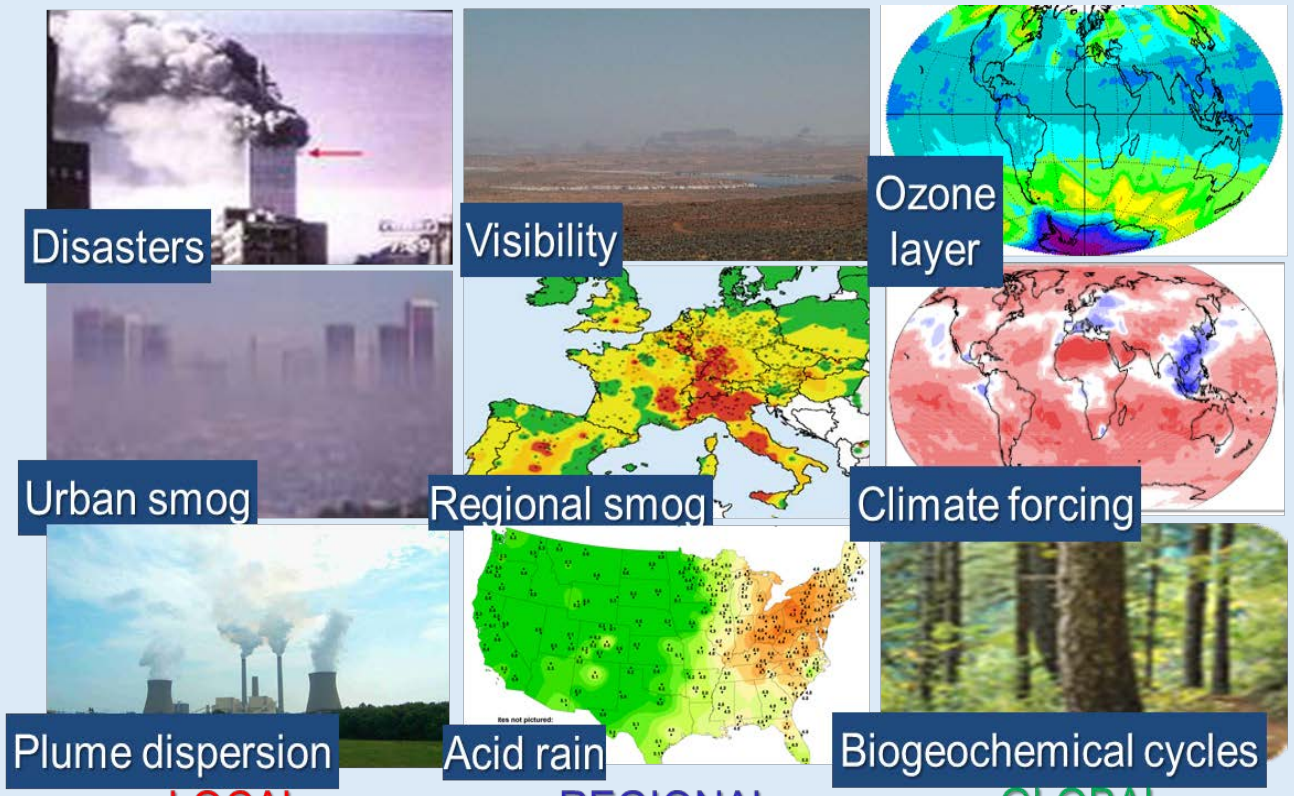
Science for Service & Policy

Advancing Atmospheric Composition Analysis and Predictions and Related Services to Meet the Growing Societal Needs

Greg Carmichael, University of Iowa

WEATHER CLIMATE WATER
TEMPS CLIMAT EAU



Atmospheric Composition Matters:
To Air Quality, Weather, Climate and More

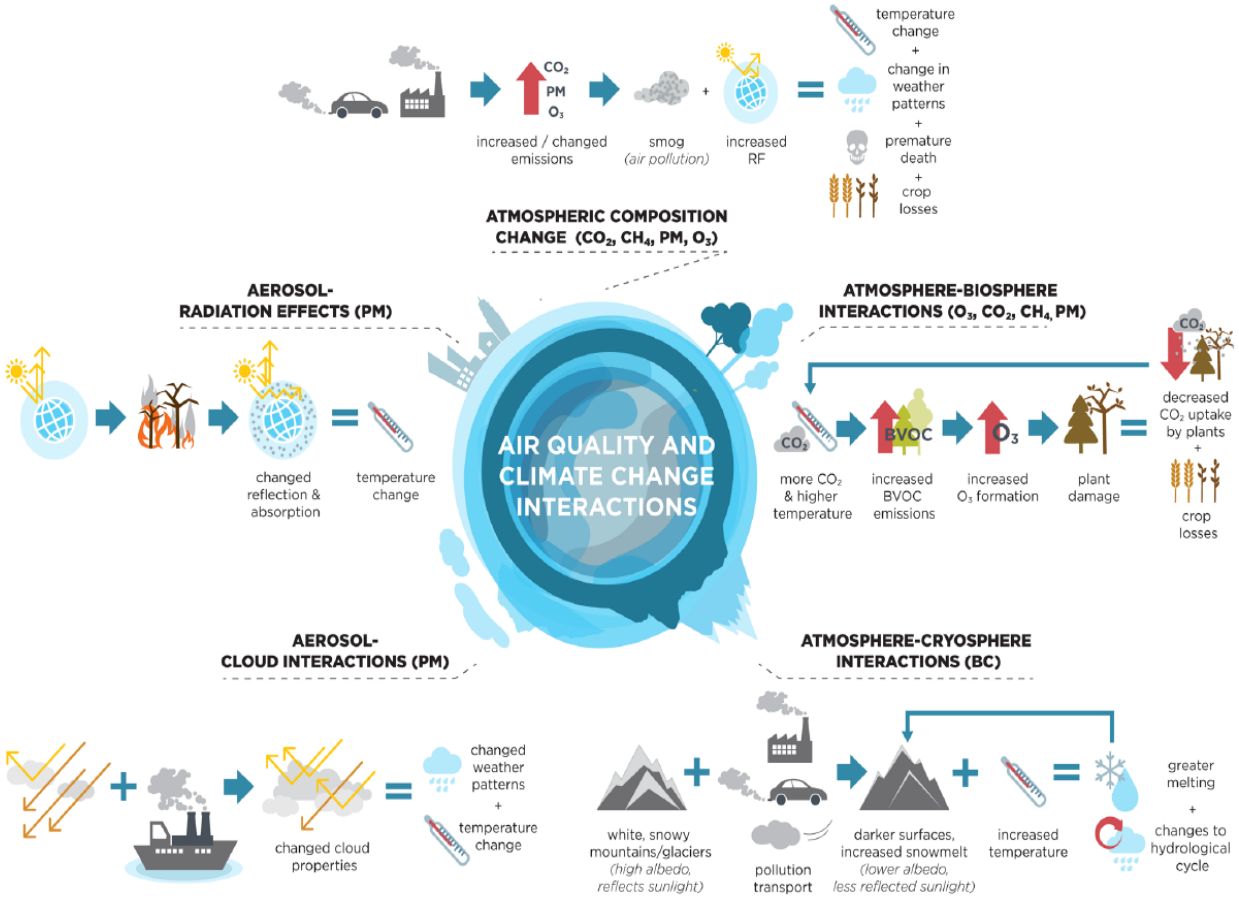
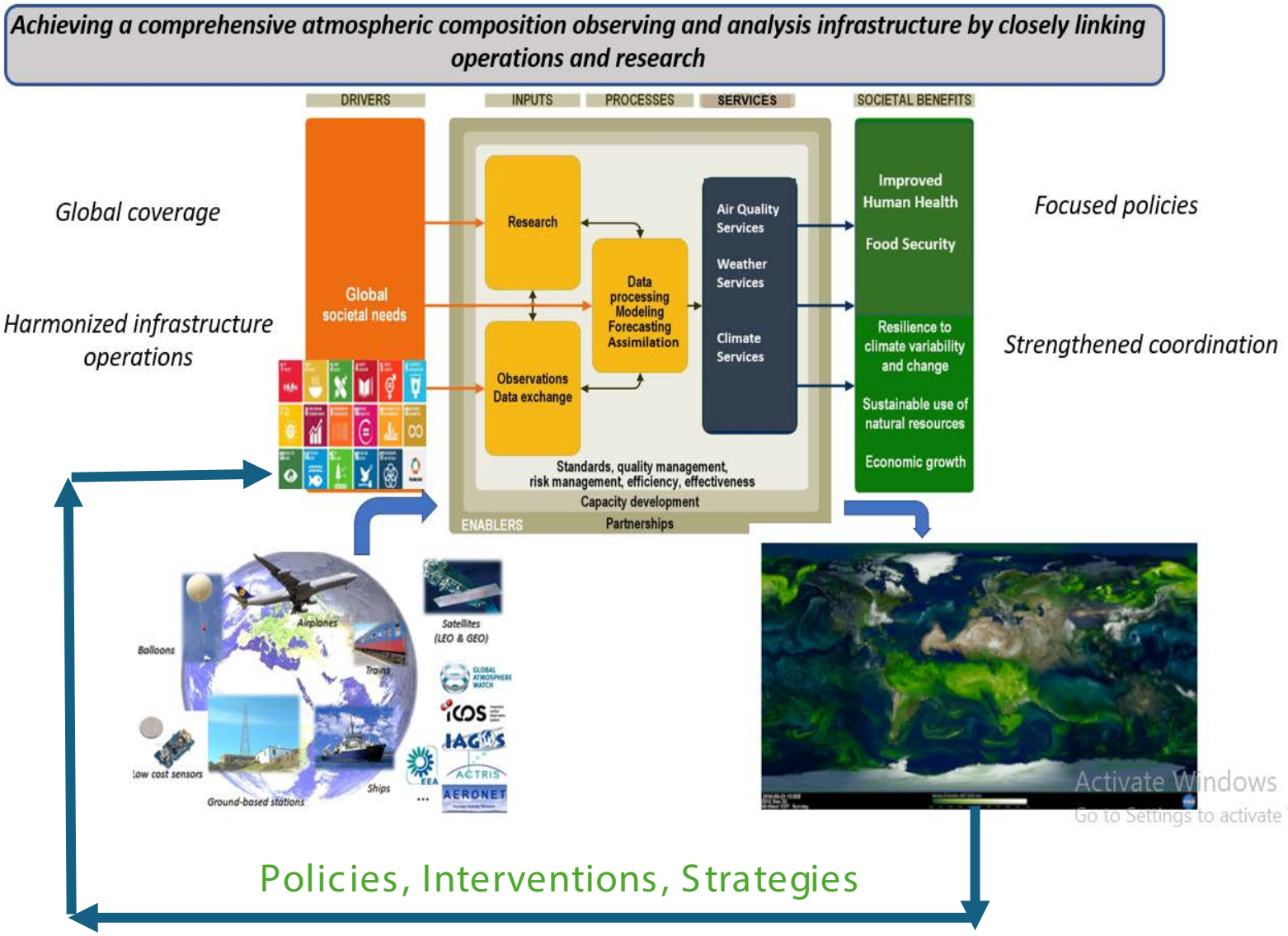


Figure from von Schneidemesser et al. (2015)

- ✓ Monitoring and prediction of atmospheric composition play critical roles in supporting societal needs related to air pollution, ecosystem and human health, food production and climate change.
- ✓ Considerable challenges remain in our ability to provide reliable and user-driven atmospheric composition information for many parts of the world.
- ✓ Concerted actions focused on advancing atmospheric composition information systems are needed to accelerate the implementation of effective emissions control strategies by several decades in the areas where it is most needed, to significantly reduce the current health and climate change burdens to societies and address related social inequalities.

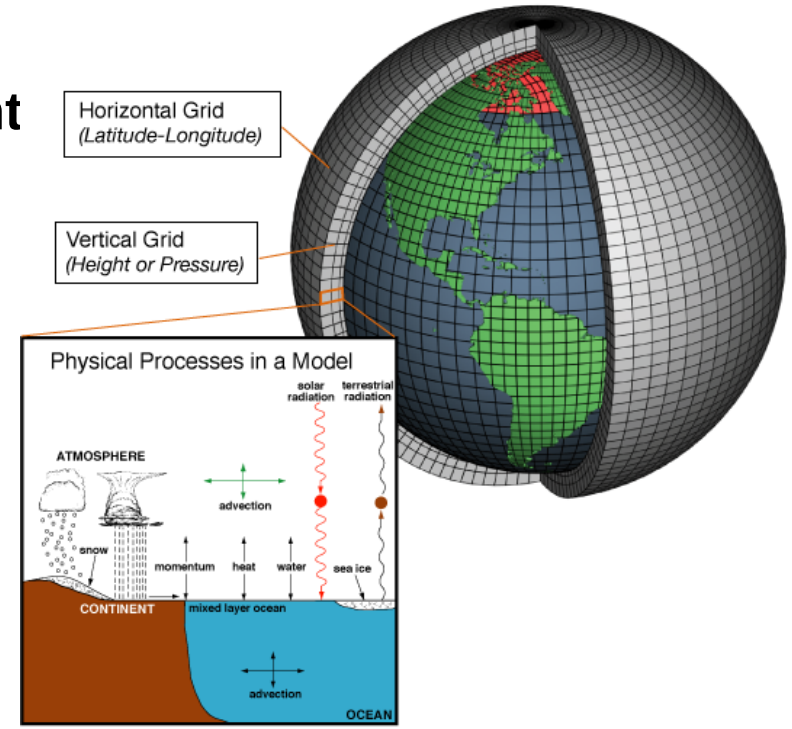
The University of Iowa

Overarching Scince Objective – Continue to improve analysis and prediction capabilities of Earth System Models to improve related services to meet the growing societal needs

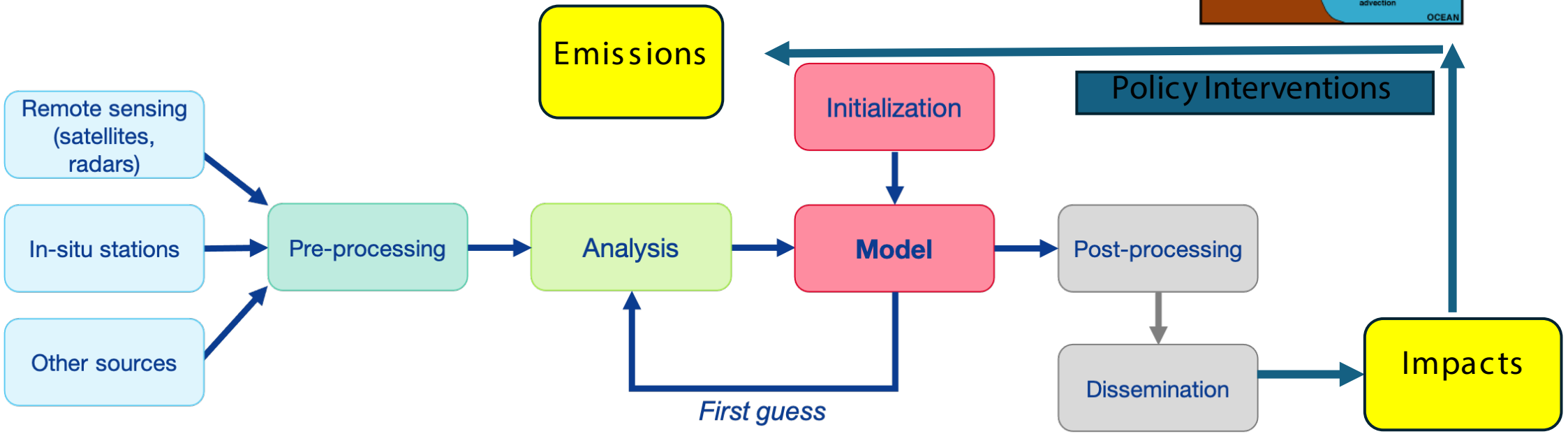


- ✓Trend toward closer linkages of weather, atmospheric composition, and climate related services
- ✓Information needed at higher resolution (and longer forecast times) to address societal needs
- ✓Further improvements in predictions require advances in observing systems, models, better assimilation systems (and better fundamental understanding), and people (increased capacity and empowering young scientists).

Air Quality Prediction is a Key Component of Air Quality Management *(mid/long term and short term applications through AQ Forecasts)*

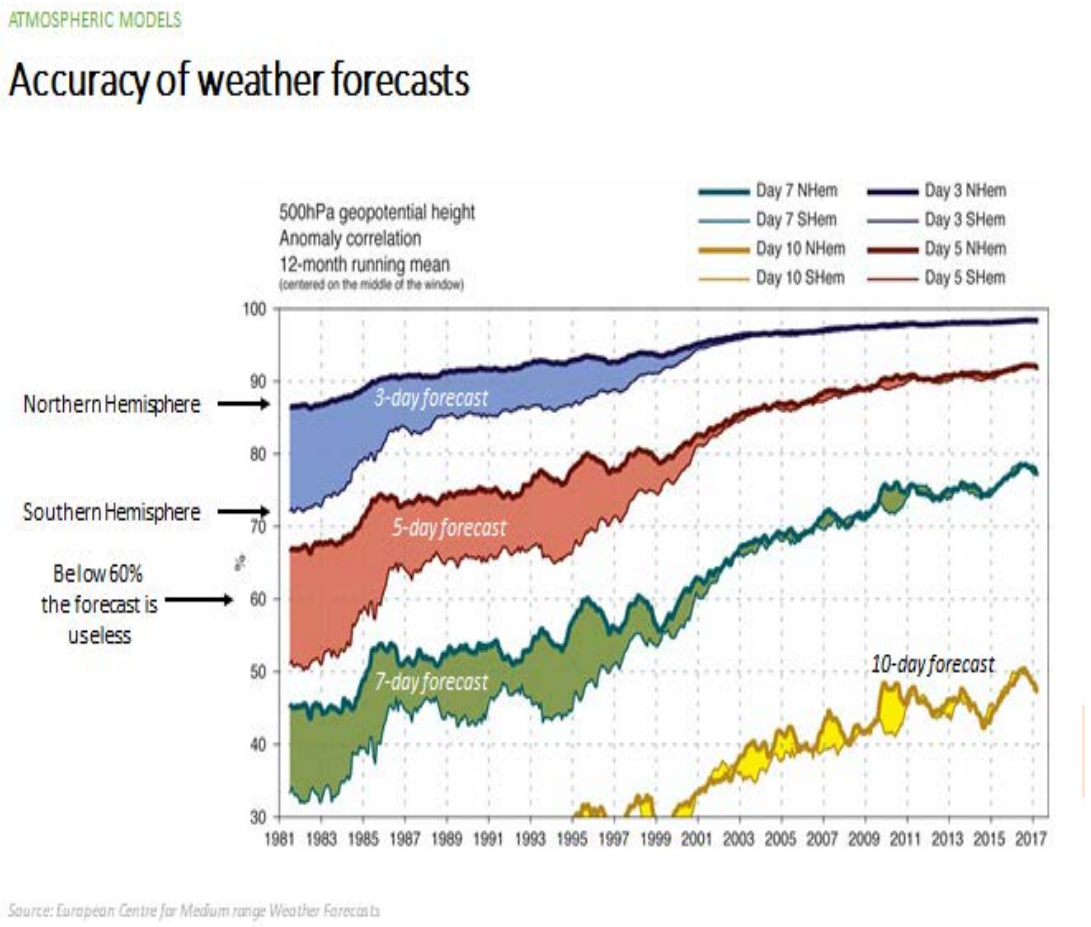


Worldwide distribution of weather stations



Lessons from Numerical Weather Prediction have improved significantly over time

- Improvements have come by advancing the observations, the models and the assimilation systems.
- The rise of ensemble forecasting (using many realizations) has transformed predictability into an envelope of possibilities (or probabilities) rather than a deterministic quantity or single prediction. This matches societal needs for clearly defining prediction uncertainty.
- Many of the detailed processes that control the evolution of weather and climate are not constrained with observations, leading to persistent errors in our predictions.
- A better paradigm for bringing together observations and models into an integrated whole would target sources of model error, which would advance model representation of weather processes, and significantly advance our predictive capabilitie.



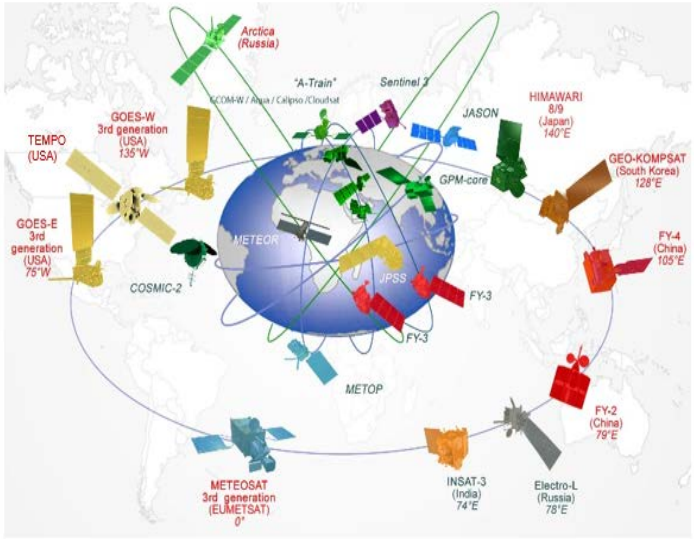
Good news! Major advances in observing systems

Good News: The global observing systems for atmospheric composition are growing

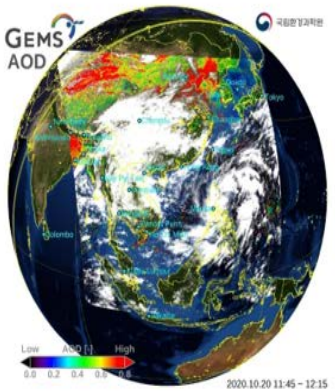
EU infrastructure investments
ACTRIS, etc.

The dawn of a new era for atmospheric composition monitoring from space

The next few years will see an unprecedented amount of satellite instruments capable of monitoring a wide range of trace gases, key greenhouse gases and aerosols.



GEMS is the first of the of the geo instruments with air quality capabilities.

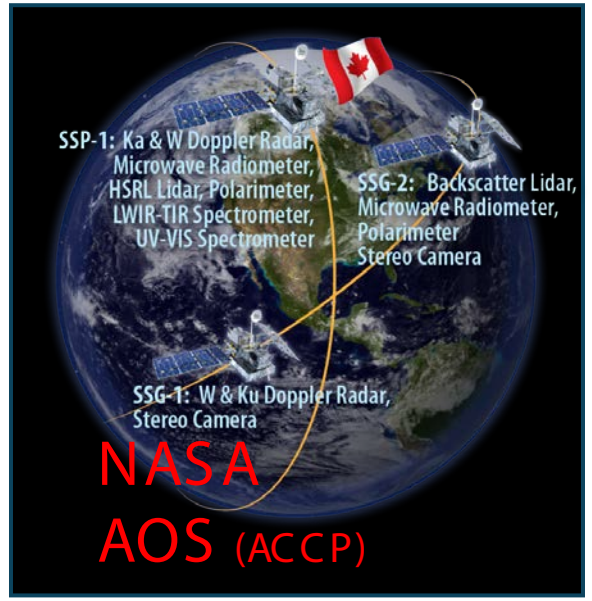


Coordination Group for Meteorological Satellites

WORLD METEOROLOGICAL ORGANIZATION · GLOBAL ATMOSPHERE WATCH · ECMWF · CGMS

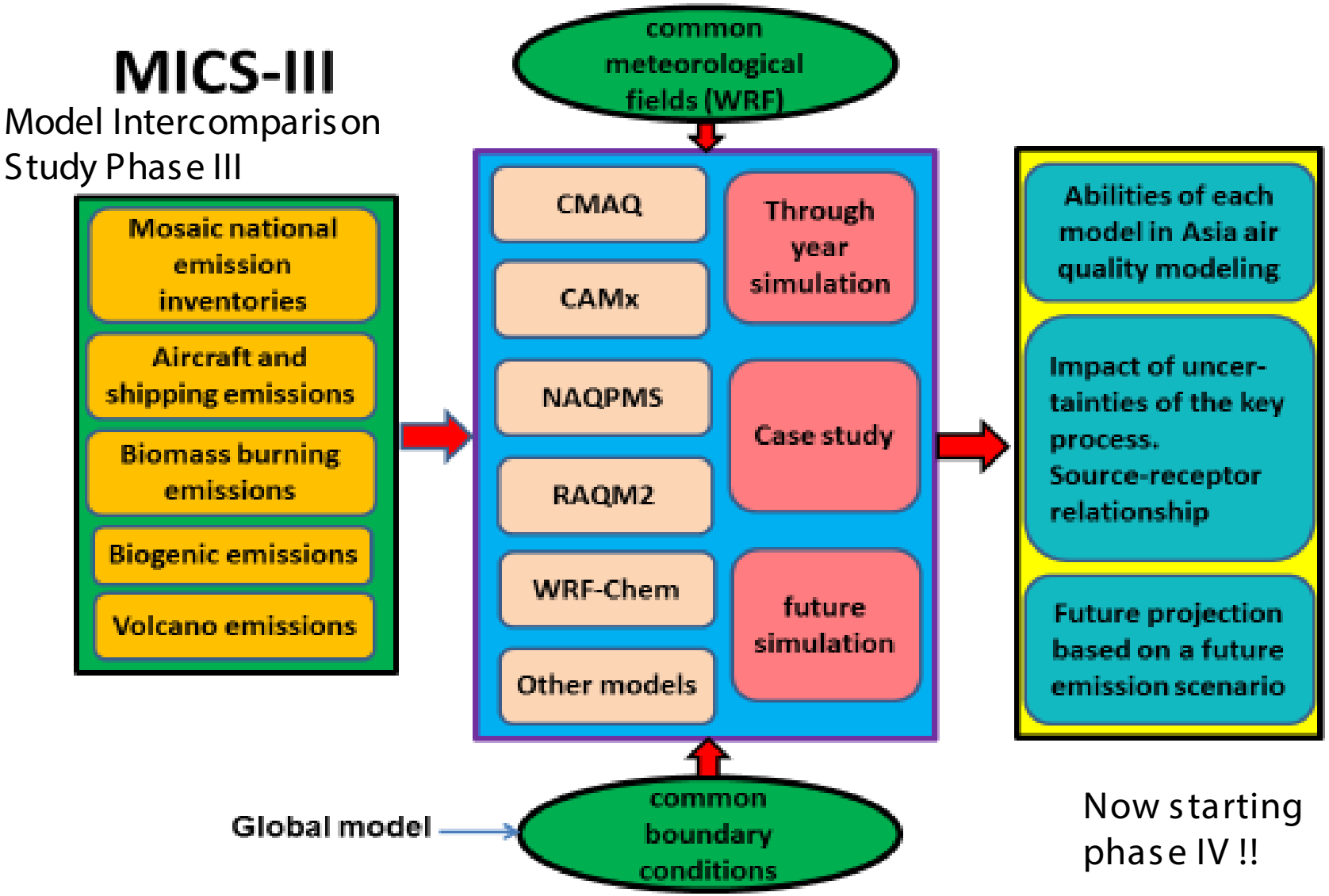
CGMS-49-GUEST-WP-07, Date 27 April 2021

TEMPO



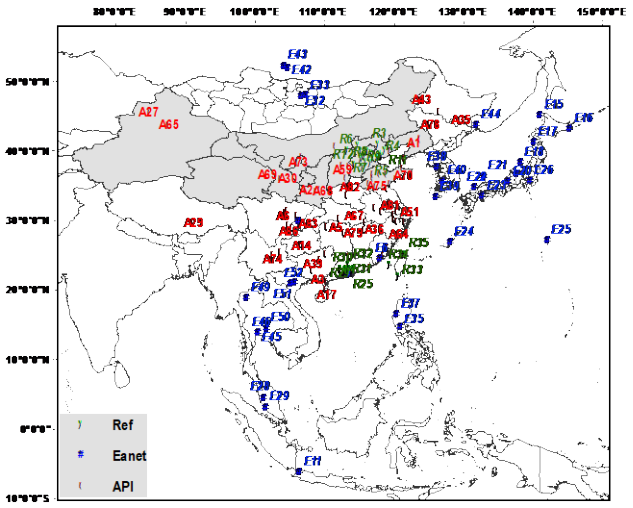
Process oriented: aerosols, clouds, convection and precipitation

What can we learn from multi-model studies?

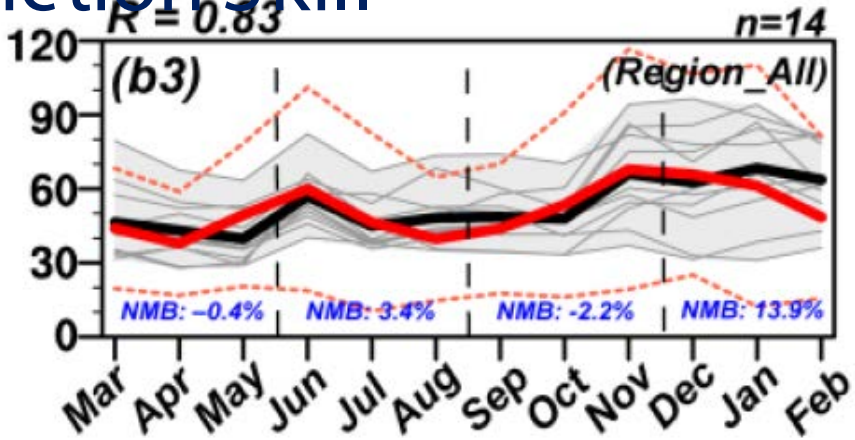


Now starting phase IV !!

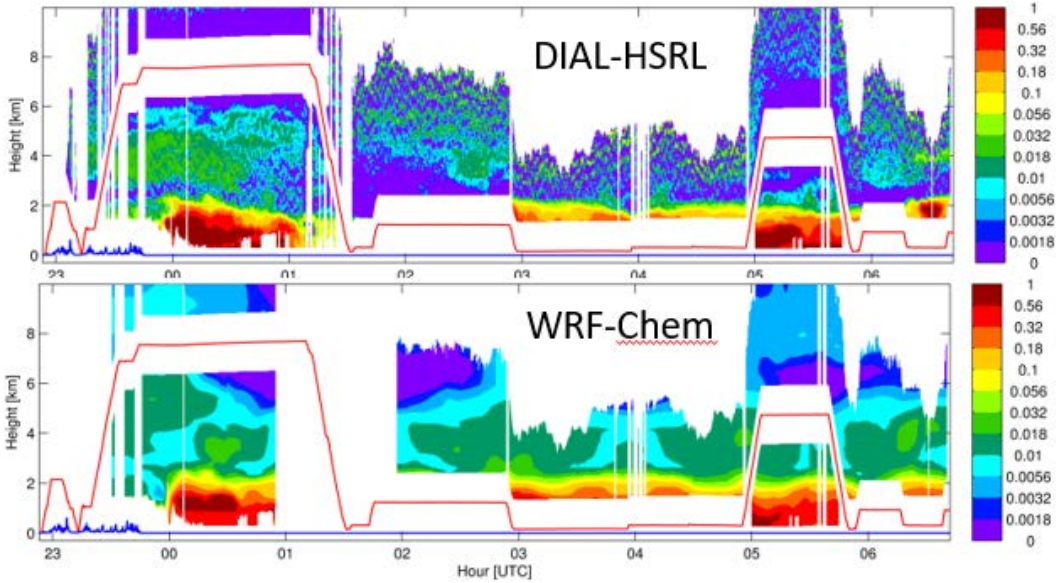
Good News! Current Air Quality Models have Appreciable Prediction Skill



PM2.5



Model Intercomparison Study Asia (Itahashi et al., ACP, 2020)

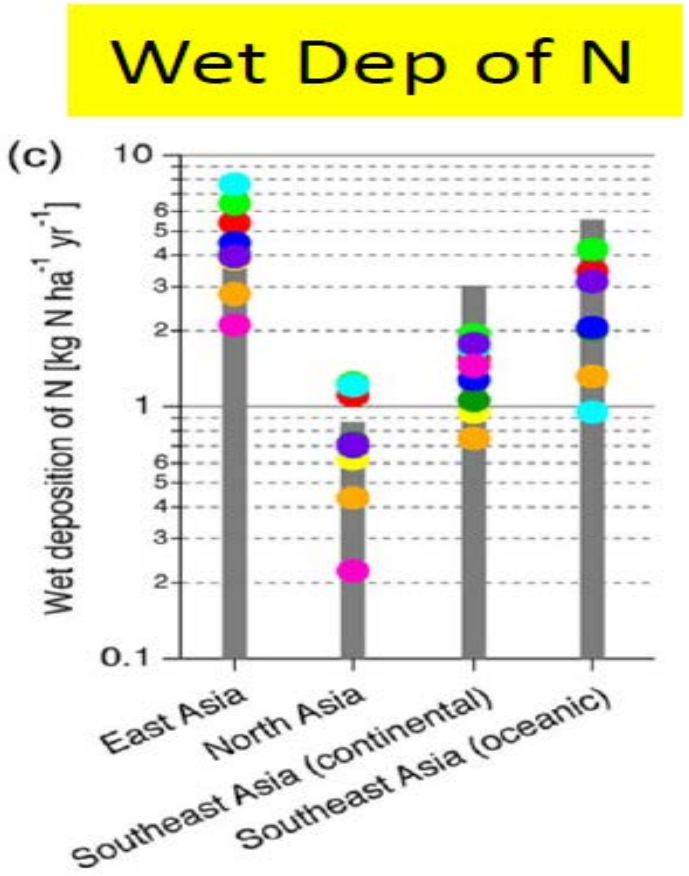


KORUS-AQ

Iowa/UCLA

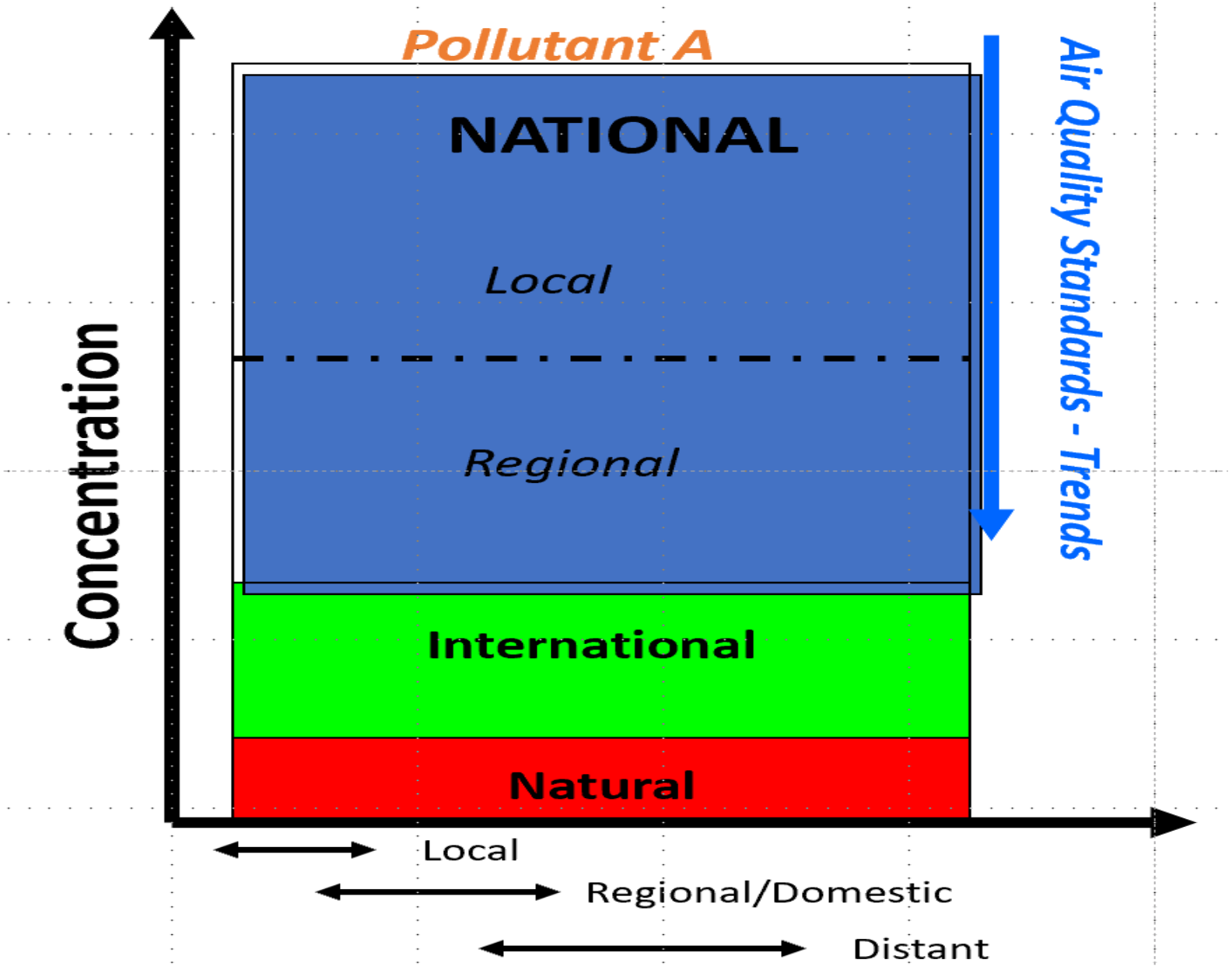
Major sources of uncertainty in AC models remain

- Emissions (anthropogenic and natural (e.g., biomass burning, wind blown dust)
- Meteorology
  - Clouds (photolysis rates, aqueous chemistry, redistribution)
  - Precipitation (removal by scavenging)
  - Planetary boundary layer height, local circulations
- Process understanding (chemistry, dry deposition, etc.)



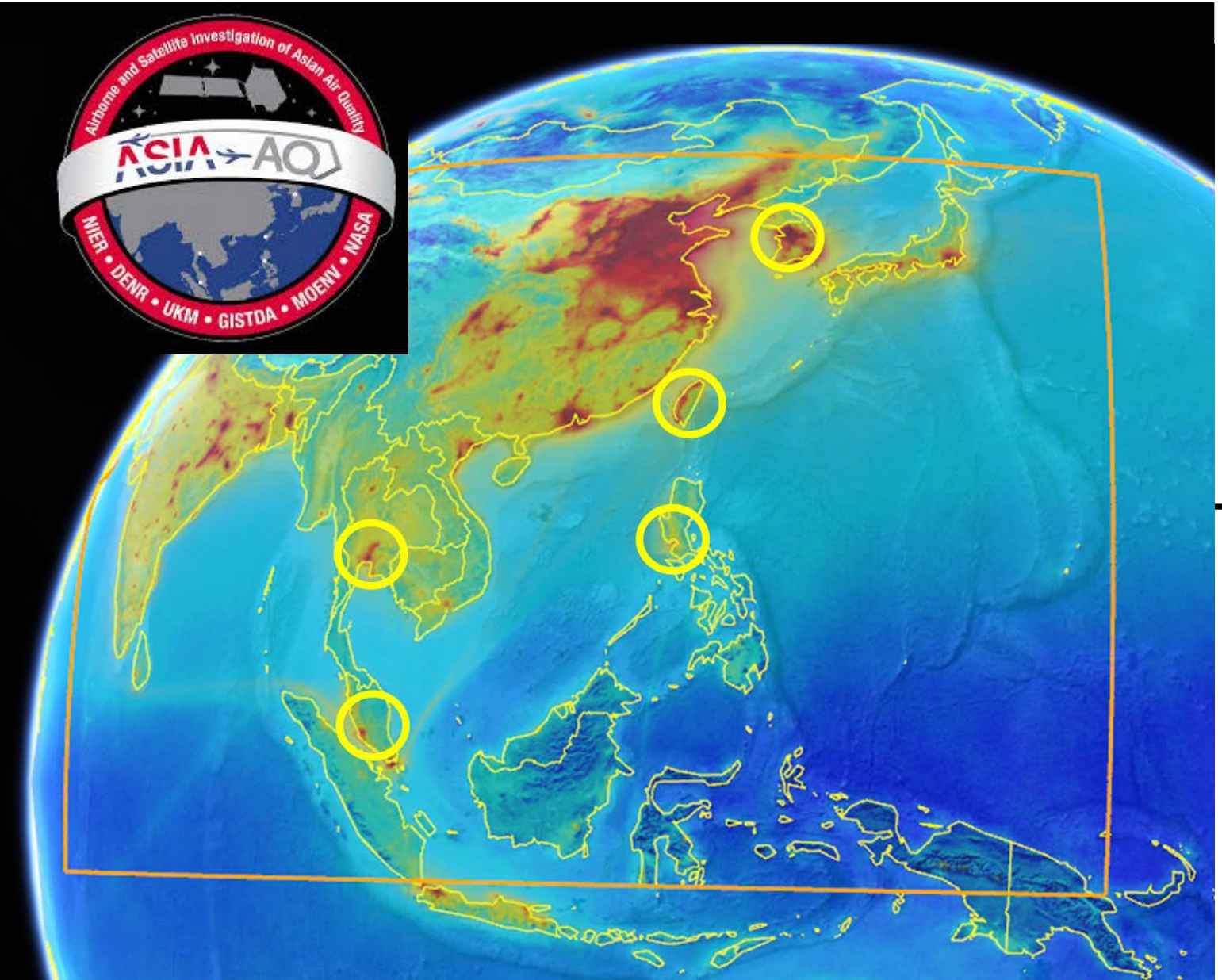
Itahashi et al., ACP, 2020

Distant Sources of Air Pollution are Becoming More Important in Air Quality Management



Improving understanding and capabilities through field experiments

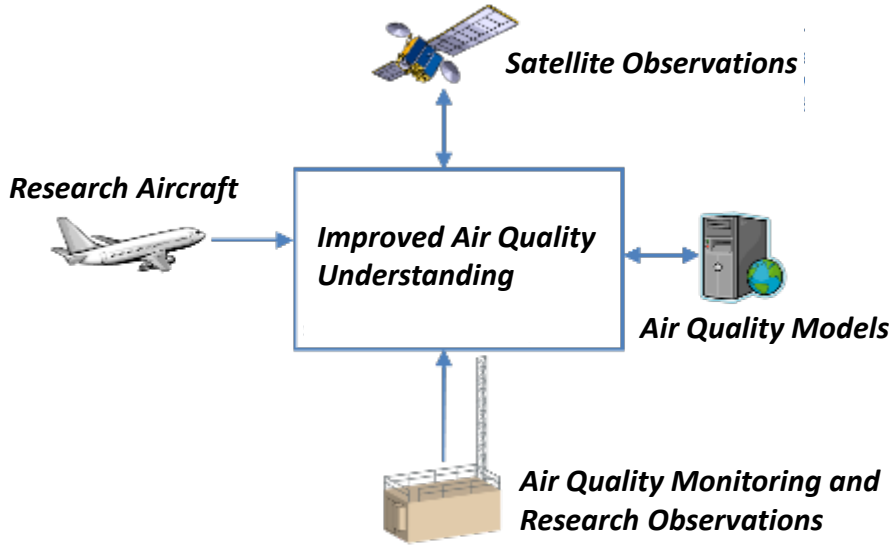
Airborne and Satellite Investigation of Asian Air Quality (ASIA-AQ)



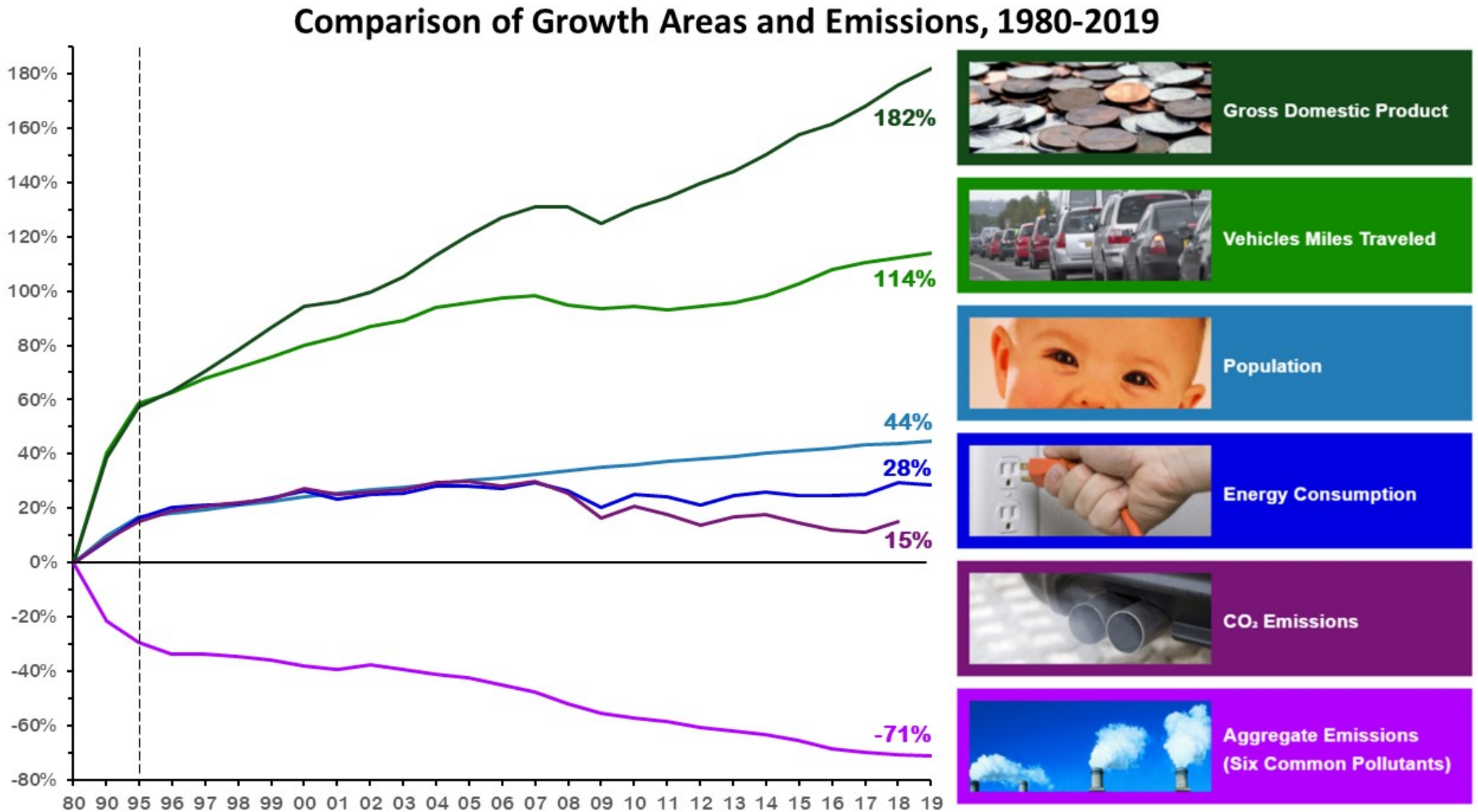
Purpose: Improve understanding of the factors controlling local air quality across Asia through multi-perspective observations and modeling

Approach: Conduct airborne sampling across multiple locations in collaboration with local scientists, air quality agencies, and other relevant government partners.

Philosophy: Openly share data during all phases, conduct joint analysis with local scientists and air quality agencies, and report findings to local governments

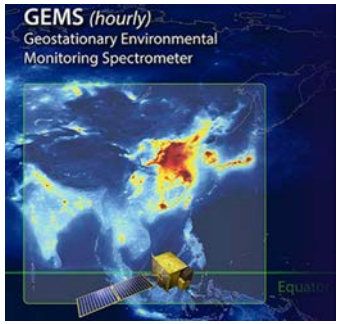


Bending the Curves



Health Impacts of Air Pollution

Growing capabilities to produce surface concentrations of $PM_{2.5}$ and other pollutants at high spatiotemporal resolution (1km, daily or finer) using established supervised machine learning techniques and data from new generation of geospatial pollution satellite sensors and low-cost sensors.



Age-specific

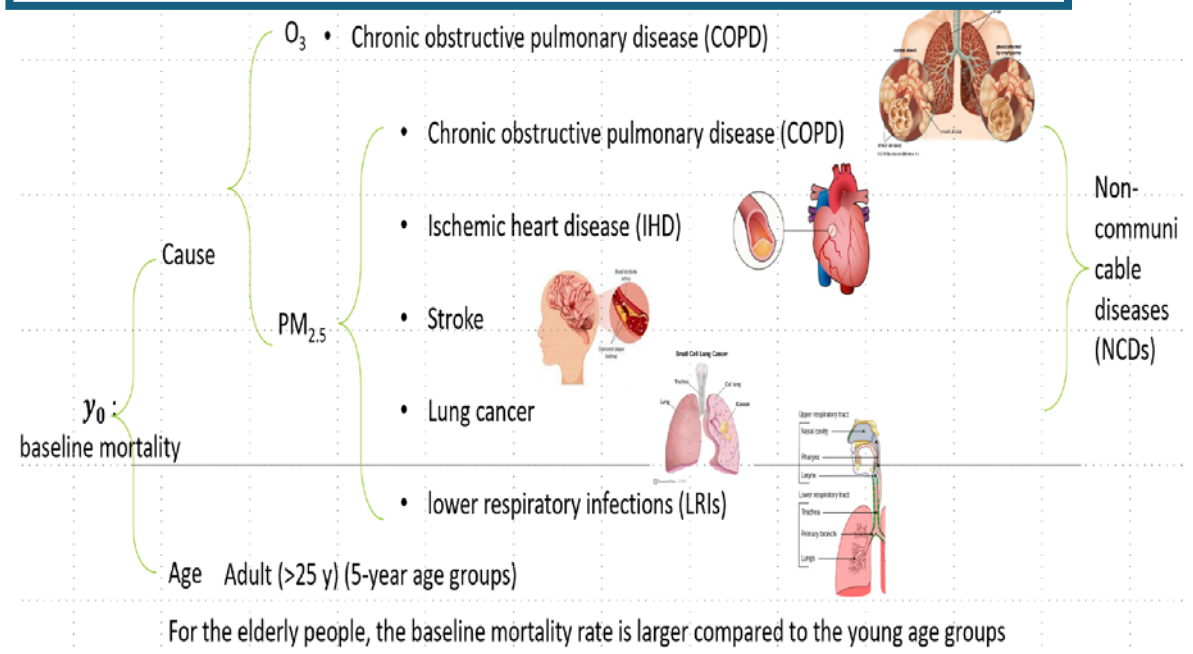
We use the following equation to estimate the excess premature deaths $\Delta Mort$ attributable to long-term $PM_{2.5}/O_3$ exposure.

$$\Delta Mort = y_0 \times Pop \times \left[1 - \frac{1}{RR}\right]$$

y_0: cause- and age-specific baseline mortality rate across countries/regions;

Pop: age-specific population under exposure for a specific country/region/grid;

RR: relative risk captures the increase in mortality that can be attributed to a given increase in the air pollutant concentration



Models also play important roles in analysis

Mortality Benefits through Policy Intervention

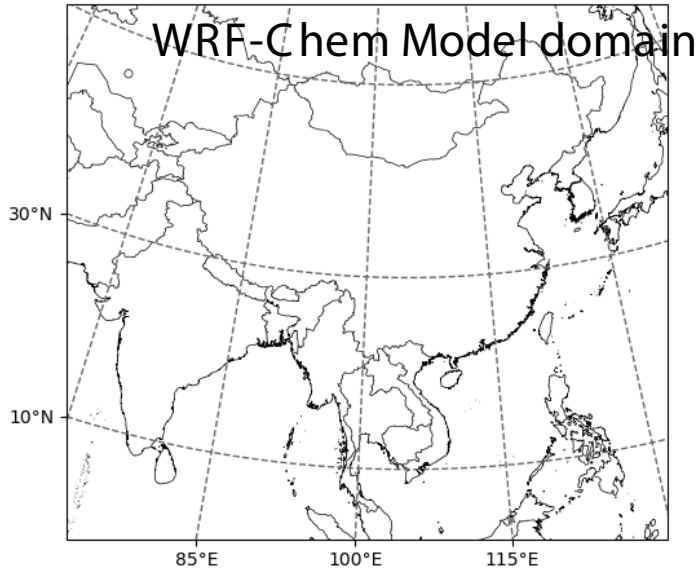
Anthropogenic emissions: ECLIPSE V6 Baseline scenario (CLE)

1. It's produced by using GAINS model

2. Gridded emissions (netcdf4 format 0.5°*0.5°) of

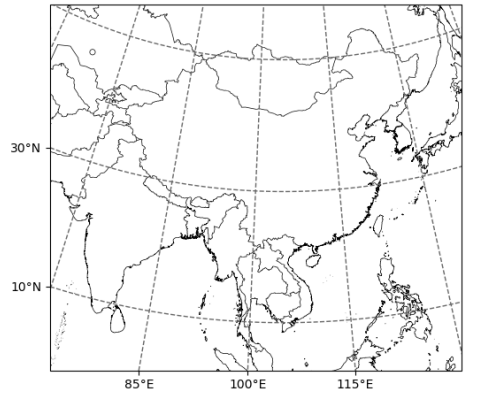
SO_2, NOx, NH_3, NMVOC, BC, OC, OM, $PM_{2.5}$, PM_{10}, CO, CH_4

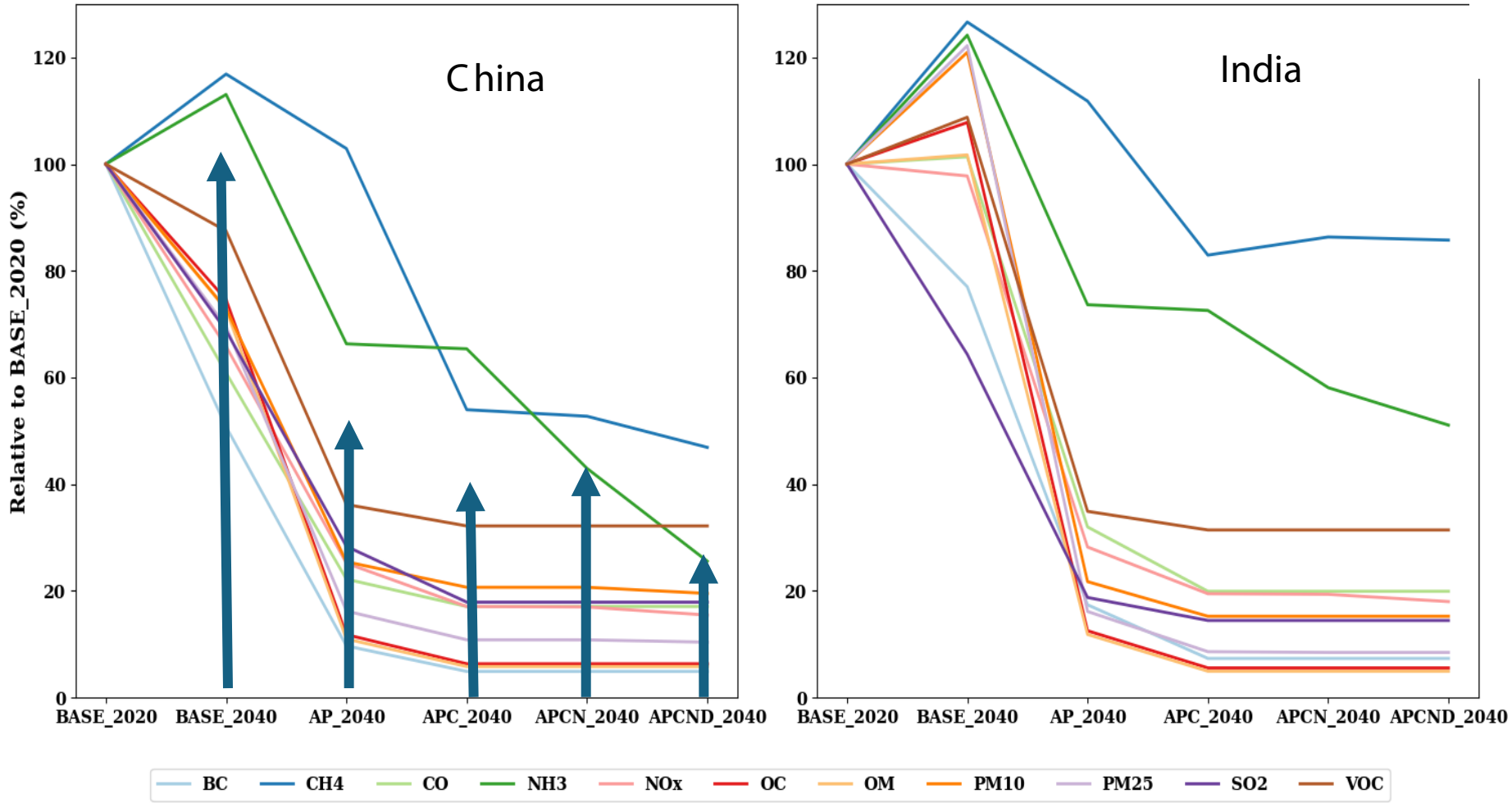
CLE (BASE)	Existing or announced air pollution reduction policies in official plans (1990, 1995, 2000, 2005, 2010, 2015, 2020, 2025, 2030, 2040, 2050)
AP	Maximum air pollution mitigation (which means take the most ambitious control strategies) (2025 2030 2040 2050
APC	AP+Climate mitigation (take decarbonization strategies to achieve the Paris climate accord and keep global temperature increase well below 2°C) (2040
APCN	APC +nitrogen measures (modifications of current agricultural practices to minimize alterations of the global nitrogen, which will reduce the NH3 and greenhouse gas emissions to the atmosphere) (2040)
APCND	APCN +"healthy diet" (dietary changes to optimize human health and environment sustainability which aims to reduce emissions



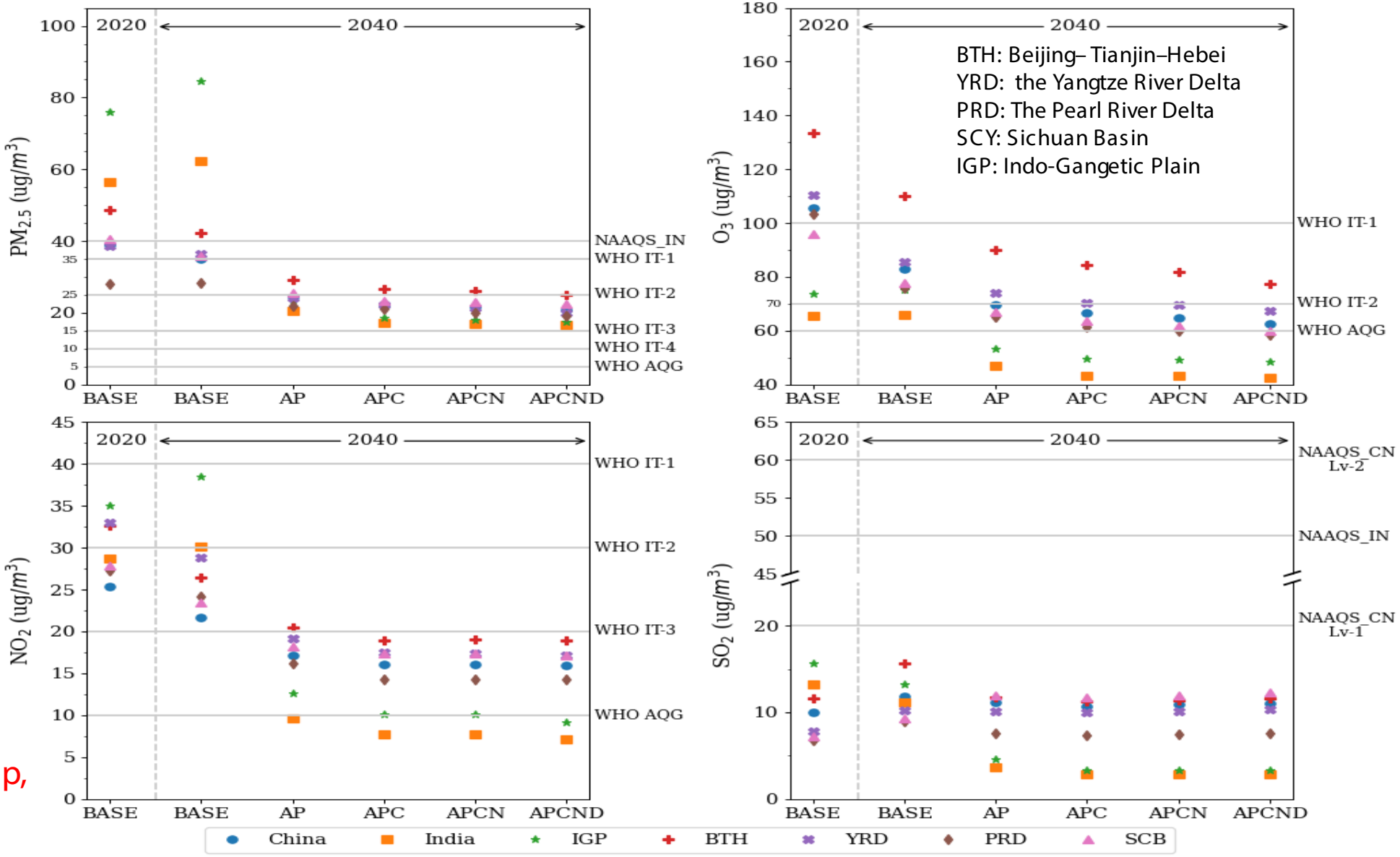
BASE2020 ---- reference, for simulation evaluation
BASE2040
AP2040
APC2040
APCN2040
APCND2040

Air Pollution & Mortality - reducing impacts by controlling emissions – pathways towards carbon neutrality





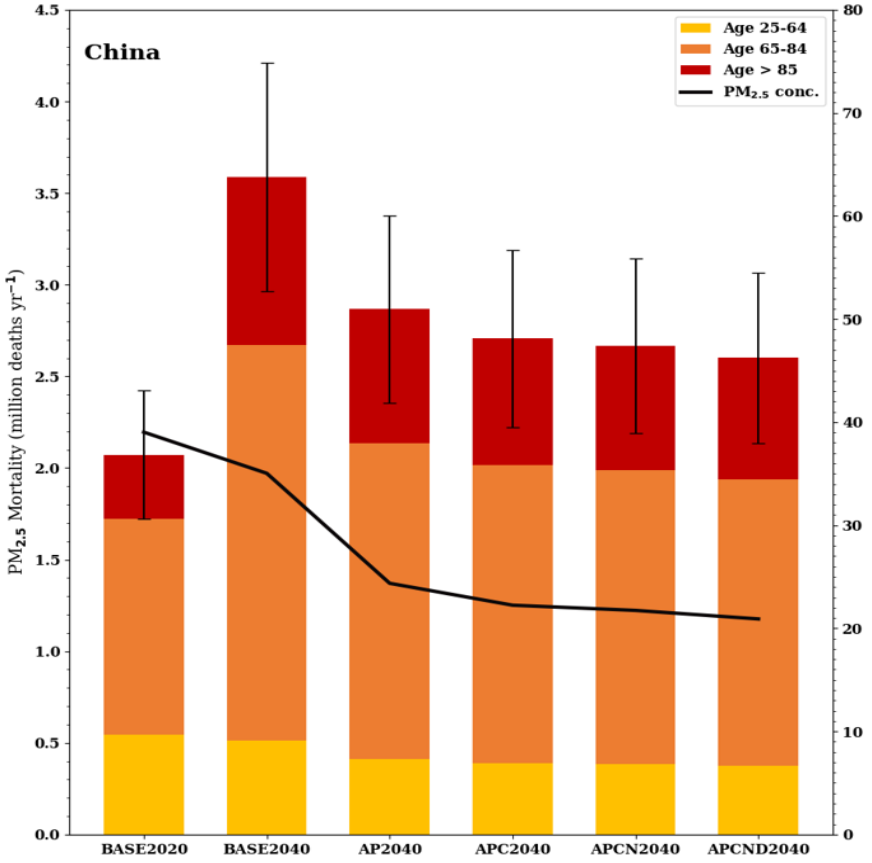
Air Pollution & Mortality - reducing impacts by controlling emissions

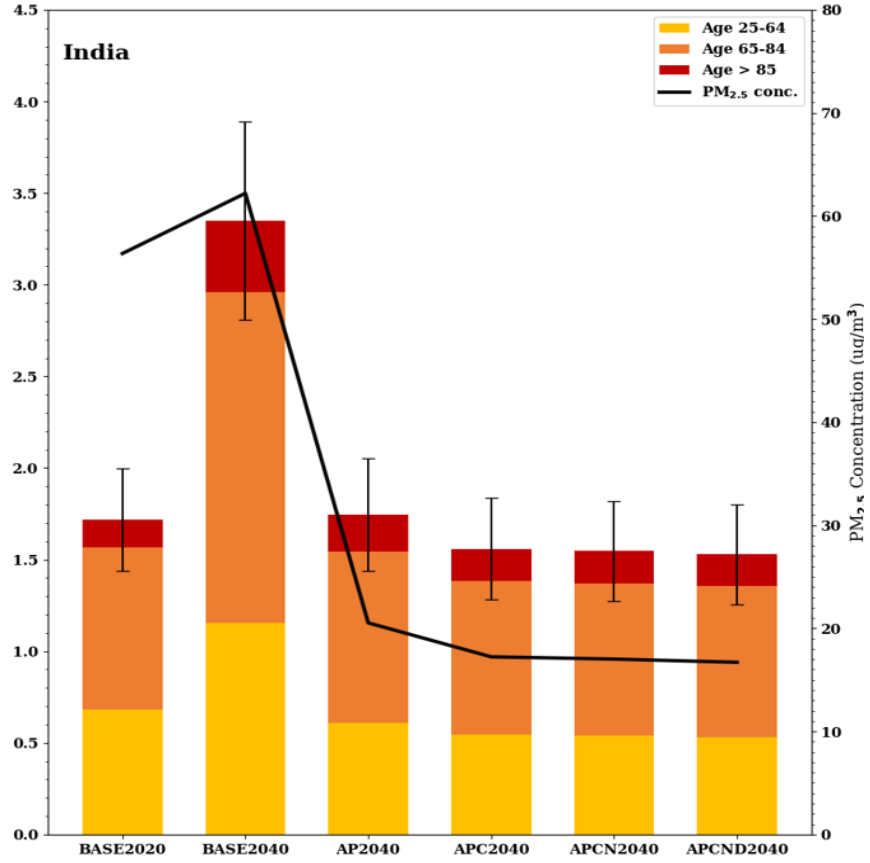


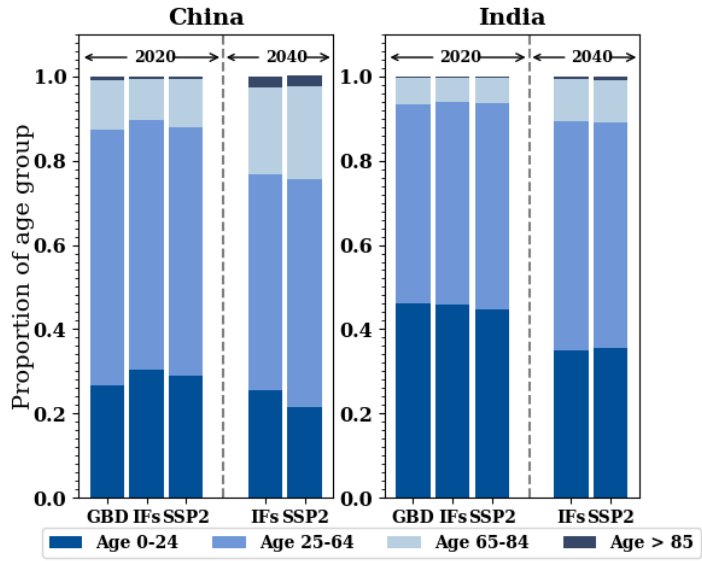
Chen et al., in prep, 2024

Despite the ongoing reduction in PM2.5 exposure in India & China, air pollution control strategies may not offset the negative effects of aging issues on mortality.

GBD/IFs/SSP2 are different data source.







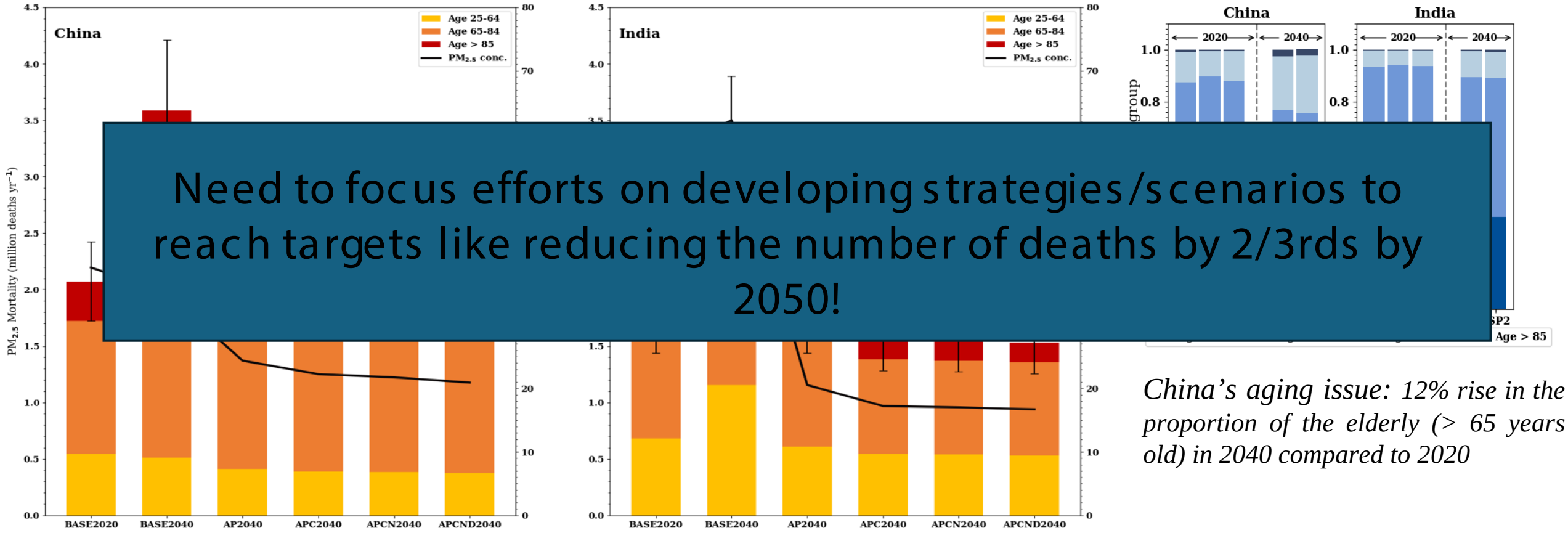
China's aging issue: 12% rise in the proportion of the elderly (> 65 years old) in 2040 compared to 2020

Age-specific mortality attributable to PM2.5 exposure estimated by GEMM under various scenarios in China and India. (GEMM - Burnett et al., 2018)

Chen et al., in prep, 2024

Despite the ongoing reduction in PM2.5 exposure in China, air pollution control strategies may not offset the negative effects of China's aging issue on mortality.

GBD/IFs/SSP2 are different data source.



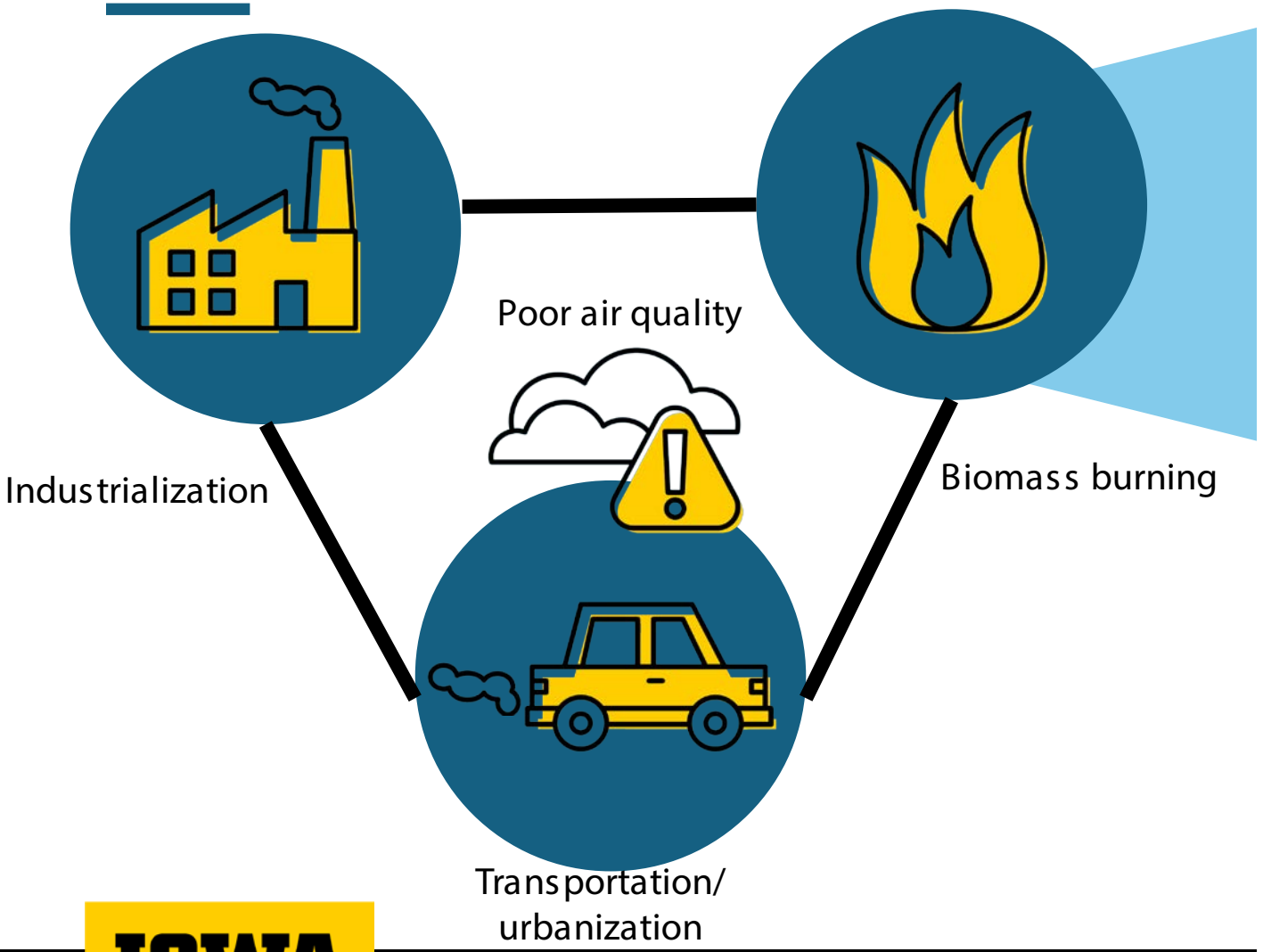
Need to focus efforts on developing strategies/scenarios to reach targets like reducing the number of deaths by 2/3rds by 2050!

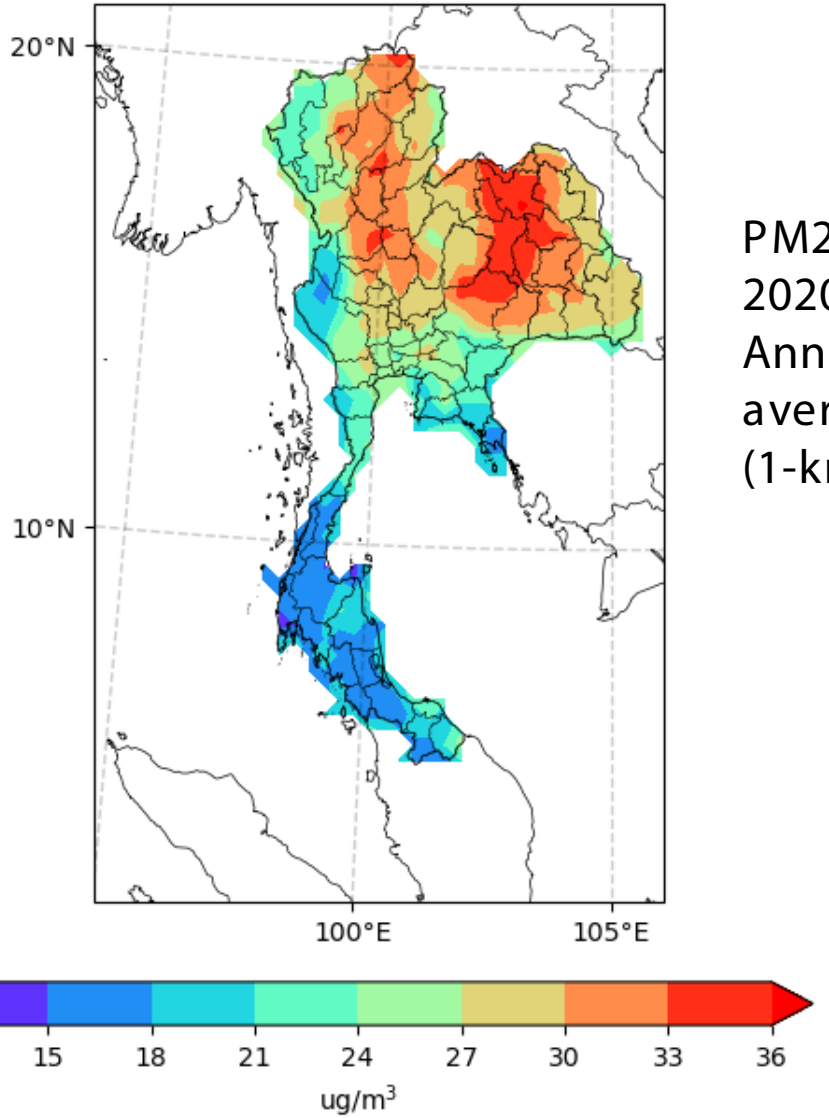
China's aging issue: 12% rise in the proportion of the elderly (> 65 years old) in 2040 compared to 2020

Age-specific mortality attributable to PM2.5 exposure estimated by GEMM under various scenarios in China and India. (GEMM - Burnett et al., 2018)

Chen et al., in prep, 2023

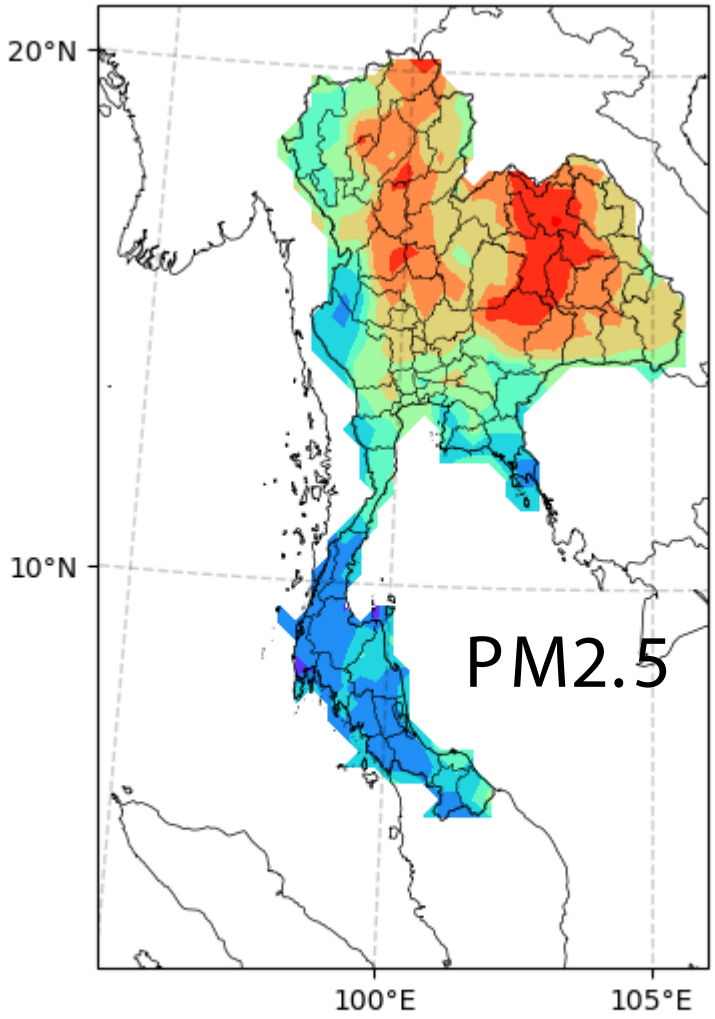
Air pollution is a critical challenge in Southeast Asia



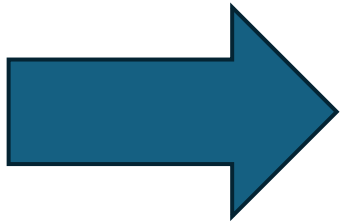


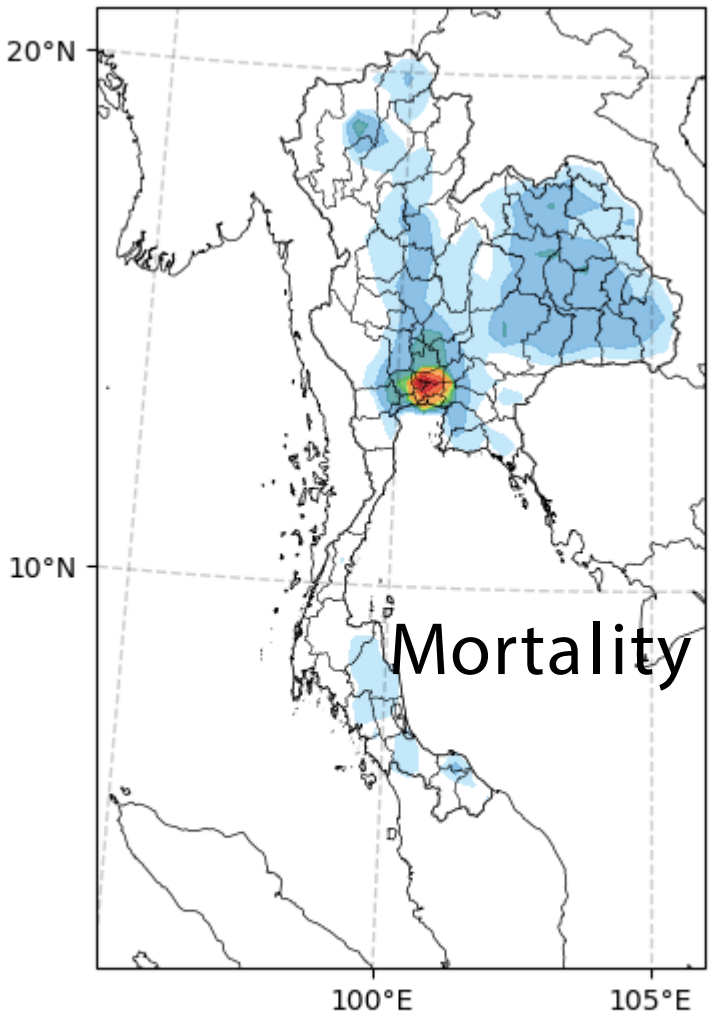
PM2.5
2020
Annual
average
(1-km)

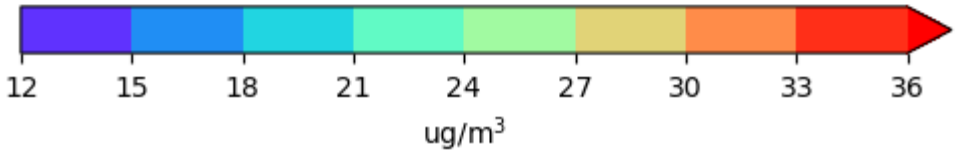
Distribution of PM2.5 and Related Mortality in 2020

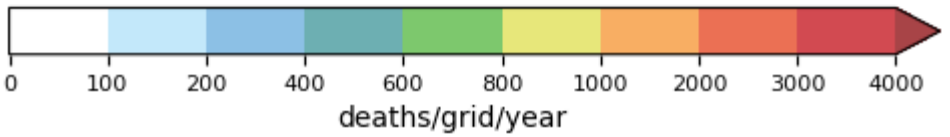


1 km distributions of PM2.5 and associated mortality

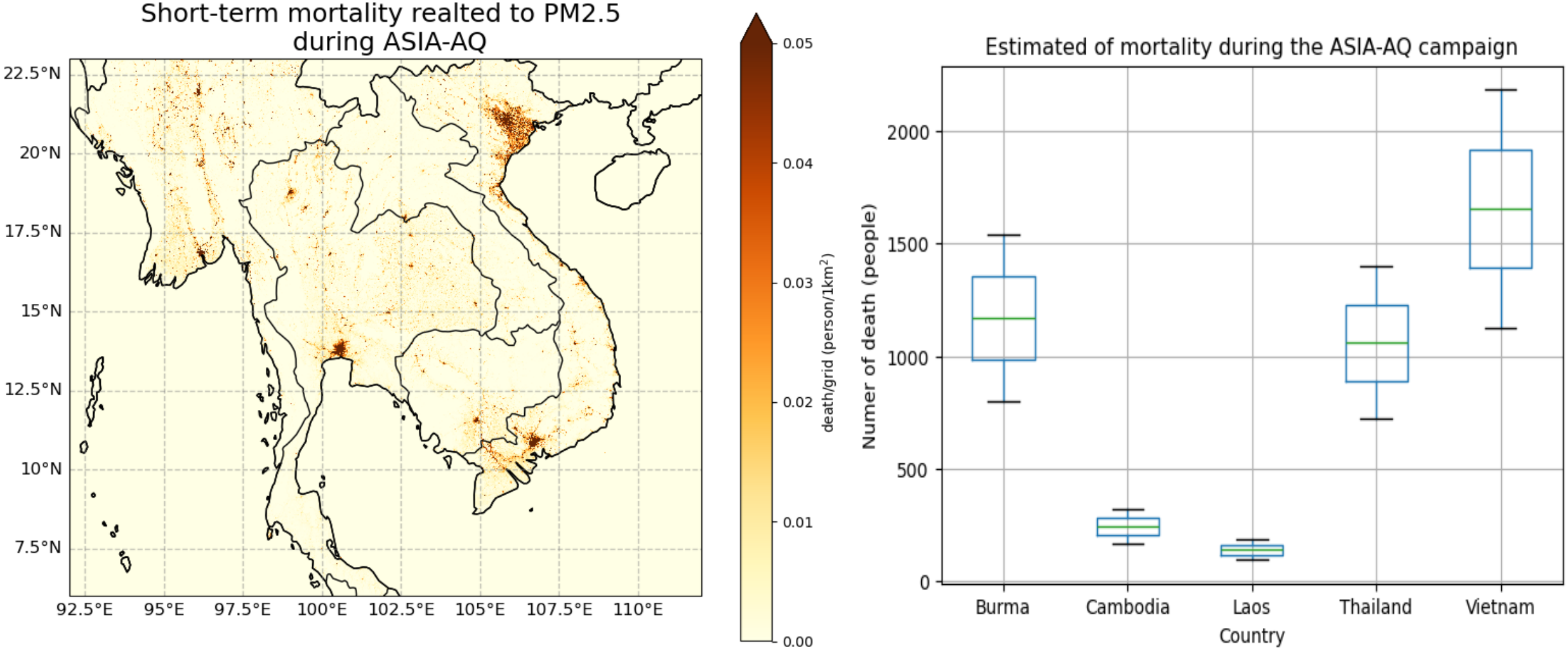






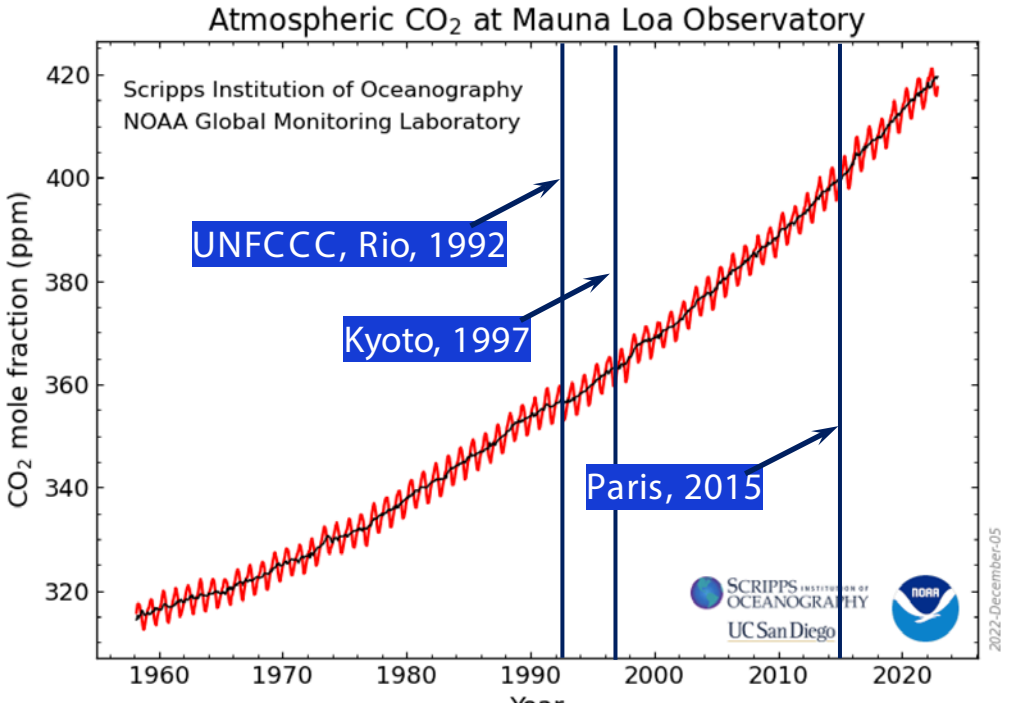


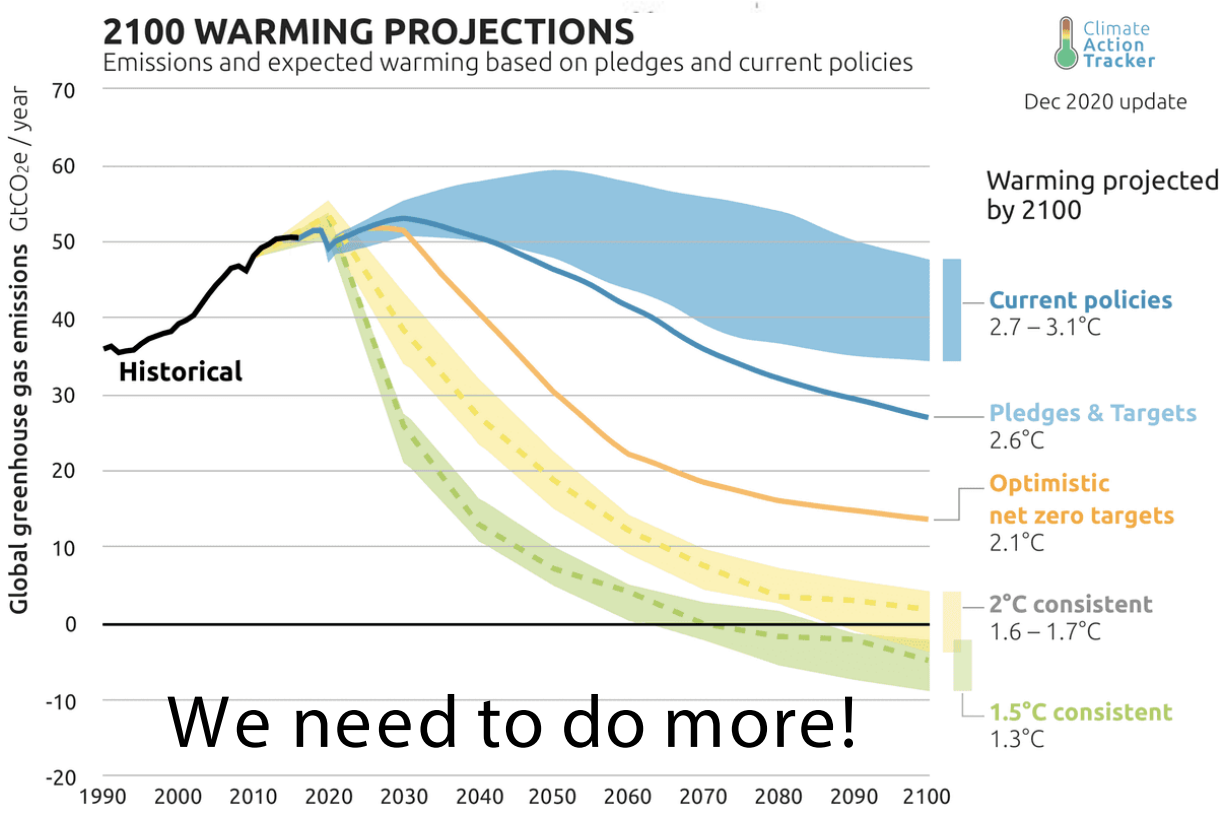
Mortality assessment (Short-term exposure) during Asia-AQ (FEB + MAR 2024)



We need to reduce GHG emissions!

But !#?





The climate responds to the atmospheric GHG concentrations, not to what we claim to be doing to reduce or offset our GHG emissions;

2023	2024 -- 2027	2028 -- 2031	2032 -- 2050
Cg-19 → G3W WMO Congress	**G3W – IPP** **Implementation Pre-Oper Phase**	**G3W – IOP** **Initial Operational Phase**	**G3W – EOP** **Enhanced Operational Phase**

GST-1
COP28

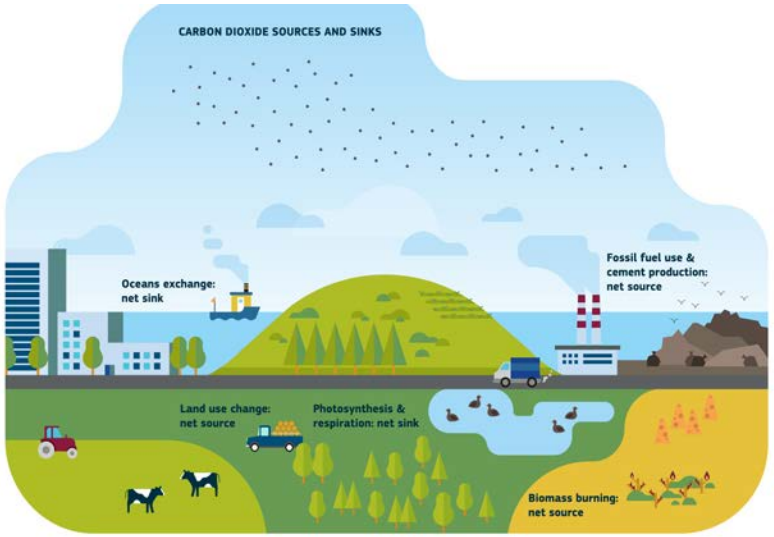
Initial Monitoring Systems

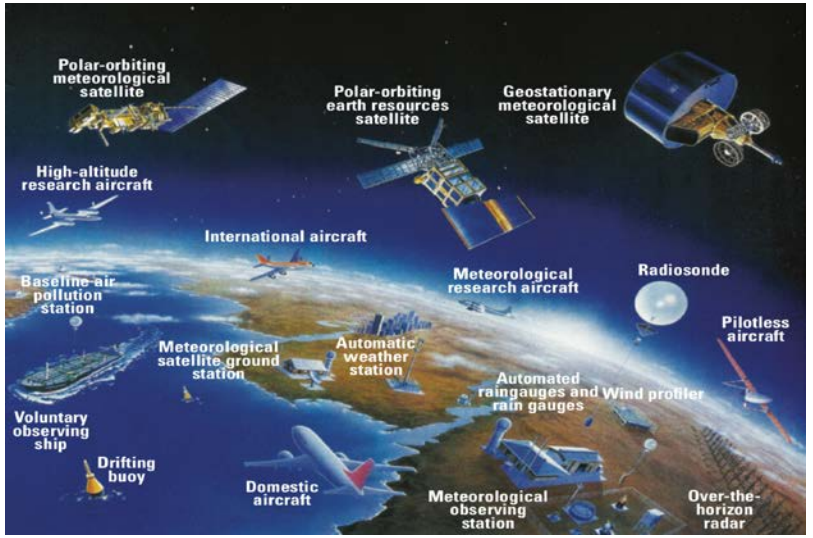
GST-2
COP33

Enhanced Systems

GST-n
ETF, NDCs

"for Measuring, Understanding, and Managing the Earth's Climate"





UN family
IPCC-IOC-
UNEP-UNFCCC-
WHO-WMO-WTO

UNFCCC
COP-SBSTA

WMO
WIGOS-WIS-WIPPS

Public-Private Partnerships

CO_2, Carbon dioxide

GHGs Earth's Observing Systems is building on Weather experience

2023 | 2024 -- 2027 | 2028 -- 2031 | 2032 -- 2050

Cg-19 → G3W
WMO Congress

G3W – IPP
Implementation Pre-Oper Phase

G3W – IOP
Initial Operational Phase

G3W – EOP
Enhanced Operational Phase

GST-1
COP28

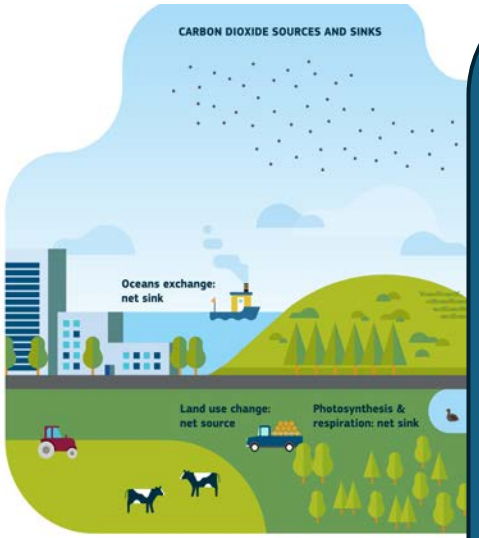
Initial Monitoring Systems

GST-2
COP33

Enhanced Systems

GST-n
ETF, NDCs

"for Measuring, Understanding, and Managing the Earth's Climate"



CO_2, Carbon

G3W will evolve and improve only through continued research efforts and advances in modeling, observing systems and human capacity

UN family
IPCC-IOC-UNEP-UNFCCC-WHO-WMO-WTO

UNFCCC
COP-SBSTA

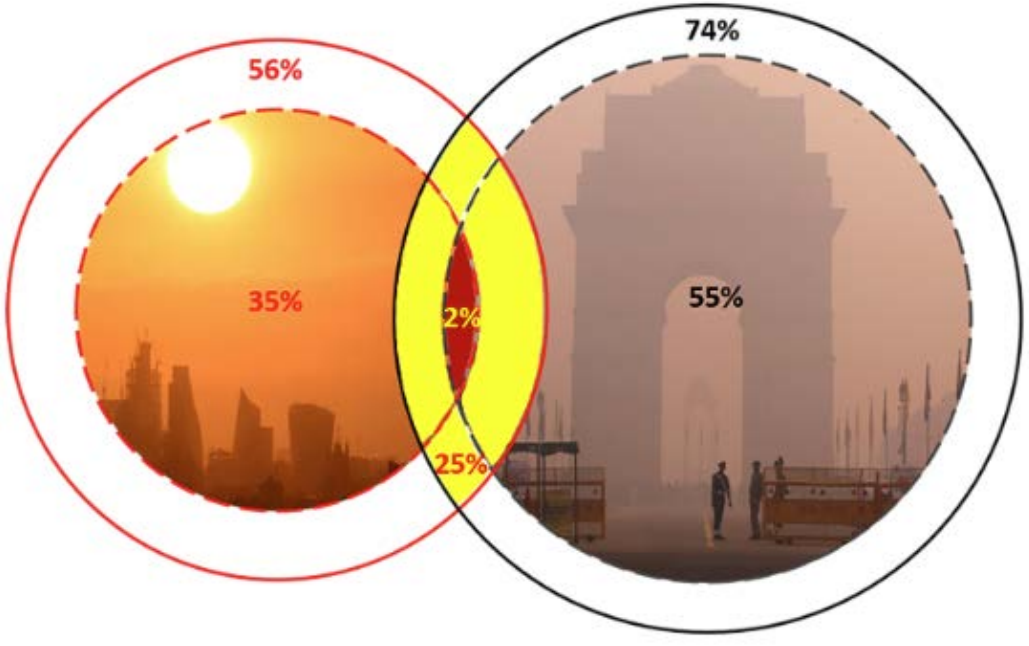
WMO
IGOS-WIS-WIPPS

Public-Private Partnerships

eather experience

Increase in the Co-occurrence of Heat and Air Pollution Extremes

PM2.5 AND Ozone remain problems

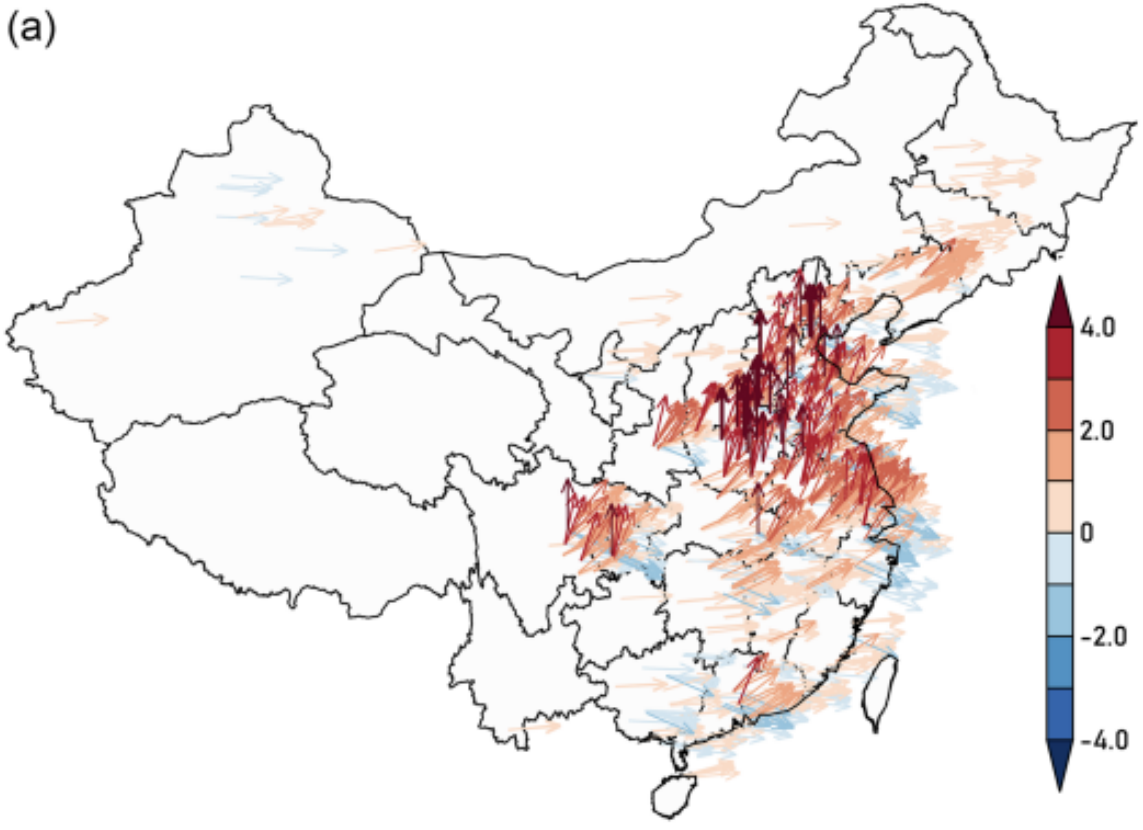


The multifold increase in the land area subjected to prolonged HHH (from 2% to 25%)


DAILY MAGAZINE
the news gateway

US World Politics Business Science Tech Sports Health Enterta

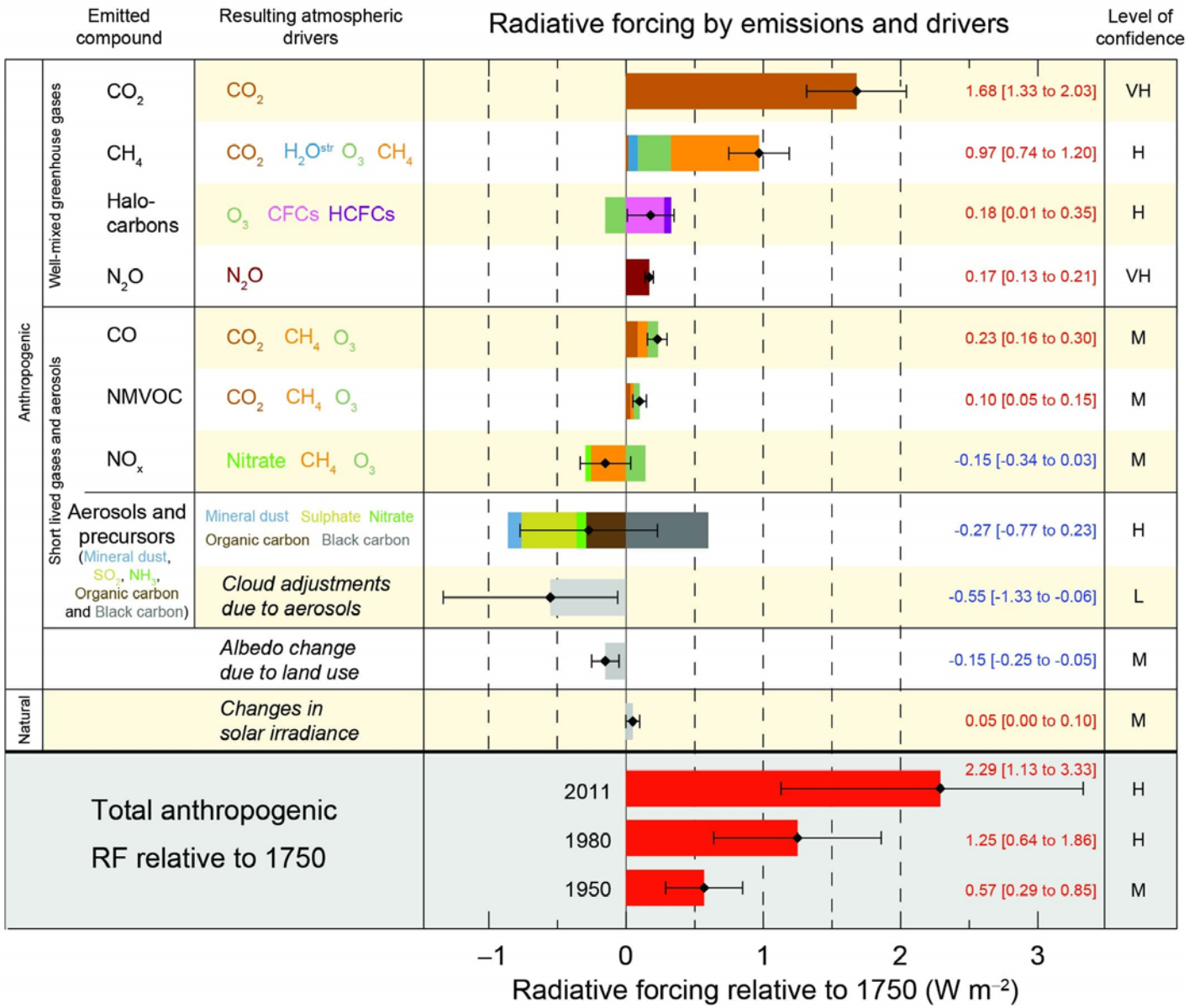
Days with both extreme heat and extreme air pollution are becoming more common - which can't be a good thing for global health



The increasing rate of joint exceedance is larger than the rate of Tw and O_3 itself. For example, Tw and O3 co-extremes increased by 7.0% in BTH, higher than the percentage increase of each at 0.9% and 5.5%, respectively.

Xiao et al., BAMS, 2022; Xu et al., AGU Advances, 2020

Critical role of super-pollutants in the next 2 decades

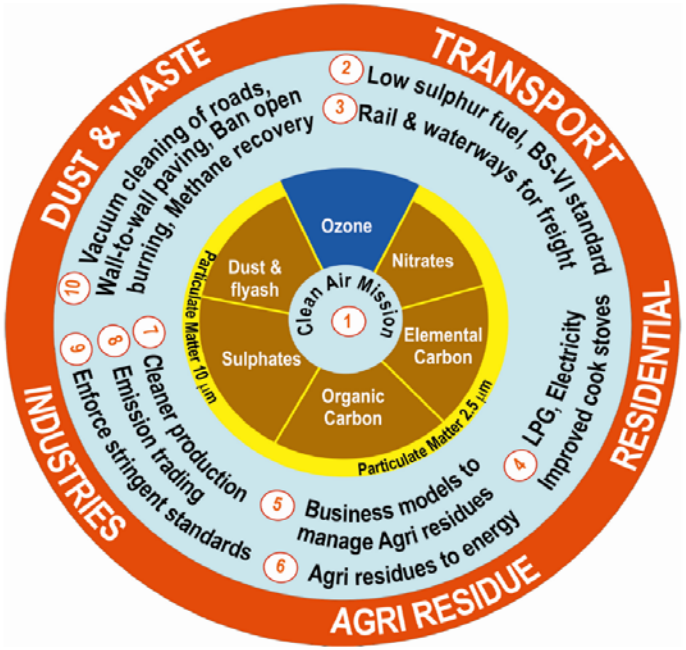


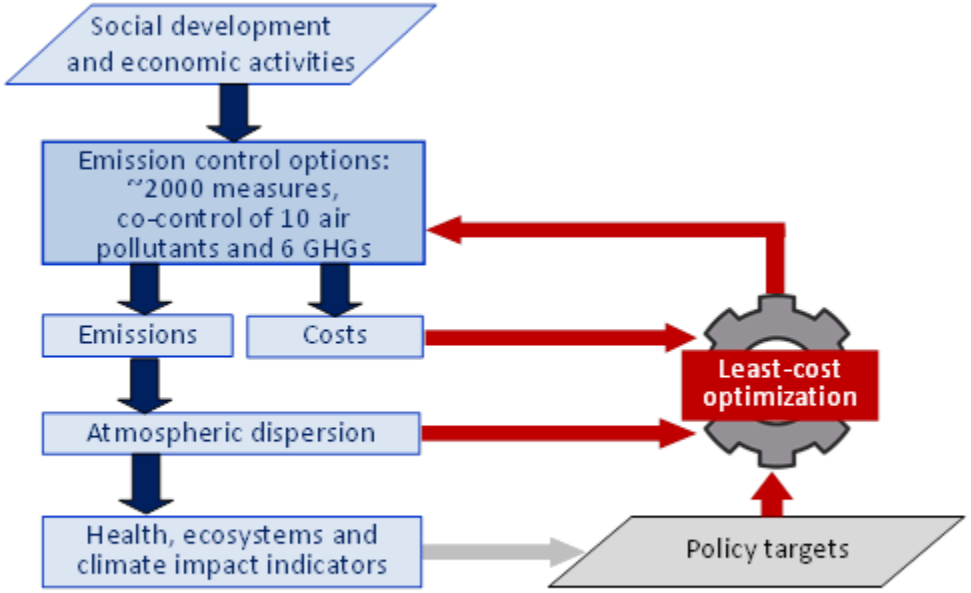
Need more locations where comprehensive suites of measurements are made together, including GHGs, isotopes, BC, ozone, and others to support increased efforts to mitigate climate change and air pollution worldwide.

Air Quality Management – Bangladesh

Integrated Analysis to help identify cost-effective control strategies

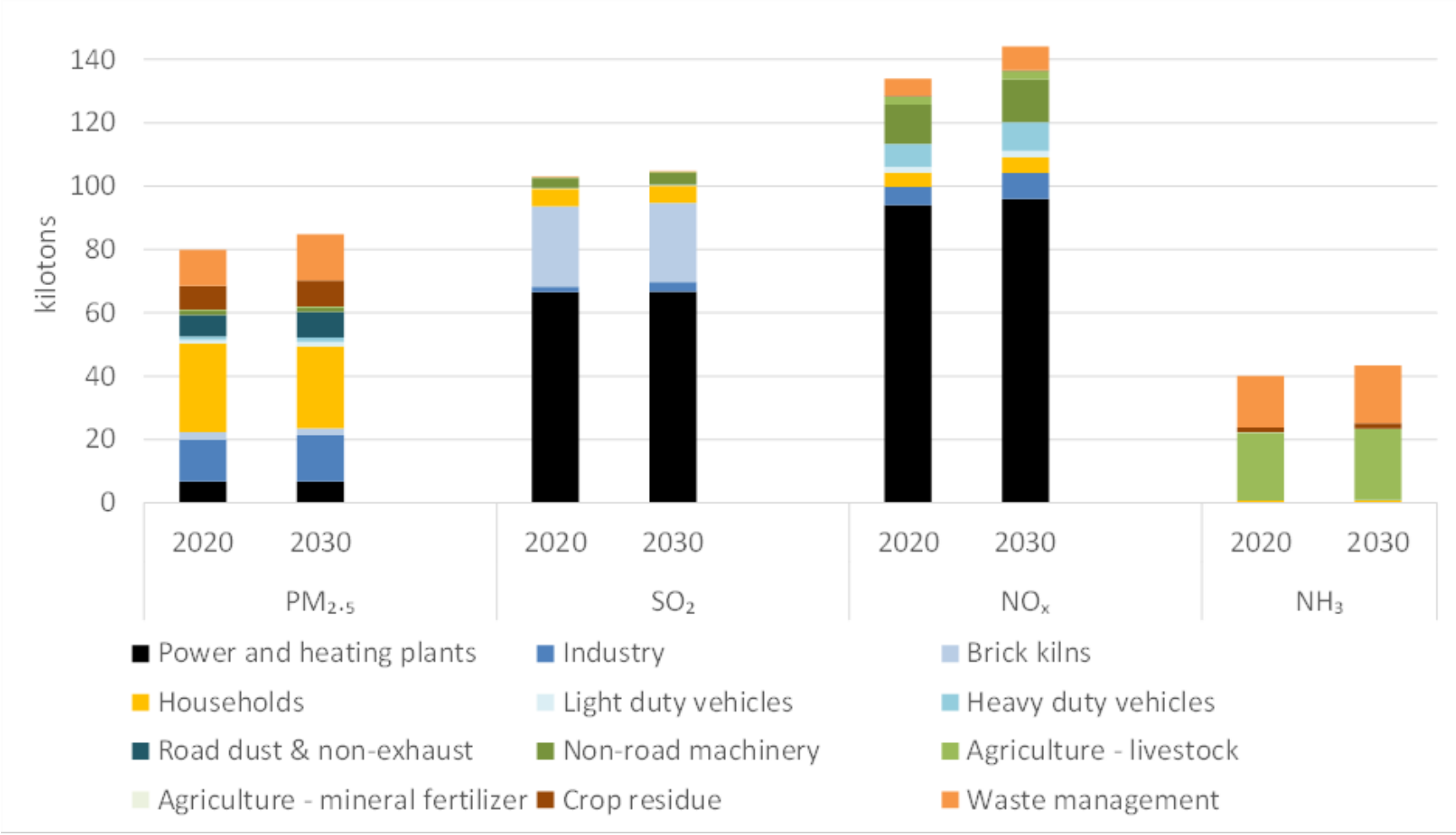
World Bank project





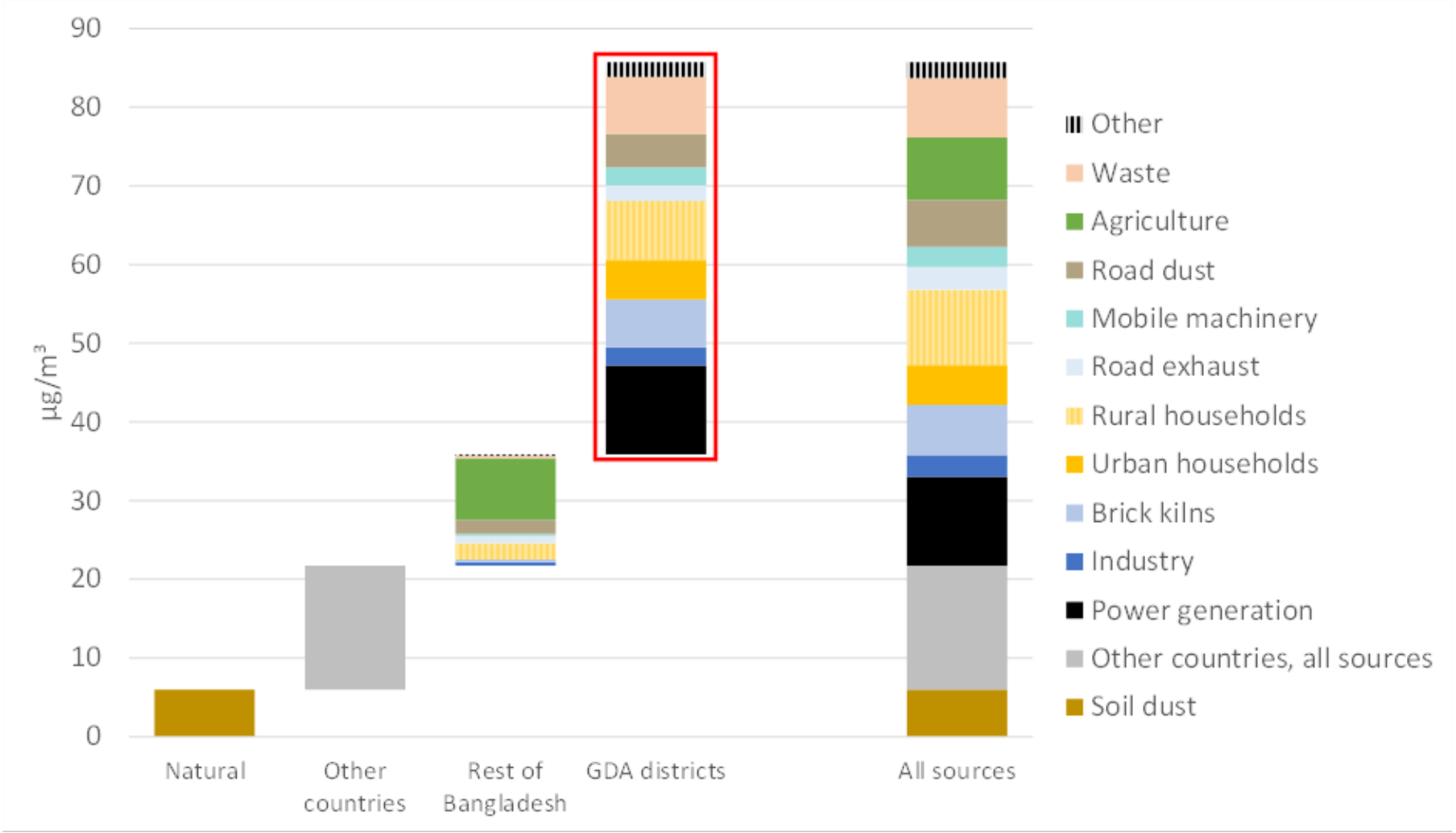
.: Information flow in the GAINS model

Socio-economic and emission trends 2020-2030, Greater Dhaka area

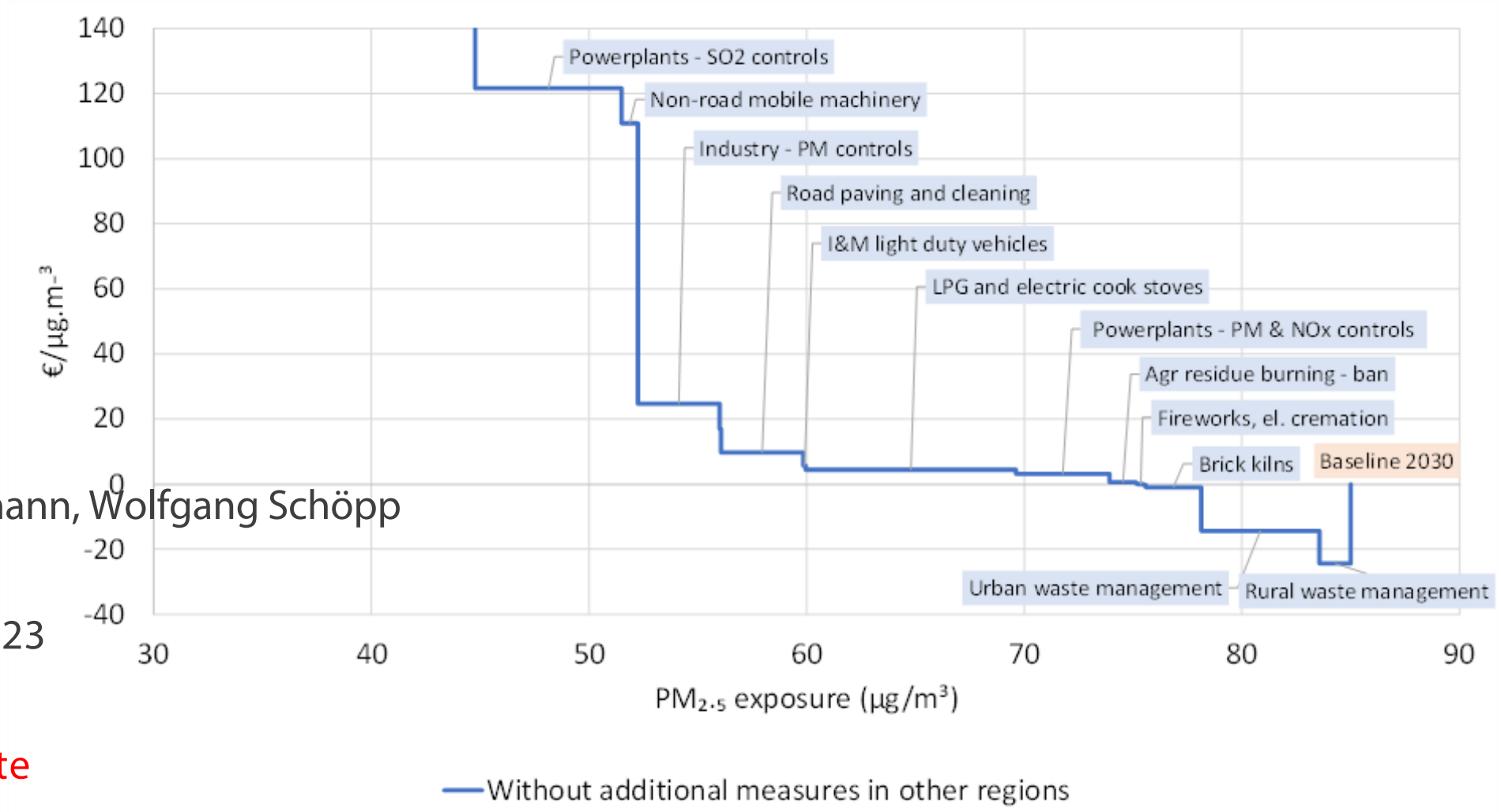


Population +10% GDP +80% Total primary energy consumption: +25%

Source apportionment for $PM_{2.5}$ exposure in GDA, Baseline 2030



Marginal cost curve for unilateral GDA measures 2030

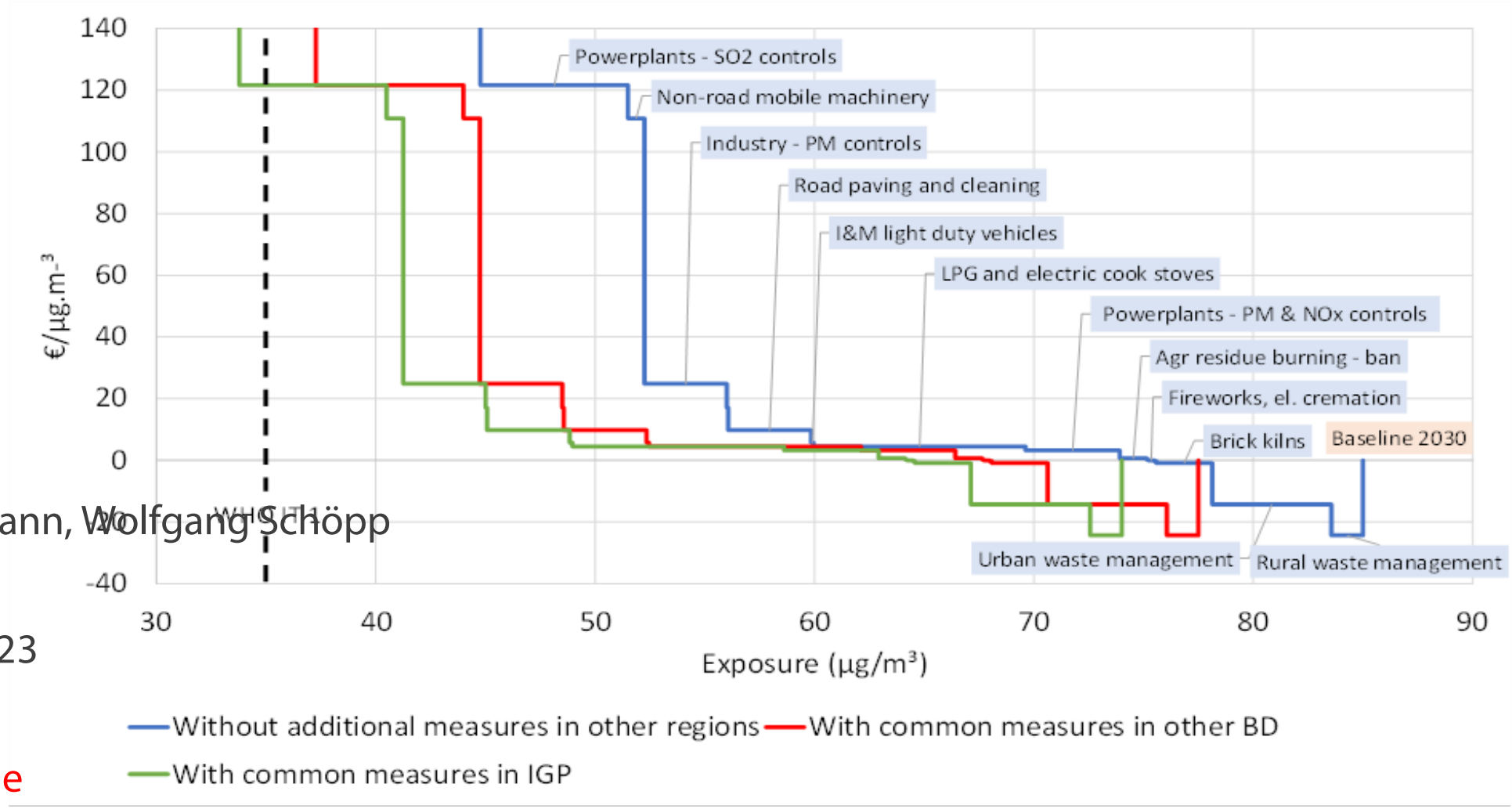


Markus Amann, Wolfgang Schöpp

May 29, 2023

Don’t quote

Marginal cost curve for cooperative AQM approaches 2030



Markus Amann, Wolfgang Schöpp

May 29, 2023

Don’t quote

Need to increase efforts to increase resiliency to air pollution and climate change and develop better adaptations while we urgently act to reduce emissions of pollutants and greenhouse gas emissions

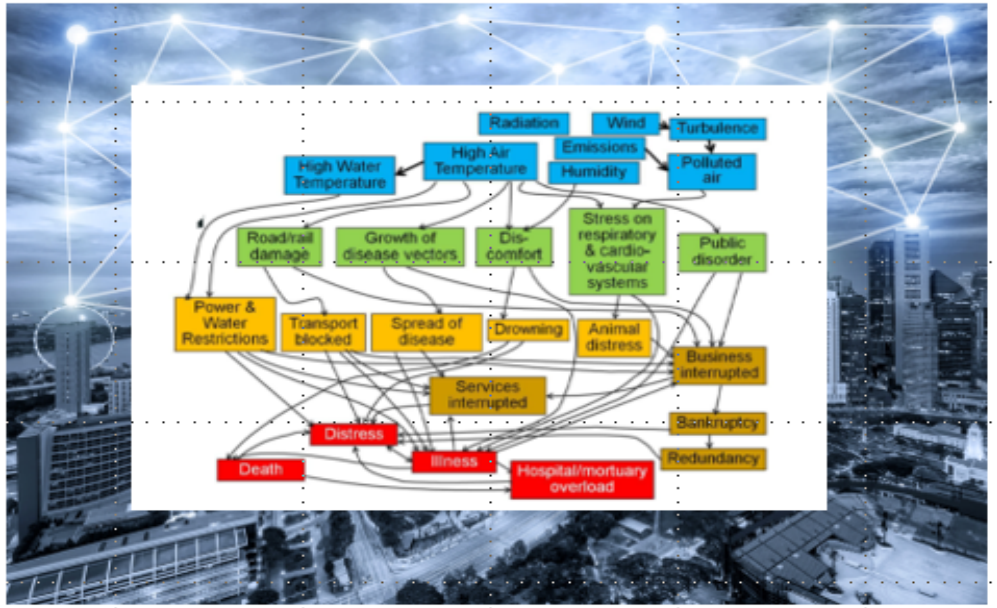
Digital twin platform to support air pollution and health studies

-- built upon an earth-system model framework to produce tailored analysis for use in time-series and case control studies requiring spatial and temporal exposure data.

Earth system air quality and met **prediction**

Machine learning prediction and pattern detection

Gridded remote sensing **observations,** surface observations, air quality reanalysis



Exposure estimates from fused gridded air quality and meteorological data from hrs to annual averages

Gridded emissions by sector, **social economic** data, mobility, traffic counts

Time-series and case control **health studies** Linking AQ and climate data (e.g., heat) to health outcomes

Intervention analysis (lockdown, recovery, emissions, green investments (trees, roofing), traffic restictions, ….)

WMO OMM

Op-ed, China Daily, July 15, 2023

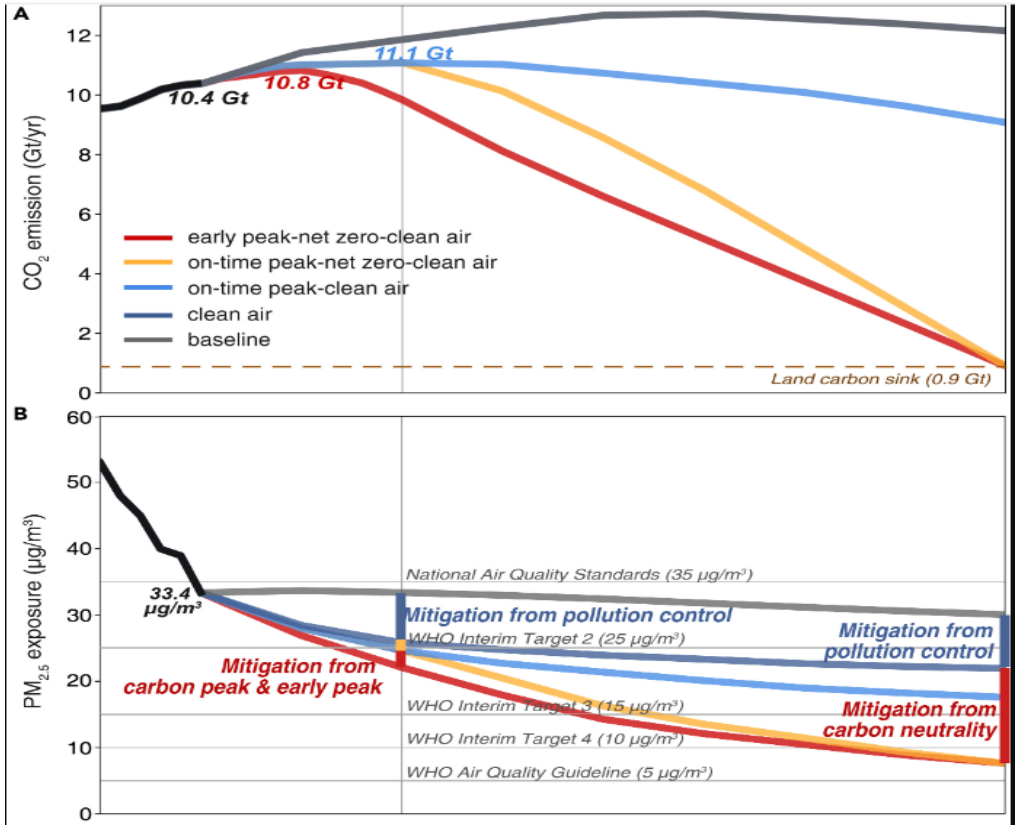
Overarching Goal:

Advancing Atmospheric Composition Predictions and Related Services to Meet the Growing Societal Needs

Bending the curves!

Learning from others!

Working together!



- ✓ Monitoring and prediction of atmospheric composition play critical roles in supporting societal needs related to air pollution, ecosystem and human health, food production and climate change.
- ✓ Considerable challenges remain in our ability to provide reliable and user-driven atmospheric composition information for many parts of the world.
- ✓ Concerted actions focused on advancing atmospheric composition information systems are needed to significantly reduce the current health and climate change burdens to societies and address related social inequalities.