# Long-term trends of anthropogenic emissions in Asia and their validation in Japan

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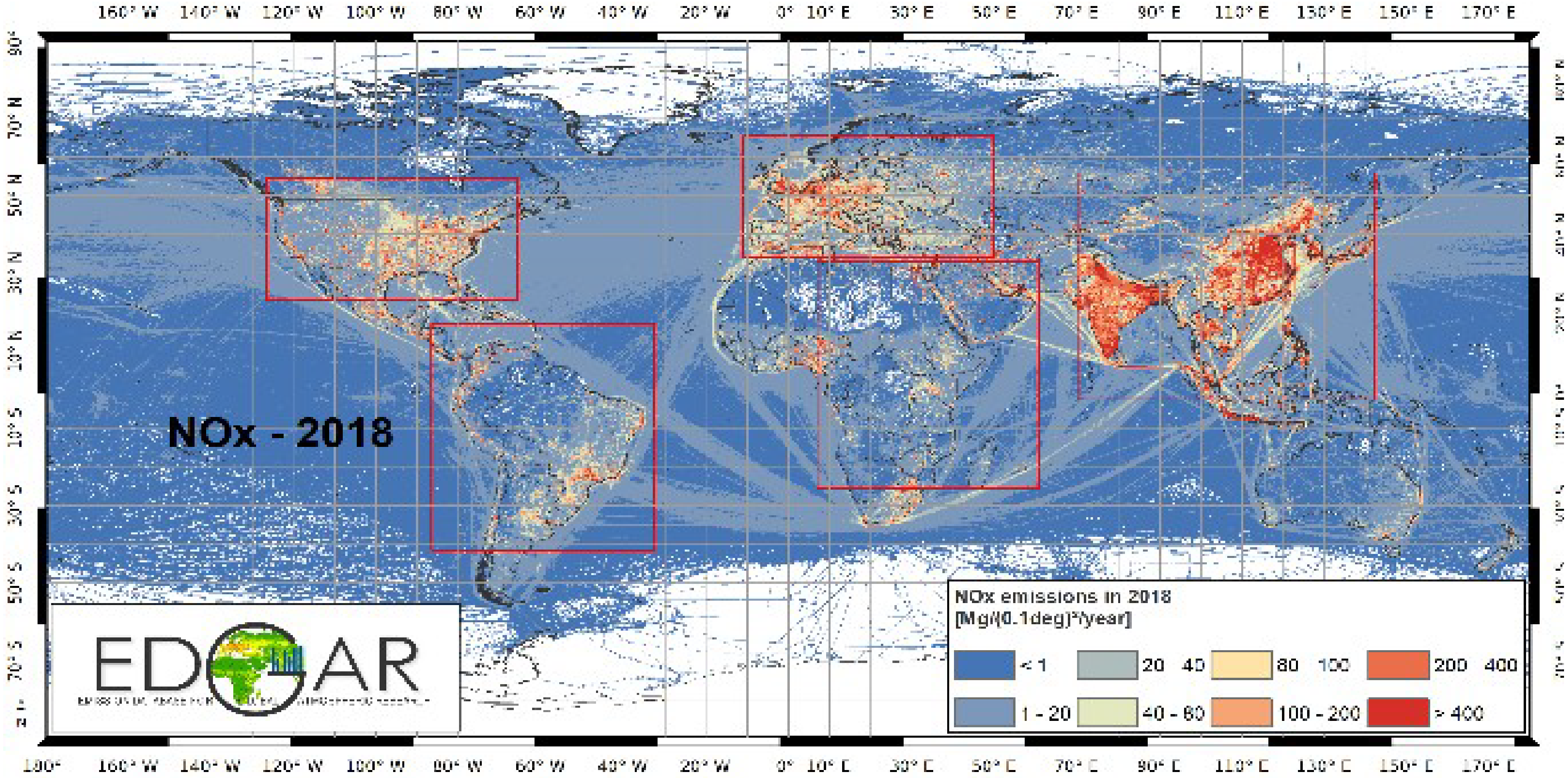
# Global emission map for NOx in 2018

HTAP_v3 emission mosaic (Crippa et al., 2023), anthropogenic emission inventory excluding LCLUC developed in the UNECE Air Convention




- ✓ Asia is most polluted region in global
- ✓ Asian emissions account for almost half of global

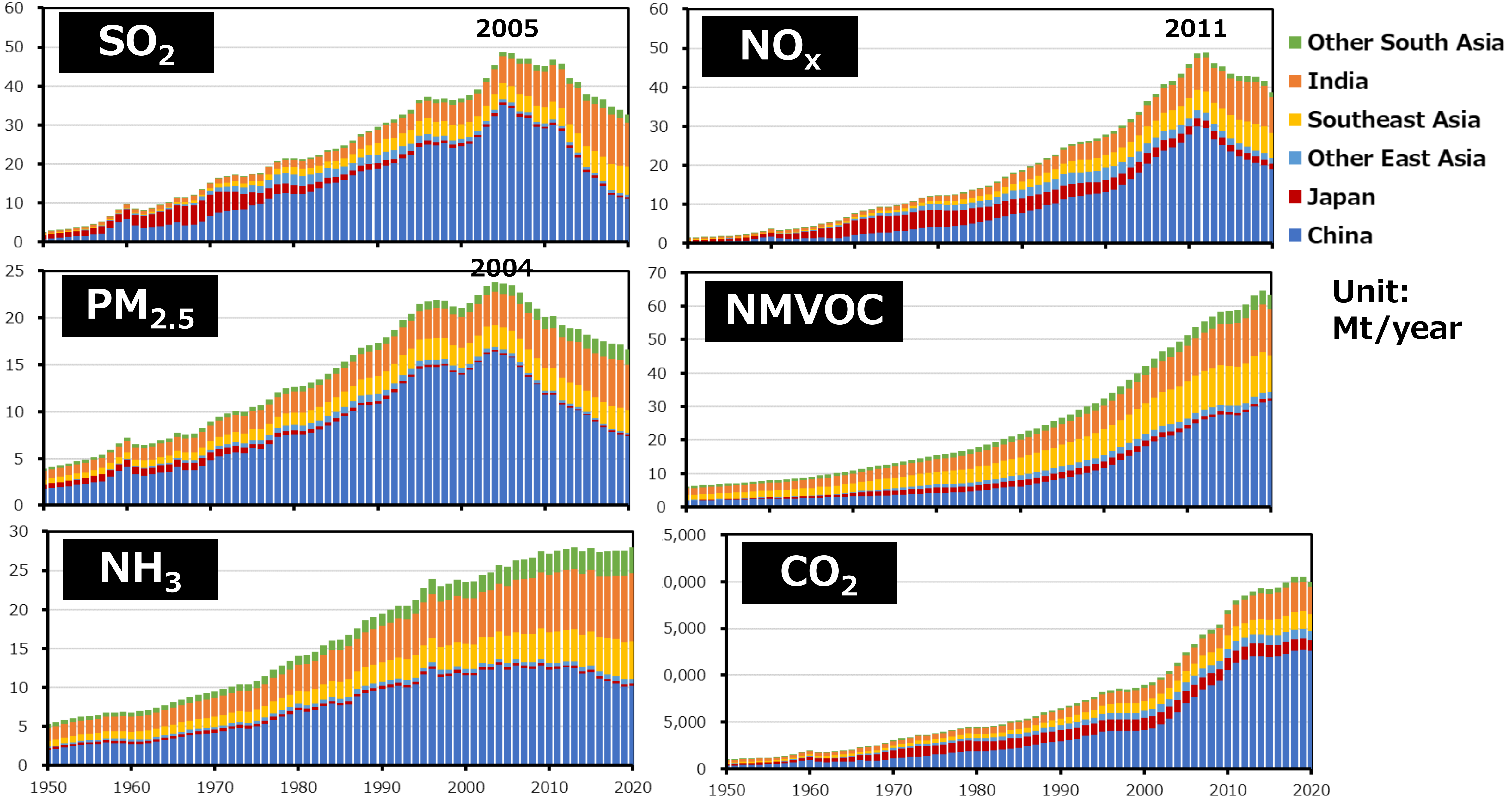
# Regional Emission inventory in ASia (REAS)

✓ **Anthropogenic, comprehensive, and historical inventory**
✓ **Version: 3.2.1 (now updating)**

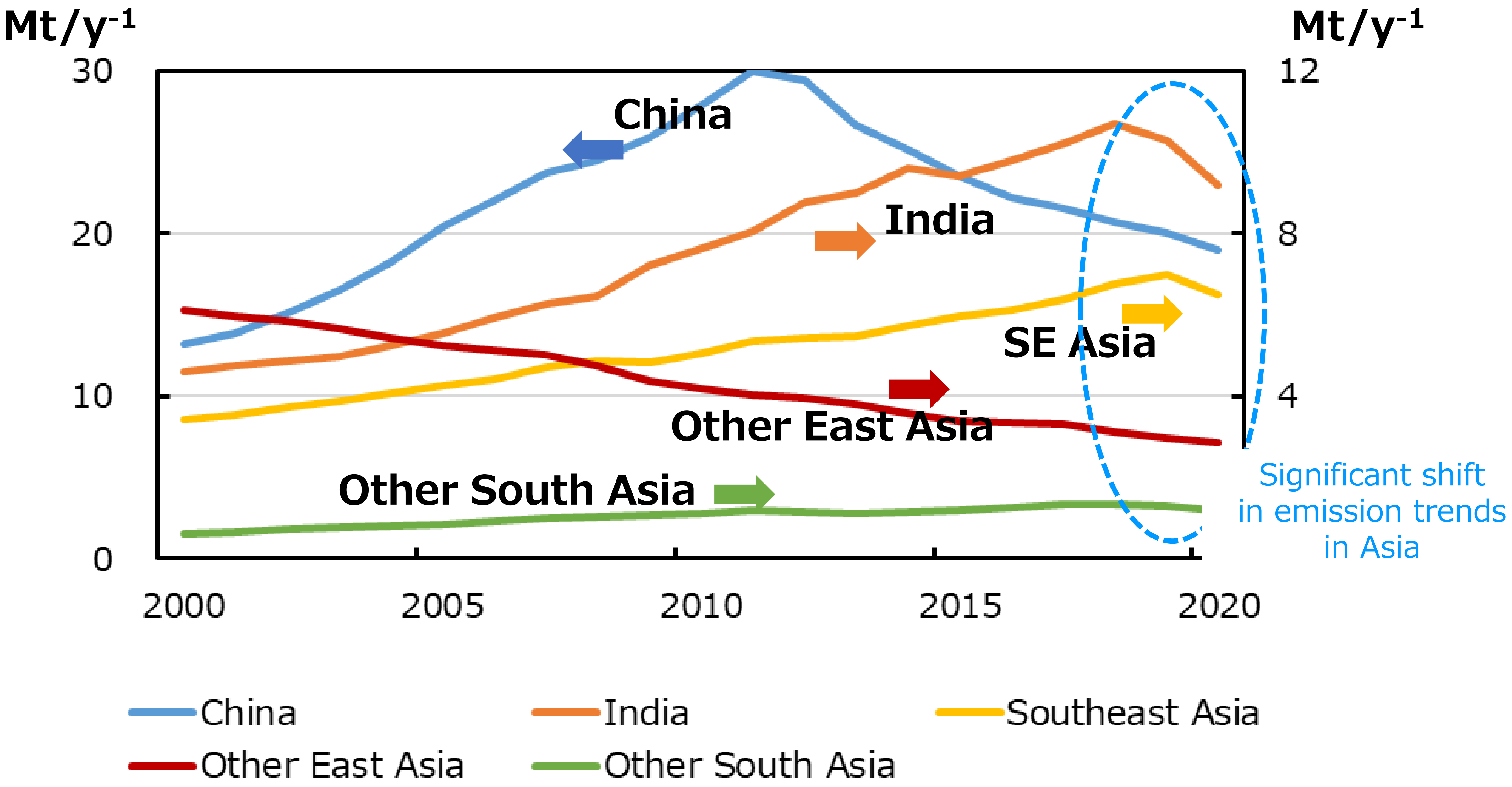
- Country and regional emissions for detailed sources
- Gridded emissions for major sources
- Target Years : 1950-2015 **(➡2020)**
- Target Areas : East, Southeast, and South Asia
- Horizontal Resolution : 0.25°× 0.25° **(➡0.1°× 0.1°)**
- Temporal Resolution : Monthly
- Target Species : $SO_2$, $NO_x$, CO, NMVOC, $PM_{10}$, $PM_{2.5}$, BC, OC, $NH_3$, $CO_2$ and **$CH_4$**

| | $SO_2$ | $NO_x$ | CO | $PM_{10}$ | $PM_{2.5}$ | BC | NMVOC | $NH_3$ | $CO_2$ | $CH_4$ |
|---|---|---|---|---|---|---|---|---|---|---|
| Combustion | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● |
| Industrial Process | ● | | ● | ● | ● | ● | ● | ● | ● | ● |
| Agriculture | | ● | | | | | | ● | | ● |
| Others | | | | | | | ● | ● | | ● |

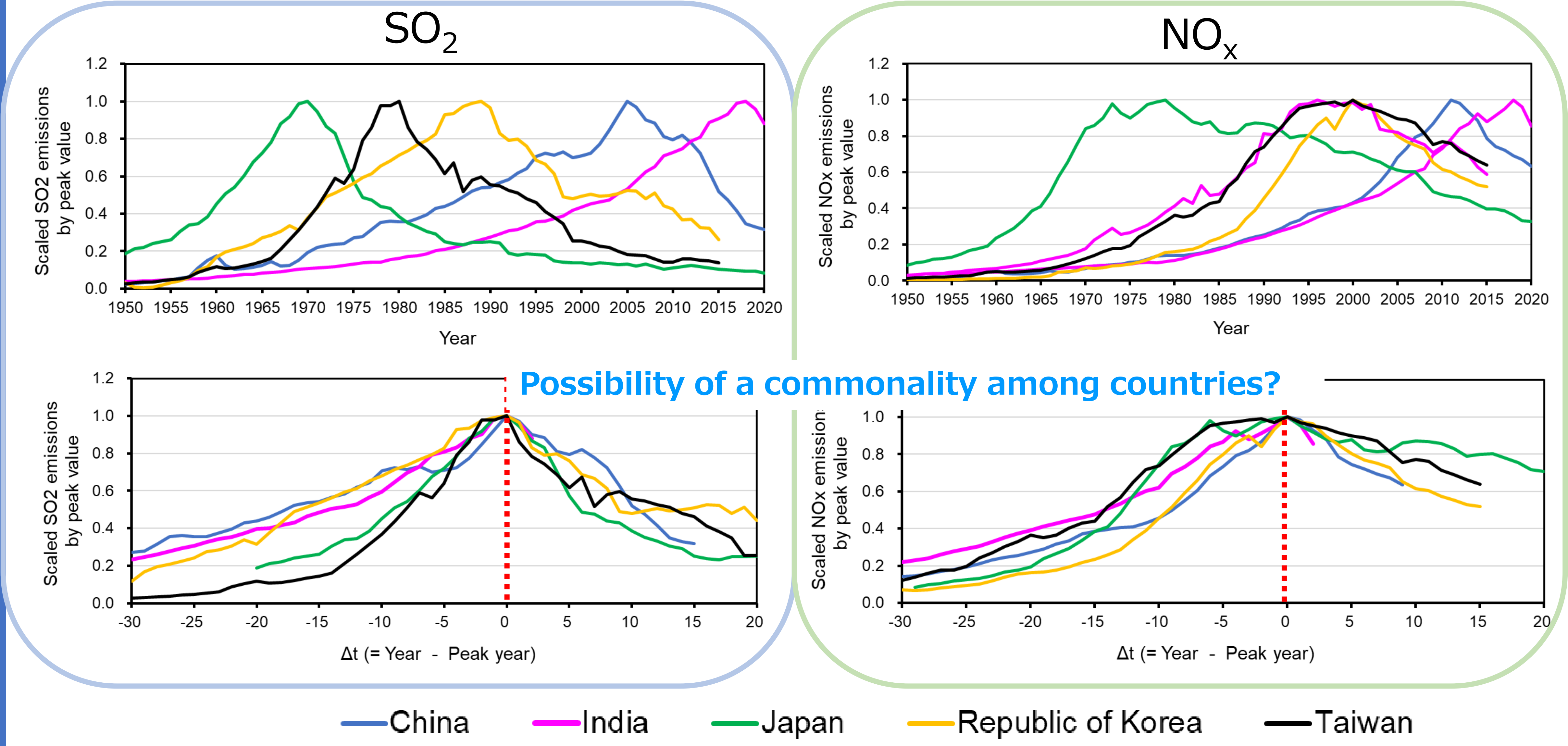
# 4 Temporal variations of emissions in Asia during 1950-2020



# Temporal variations of NOx emissions after 2000

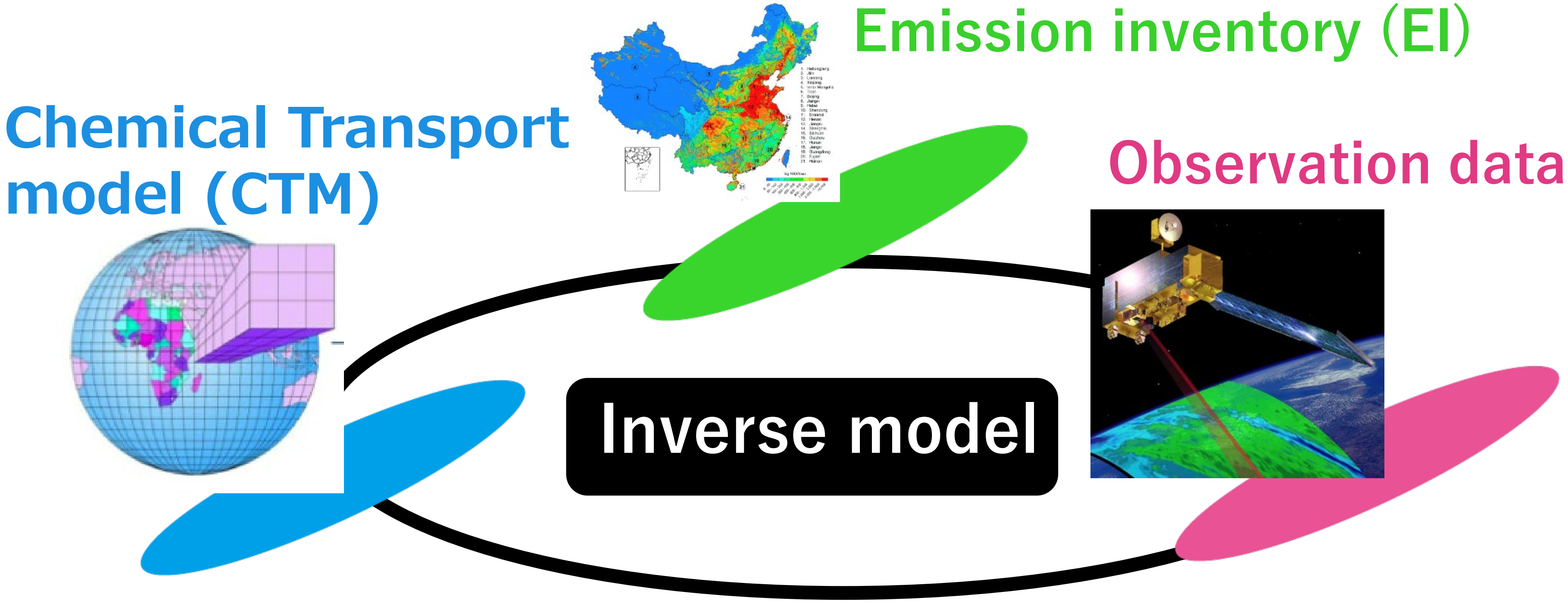


# Similarity of $SO_2$ and NOx emission changes in China, India, South Korea, Taiwan and Japan




(Note) y axis is scaled by the peak emission during 1950-2020.

# Inverse modeling using satellite data




**Inverse modeling integrates EI (a priori data), CTM and observation data to complement (optimize) emissions.**

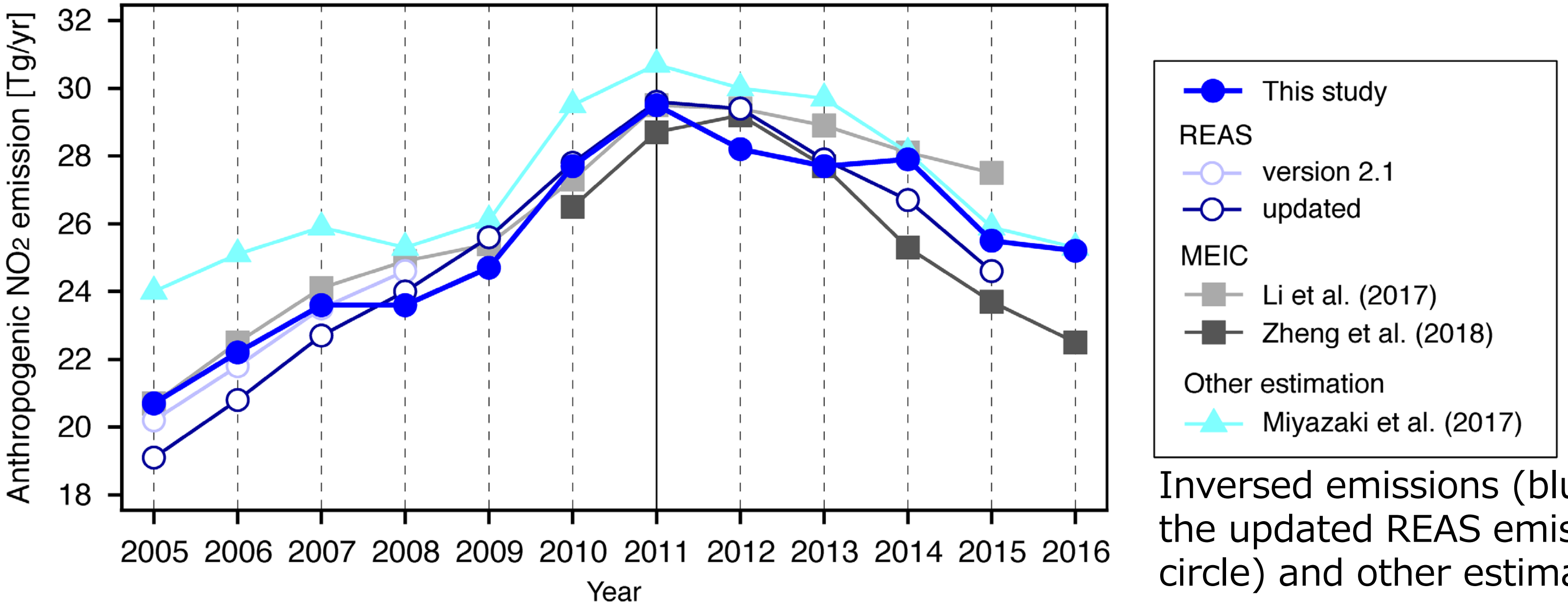
## ＝Inverse estimation of emissions

Bottom-up approach: Estimate emissions from statistical data
Top-down approach : Estimate emissions from observations and CTM

# 8 Temporal variation of annual NOx emissions over China and India

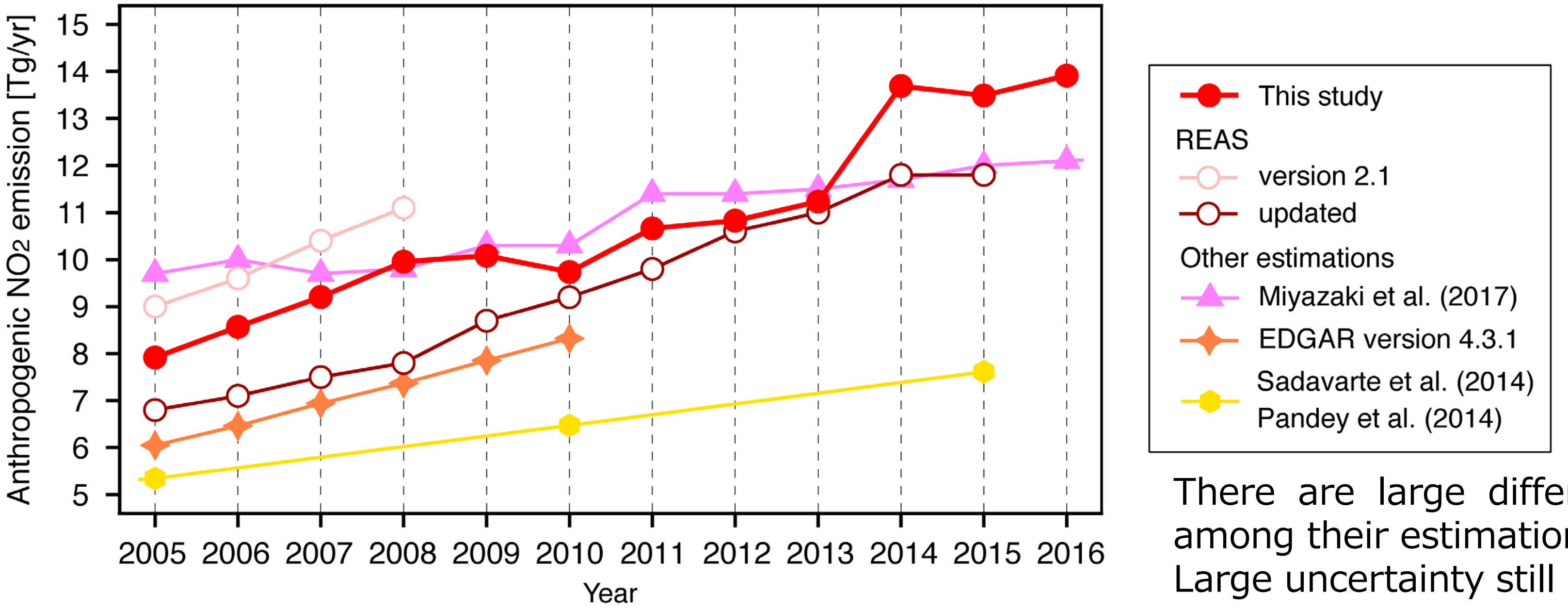
Itahashi et al. (2019)

China




Inversed emissions (blue line) are consistent with the updated REAS emissions (black line with open circle) and other estimations.

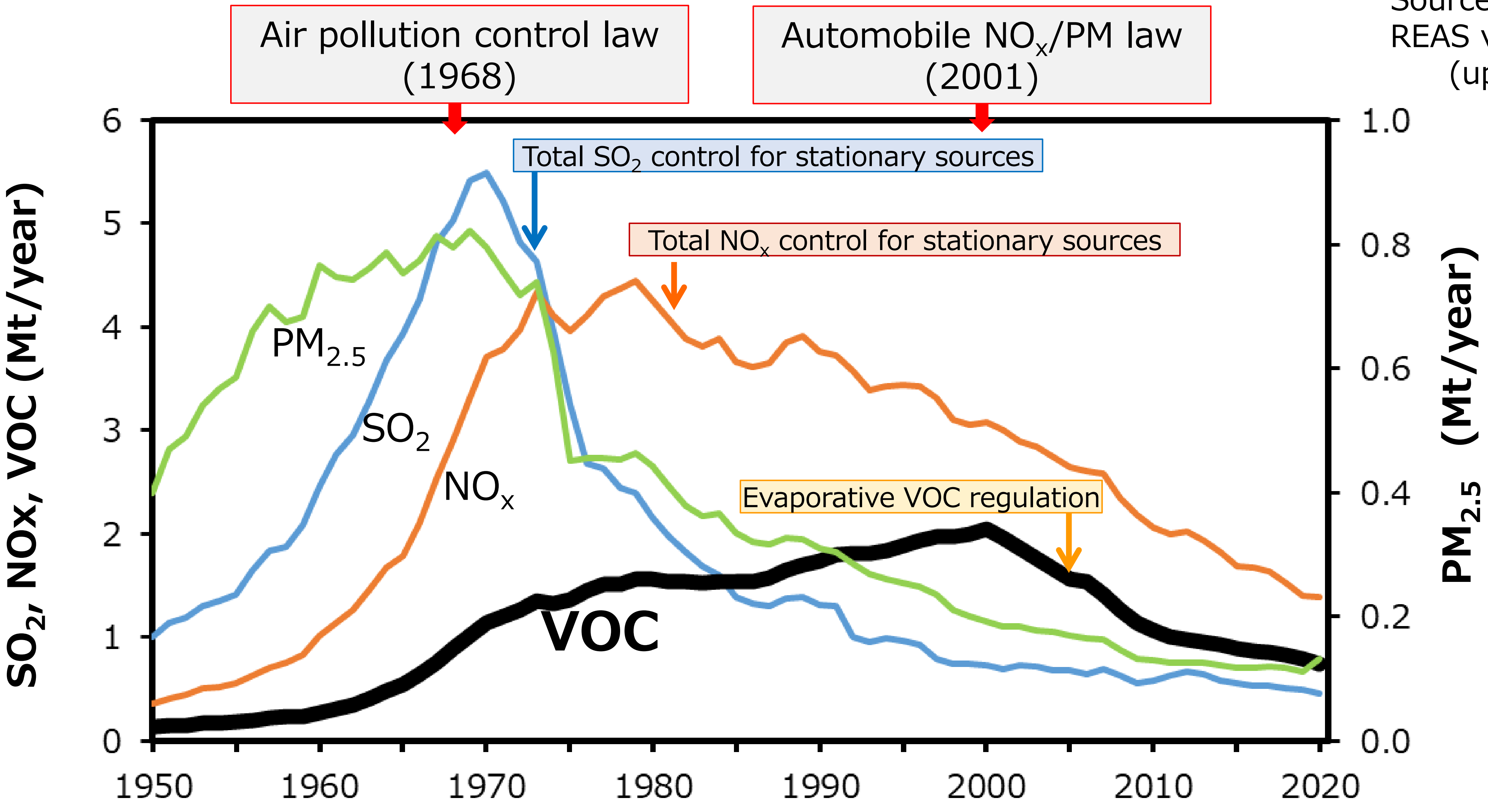
India




There are large differences in emission amount among their estimations.
Large uncertainty still remains.

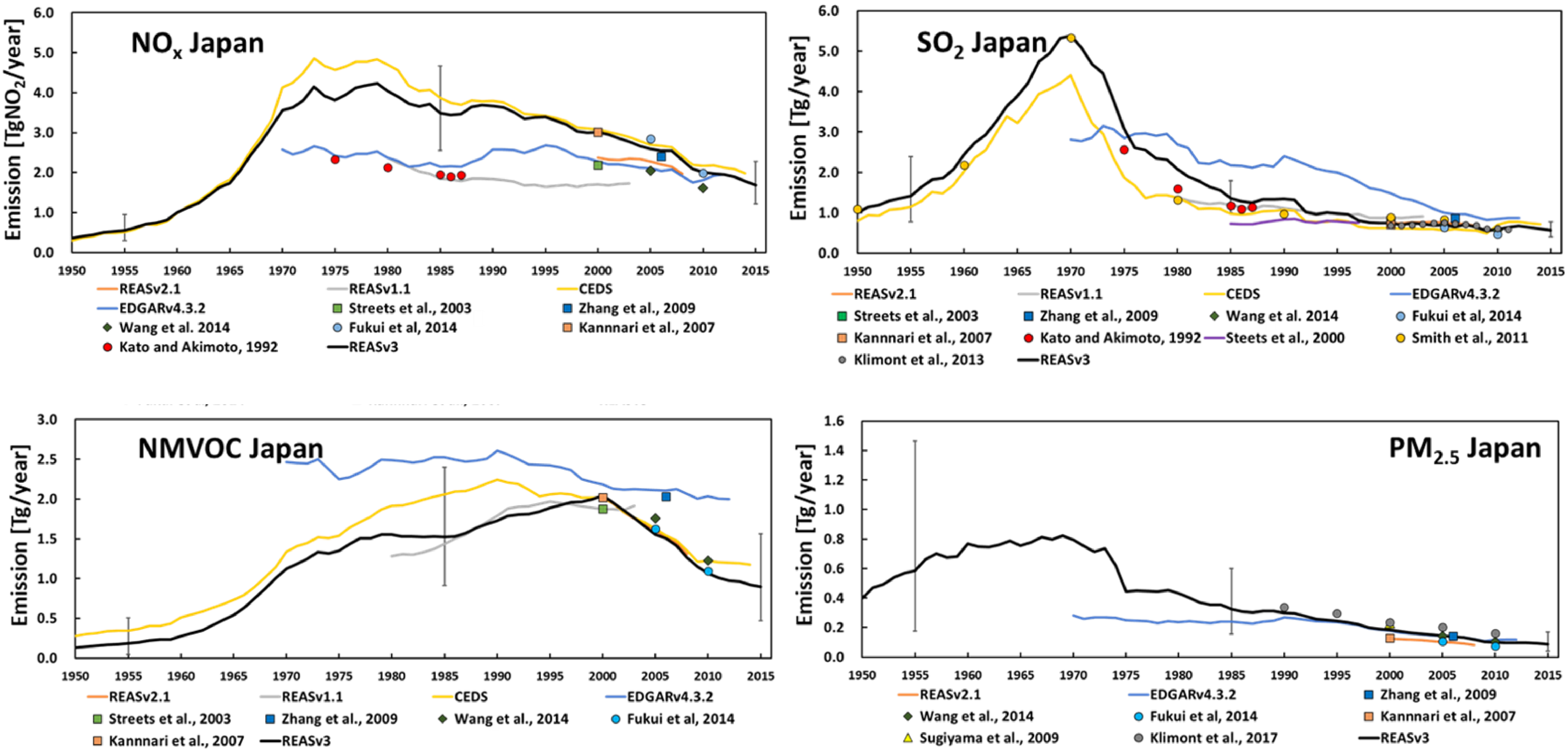
# Historical emissions in Japan during 1950-2020 (Japanese case as good example of effects of emission control)

Source: REAS v3.2.1 (updated)




The peak year depends on the balance of emission control implementation and changes of activities related to emissions .

# Uncertainties of Japanese emissions



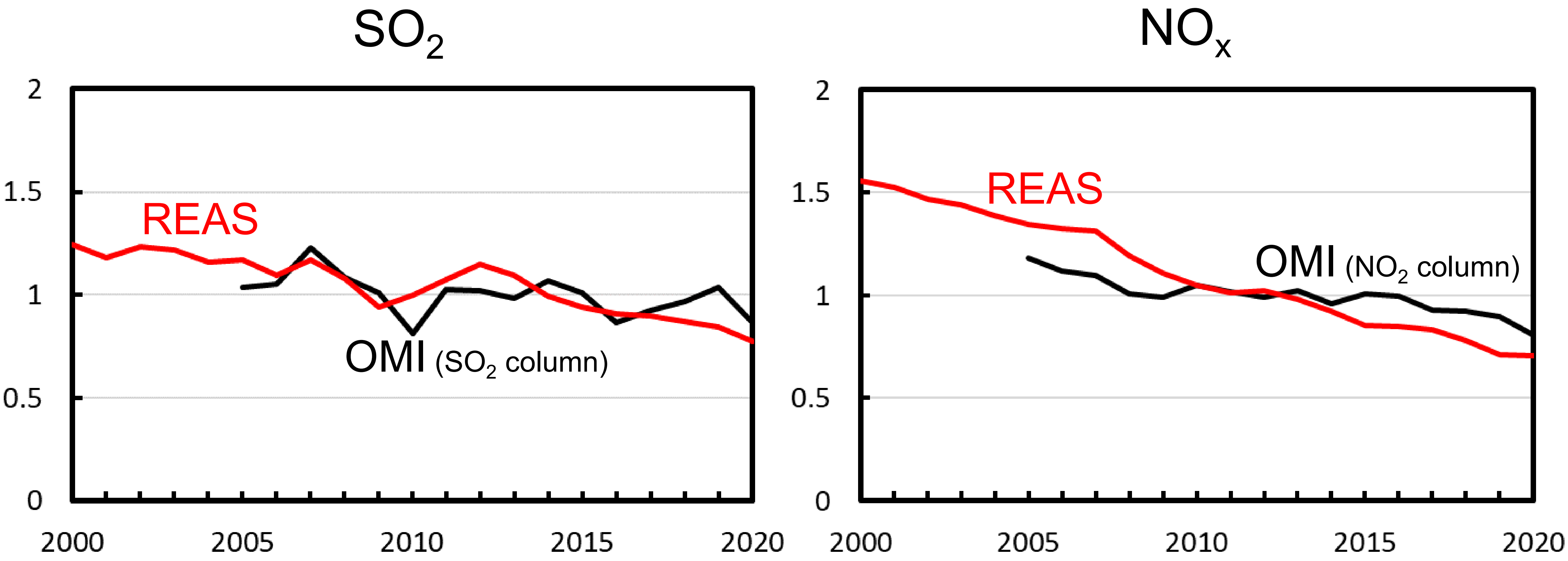

Kurokawa and Ohara (2020)

# Topics on validation of emission trends in Japan

1. Historical variations of air pollutants emissions over Japan
   (using OMI column density and AQ monitoring data)

2. Trend of $CO_2$ emissions in urban areas
   (using observed data in $CO_2$ monitoring stations)

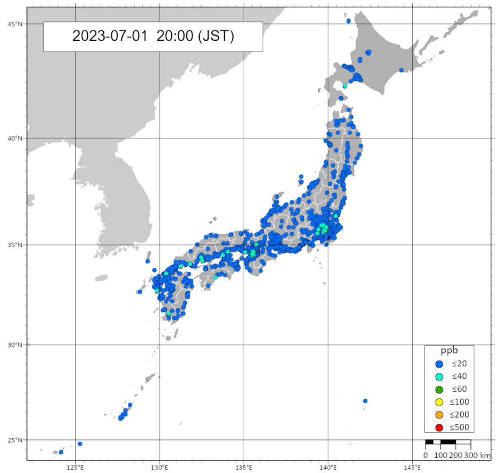
# Comparison of trends of REAS inventory and OMI over Japan



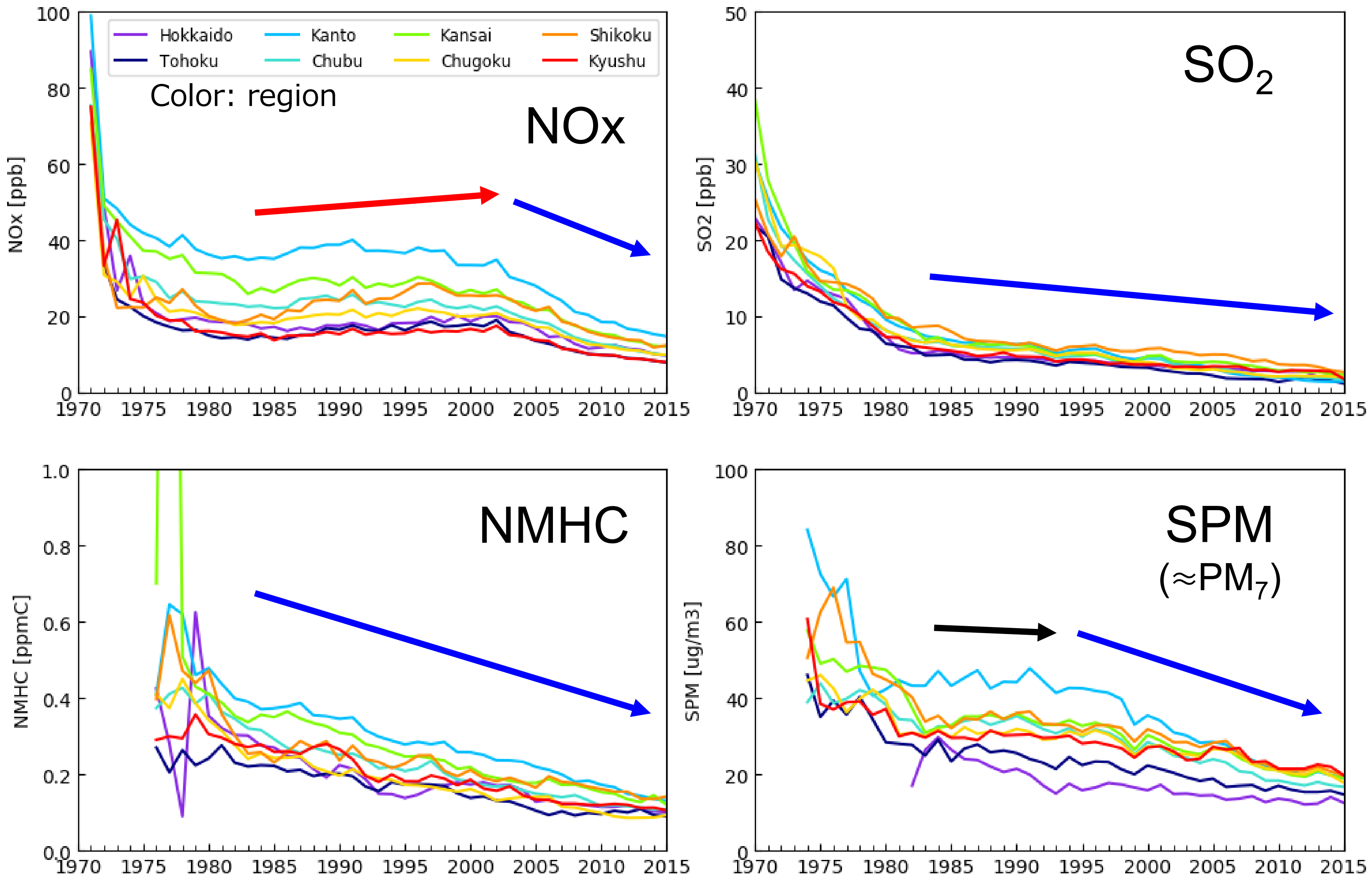

(Note) y axis is scaled by the average value during 2005-2020.

# Long-term variations of annul mean concentrations observed at monitoring stations across Japan

Map of Monitoring stations (for NOx)

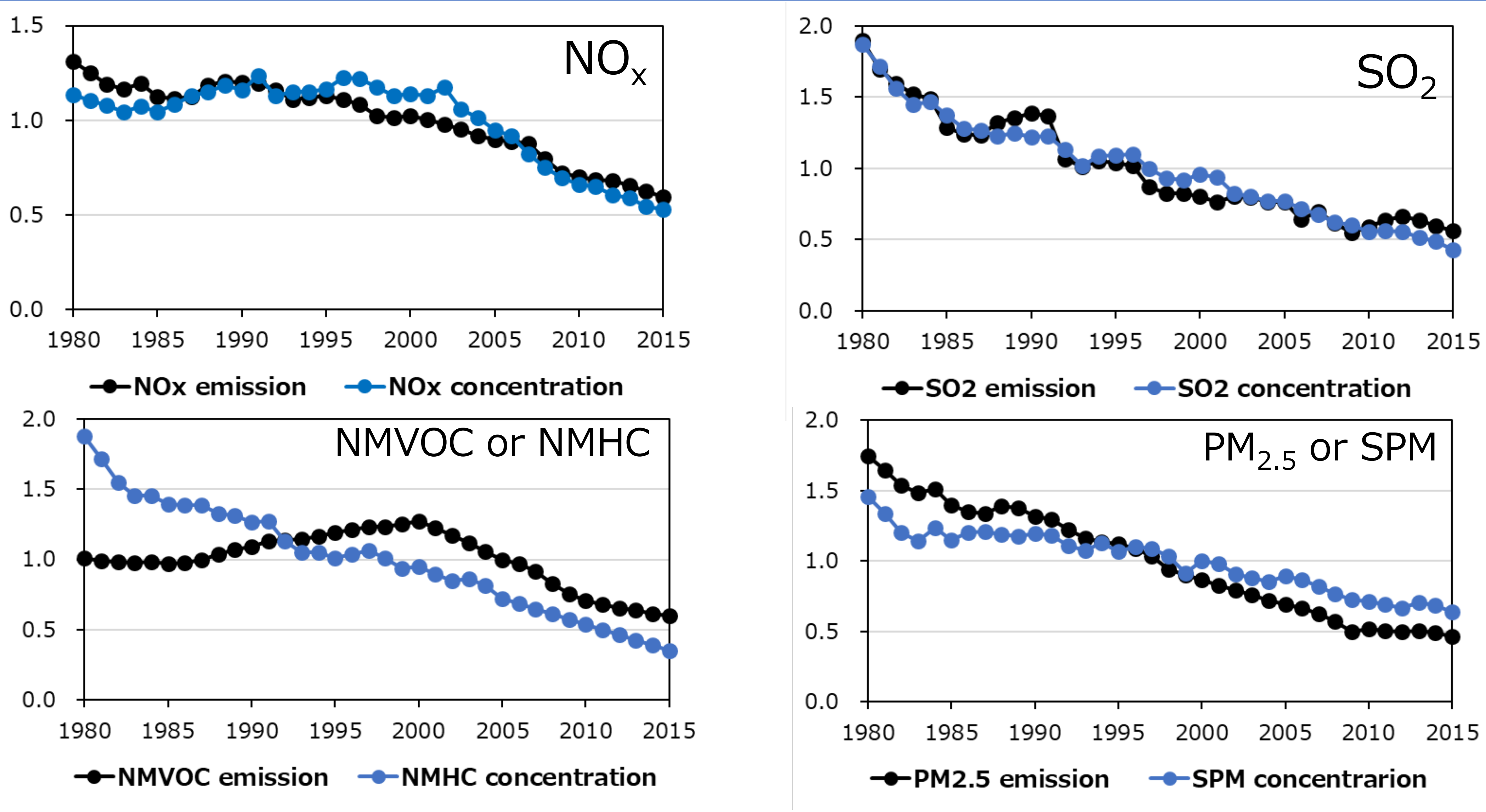



(N = 1200～1300)




(Provided from Dr. Natsumi Kohno)

# Comparison of emissions and ambient concentrations of $SO_2$, $NO_x$, NMVOC (NMHC) and $PM_{2.5}$ (SPM)




(Note) y axis is scaled by the average value during 1980-2015.

# Trend of $CO_2$ emissions in urban areas?

- The **urban emissions of GHG** were estimated to be about **70% of the global share** in 2020 and continue to increase [*Lwasa et al.*, 2022].
- However, the emission inventories for anthropogenic sources in urban area are considered to have **large uncertainties** [*Gurney et al.*, 2021].
- Therefore, it is becoming a **science-based information for tracking and verifying $CO_2$ emission reduction** in urban area based on observing system as well as modeling and analysis methods.
- However, **there is no research that has verified the long-term trend in $CO_2$ emissions** in cities over a period of more than ten years.

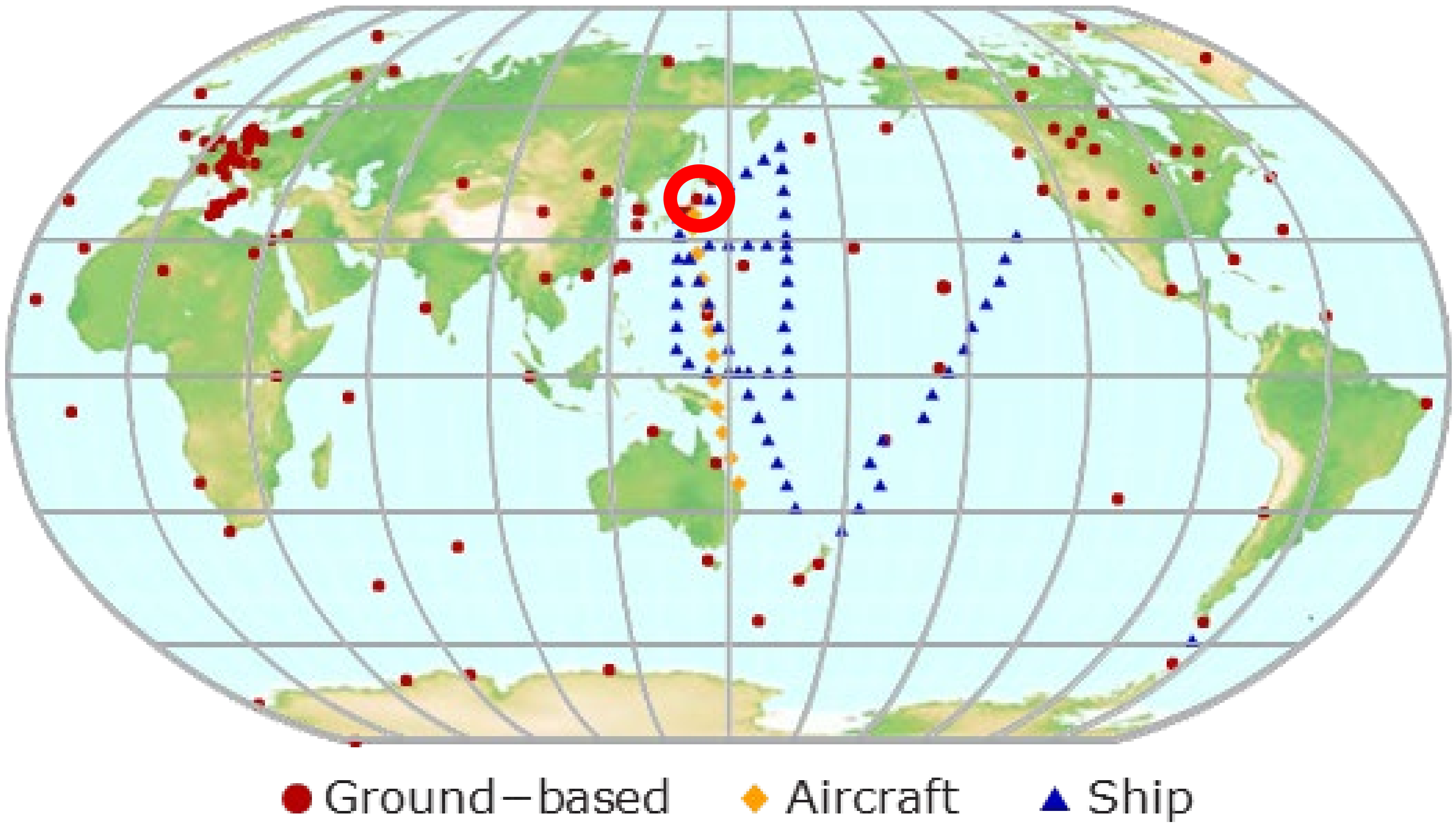
# Purpose of this study

- **To verify the estimated reduction of $CO_2$ emissions in the urban area** of Tokyo Metropolitan Area (TMA), using approximately 20 years of $CO_2$ concentration monitoring data from 2002 to 2020

- To demonstrates that long-term continuous and high-precision **observations of $CO_2$ concentration can scientifically track and verify the effectiveness of $CO_2$ emission reduction** policies and actions in the region

# GAW global network for $CO_2$ in the last decade

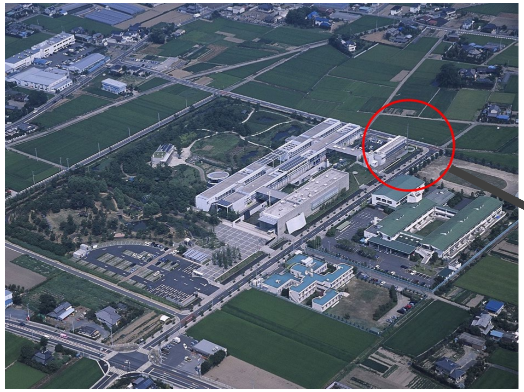
Two ground-based stations are operated by our institute and are a part of a global network of 184 stations which are regularly reported to the World Data Centre for Greenhouse Gases (WDCGG) of WMO.




World Meteorological Organization: WMO Greenhouse Gas Bulletin, No.19, https://library.wmo.int/idurl/4/68532, 2023.

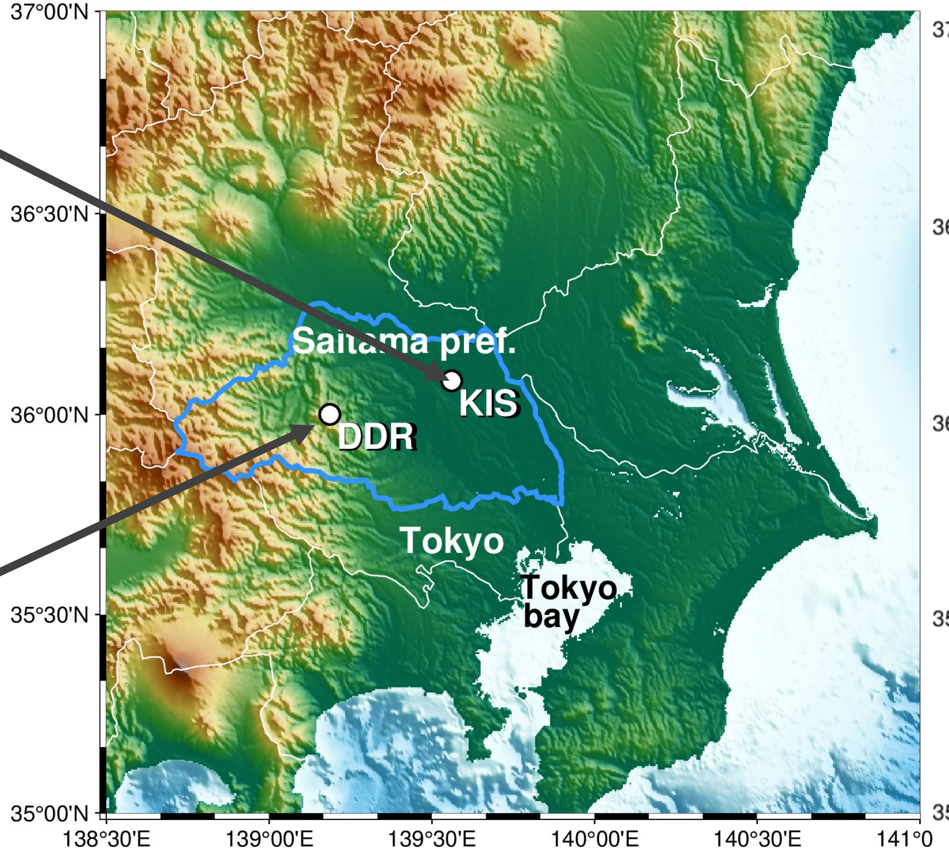
# Monitoring stations

KIS (Rural site)

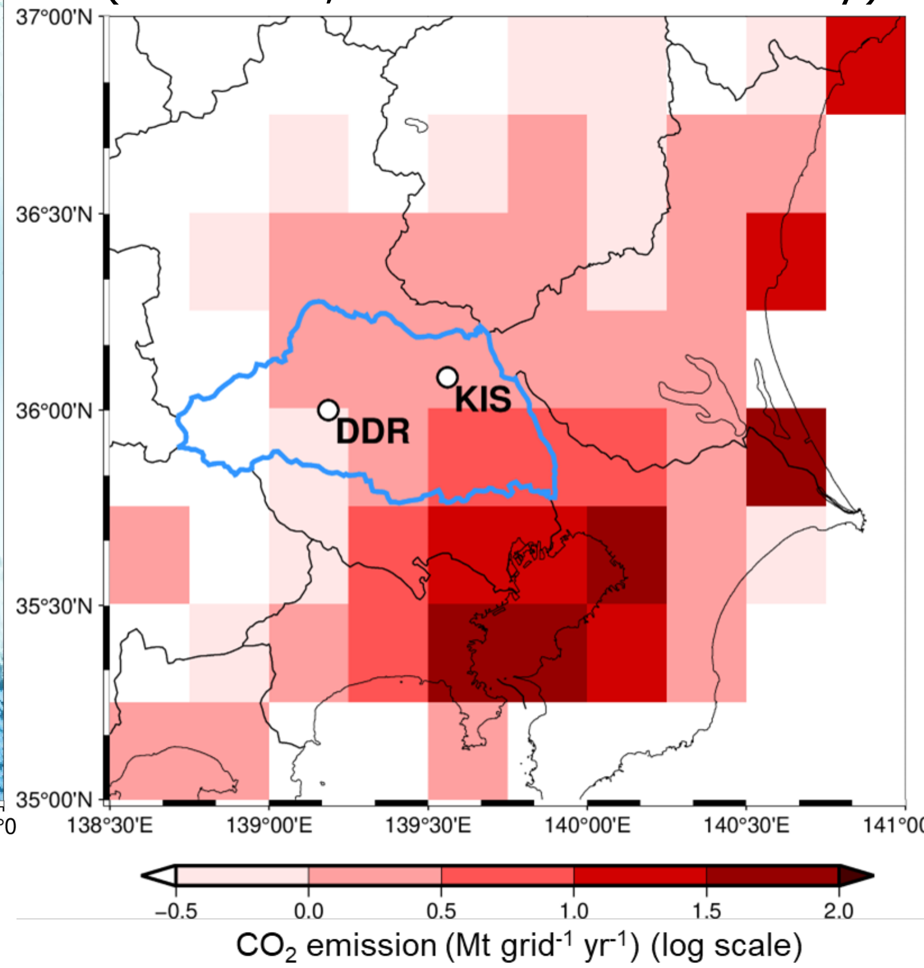


DDR
(Mountainous site)


Topography

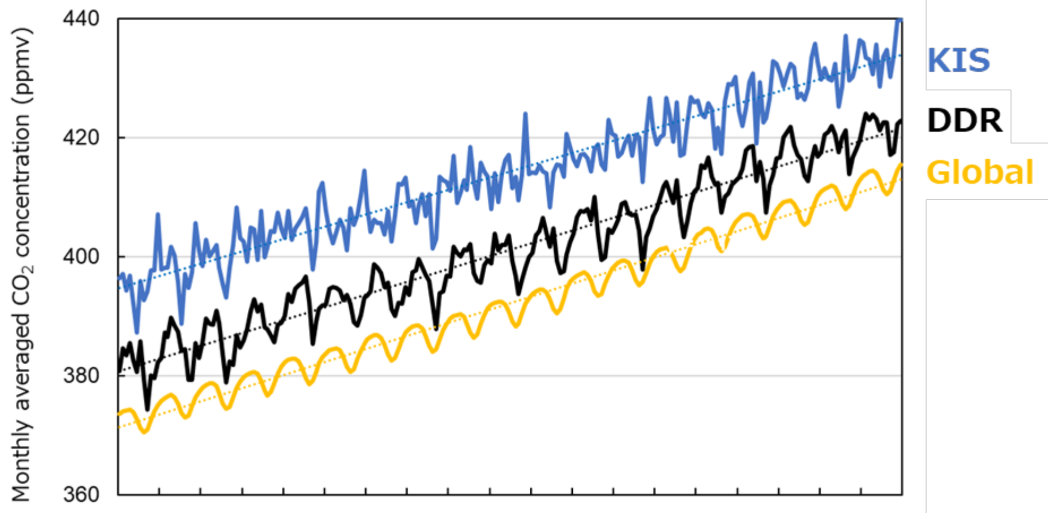



$CO_2$ emission map
(for 2015; from REAS inventory)

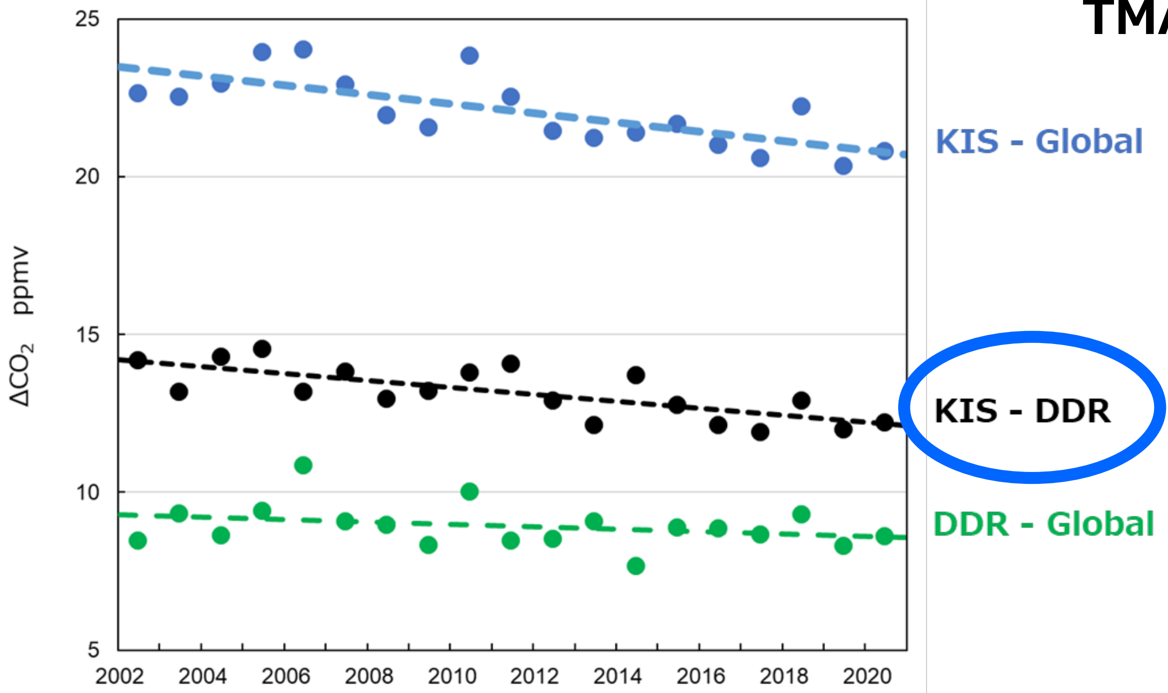


# Temporal variations of $CO_2$ concentrations observed in two stations (DDR and KIS) and global mean

Monthly $CO_2$ concentrations




Annual mean $CO_2$ differences ($\Delta CO_2$)




[Annual rate]
2.06 ppm $yr^{-1}$ for KIS
2.15 ppm $yr^{-1}$ for DDR
2.19 ppm $yr^{-1}$ for the global mean

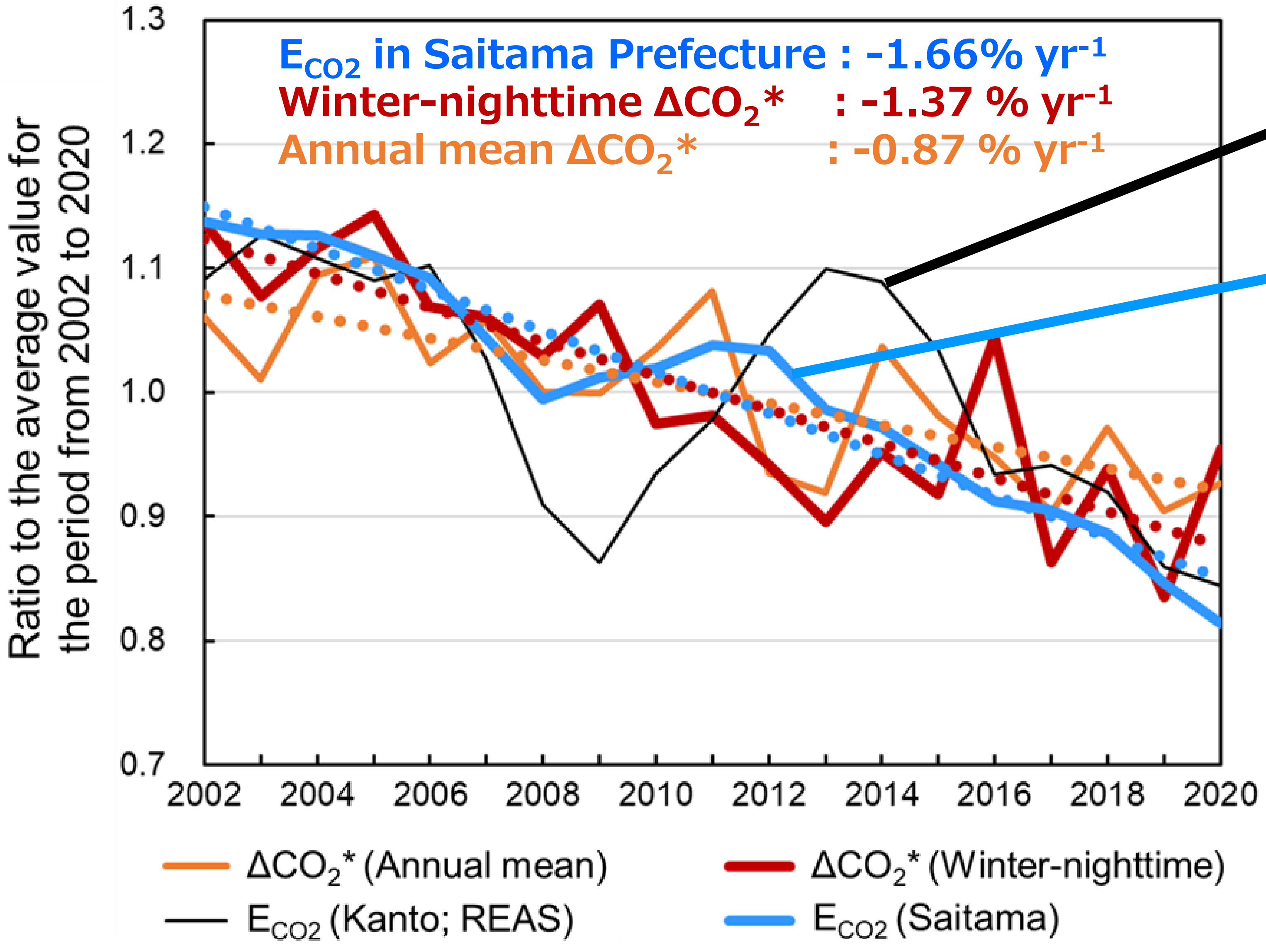
**KIS < DDR < global**

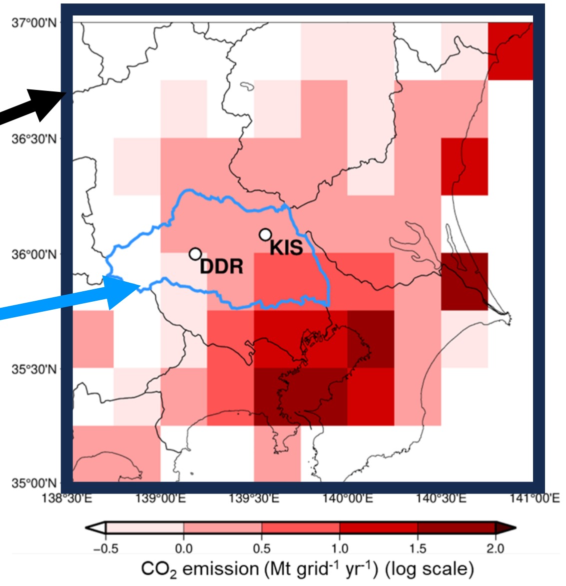
**This suggests the possibility of a reduction in $CO_2$ emissions in TMA.**

**$-0.11 \pm 0.024$ ppm $yr^{-1}$**

**Does this trend match that of regional $CO_2$ emission?**

# Comparison with the annual average and winter-nighttime average of $\Delta CO_2^*$ (=KIS-DDR) and the annual emissions of $CO_2$ ($E_{CO2}$)



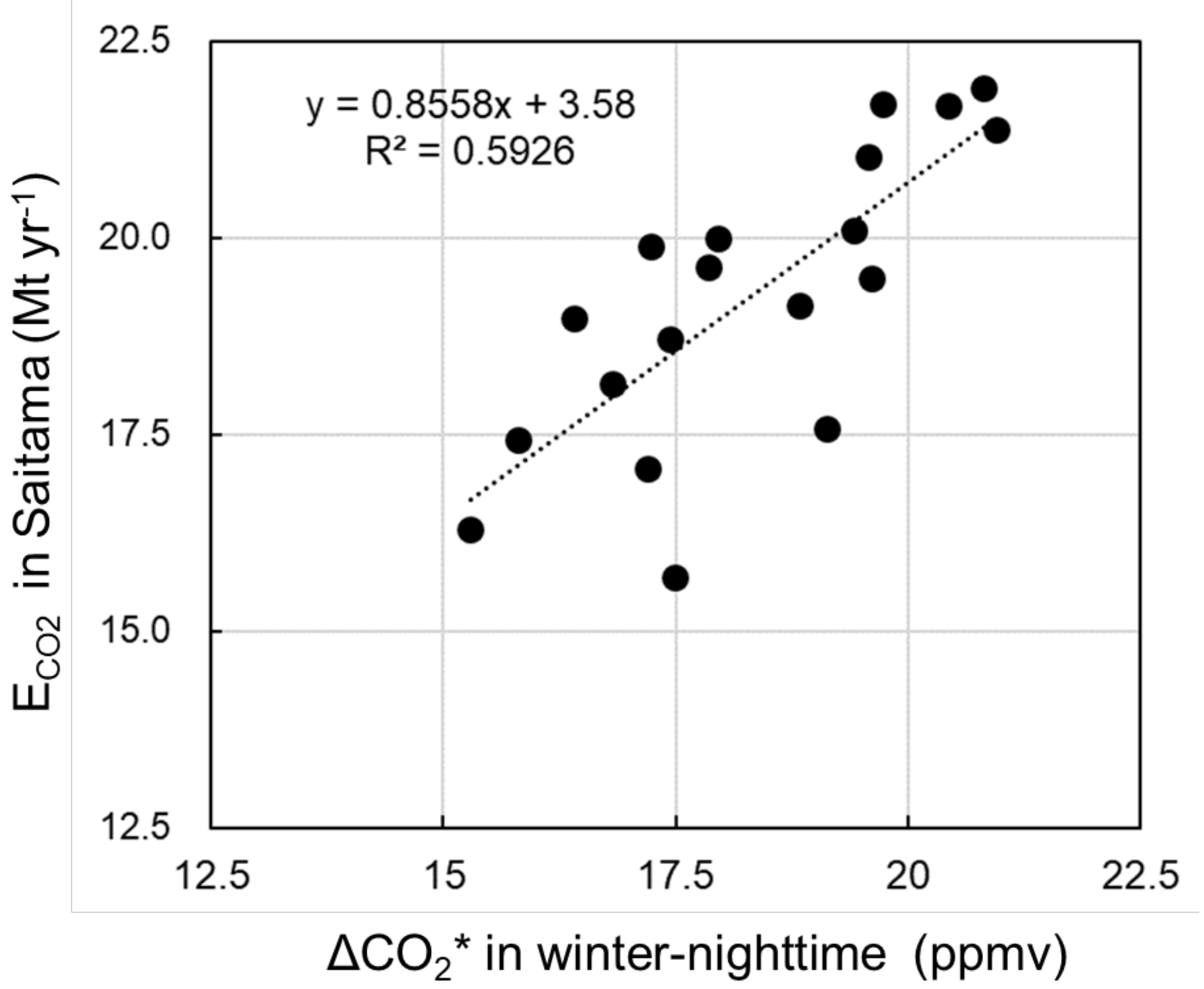

**The long-term trend of winter-nighttime $\Delta CO_2^*$ closely match with the $E_{CO2}$ in Saitama Prefecture.**

**Annual mean $\Delta CO_2^*$ change rate is slightly smaller.**

**Winter-nighttime is good condition for detecting the regional $CO_2$ emissions.**

**$\Delta CO_2^*$ has the ability to track the temporal changes in regional $CO_2$ emissions.**

# Relationships between $\Delta CO_2$* (winter-nighttime) and $E_{CO2}$ in Saitama prefecture



# Summary of $CO_2$ trend analysis

## It was the first time to demonstrate the long-term reduction of $CO_2$ emissions in mega cities by observations!

- This study demonstrates that the **long-term continuous observations of $CO_2$ concentrations in multiple stations can scientifically track and verify the effectiveness of emission reduction** policies and actions in the region.

- Furthermore, it can be verified through the observation of $CO_2$ concentration that **the long-term trend in anthropogenic $CO_2$ emissions inventory** from local government (Saitama prefecture) **has high certainty**.

- **To quantitatively understand**, analyses using chemical transport models and inverse **modeling are considered to be useful**.

# Important challenges for emission inventory in Asia

- Developing a methodology to reduce the uncertainty of EI using a top-down approach
- Developing national EIs in each country and capacity building in Southeast and South Asia
- Future prediction of EIs under decarbonization scenarios

## Questions and Interests

Email: tohara@nies.go.jp