Predicting fossil fuel CO2 using air quality emissions and emerging CO2 satellite observations for global carbon cycle assessment

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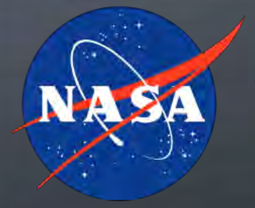

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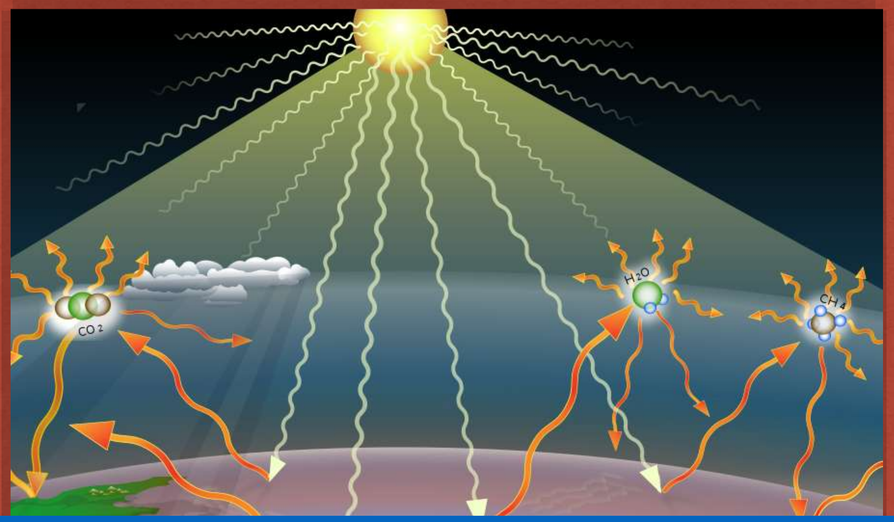
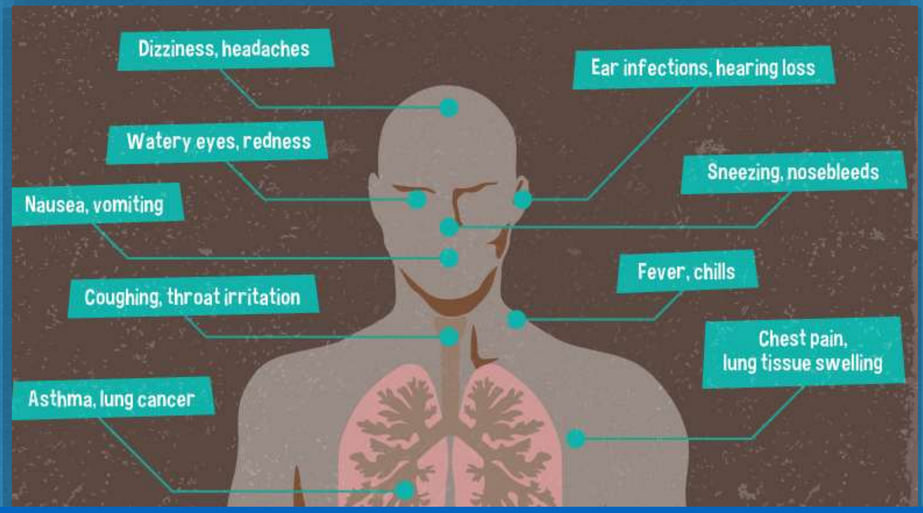
Co-emitted GHG and air pollutants

GHG
Fossil fuel CO2 (FFCO2)



Air pollutants

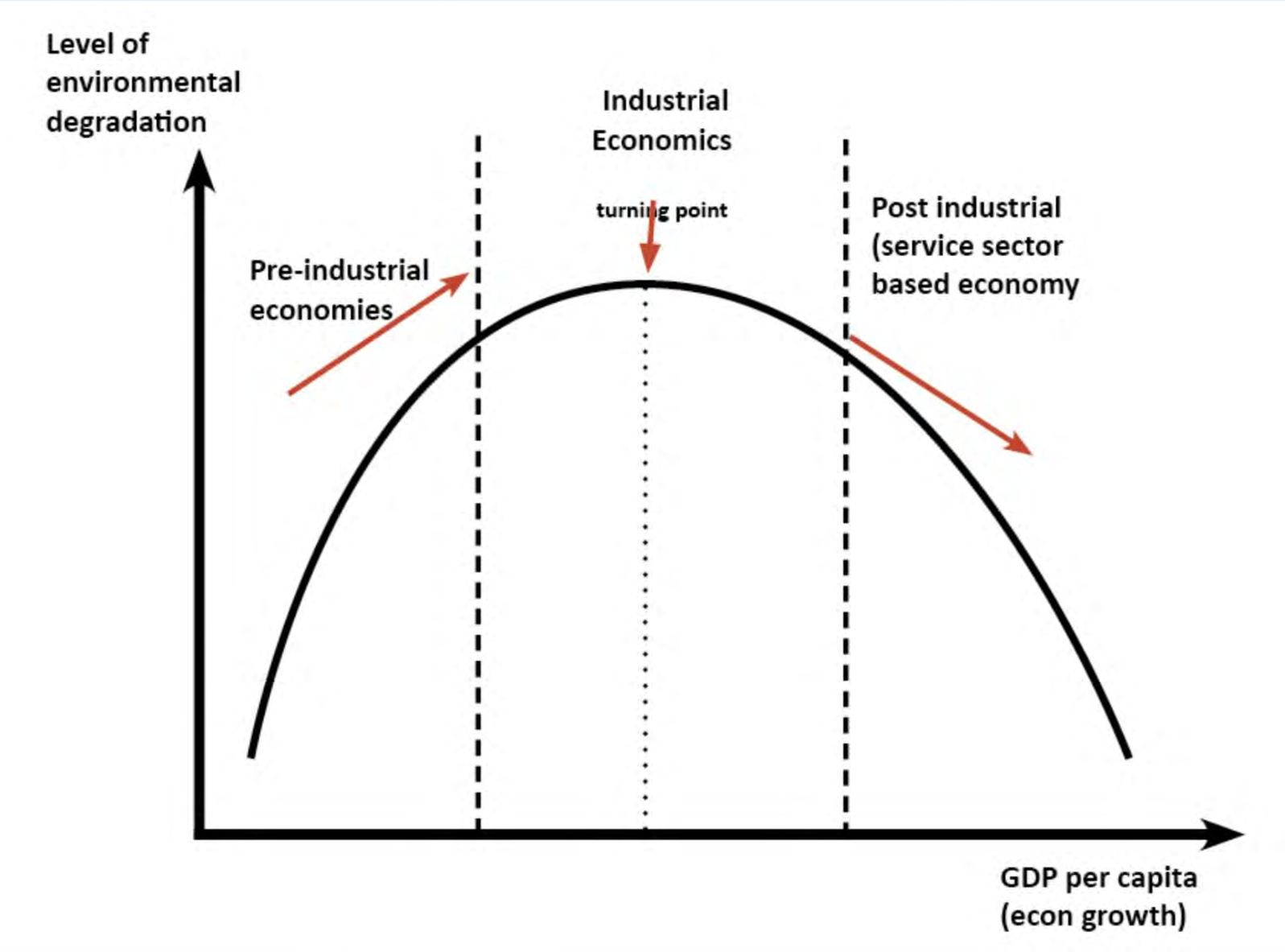


How does AQ info help FFCO2 estimates? How will changes in AQ mitigation impact carbon emissions?

Both emissions are driven by common activity, but differ by their relative contribution.

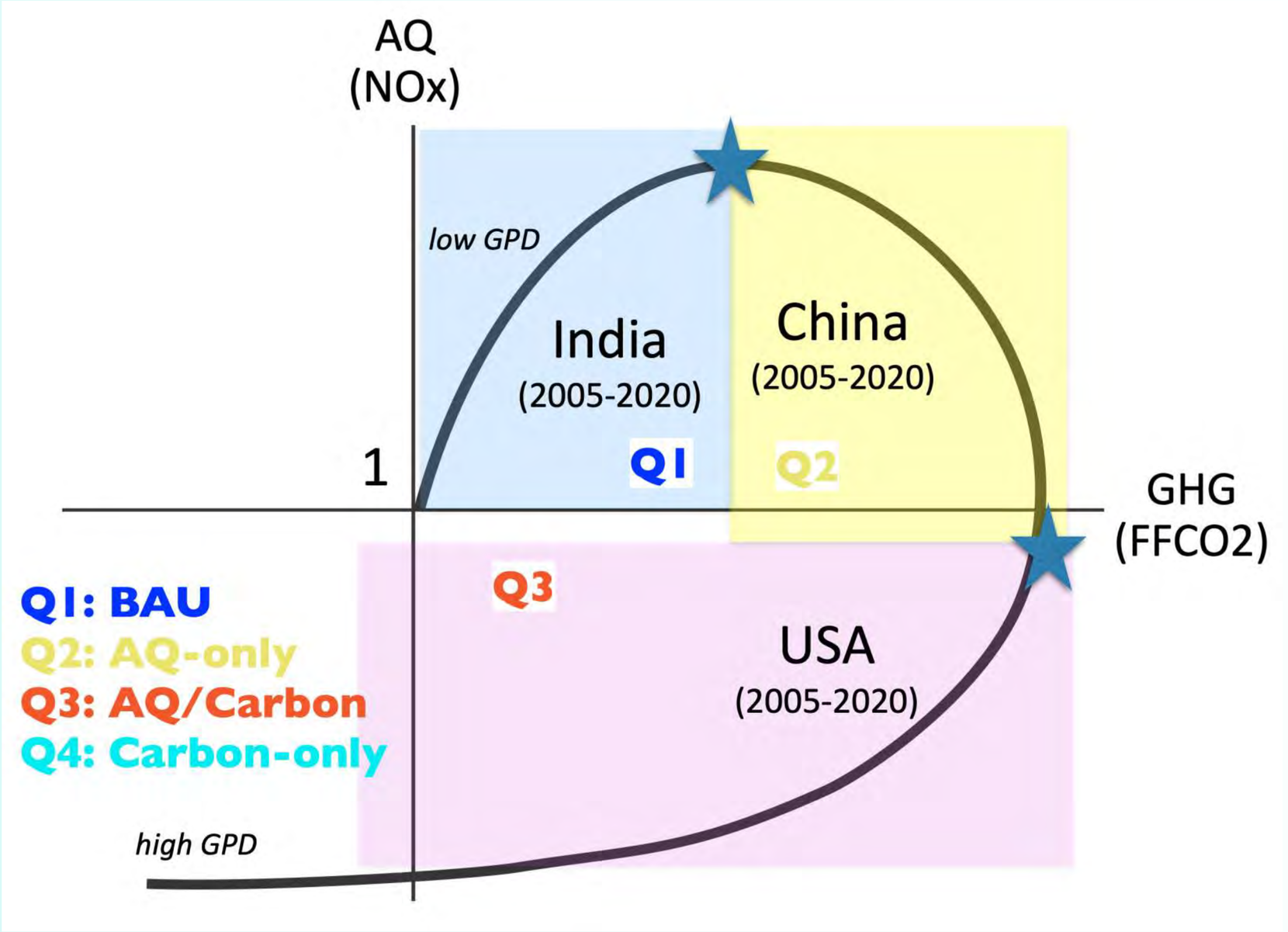
The coevolution can provide insight into the underlying anthropogenic processes.

Environmental Kuznets Curve (EKC)



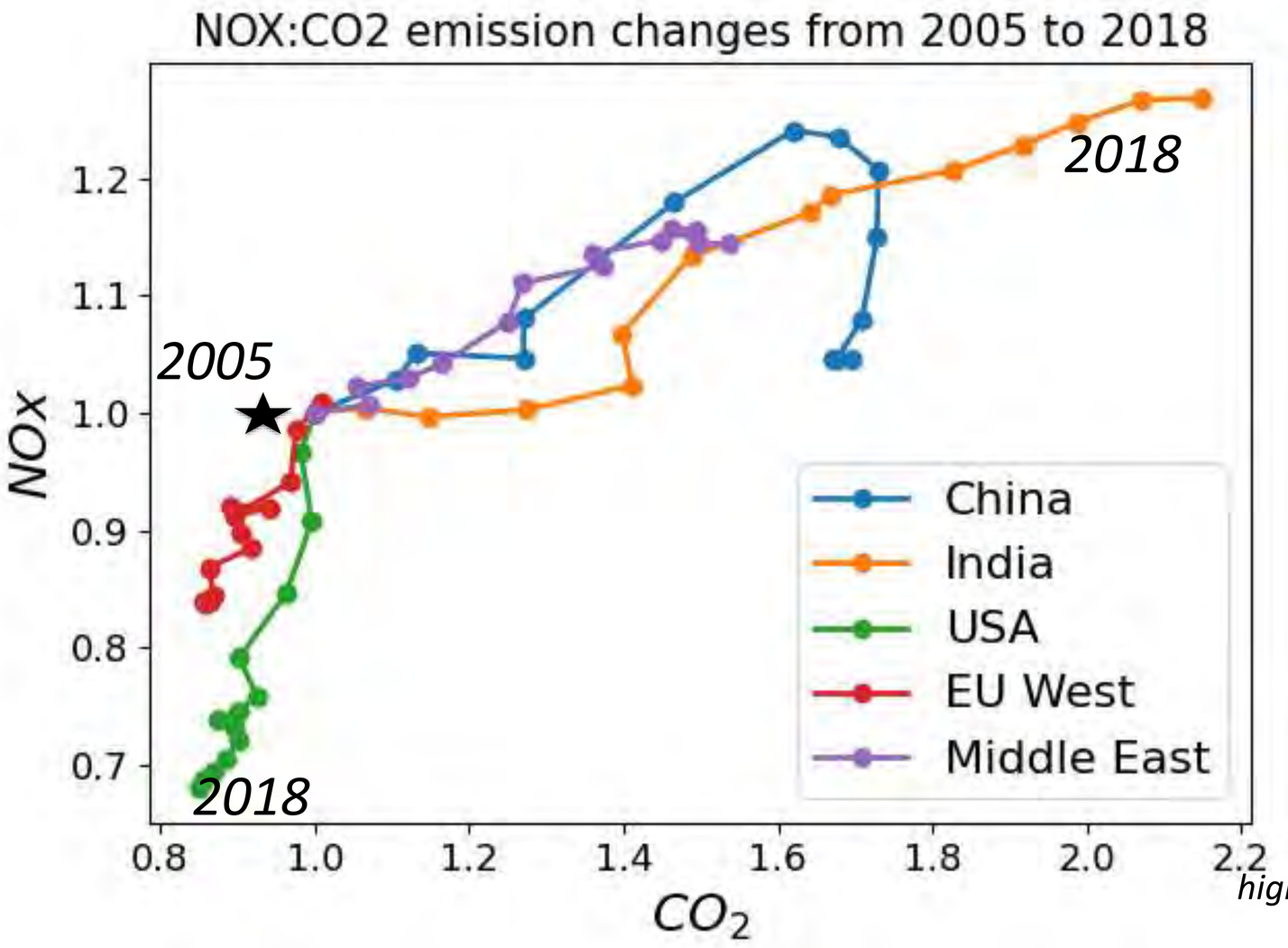
Changes in environmental degradation/improvement correspond to economic growth

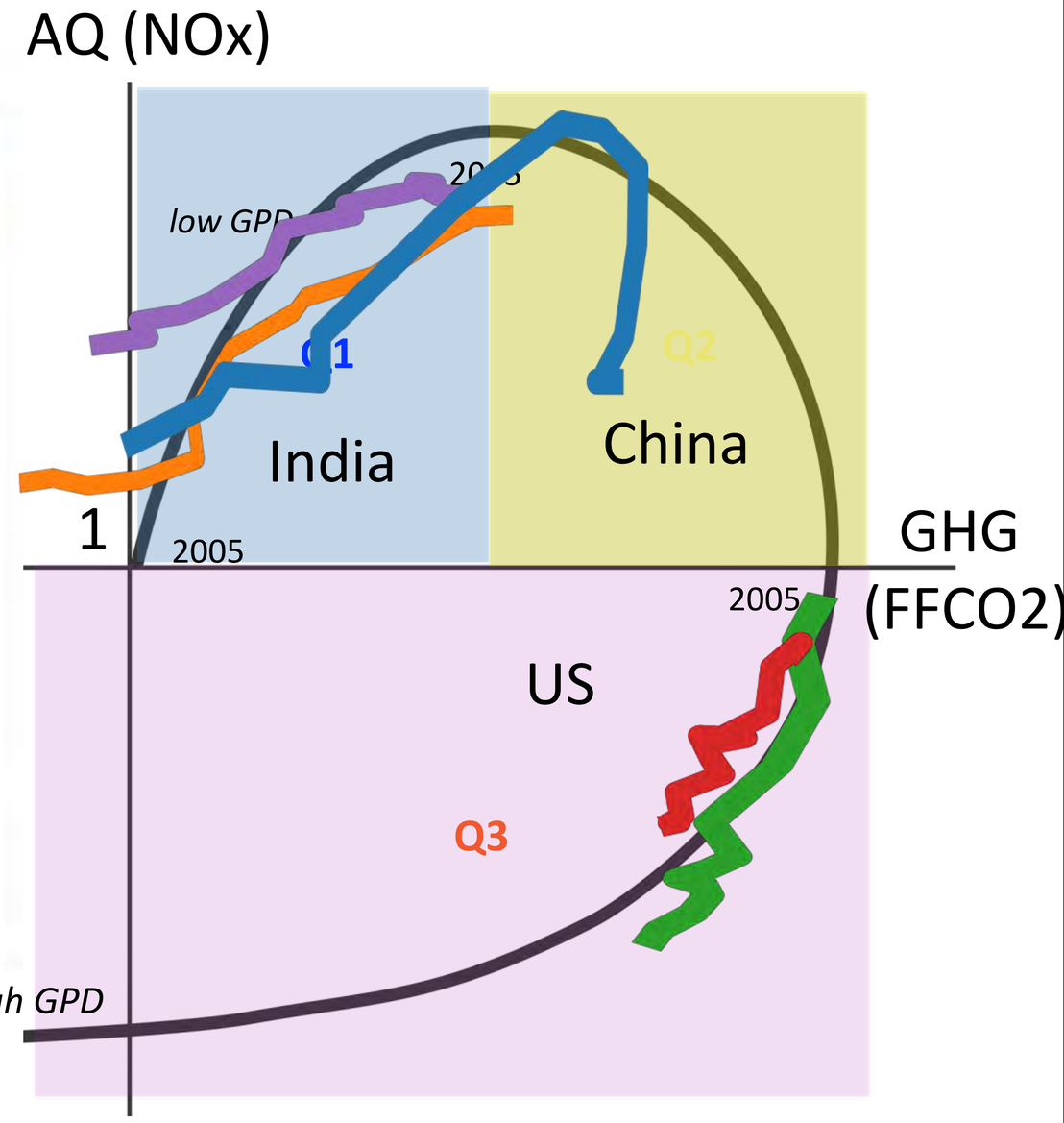
Modified environmental Kuznets Curve (MEKC)



MEKC combines GHG and AQ emissions wrt GDP into a single graph

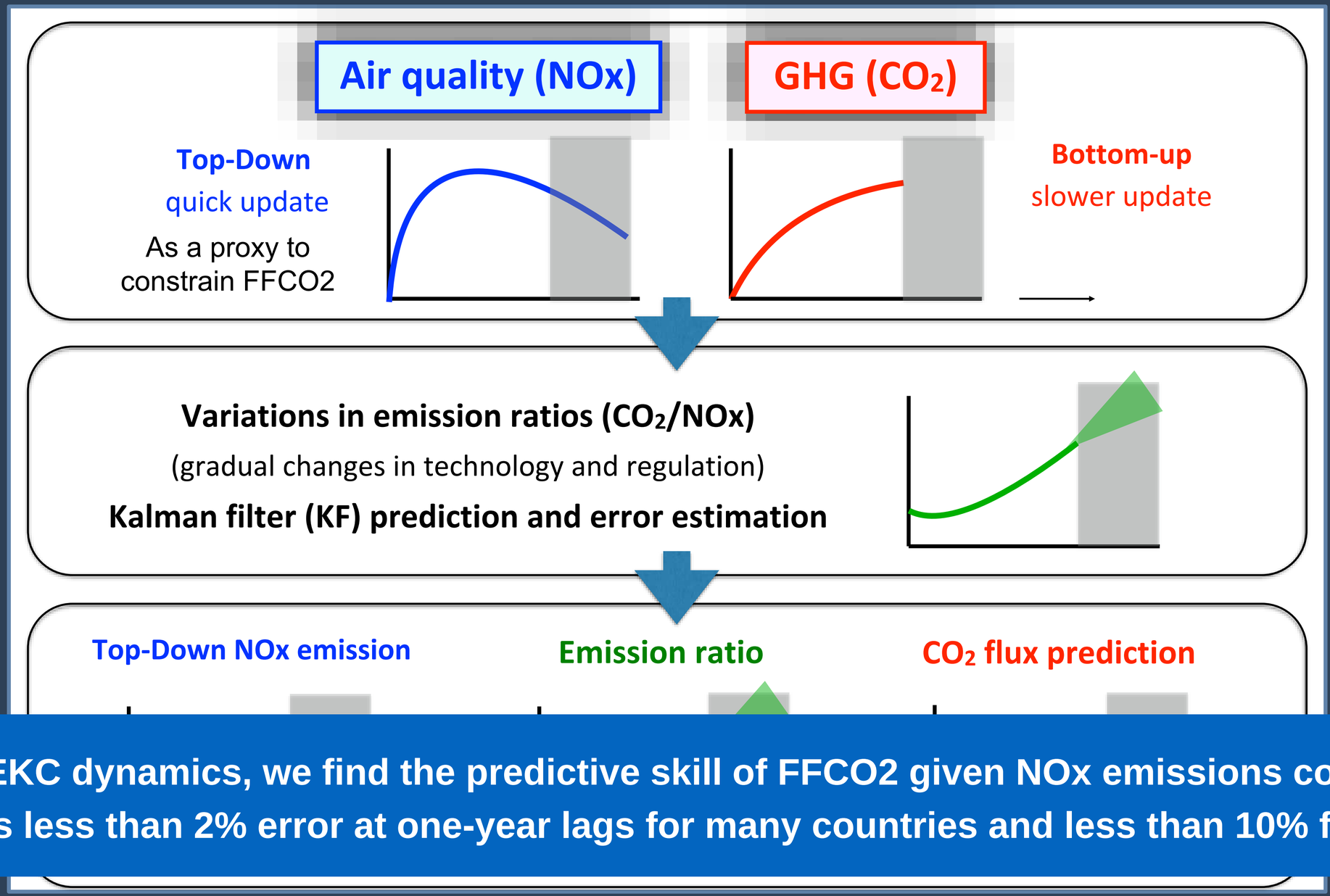
India, China, and USA are at different points along the MEKC trajectory





Does knowing MEKC trajectory give us predictive skill in CO2?

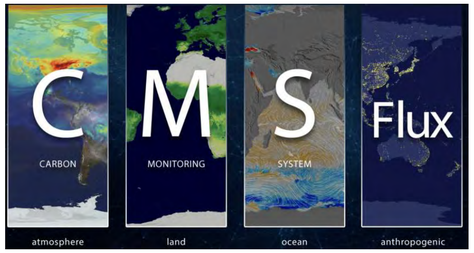
CO_2 flux prediction with Kalman Filter using top-down NOx emissions

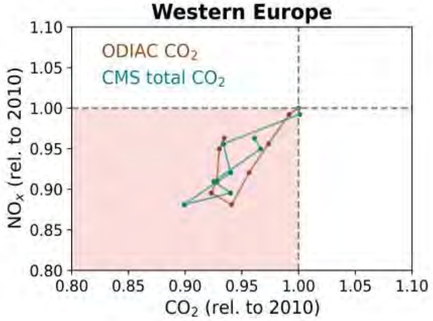


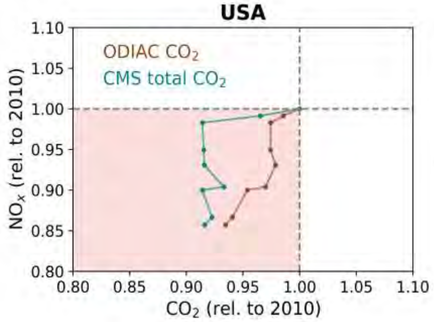
Given the MEKC dynamics, we find the predictive skill of FFCO2 given NOx emissions constrained by satellite data is less than 2% error at one-year lags for many countries and less than 10% for 4-year lags.

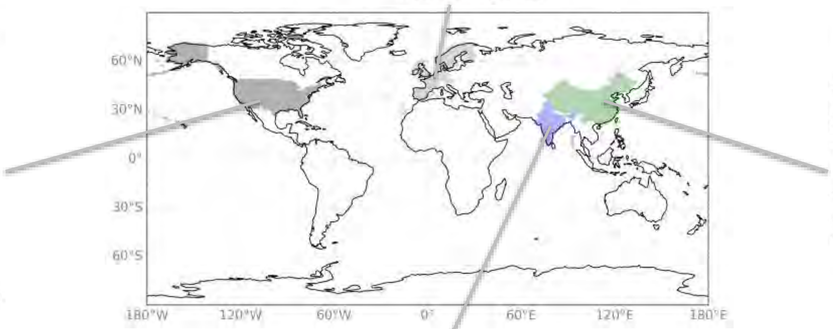
Top-down CO2 and NO2: CMS-Flux and MOMO-Chem

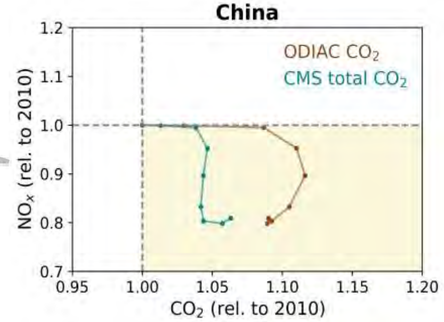
- Long-term objective is to use top-down CO2 (CMS-Flux) and NO2 (MOMO-Chem) to quantify MEKC.
- Winter-time estimates show differences between bottom-up and top-down CO2.
- Posterior CO2 includes both natural and anthropogenic sources
- Difference in trends are significant whether attributable to natural or anthropogenic sources.



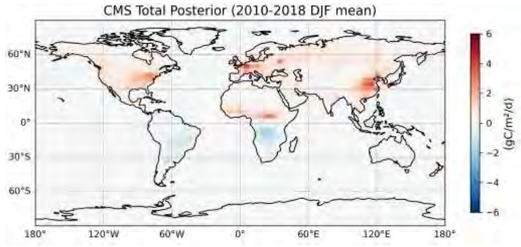




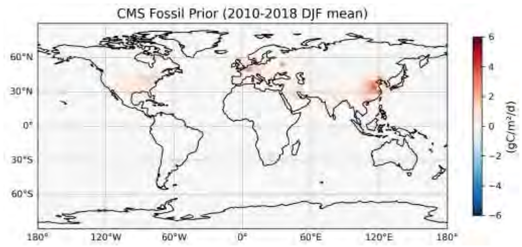


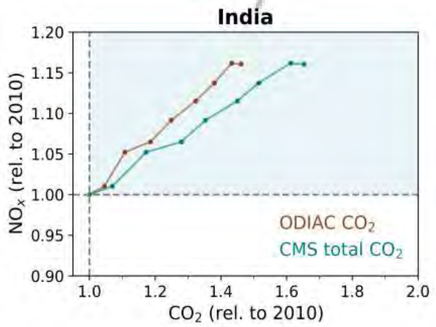


Total CO2 Flux



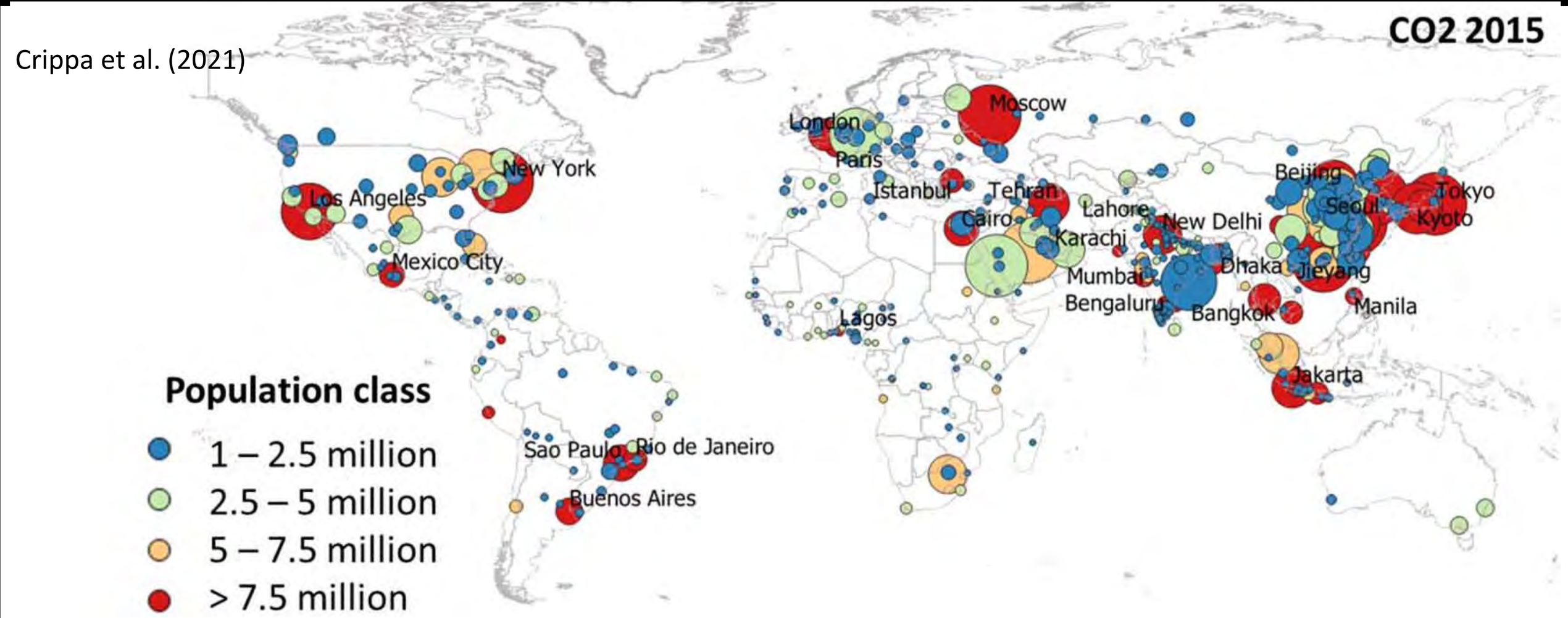
Prior Fossil Fuel Flux





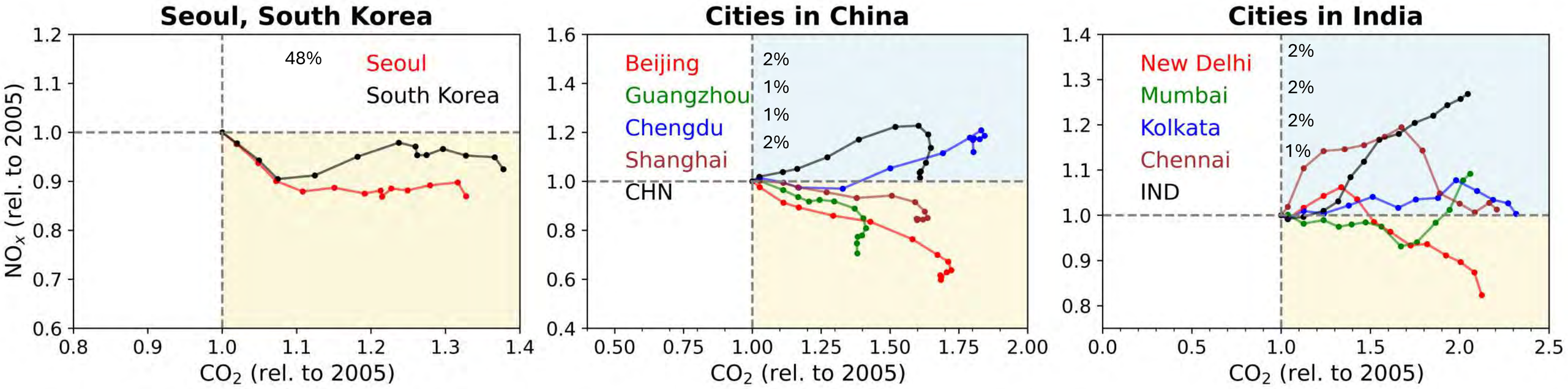
How do urban center impact MEKC?

Crippa et al. (2021)



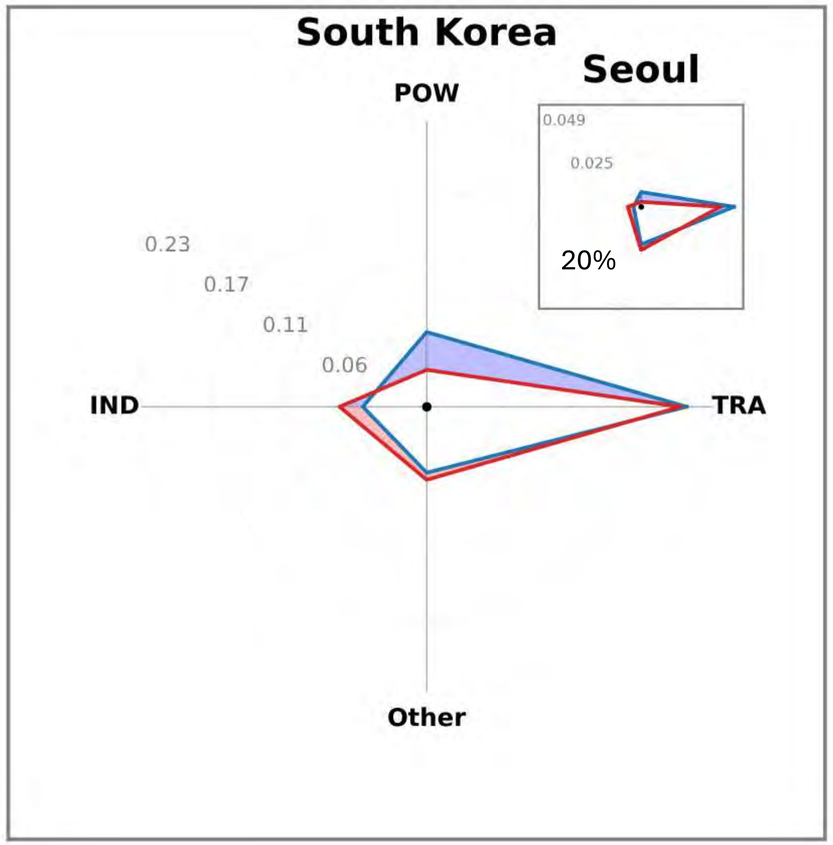
- **Urban areas emit ~1/3 of global anthropogenic GHGs and the most of air pollutants.**
- **Megacities (>10 million) in high-income countries are reducing emissions.**
- **Urban emissions in developing regions continue to increase.**
- **Highlights the need for region-specific urban mitigation strategies.**

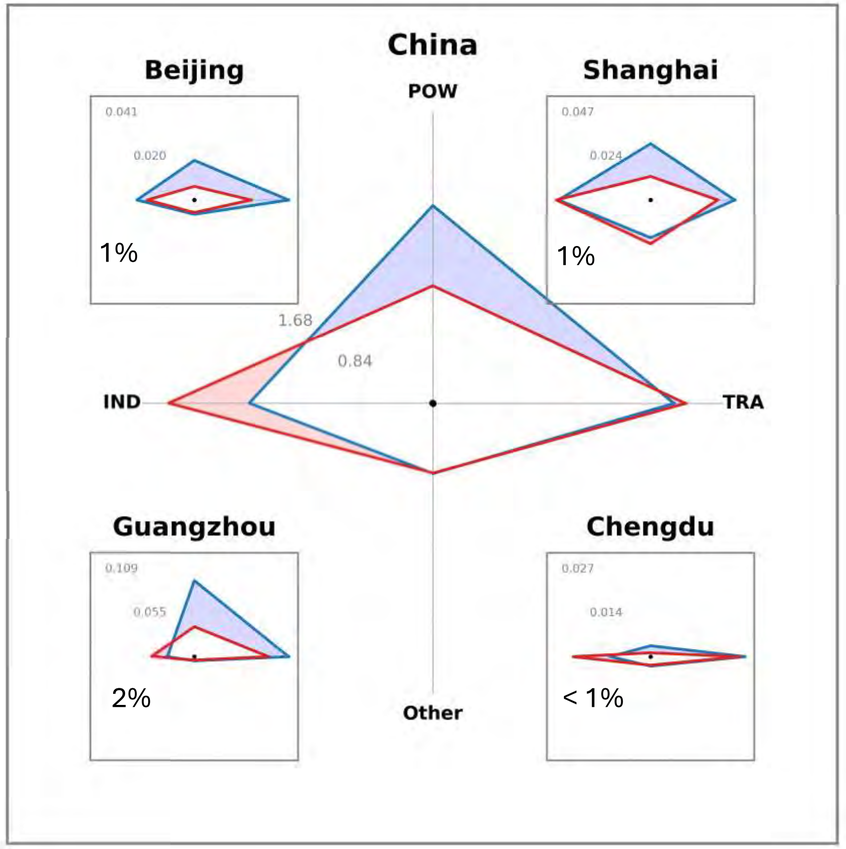
City-scale MEKC changes from 2005-2018

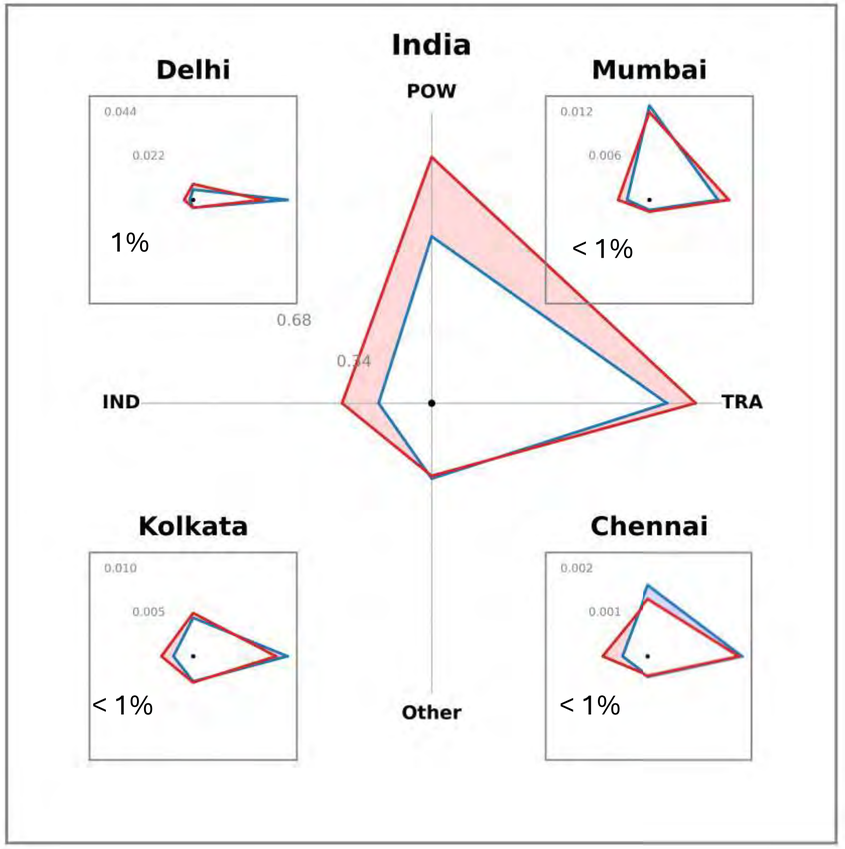


- In South Korea, city-scale and country-scale MEKC agree well as 48% of the population resides in Seoul (top-down NOx, ODIAC CO2).
- In China and India, city-scale MEKC reveals strong spatial heterogeneity among cities.
- In particular, it appears that some cities tend to lead relative to the country totals.

Sectoral level changes from 2005-2018







In China, NOx emission reduced but shifted from power to industrial.

- Developed cities like Beijing and Shanghai reduced emissions across all sectors
- Implies increases in industry occurs elsewhere in China (spatial shift)

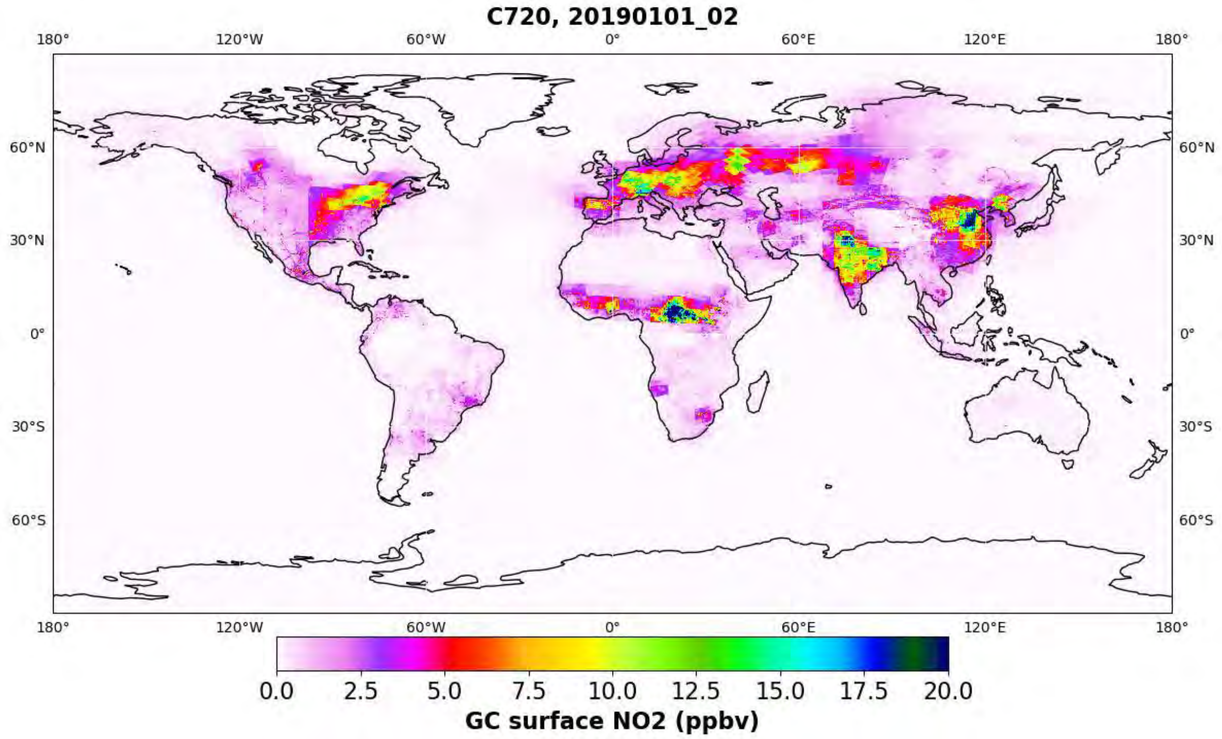
In India, emissions increased substantially across power, industry, and transportation (Q1 behavior)

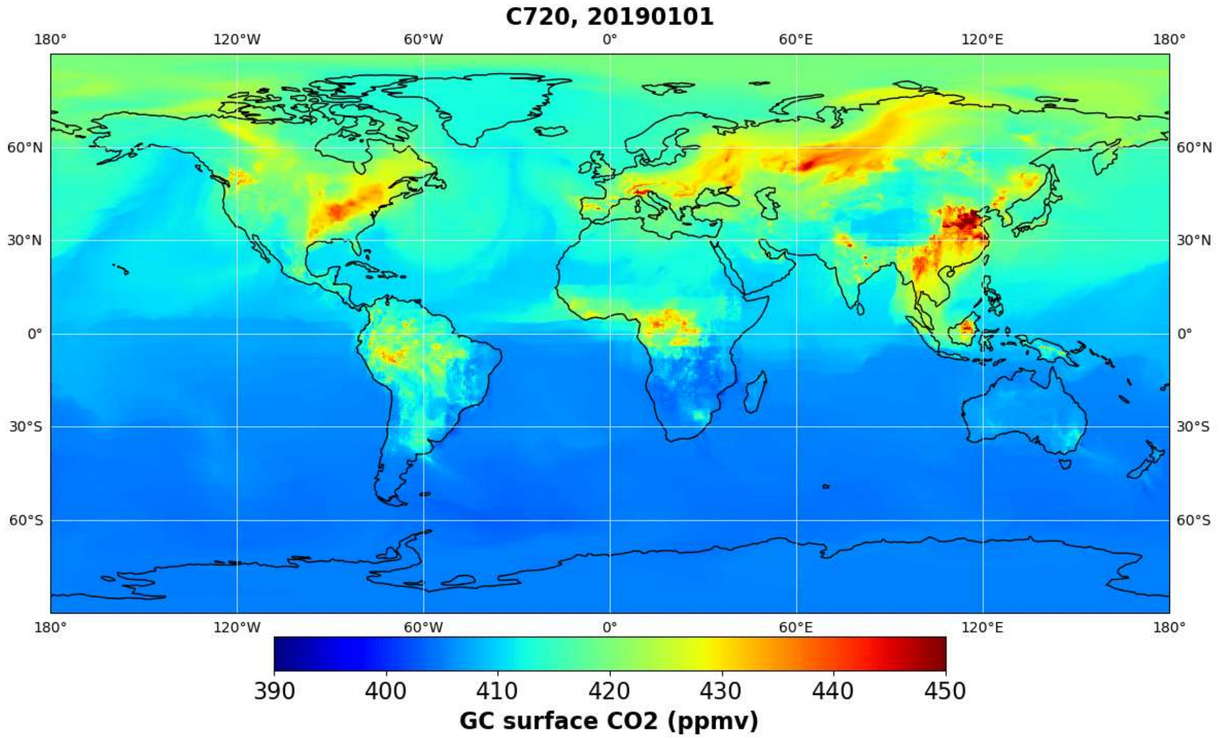
- Cities like Mumbai and Delhi show weaker increases relative to country

In some cases like S. Korea, city and country emissions coalign.

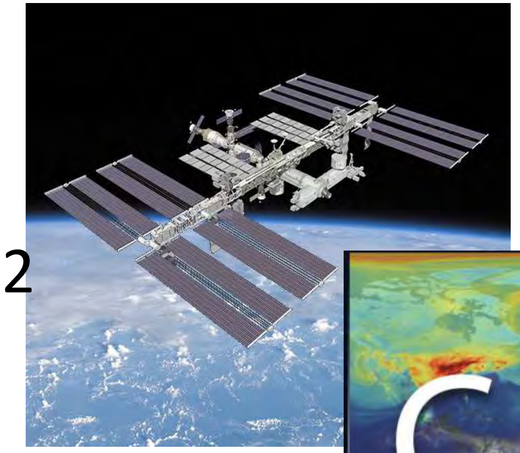
Towards higher resolution NO2 and CO2

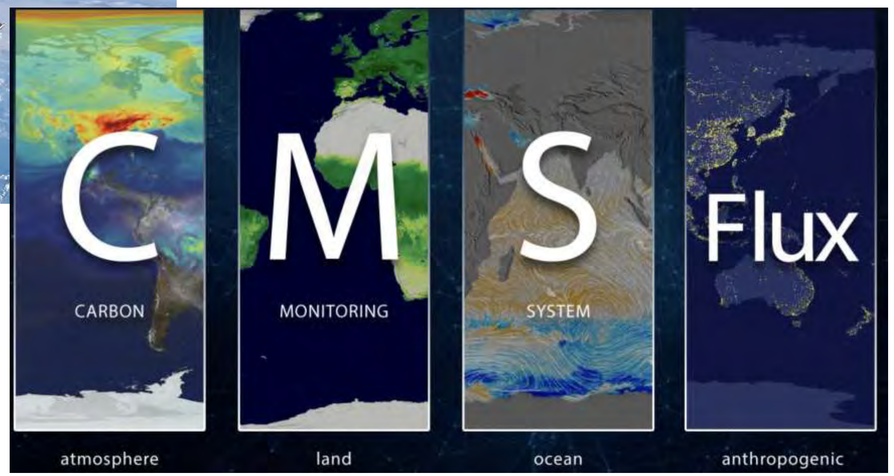
To utilize GOSAT-GW (and CO2M) to understand city-scale through MEKC, we are working high-resolution global modeling (11km) using GEOS-Chem High Performance (GCHP)



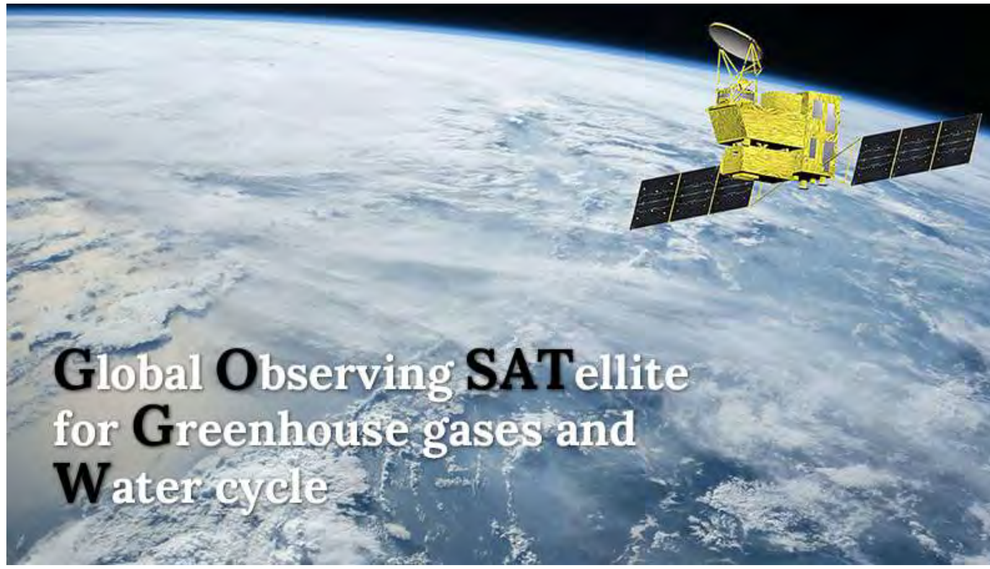


OCO-2/3 CO2

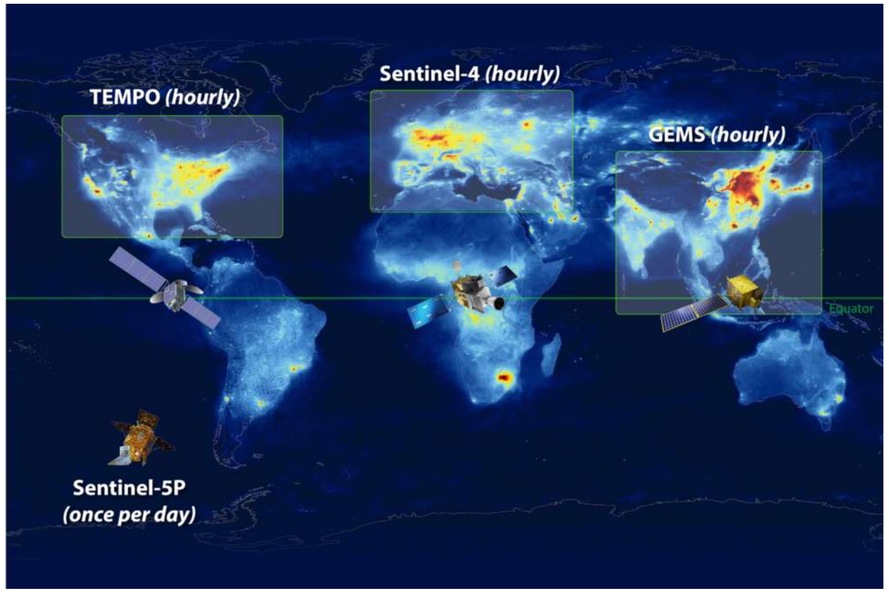




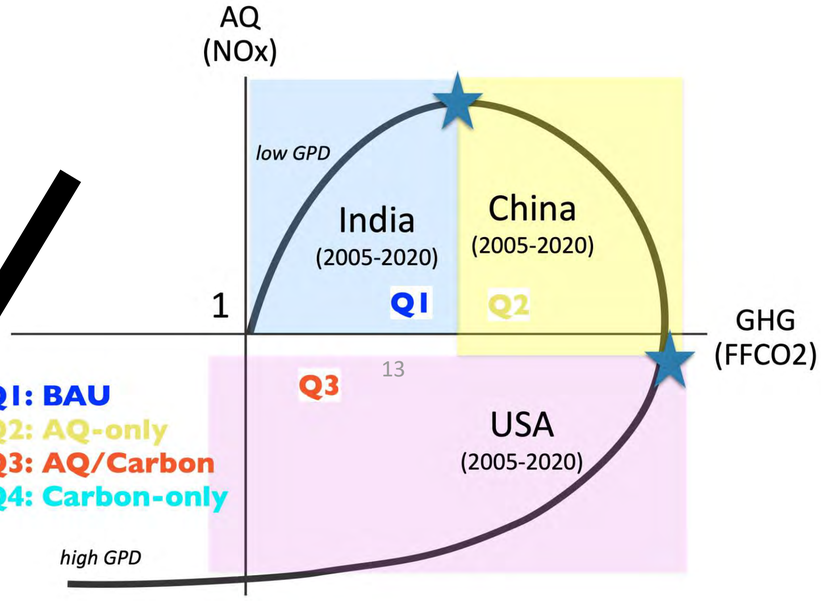
GOSAT-GW NO2 & CO2



MOMO-Chem
with TROPOMI, GEMS, TEMPO



MEKC



New L4 FFCO2 products

Predictability of fossil fuel CO2 from air quality emissions

Miyazaki and Bowman, *Nature communications*, 2023
Yang et al., *in prep*

- MEKC provides a useful framework to understand co-evolution of air quality and carbon emissions under macroeconomic growth.
- CMS-Flux (and other top-down) estimates can provide insight for CO2, but can't resolve urban-scale fluxes or differentiate between natural and anthropogenic fluxes.
- City-scale estimates sometimes "lead" country scale reflective of discrepancies between local socioeconomic and country-scale drivers.
- Sectoral shifts provide insight into the drivers of MEKC for different phases.
- Updates to CMS-Flux and MOMO-Chem towards high resolution modeling can better support GOSAT-GW.

GHG
Fossil fuel CO2 (FFCO2)

Air pollutants