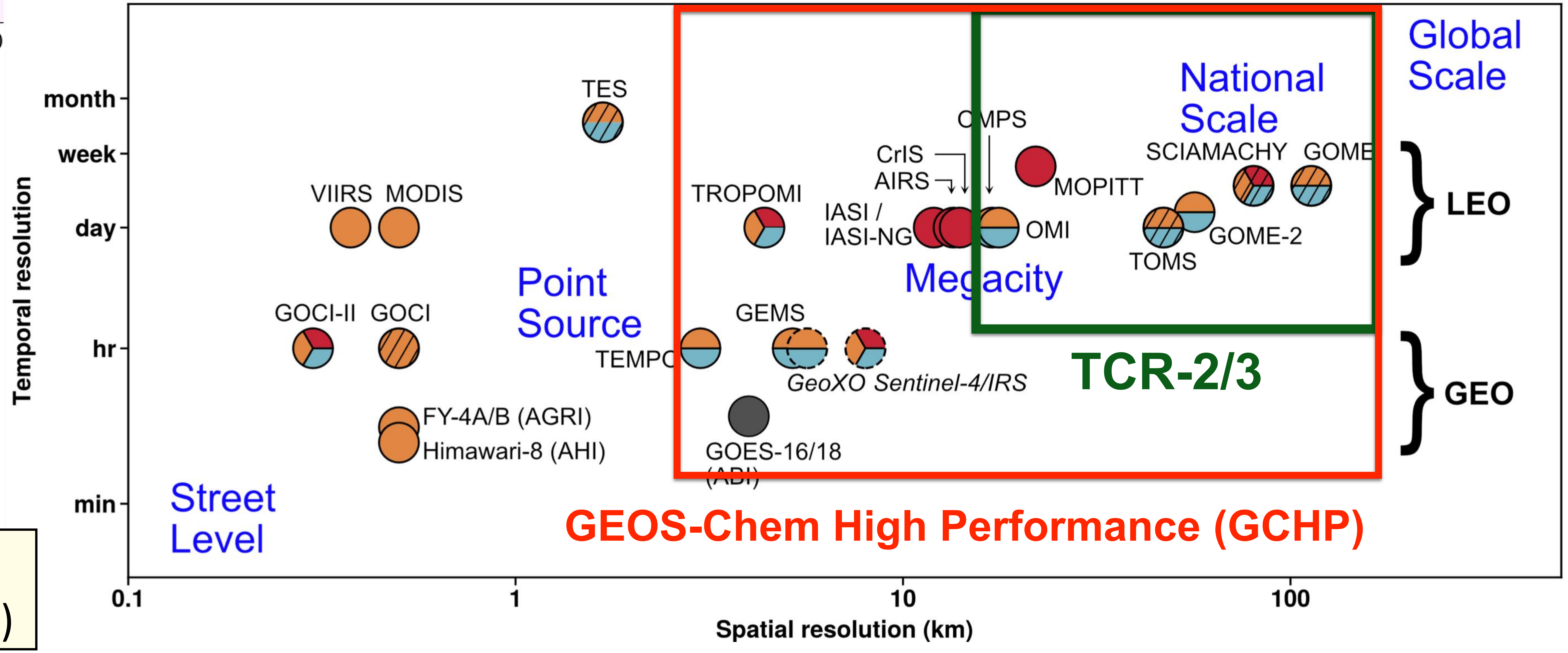
- **Substantial impacts of wildfires**
- **Lower vs upper troposphere**

Kim et al. (in prep)

Integration of satellite trace gas and aerosol measurements

- Simultaneous trace gas–aerosol DA improves agreement with PM2.5 observations.
- Current satellite constraints (TROPOMI + VIIRS) outperform older satellite constraints (OMI + MODIS).
- Optimized aerosol speciation and emissions provide more actionable information for targeted air-quality policy.

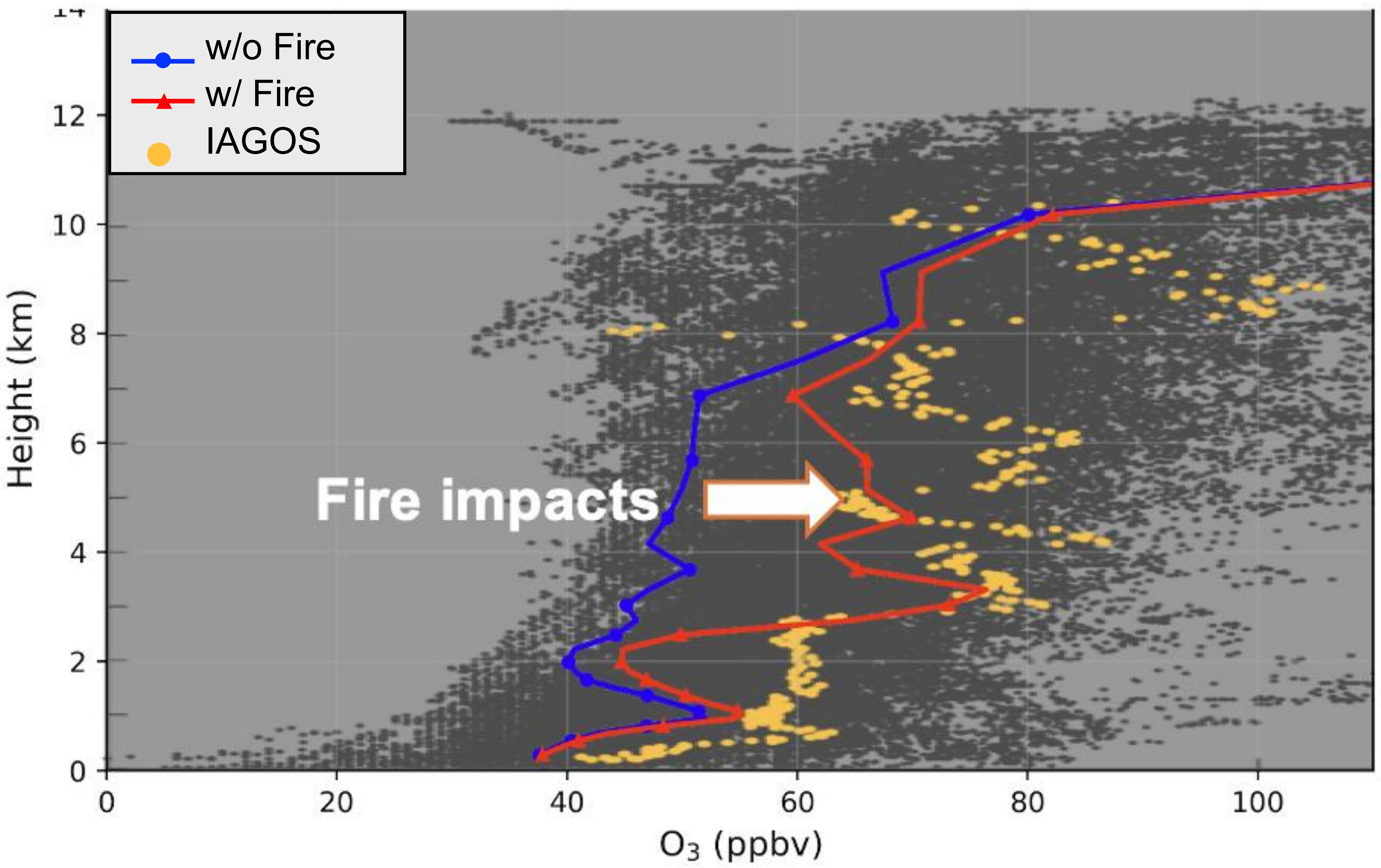
Sekiya et al. (in review)



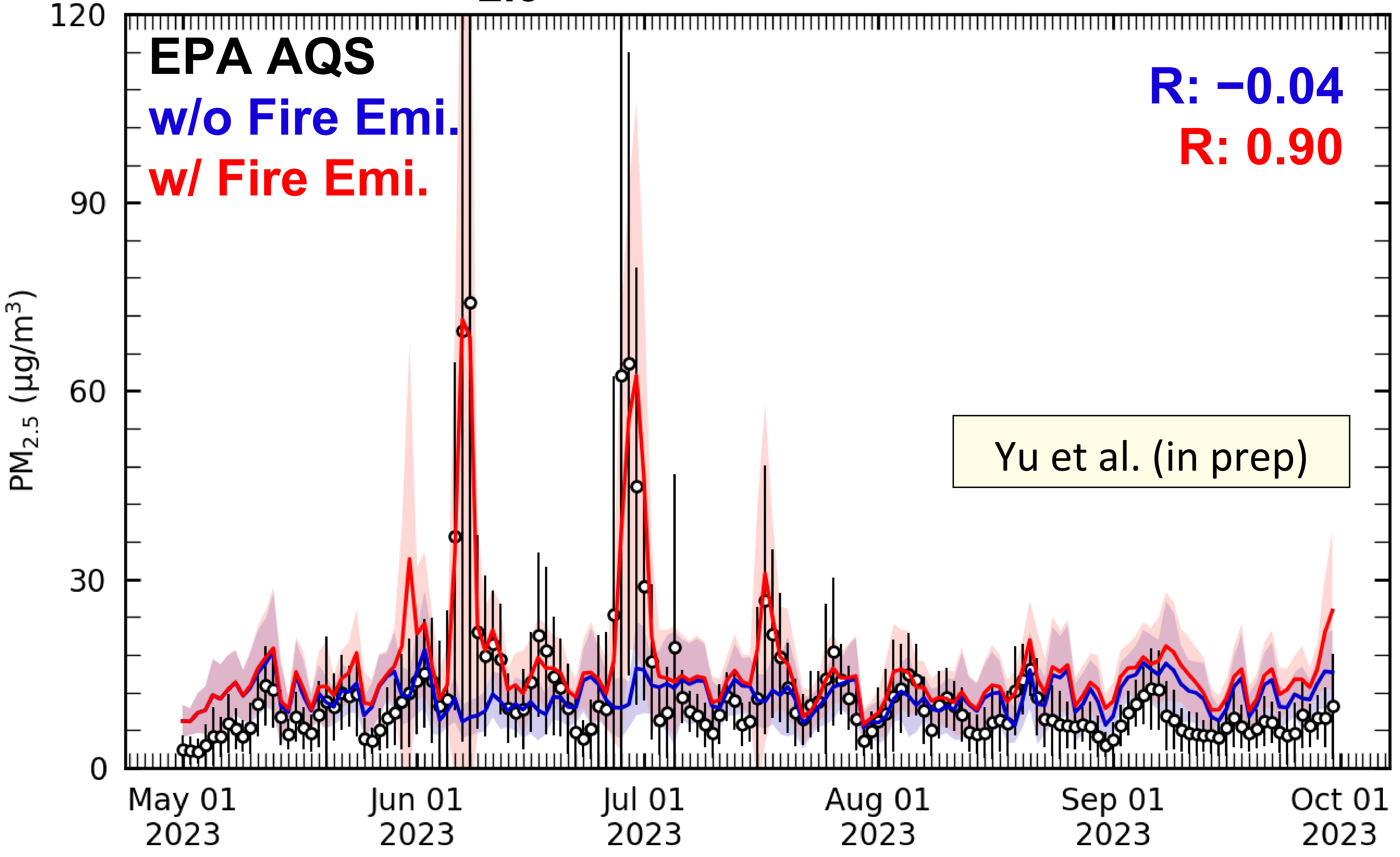
He et al., 2025 (BAMS)

Impacts of the 2023 Canadian Wildfires

Ozone: IAGOC profiles over Toronto



$PM_{2.5}$**:** U.S. northeast time-series



Despite lower ozone production efficiency than in the tropics, the global radiative impact is comparable.

- Ozone RF reaches up to ~10% of the total anthropogenic ozone forcing since the pre-industrial era.
- Aerosol-induced cooling exceeds the magnitude of the total post-industrial anthropogenic aerosol–radiation forcing.

Summary

- MOMO-Chem multi-scale, multi-constituent DA strengthens NASA's capability to connect satellite observations with air-quality and climate applications.
- Enhanced integration of satellite, in situ, and airborne campaign observations will improve understanding of the variability and drivers of tropospheric ozone across scales.
- Continued assessment of evolving observing systems will help evaluate the value of current satellite constellations and inform the design of future atmospheric composition missions.

Current & future applications: Satellites (GOSAT-GW, CO2M, GEMS, TEMPO, GEO-XO, Sentinel-4), aircraft missions (ASIA-AQ), scientific focuses (AQ+GHG, trace gas + aerosol, OH, wildfires, NOx+VOCs), techniques (DA+ML).