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

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Chair, WMO SSC Global Atmospheric Watch (GAW)
Co-chair, Study team for the Global Greenhouse Gas Watch

May, 2024

The University of Iowa

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

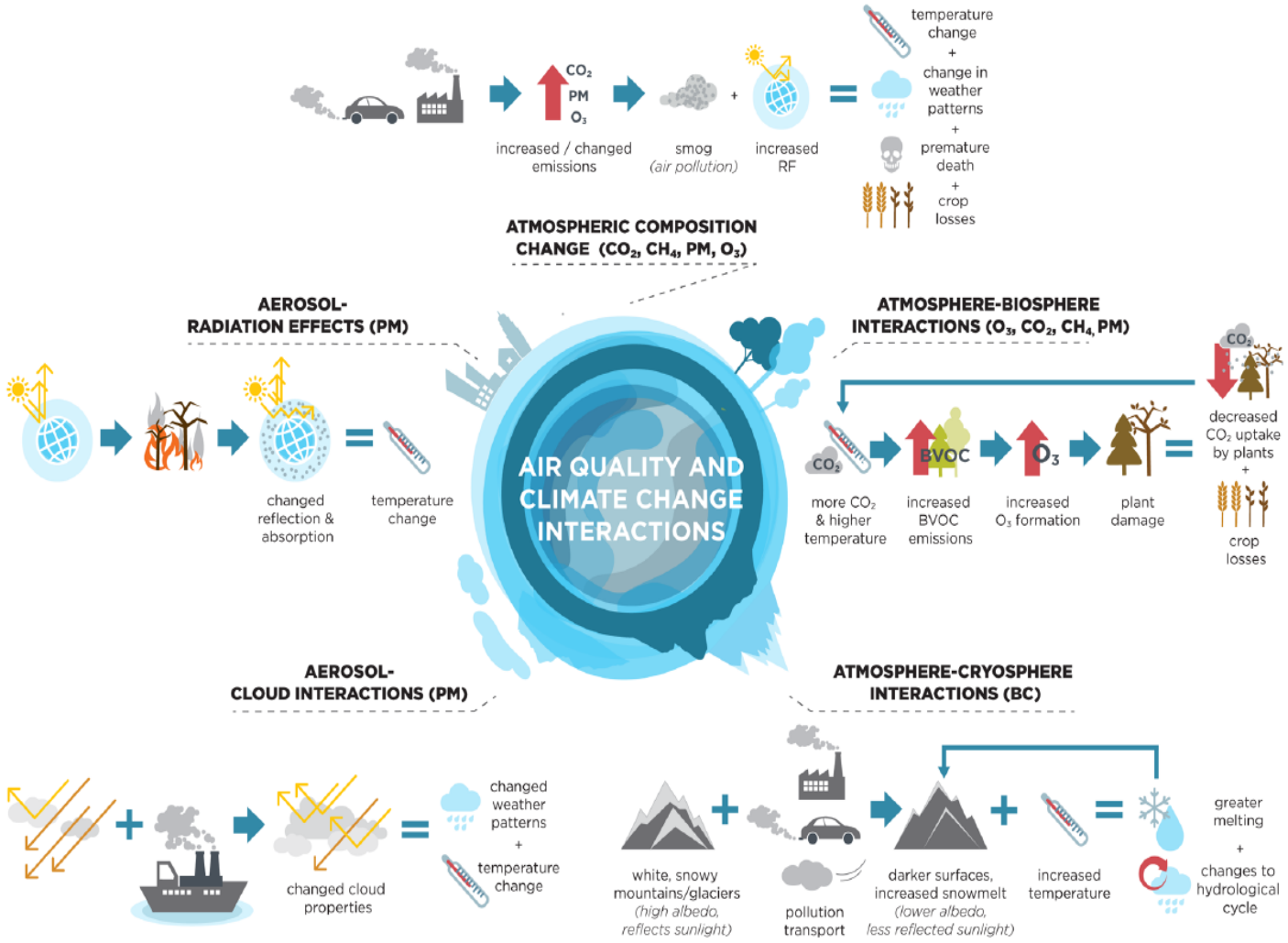

Figure from von Schneidemesser et al. (2015)

- ✓ 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 significantly reduce the current health and climate change burdens to societies and address related social inequalities.

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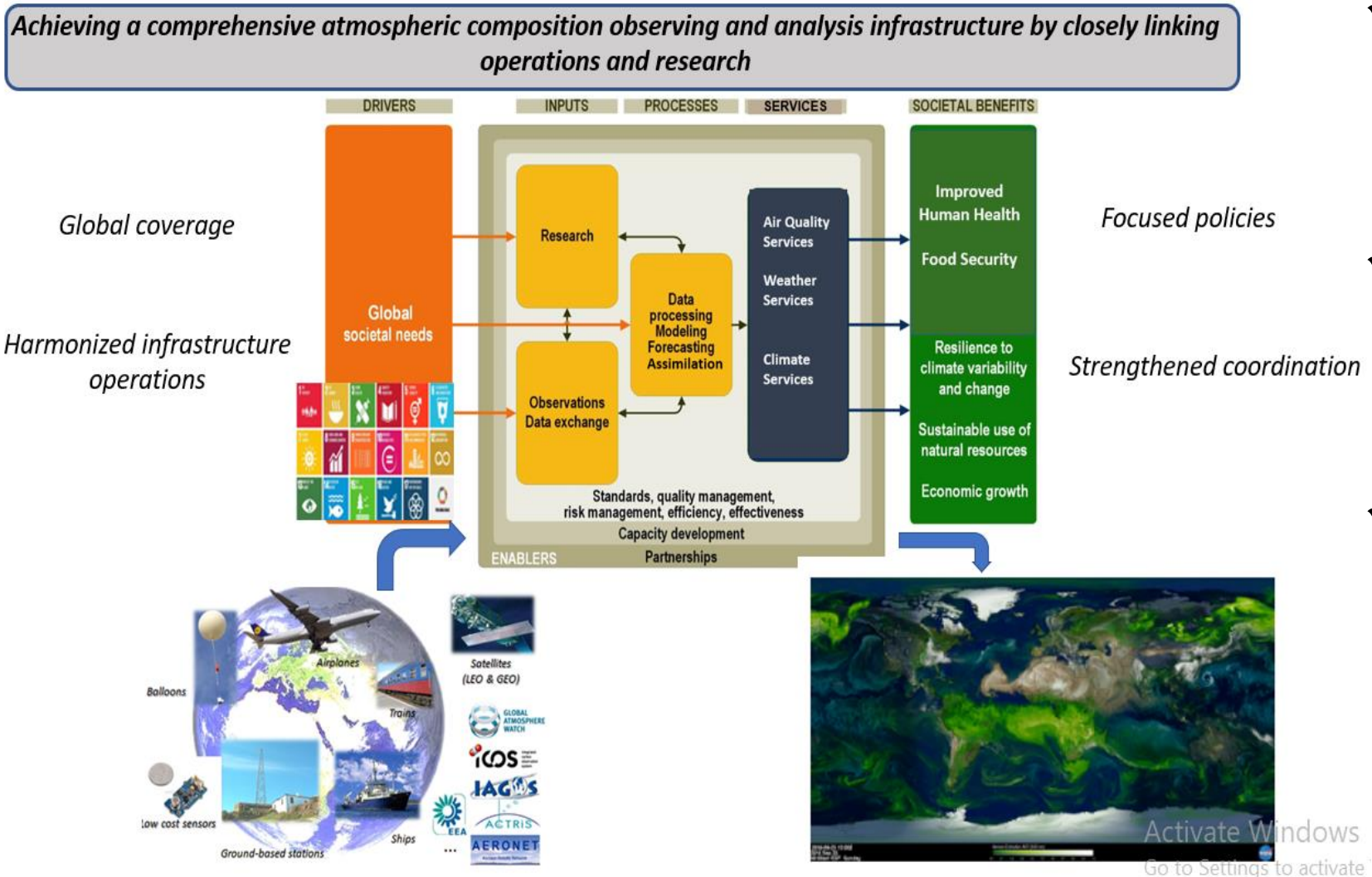
Overarching Objective – *Continue to improve analysis and prediction capabilities of Earth System Models to improve related services to meet the growing societal needs*



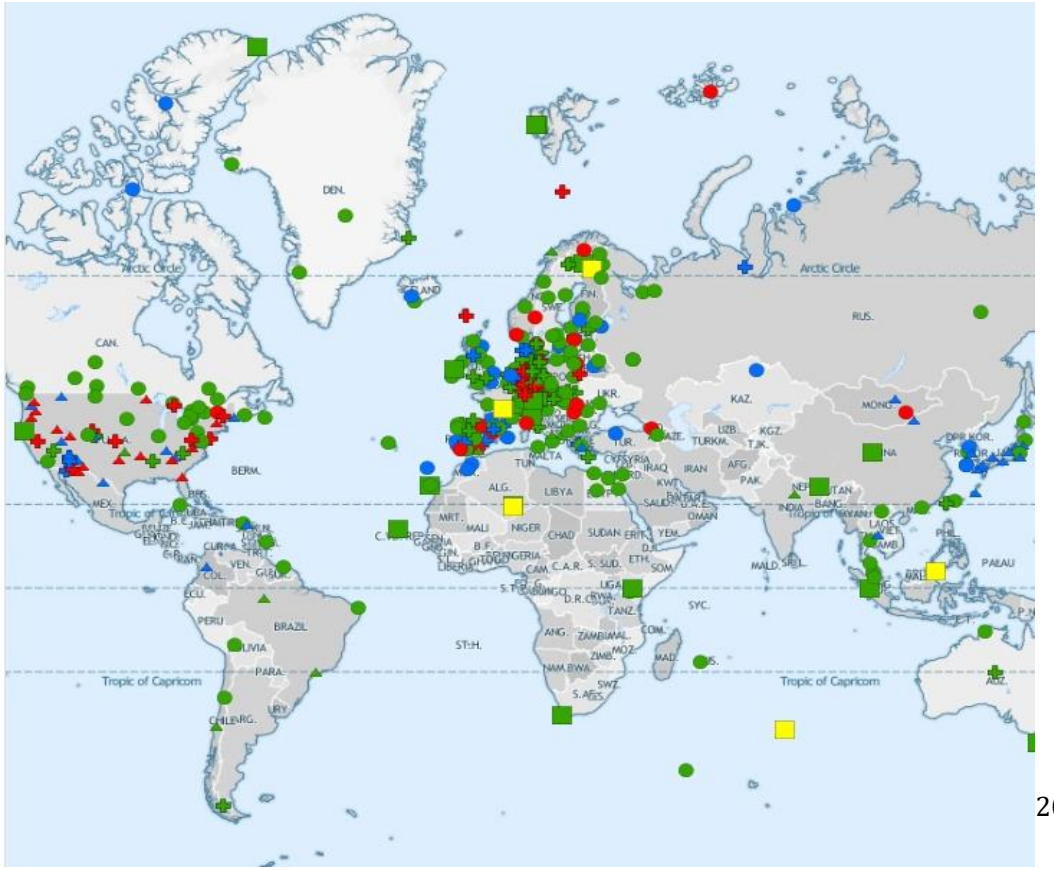
- ✓Trend toward closer linkages of weather, atmospheric composition, and climate related services
- ✓Information needed at higher resolution (and longer forecast times) to address societal needs
- ✓Further improvements in predictions require **advances** in observing systems, models, better assimilation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

WMO Global Atmosphere Watch (GAW)

- *Based on partnerships involving contributors from **100 countries** (including many contributions from research community)*
- *Maintains and applies **long-term systematic** observations of the chemical composition and related physical characteristics of the atmosphere*
  - *Emphasizes **quality assurance and quality control***
- *Delivers integrated products and services of relevance to society.*

New Science & Implementation Plan 2024-27

Action: *Strengthen the atmospheric composition measurement and data infrastructure and contribute to understanding trends and variability*



2011

WMO/GAW Surface observations

- ✓ **High-quality global atmospheric composition observations are of critical importance to society** and are needed to estimate exposure for health assessments, document trends in greenhouse gas emissions, and monitor compliance to conventions and protocols.

- ✓ Unfortunately**, the current observing networks for atmospheric composition are fundamentally inadequate** to support the increasing number of the environmental regulations and societal applications.

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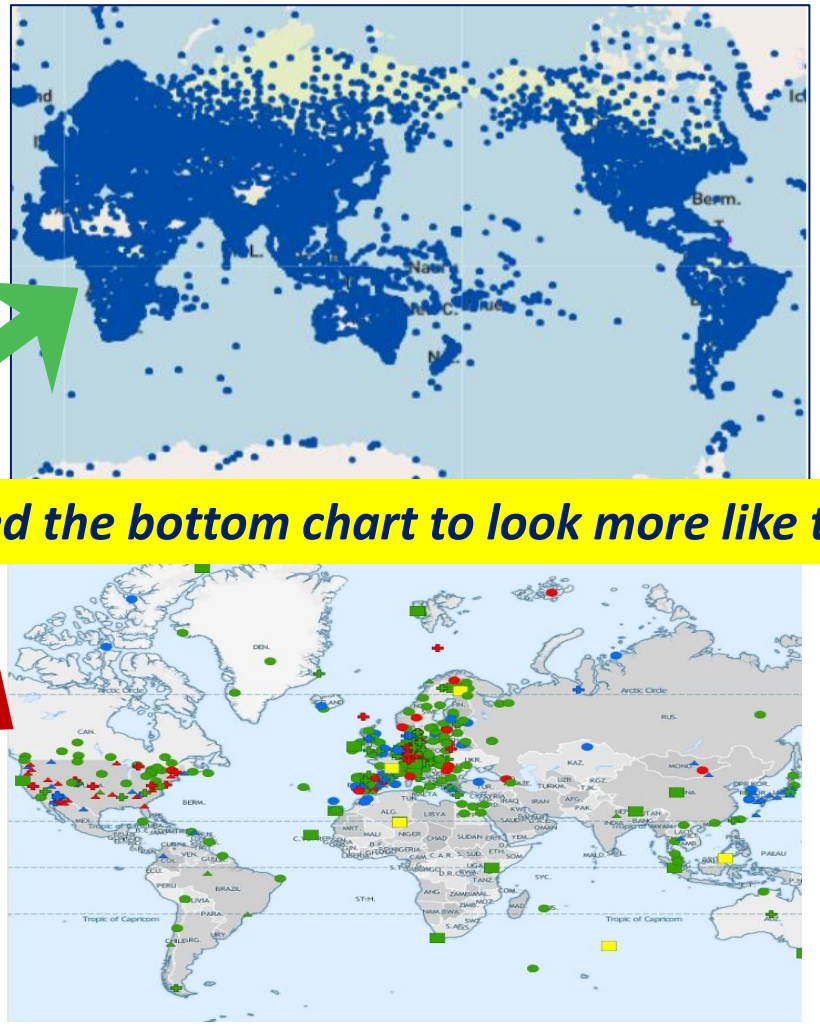

"We need the bottom chart to look more like the top chart!"

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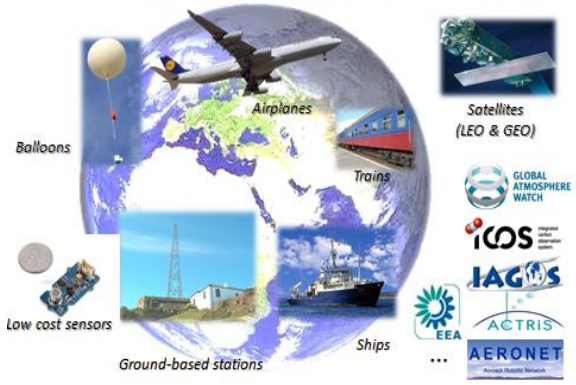
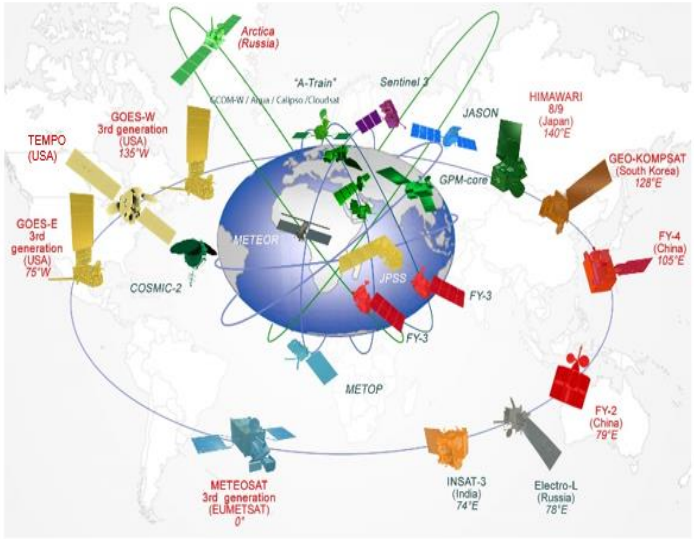
Good news! *Major advances in observing systems*

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

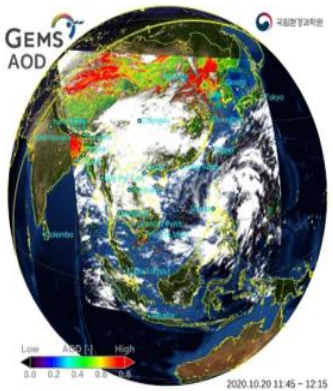


The dawn of a new era for atmospheric composition monitoring from space

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.



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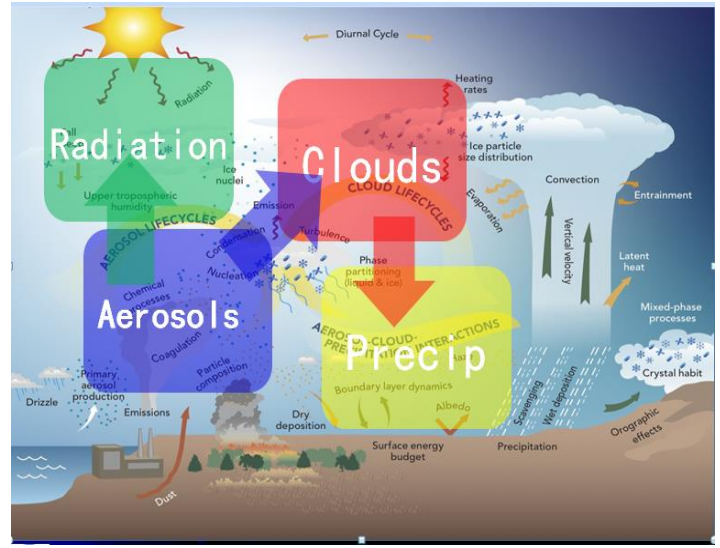


infrastructure investments ACTRIS, technologies, low-cost sensors, sondes, aircraft, etc.

Coordination Group for Meteorological Satellites

WORLD METEOROLOGICAL ORGANIZATION

GLOBAL ATMOSPHERE WATCH

ECMWF CGMS

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

GAW SIP2024 Strategic Objective B

Improve predictive capabilities and analysis through applied research aimed at advancing the understanding of the roles and fate of aerosols, reactive gases, stratospheric ozone and greenhouse gases and their interactions in the Earth System.

Activity SO-B1: Advance modelling science through improving the understanding and representation of critical atmospheric composition related processes in the Earth System.

Activity SO-B2: Further develop techniques and tools to integrate atmospheric composition data with models.

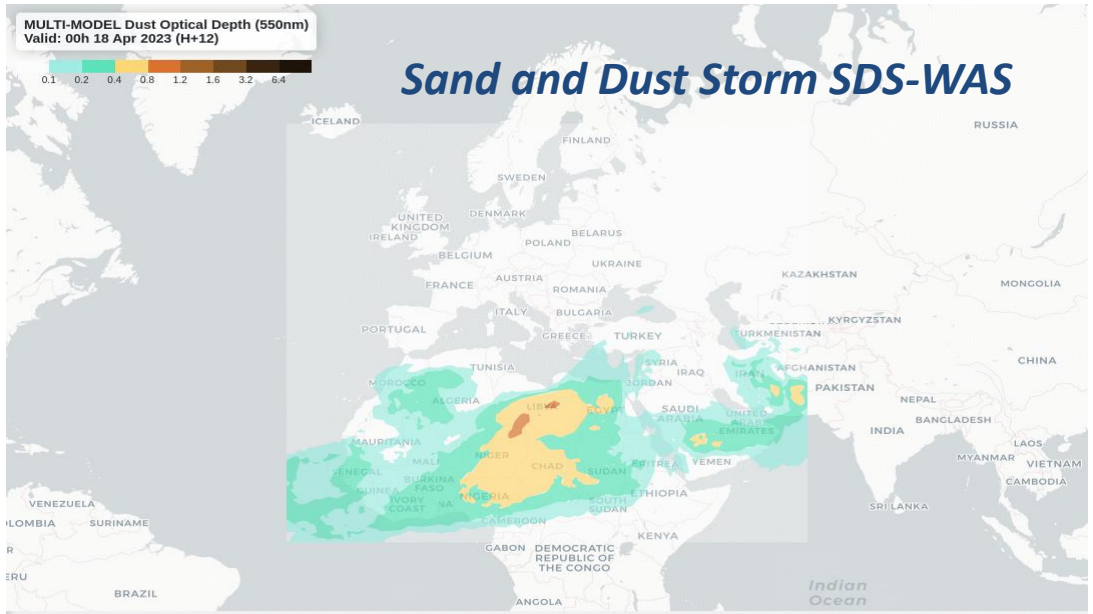
Activity SO-B3: Advance integrated weather-climate-chemistry modelling capabilities.

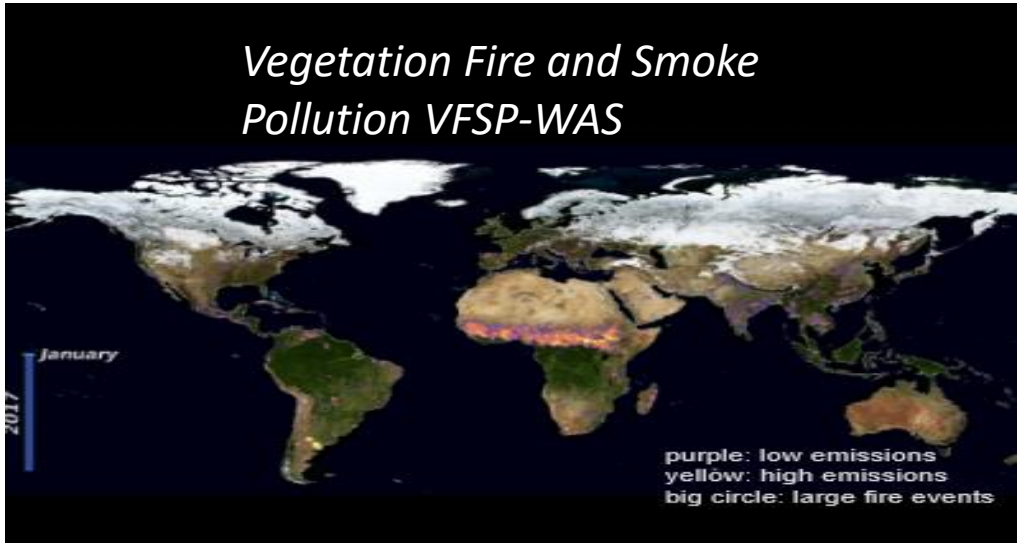
Activity SO-B4: Demonstrate enhanced global to local/urban prediction and analysis of atmospheric composition related hazards.

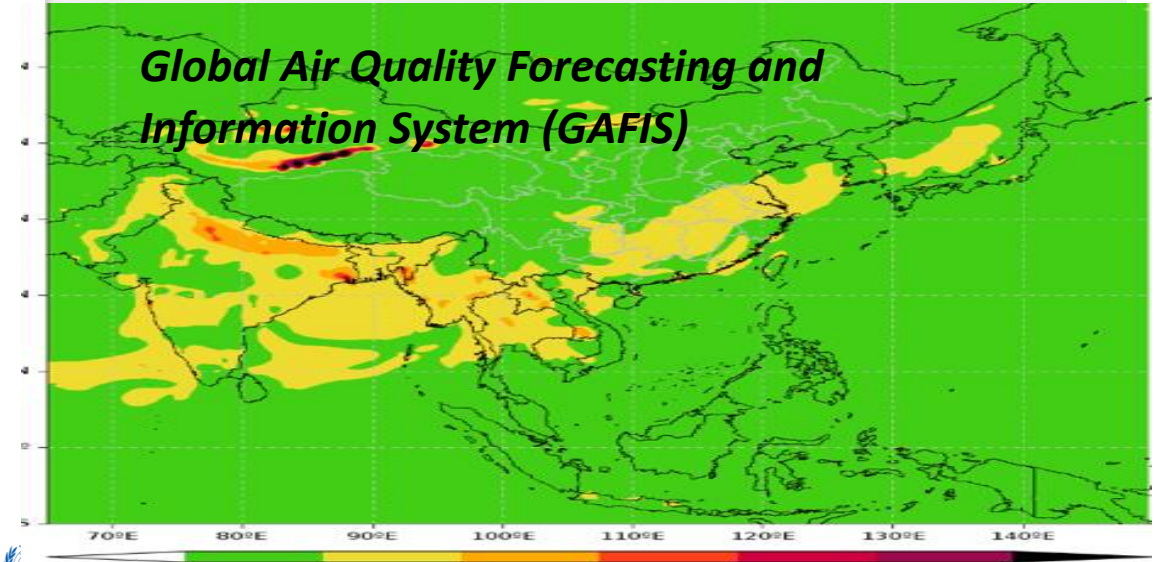
GAW modeling-related priorities

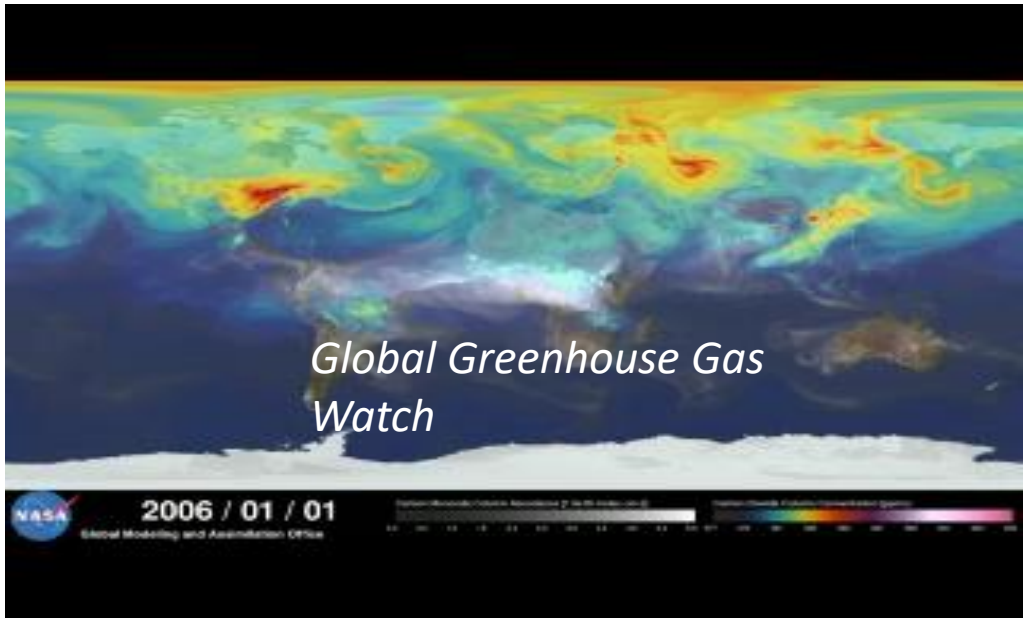
- Atmospheric Composition (AC) in ESM
  - role of aerosols and reactive gases in ESModels
  - coupled chemistry, meteorology & climate feedbacks
  - Urban environments
- Data assimilation technology development and evaluation
  - Data Assimilation, Data Fusion, Data Quality for model applications
  - Source inversion (aerosols, reactive gases, GHG)
  - Parameter estimation
- Topical contributions
  - vegetation fires: monitoring, prediction, emission assessment, plume modelling
  - wind-blown dust: monitoring, modelling, biological composition of dust
  - ABL processes: surface-atmosphere exchange, weather, AQ, and climate impact
- Assessments
  - Model intercomparison studies
  - S2S
  - Metrics for evaluation
- New contributions
  - Machine Learning and AI in ESModelling
  - bioaerosols: monitoring, modelling

GAW-related Warnings and Forecast Services





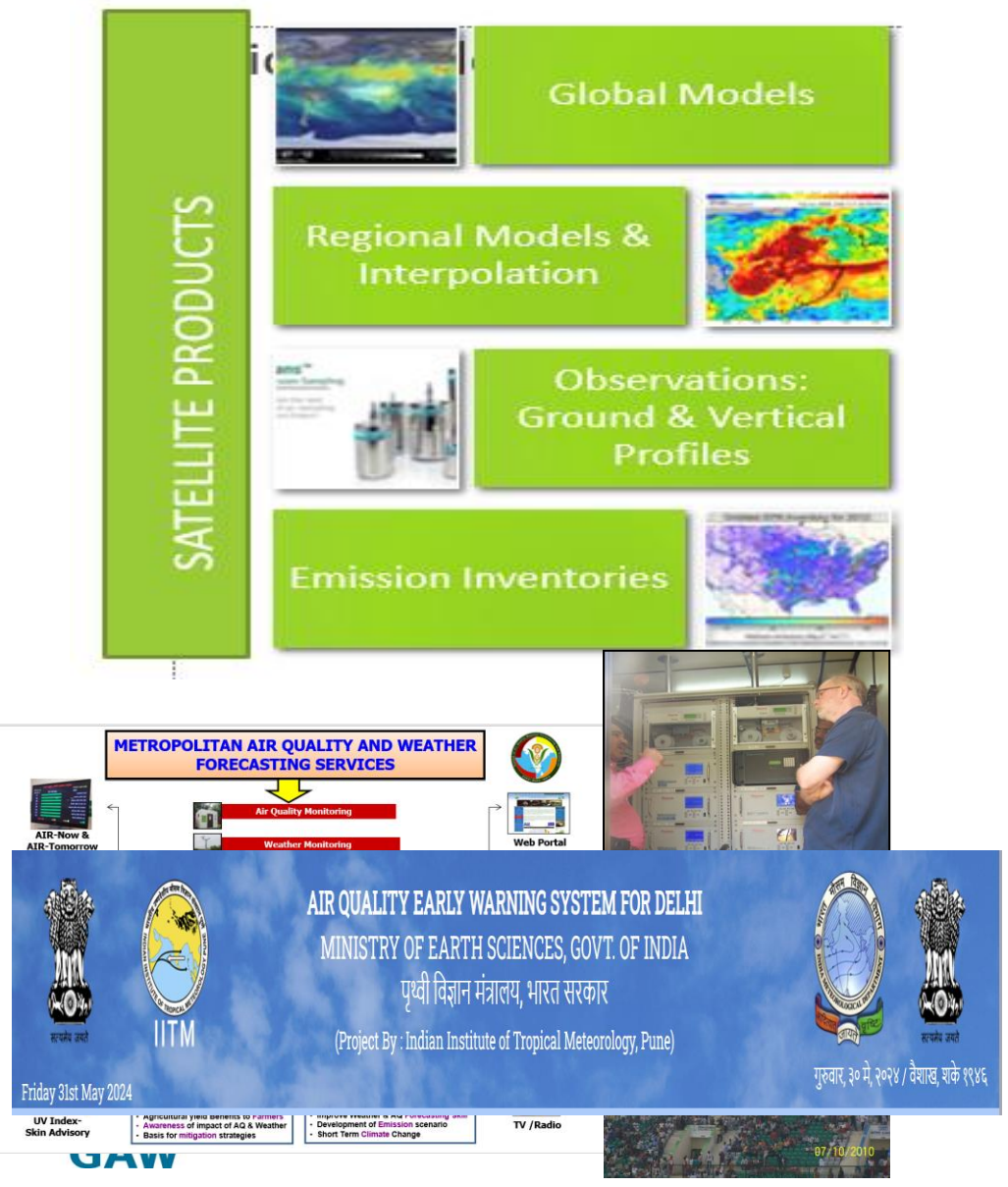




https://community.wmo.int/en/activity-areas/gaw/science-for-services/sds-was

WMO | IMO-WMO

GAW Air Quality Forecasting & Information System -- a constellation of observations, estimates, models, emissions inventories



Modeling: AI & chemical transport models link sources to observed pollution level & observed pollution to sources. Global models help with local vs long-range transport, regional models often have higher resolution & can be more customized.

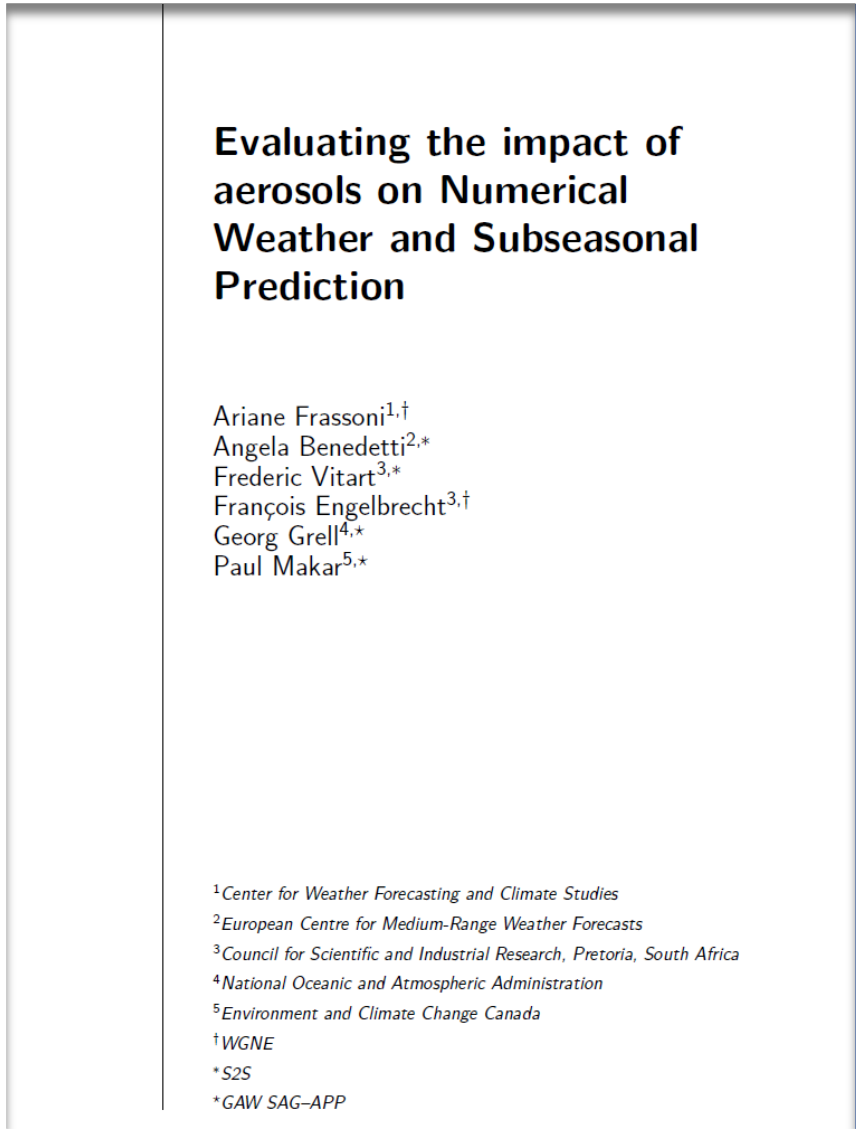
Monitoring: Measurements of concentrations and chemical composition of pollution at ground & diff heights, including via satellite products, improves model accuracy, spatial resolution, source attribution – if data are managed, labelled well.

Emission Inventories: **Bottom-up:** Based on activities data (essentially economic data) & emissions factors. **Top-down:** inverse estimates using observations and models. Higher spatial, temporal granularity of emission inventories improves attribution, estimation.

Joint WGNE – WWRP S2S – GAW APP SAG Aerosol Impact study

- To explore the importance of **interactive aerosols in short to medium-range and subseasonal predictability**, it is necessary to coordinate a **systematic and statistically robust study** and associated database to support the analysis.
- This project proposes the development of the 2nd phase of the WGNE Aerosols project but now including a joint collaboration between WWRP/S2S Steering Group and the WMO Global Atmosphere Watch (GAW) Scientific Advisory Group (SAG) on Modelling Applications (SAG–APP).
- The WGNE-S2S-GAW Aerosols project (WGNE-S2S-GAW-Aer) consider a longer period of evaluation and will consider two main components:

- *one is built on WGNE-AerI by running higher resolution regional models in order to address the importance of interactive aerosols on weather predictability;*
- *the second component considers sub-seasonal reforecasts experiments based on ensemble approach in a global scale in order to address the importance of interactive aerosol on sub-seasonal predictability.*



Evaluating the impact of aerosols on Numerical Weather and Subseasonal Prediction

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François Engelbrecht[3,†]
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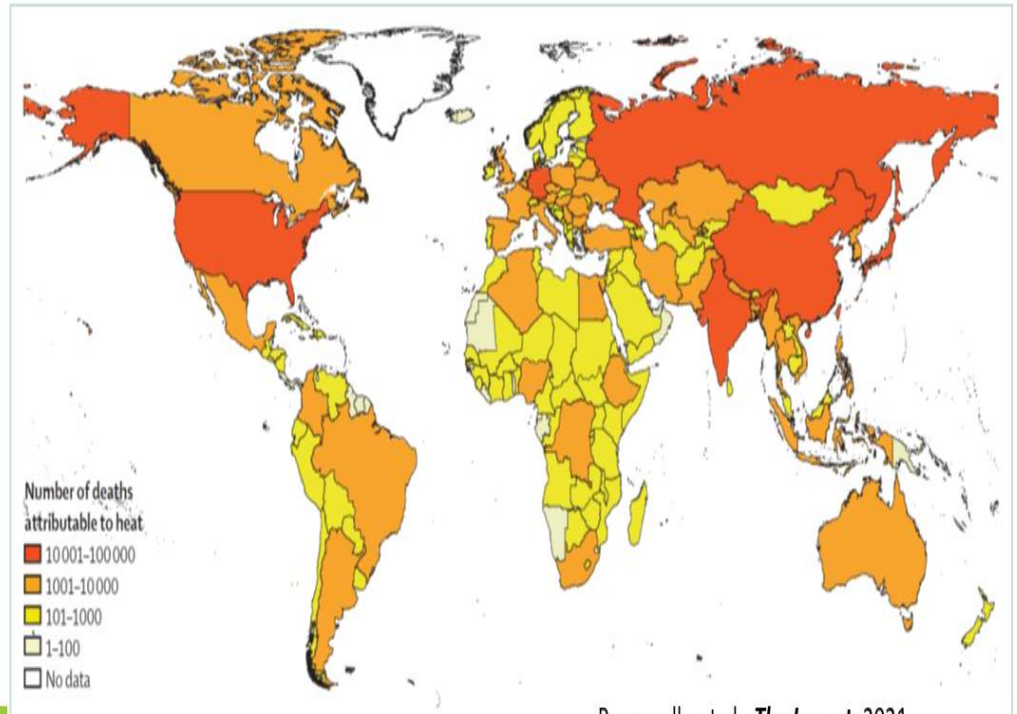
[3] *Council for Scientific and Industrial Research, Pretoria, South Africa*
[4] *National Oceanic and Atmospheric Administration*
[5] *Environment and Climate Change Canada*
[†] *WGNE*
[*] *S2S*
[*] *GAW SAG–APP*

Climate + Weather + AQ Interactions

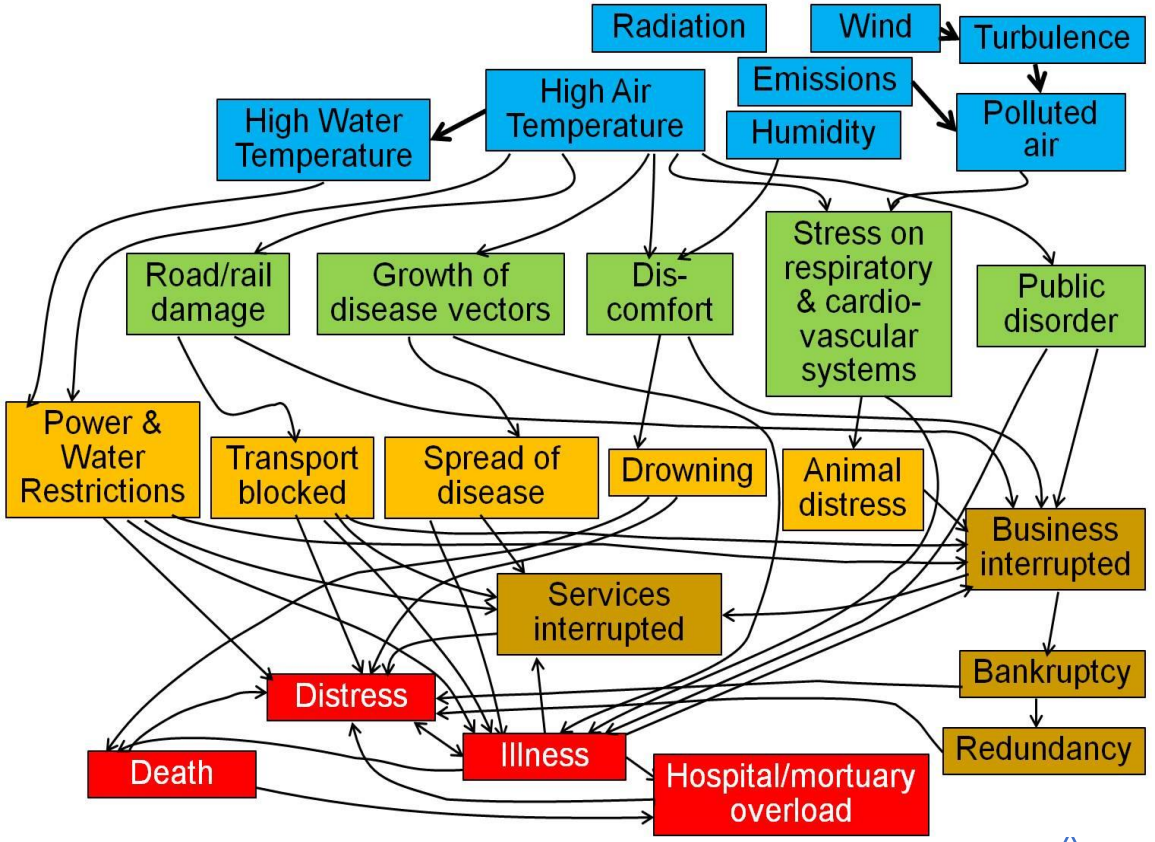
Early Warning for All (EW4A)

Mortality and heatwave in 2019: for 65 and above

Heat-related deaths in people older than 65 years reached a record high of an estimated **345 000 deaths in 2019**; between 2018 and 2019, all WHO regions, except for Europe, saw an increase in heat-related deaths in this vulnerable age group

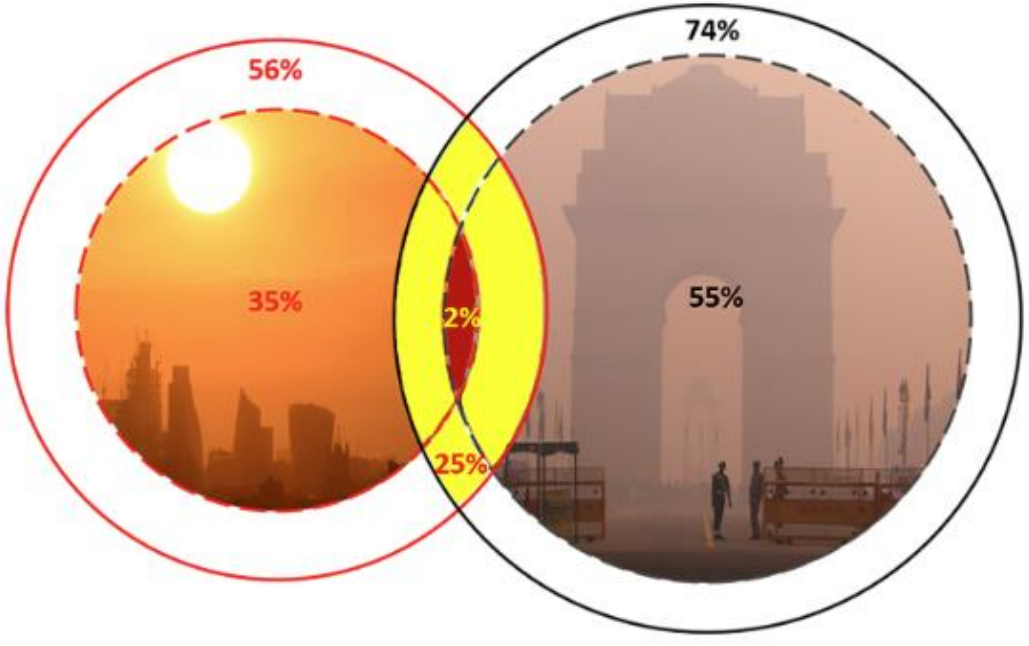


Romanello et al., *The Lancet*, 2021



<u>Simplified impact cascade for heat/air pollution</u>. Blue/green shows cascade of physical processes and relevant parameters. Beige/brown are 1st & 2nd order socio-economic impacts. Red shows human impacts.

Increase in the Co-occurrence of Heat and Air Pollution Extremes are Expected with Climate Change



The multifold increase in the land area subjected to prolonged HHH (from 2% to 25%)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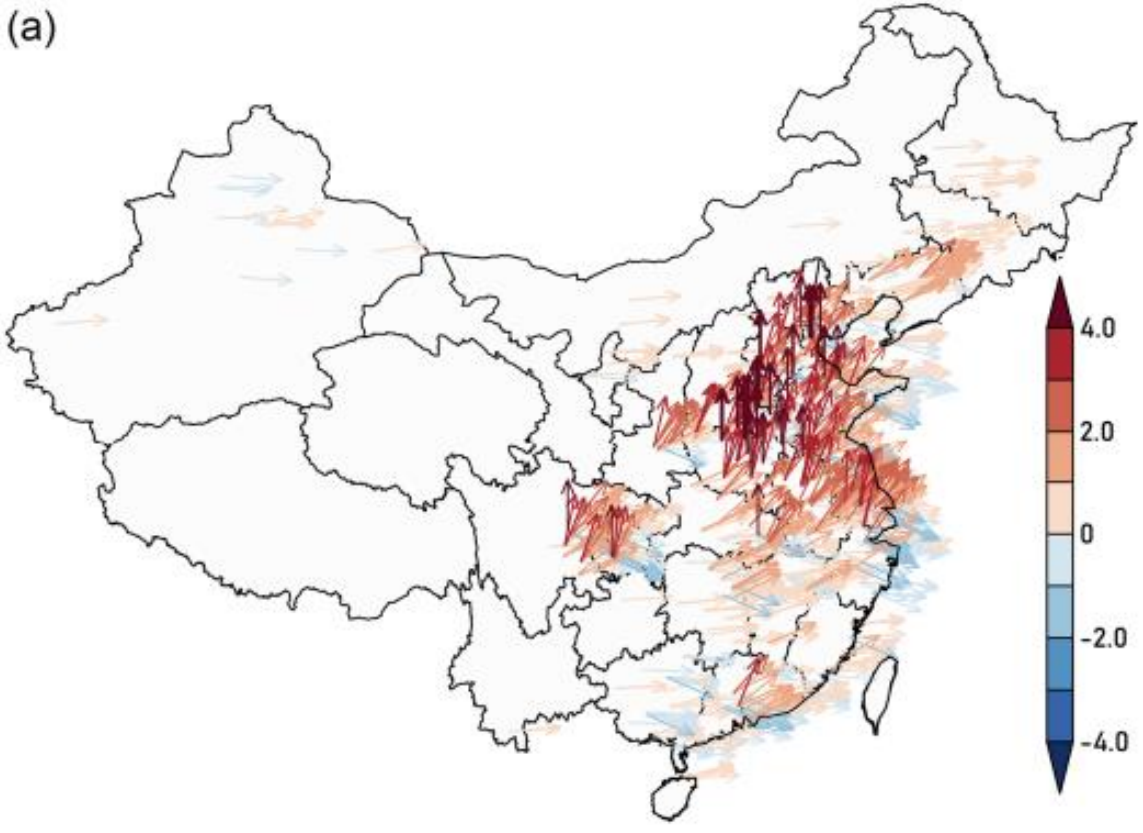
Days with both extreme heat and extreme air pollution are becoming more common - which can't be a good thing for global health



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

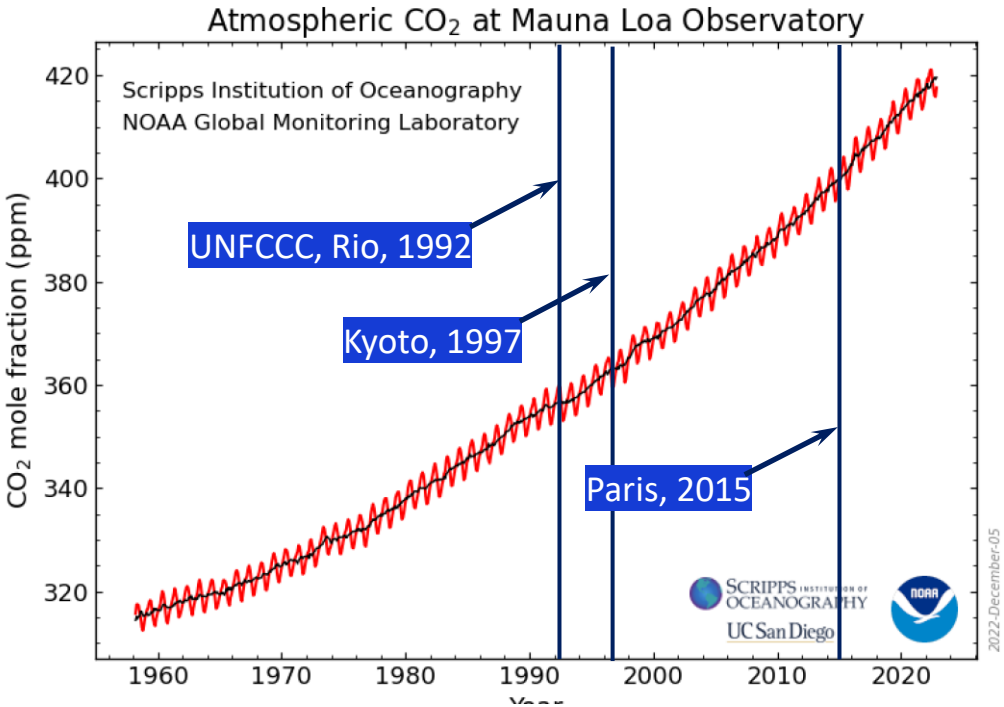
We need to reduce GHG emissions!

But !#?

- The Paris Agreement has been adopted with the aim of limiting climate change via reducing net anthropogenic greenhouse gas (GHG) emissions;
- Paris focuses on accurate reporting of anthropogenic GHG emissions; however, GHG fluxes driven by natural processes are often much larger and are not explicitly taken into account;
- Natural fluxes respond to anthropogenic emissions and climate change in ways not yet understood;

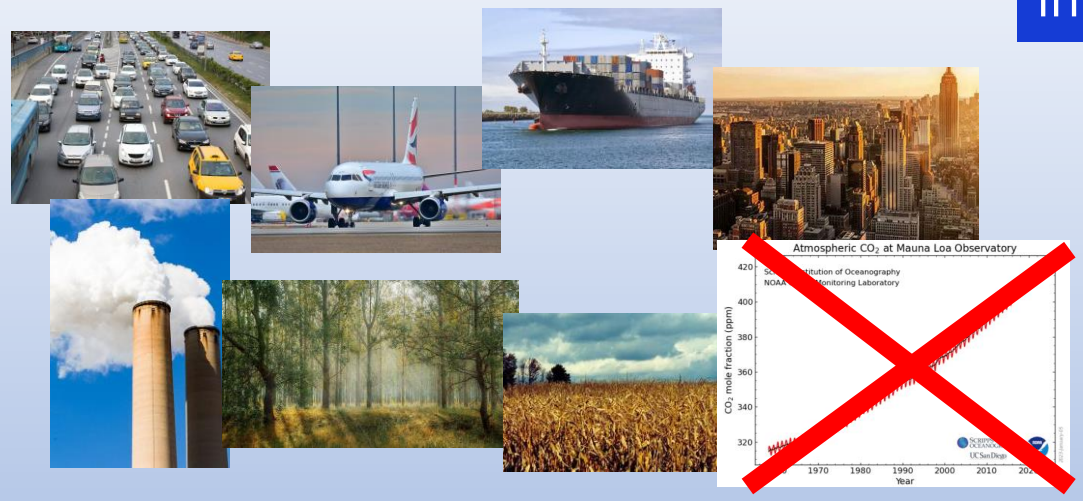
- In UNFCCC parlance, ”Emissions” can be positive as well as negative (GHG removals), but
- Accounting for negative emissions (carbon *offsets* and *credits*) is problematic, poorly regulated and ineffectively monitored, leading to risk of overestimating of impact, double counting,…;

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



Improving greenhouse gas emissions - top-down & bottom-up emissions approaches are necessary

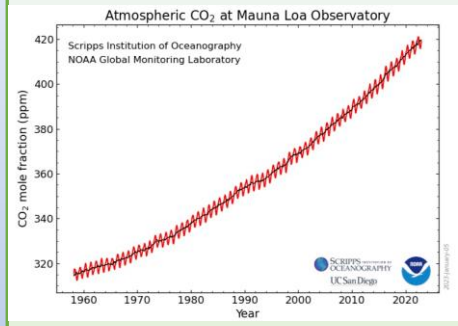
Bottom up: *Add up individual sources and sinks carbon and calculate overall contributions;*

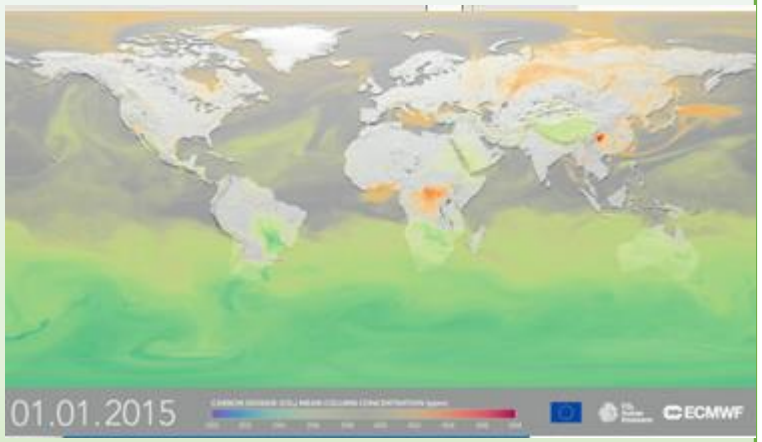


- Can provide very accurate estimation of anthropogenic ***emissions***;
- Bulk data national only, 1-2 years delayed;
- Does not work well in developing countries;
- Not applicable to most natural sources/sinks;

Almost all activities under IPCC and the Paris Agreement are based on bottom up

Global infrastrucure required for top-down GHG monitoring is very similar to WMO-coordinated infrastructure for weather prediction and climate analysis;





- Direct link to "centralized accounting";
- Global coverage, spatially disaggregated;
- Estimates of *net* ***fluxes*** rather than of emissions;
- Can be made available in near-real time;

Top-down technology mature, used by Parties individually, not yet in context of Paris Agreement

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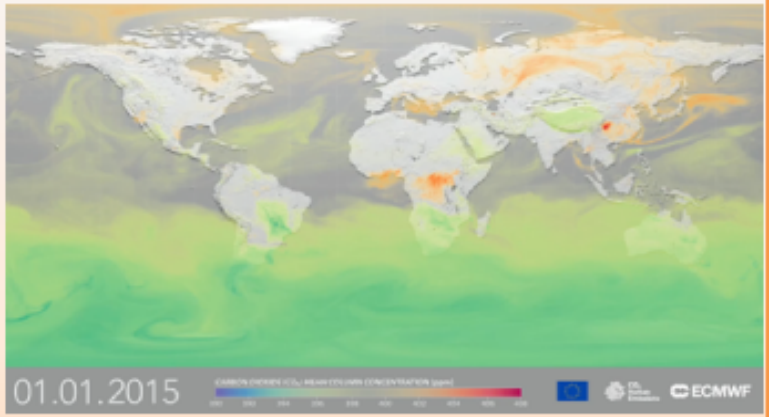

Reconciliation

together

Improved Emissions

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WMO Global Greenhouse Gas Watch: *an internationally coordinated operational monitoring of greenhouse gas fluxes in support of climate change mitigation action under the Paris Agreement*

Key elements

- Integrated global greenhouse gas observing system (spanning surface to space-based);
- 24/7 operational GHG modeling/assimilation (multiple systems), providing top-down flux estimates;
- Routine internationally coordinated intercomparison and verification of model output;

Primary output

- Time-continuous global fields of CO2, CH4 and N2O concentrations;
- Consolidated, top-down, monthly estimates of GHG fluxes at global 100 x100 km resolution (1 x 1 km goal);

Users of GGMI output

- Parties to the Paris Agreement (e.g., as input to GST and support for national reporting);
- Regional and local users, e.g., via IG3IS;
- Carbon markets, e.g., verification of offsetting;
- Science community working on GHG budgets;
- IPCC, for emission pathways, future scenarios;

- Governments of 193 countries now committed to developing coordinated top-down GHG flux estimation with open access to input and input data;

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

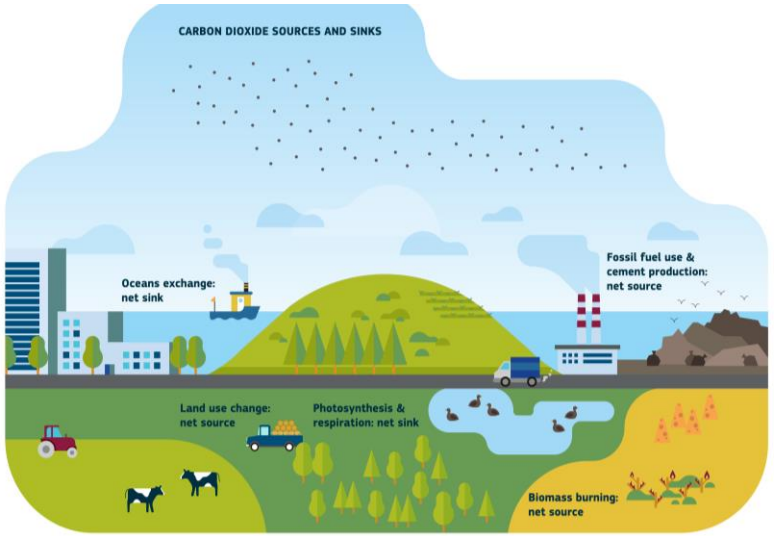
Initial Monitoring Systems

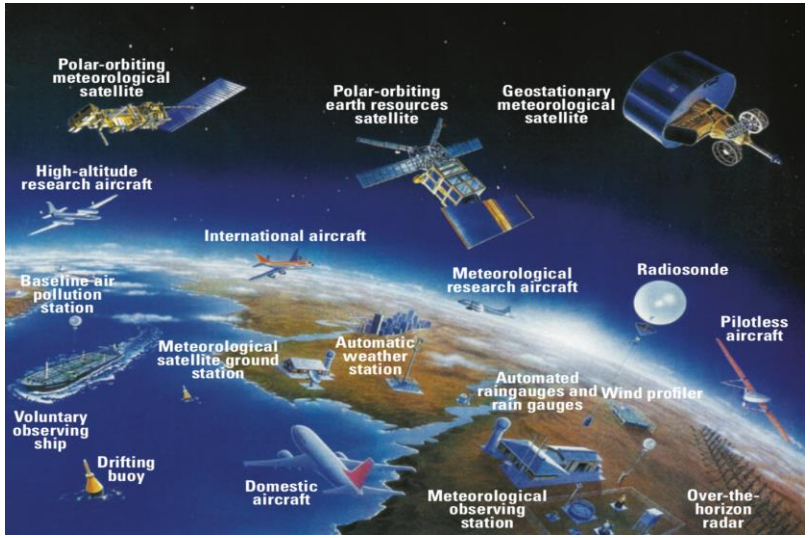
GST-2
COP33

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

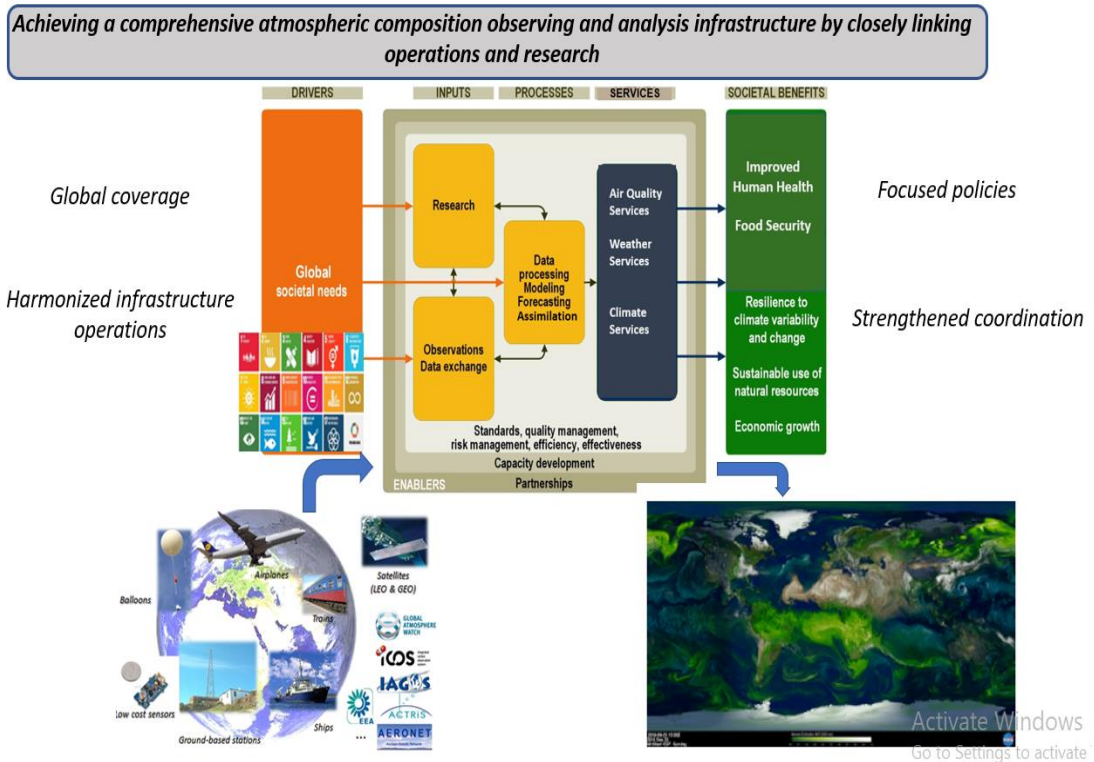
GHGs Earth's Observing Systems is building on Weather experience

Implementation plan: G3W long-term vision

waiting approval at WMO EC June 10, 2024

Overarching Goal:

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



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- ✓ 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.

GAWSIP2024 - *Research Enabling Atmospheric Composition Services*

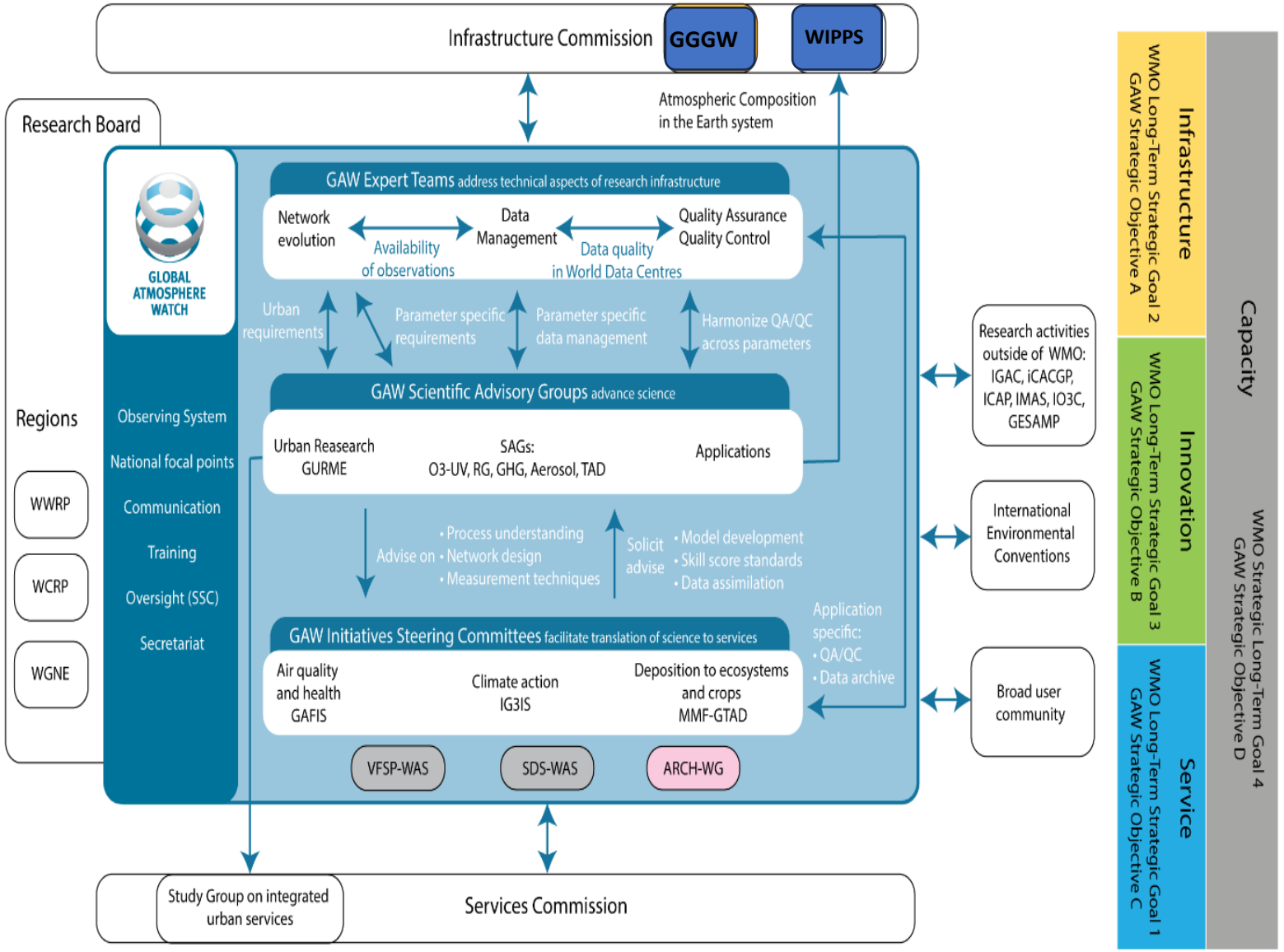
Strategic Objectives:

A. Improve observations and data management

B. Enhance applied research and modelling

C. Promote applied science for the development of services

D. Building capacity



Thank You !!!

WEATHER CLIMATE WATER
TEMPS CLIMAT EAU

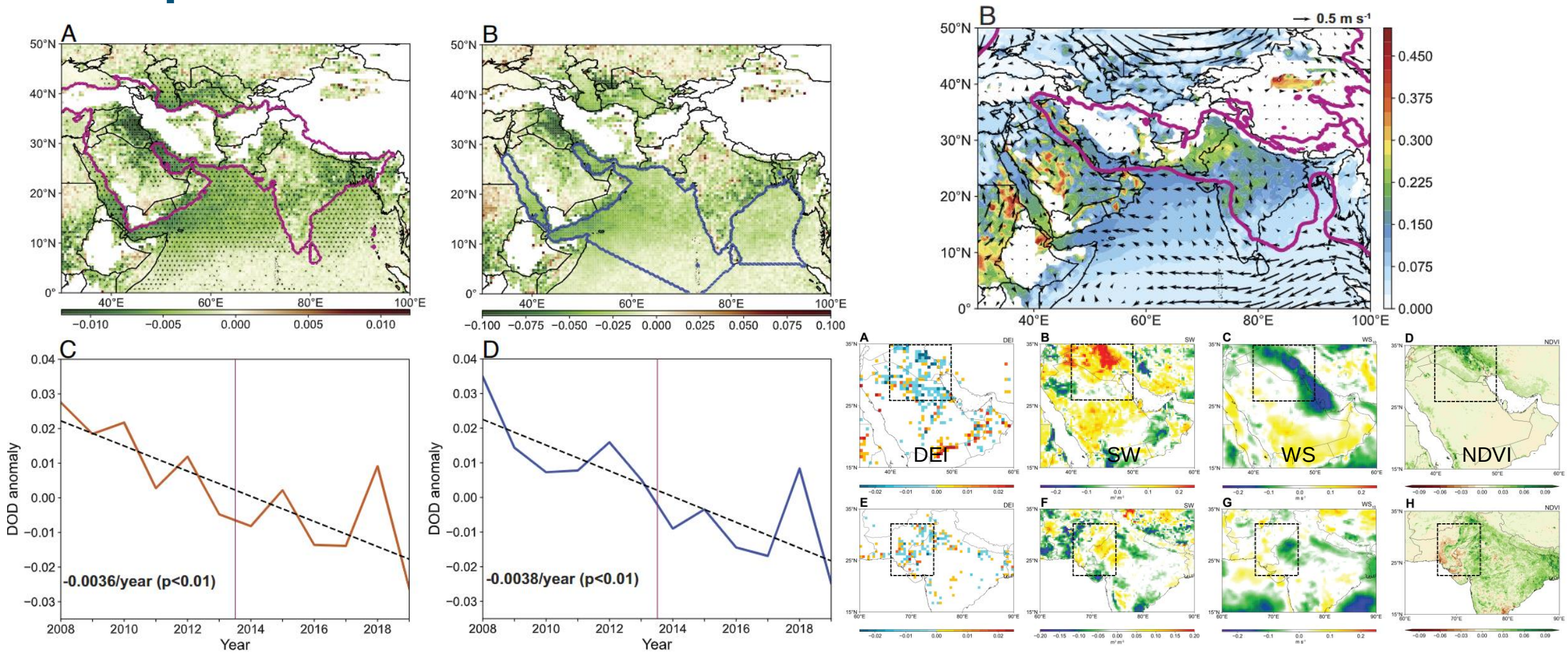
WMO OMM

World Meteorological Organization
Organisation météorologique mondiale

Get in touch with us at
gaw@wmo.int

Backup slides

Arctic amplification-induced decline in West and South Asia dust



- A consistently decreasing trend of dust loading in West and South Asia over the last two decades
- Arctic amplification results in anomalous mid- latitude atmospheric circulation, particularly a deepened trough stretching from West Siberia to Northeast India, which inhibits both dust emissions and their downstream transports

Wang et al., PNAS, 2024

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

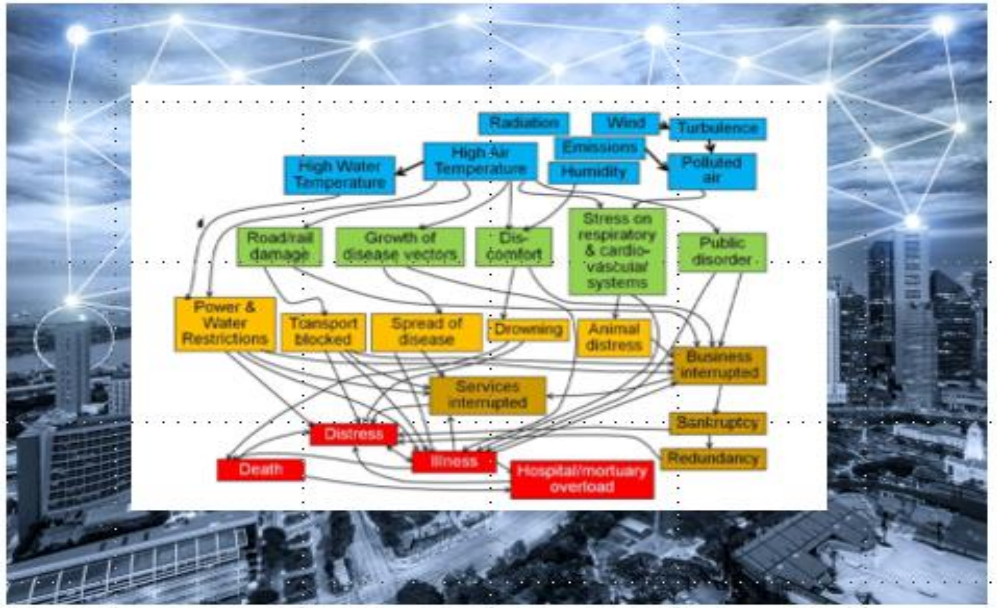
Digital twin platform to support air pollution and health studies

-- 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

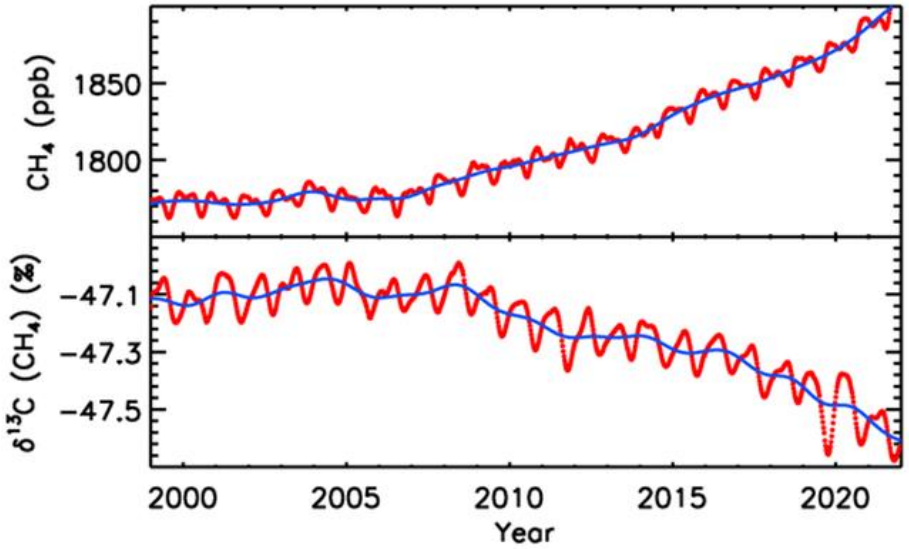
Intervention analysis (lockdown, recovery, emissions, green investments (trees, roofing), traffic restictions, ….)

WMO OMM

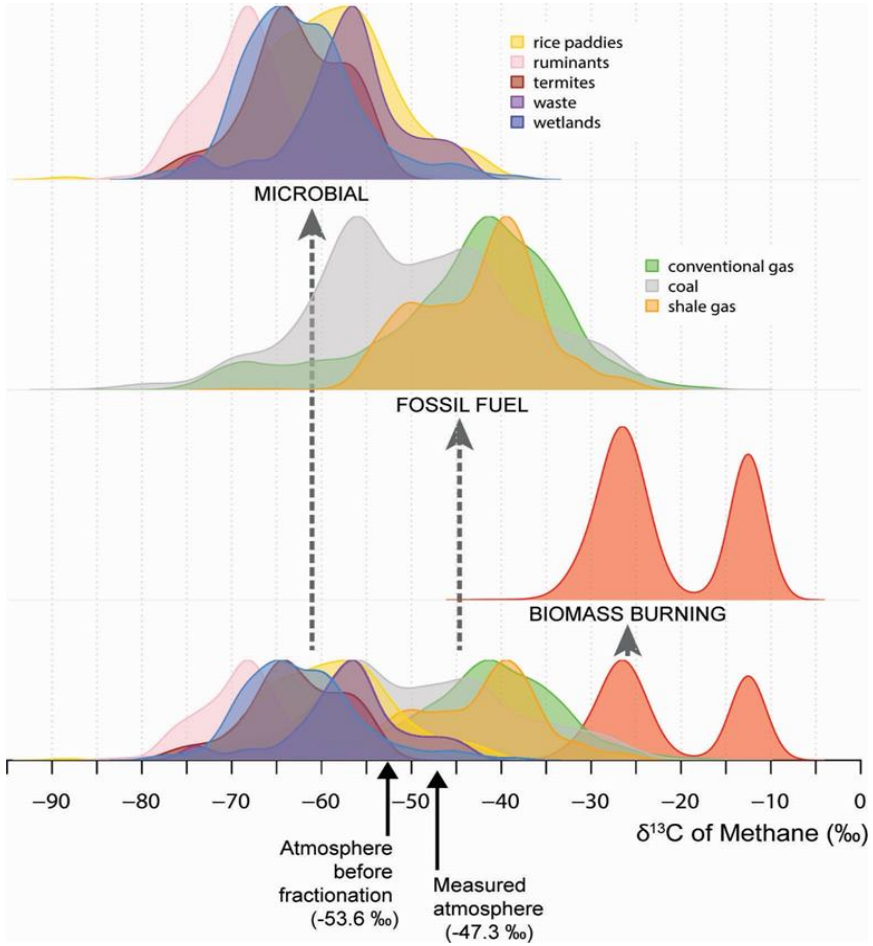
Op-ed, China Daily, July 15, 2023

Information needed beyond net fluxes for understanding trends and to inform mitigation strategies

Methane sources and isotopic composition

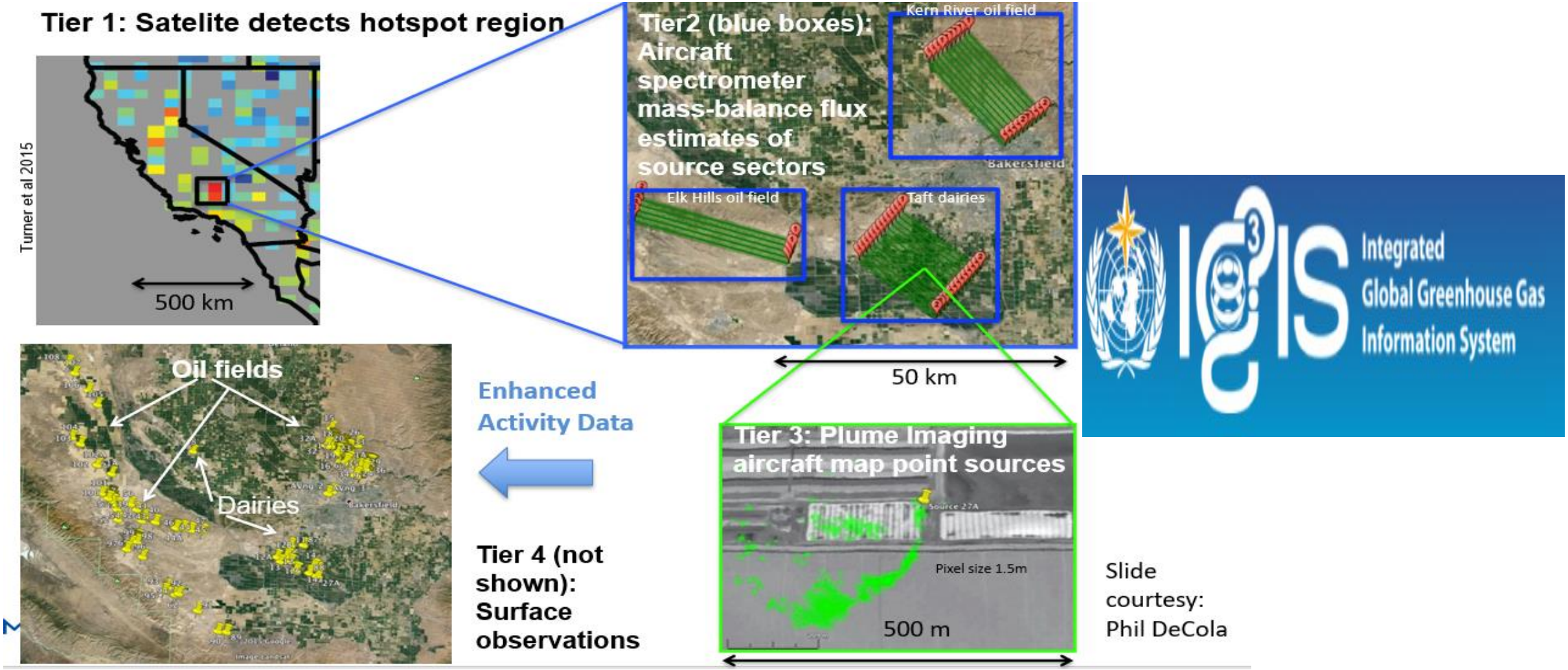


Though there are several hypotheses for the renewed CH_4 increase, the most plausible one is that an increase has occurred in some or all sources of microbial (wetlands, ruminants or waste) emissions, which contain relatively little ^{13}C. The La Niña phase that started in 2020 and is still ongoing might well have contributed to the recent record increases in the global growth rate of methane.



Growing capabilities to identify specific sources
Importance of multi-tiered strategies for targeting GHG emissions
(including observations, models and approaches)

Example targeting methane super emissions



WMO Sand and Dust Storms Warning advisory and Assessment System (SDS-WAS)

International coordination of research for weather and climate

Identification and assessment of SDS impacts

Promoting the use of current available SDS products

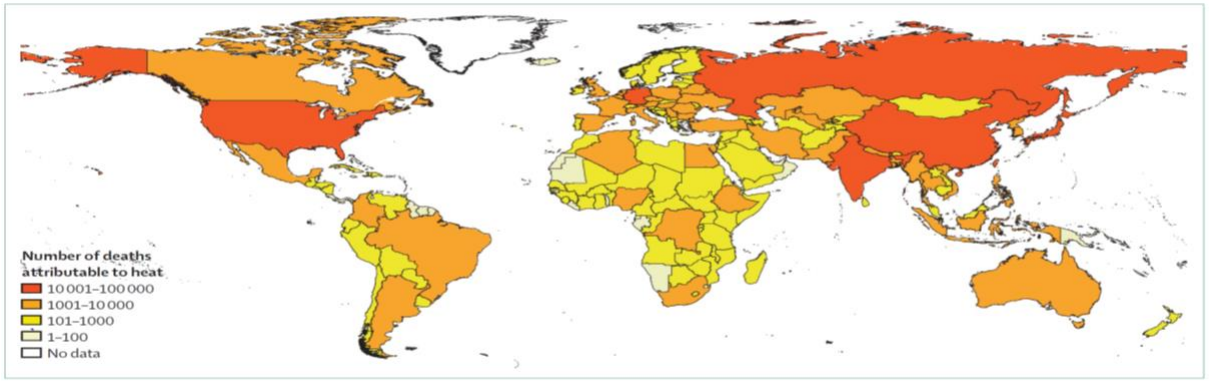
Building capacity and facilitate access to the available services

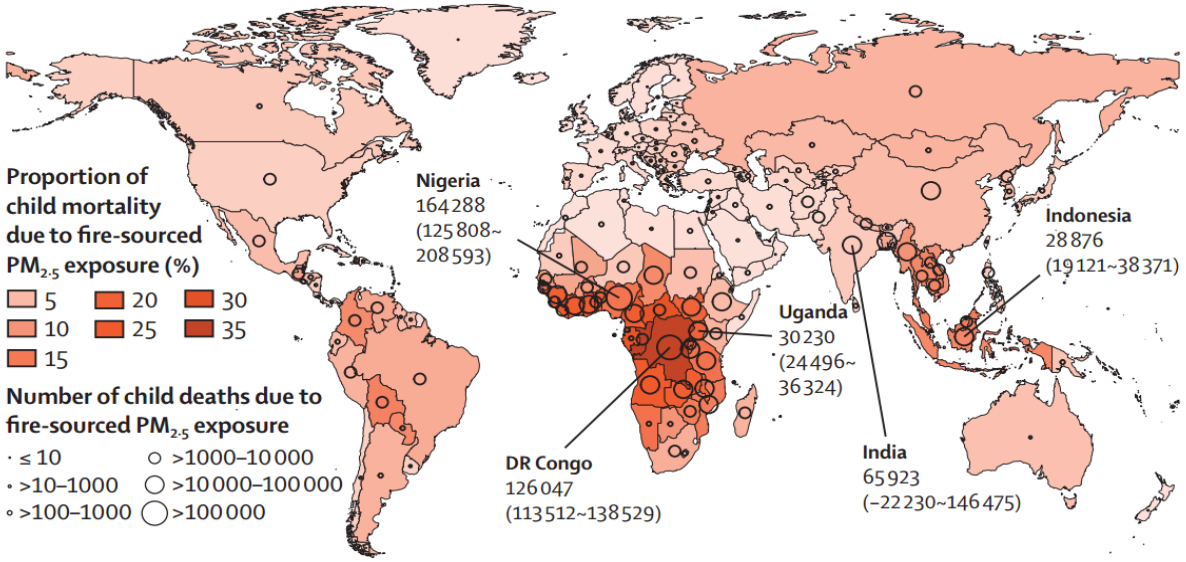
Dissemination and awareness

https://community.wmo.int/en/activity-areas/gaw/science-for-services/sds-was

Overarching Objective – *Continue to improve analysis and prediction capabilities to improve related services to meet the growing societal needs* **Climate + AQ**

Heat wave attributable deaths: 345 000 deaths in 2019





Xue et al., ***Lancet Planet Health***, 2021

- There remain many important research questions on the roles of air pollution and climate change on human health.
- We also do not know the full spectrum of health outcomes where air pollution and climate change play a role.
- We do know that the health impacts are disproportionally felt by the most vulnerable, including children, older populations, ethnic minorities, those with underlying health conditions, and under-resourced communities.
- We also know that reducing air pollution exposures and global warming requires effective strategies to reduce emissions.

A better understanding of the health implications of air pollution and climate change offers the opportunity to prevent, mitigate and adapt in ways to improve life-span human health.