



Climate change and air quality:
challenges and objectives for the
atmospheric research.

Research Infrastructures (RIs) for
Atmospheric Composition

Sara Basart - sbasart@wmo.int

IR0000032 – ITINERIS, Italian Integrated Environmental Research Infrastructures System
(D.D. n. 130/2022 - CUP B53C22002150006) Funded by EU - Next Generation EU PNRR-
Mission 4 “Education and Research” - Component 2: “From research to business” - Investment
3.1: “Fund for the realisation of an integrated system of research and innovation infrastructures”



Research Infrastructures (RIs) for Atmospheric Composition

Sara Basart (sbasart@wmo.int)

Scientific Officer

WMO Science and Innovation Department

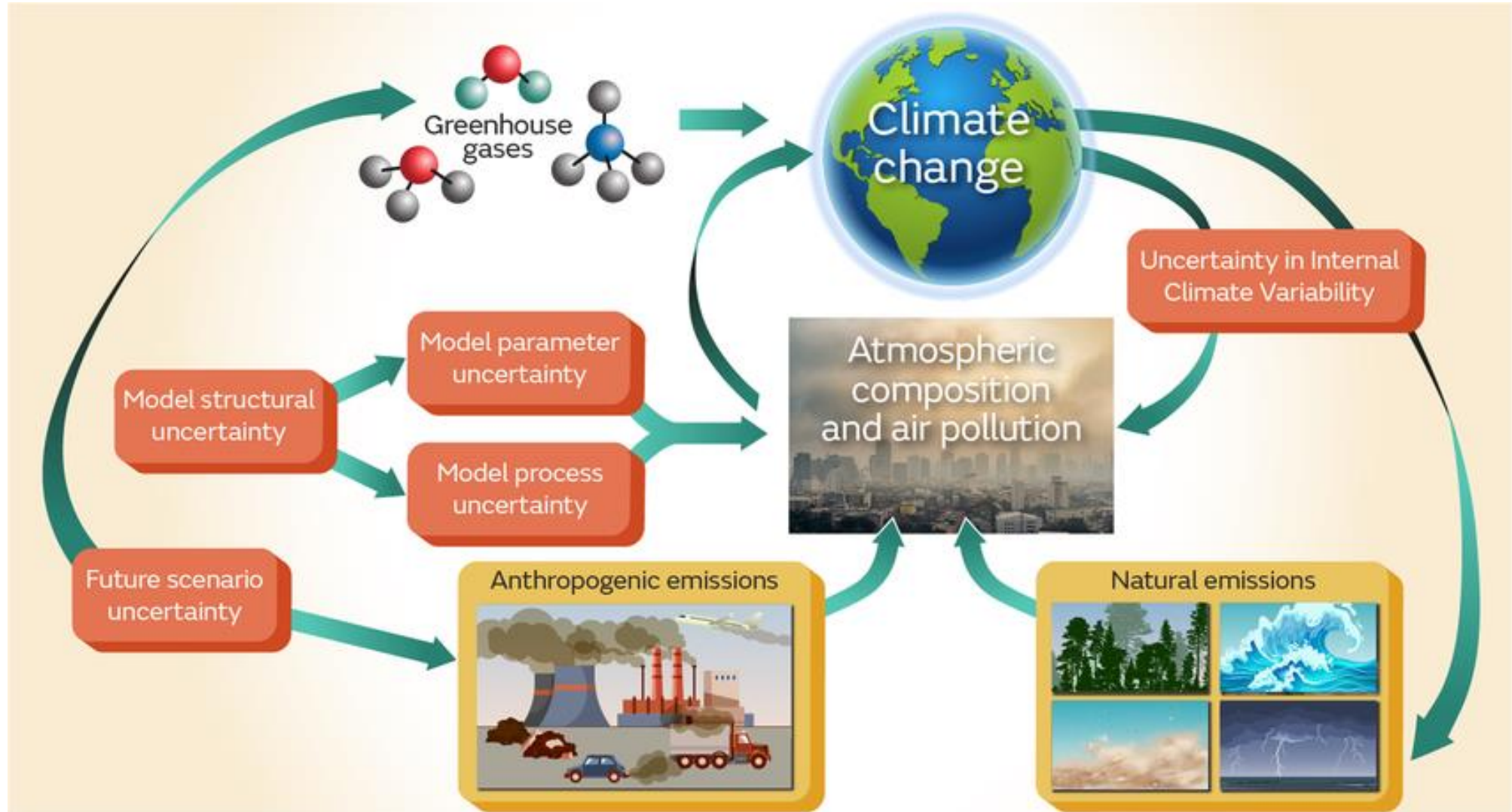


WORLD
METEOROLOGICAL
ORGANIZATION

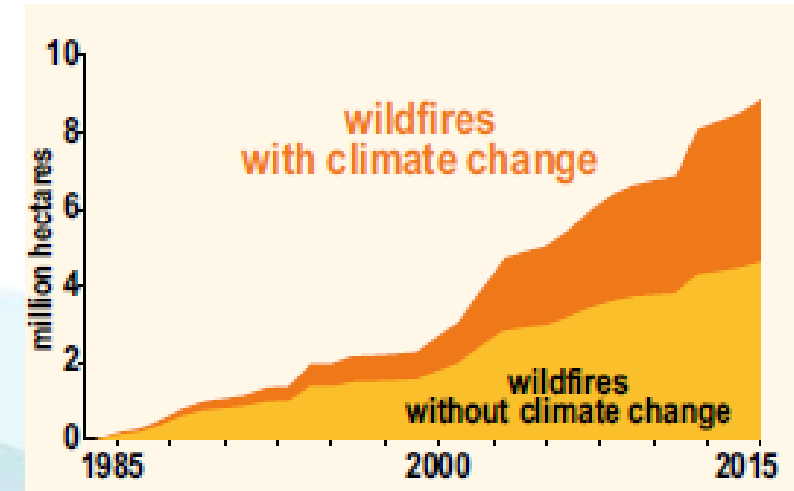
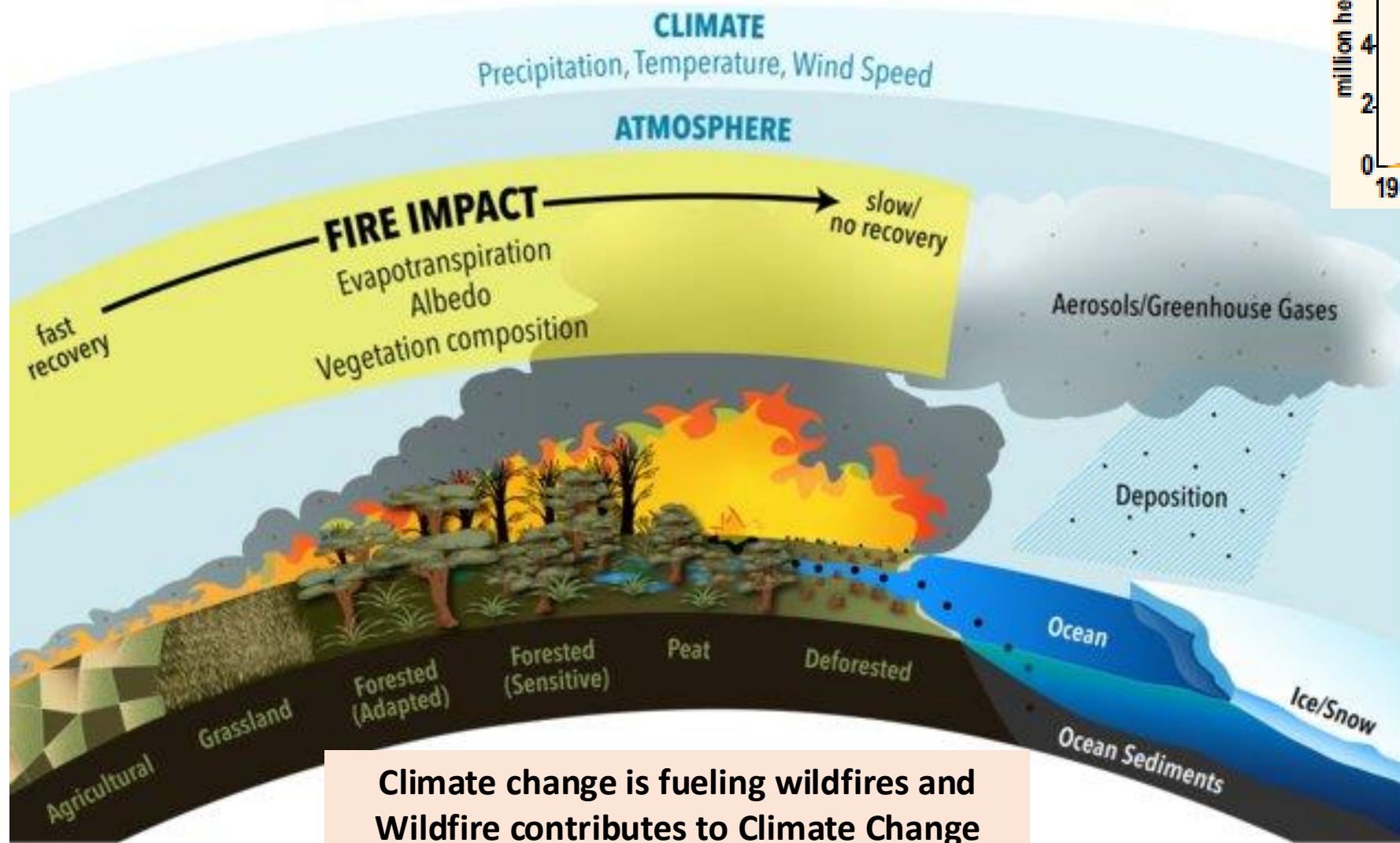


Scientific Scope | Atmospheric Composition

Which source of uncertainty is more important for projections of **future atmospheric composition and air quality**?



Wildfires and Climate



Lower emissions that would limit the global temperature increase to $<2^{\circ}\text{C}$ would reduce projected **increases of global burned area to 30% to 35%** and **projected increases of fire frequency to ~20%**.
(IPCC, 2021)

Climate change is fueling wildfires and Wildfire contributes to Climate Change

Research Infrastructures

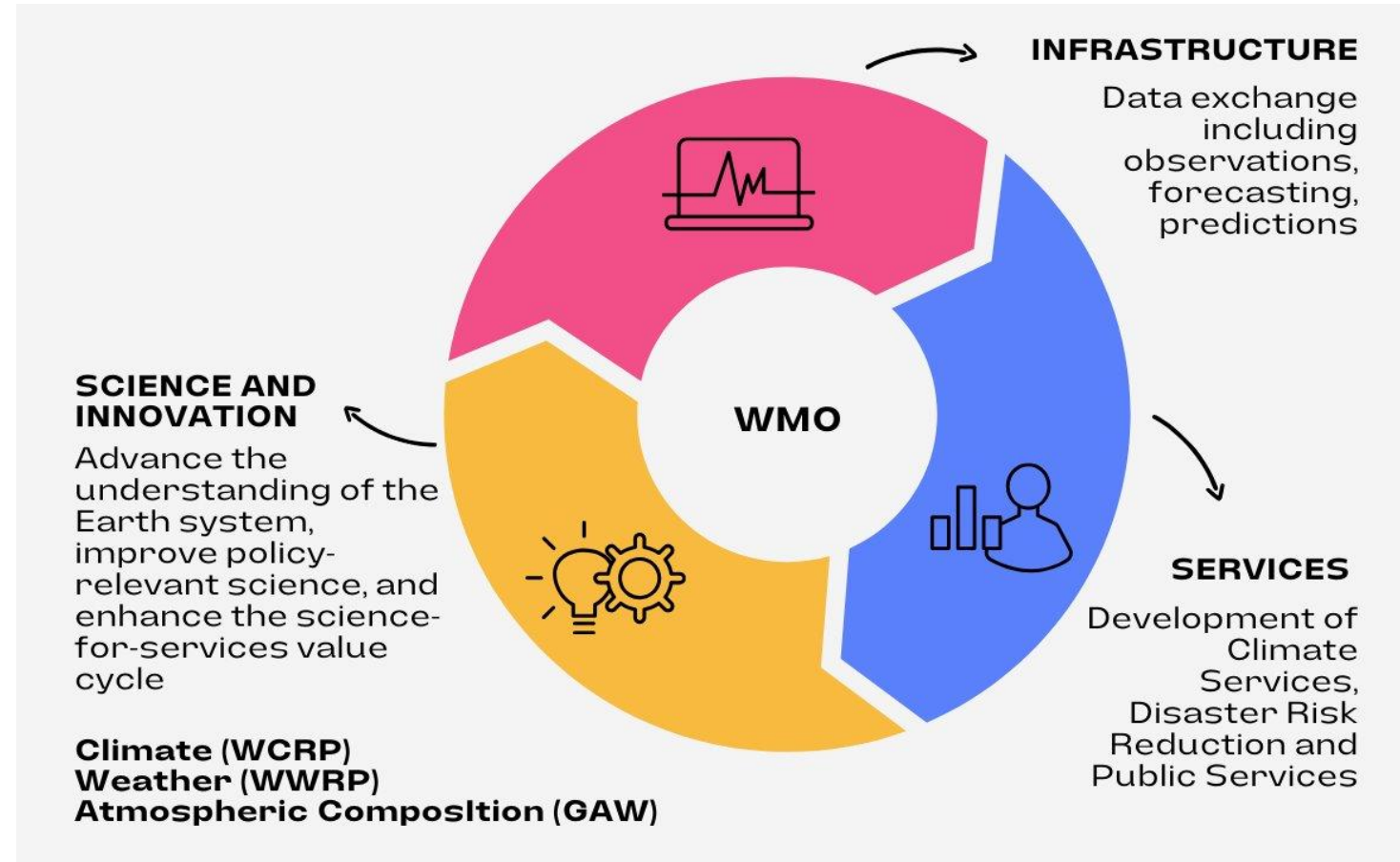
They refer to facilities, resources, and services used by the scientific community to conduct research and foster innovation.

They include:

- major scientific equipment or sets of instruments;
- collections, archives or scientific data;
- computing systems and communication networks;
- any other research and innovation infrastructure of a unique nature which is open to external users;

World Meteorological Organization (WMO)

- UN specialized agency on weather, climate and water.
- It's supported by 193 Members and the headquarters is in Geneva (Switzerland).
- Coordinates work of > 300,000 national experts from meteorological and hydrological services, academia and private sector.
- Co-Founder and host agency of IPCC.



WMO Research-Operations Departments

The WMO Global Atmosphere Watch (GAW) Programme

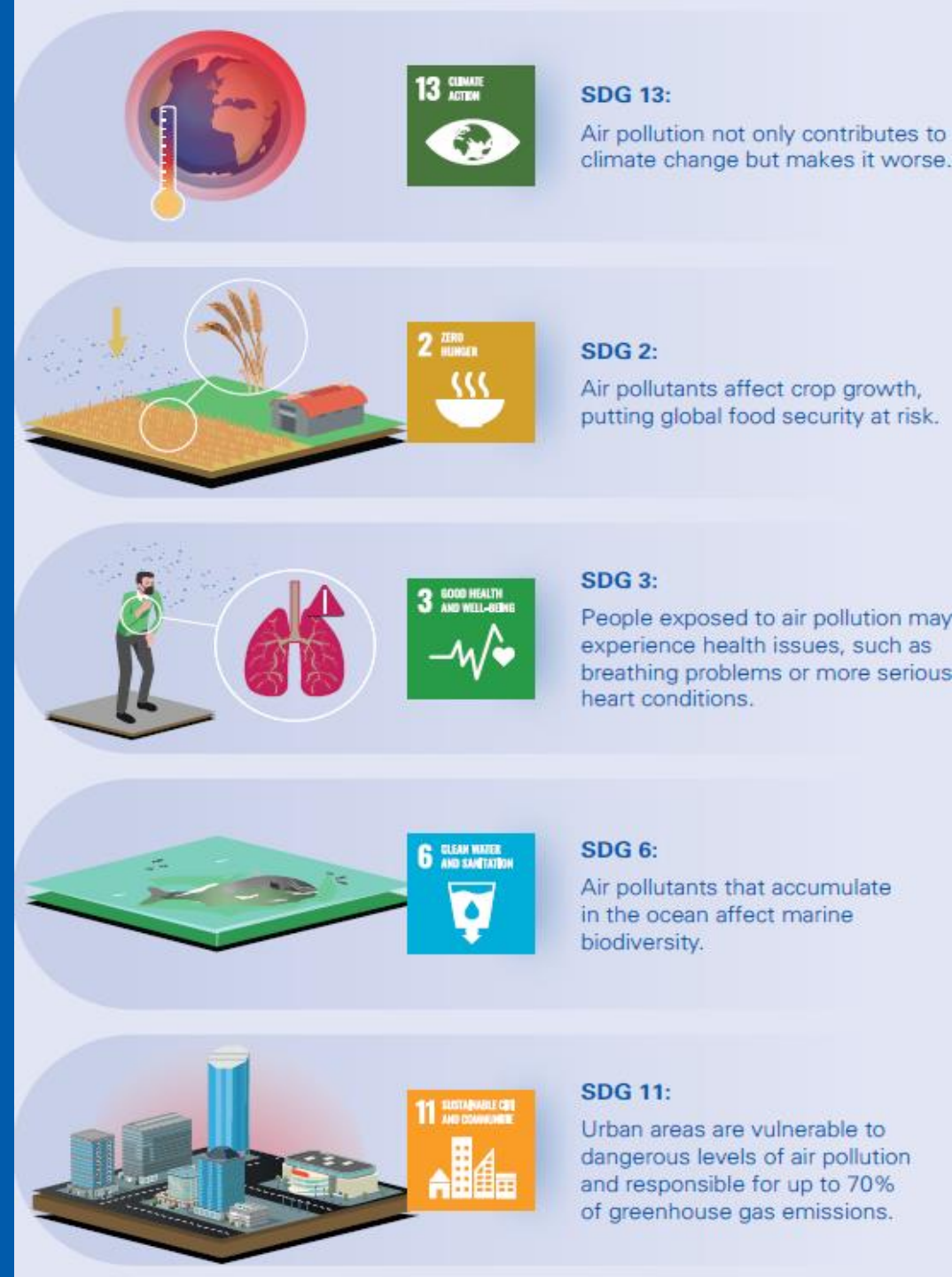


Advance and enhance science, services and infrastructure related to atmospheric composition, and support policies for society through applied research aimed at improving the understanding of the roles of aerosols, reactive gases, stratospheric ozone and greenhouse gases and their interactions in the Earth System



Support to international conventions and SDGs

- The Convention on Long-range transboundary Air pollution (LRTAP)
- The Montreal Protocol and Vienna Convention (*ozone*)
- The UN Framework Convention on Climate Change (UNFCCC)
- Climate and Clean Air Coalition (CCAC)
- The Convention on Biodiversity
- The Group of Experts on the Scientific Aspects of Marine Environmental Protection (GESAMP)
- UN Coalition for Combating Sand and Dust Storms



The GAW Programme: 4 pillars

Monitoring Infrastructure: provision of atmospheric composition data from GAW stations;

Scientific assessments: advancing scientific understanding through analysis of global data sets;

Science-for-Services Initiatives: engage with user communities for supporting services and policies;

Capacity Building and education: provide training opportunities for all GAW users from all regions;



Filling the gaps by **integrating** other sources of information including low-cost sensors, satellites and models

Long-term and high-quality control

GAW Scientific Assessments

- Publish community assessment reports and high-level scientific papers on the state of the atmosphere and its evolution,
- Provide technical recommendations for monitoring atmospheric composition and modelling
- Contribute to international reports

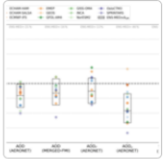
<https://doi.org/10.5194/acp-21-87-2021>
© Author(s) 2021. This work is distributed under the Creative Commons Attribution 4.0 License.

Article Assets Peer review Metrics Related articles

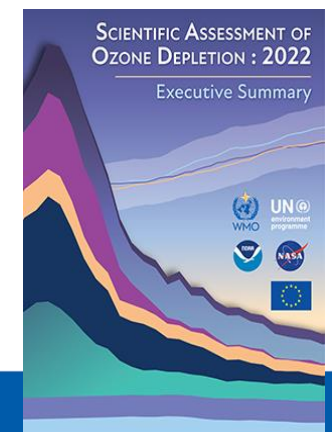
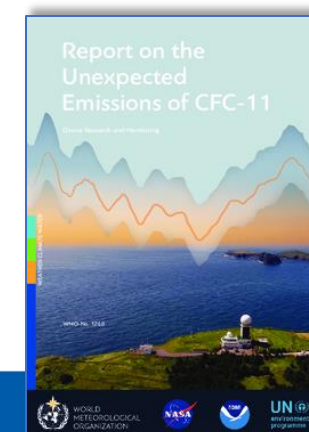
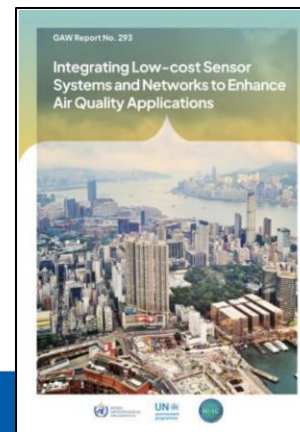
Research article | © ⓘ

06 Jan 2021

AeroCom phase III multi-model evaluation of the aerosol life cycle and optical properties using ground- and space-based remote sensing as well as surface in situ observations

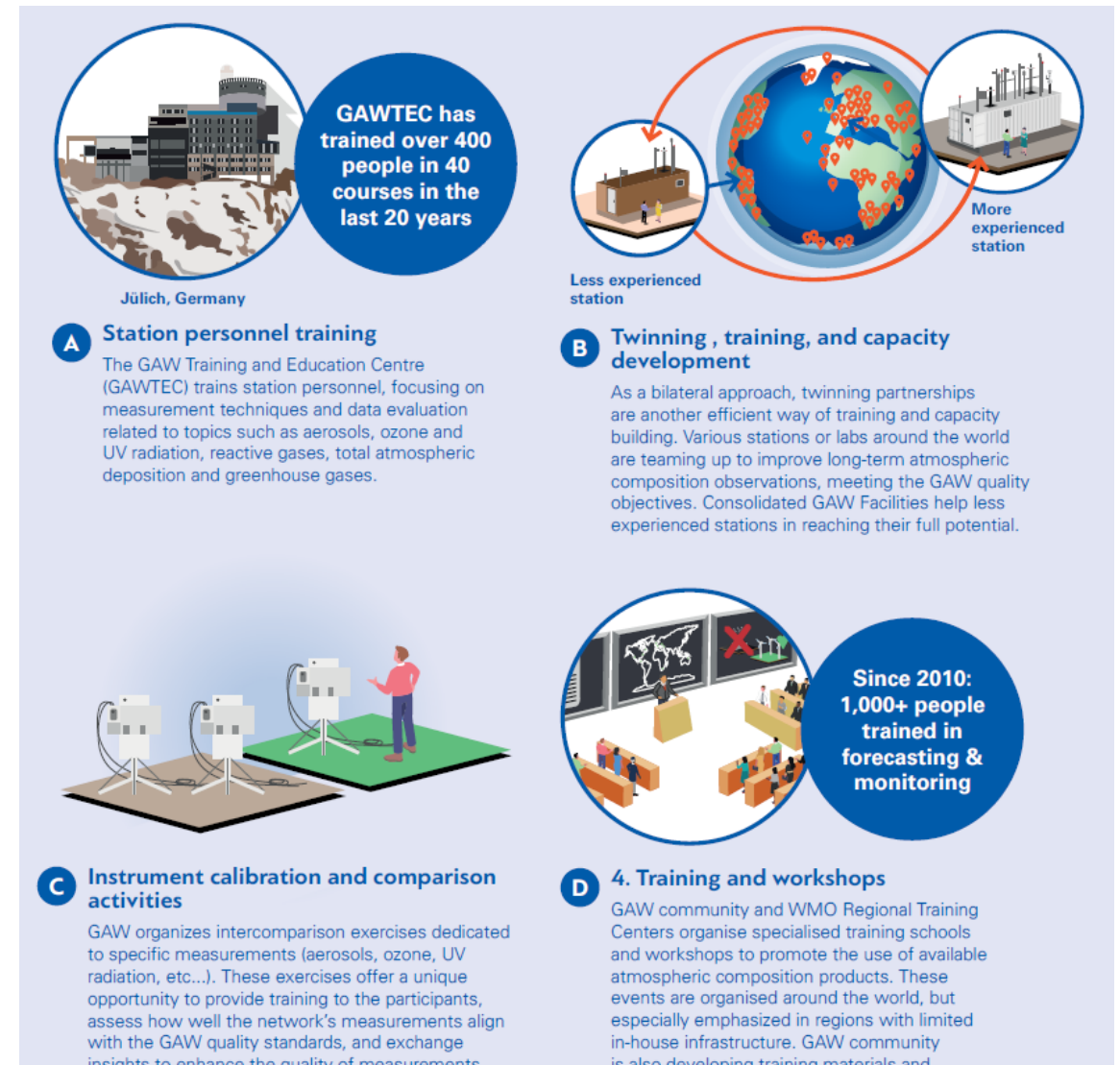


Jonas Giliš, Augustin Mortier, Michael Schulz, Elisabeth Andrews, Yves Balkanski, Susanne E. Bauer, Anna M. K. Benedictow, Huiheng Bian, Ramiro Checa-Garcia, Mian Chin, Paul Ginoux, Jan J. Griesfeller, Andreas Heckel, Zak Kipling, Alf Kirkevåg, Harri Kokkola, Paolo Laj, Philippe Le Sager, Marianne Tronstad Lund, Cathrine Lund Myhre, Hitoshi Matsui, Gunnar Myhre, David Neubauer, Twan van Noije, Peter North, Dirk J. L. Olivíé, Samuel Rémy, Larisa Sogacheva, Toshihiko Takemura, Kostas Tsigaridis, and Svetlana G. Tsyro



Capacity Development

- Provision of training to GAW station operators through the Global Atmosphere Watch Training & Education Centre (GAWTEC)
- GAW stations instrument intercomparison and calibration campaigns
- Training on data quality control, data use, modelling tools and quality assurance procedures

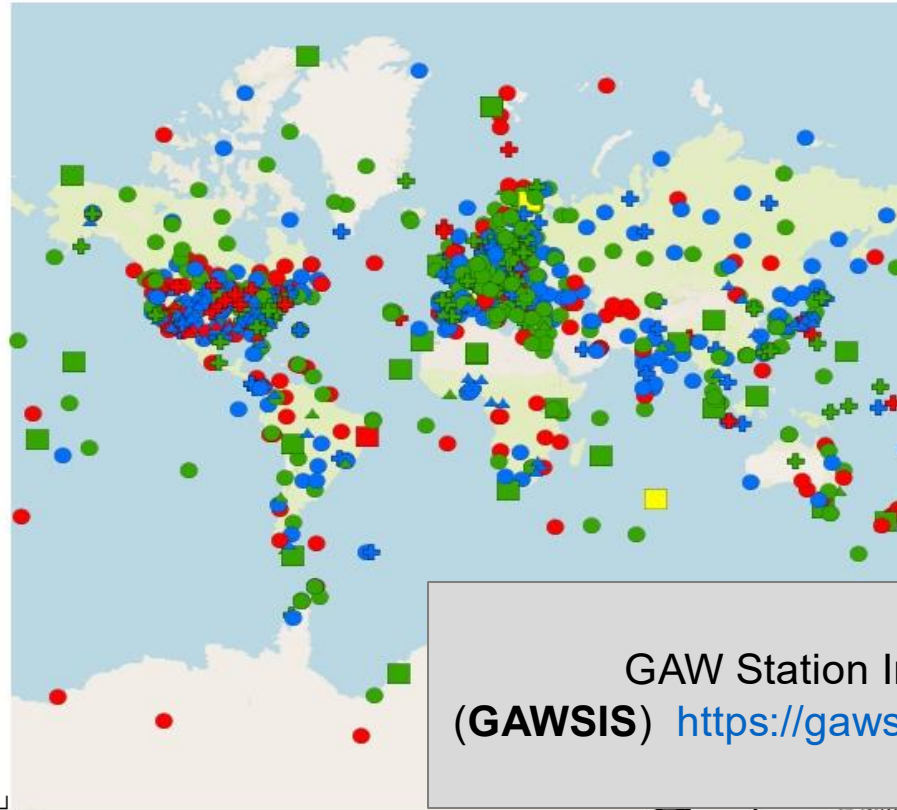


GAW Research Infrastructure

Strengthen the atmospheric composition measurement and data infrastructure and contribute to understanding trends and variability and extremes.

- More than 200 parameters
- Intercomparisons
- Measurement guidelines
- World Data Centers

Filling gaps:
LCS and satellites,
but also National
AQ networks
Integration!



GAW Station Information System
(GAWSIS) <https://gawsis.meteoswiss.ch/GAWSIS/#/>

*Open access with emphasis
in QA and QC*



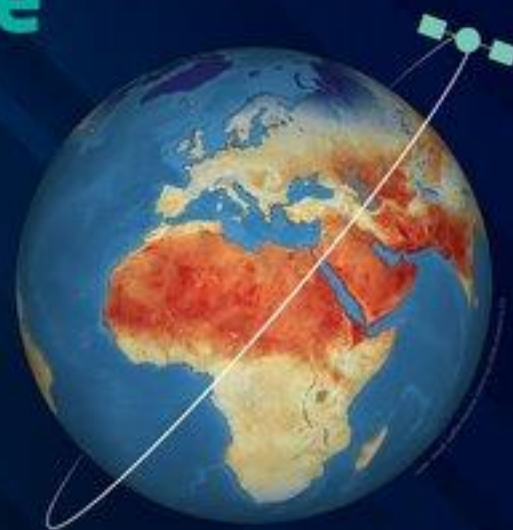
Schweizerische Eidgenossenschaft
Confédération suisse
Confederazione Svizzera
Confederaziun svizra
Swiss Confederation
Federal Department of Home Affairs FDHA
Federal Office of Meteorology and Climatology MeteoSwiss

- | | | |
|-----------------------|--------------------|---|
| Global | Operational | ● |
| Regional | Partly operational | ● |
| Contributing networks | Non-reporting | ▲ |
| Local | Closed | ★ |
| Other networks | Planned | + |
| | Pre-operational | ● |
| | Stand-by | ● |

Weather versus Climate



The difference between weather and climate is a matter of time



Weather

refers to short-term changes in the atmosphere. It can change minute-to-minute, hour-to-hour and day-to-day

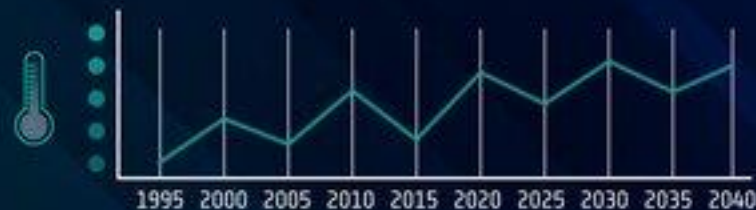


Climate

describes the average weather conditions in a specific area over a long period of time – 30 years or more



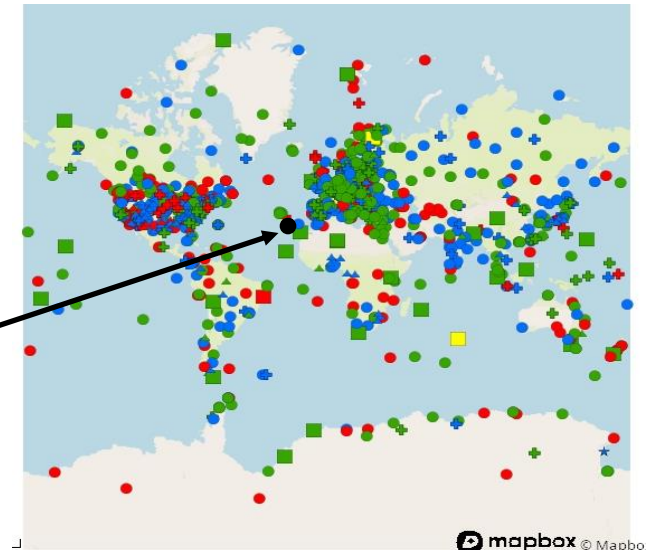
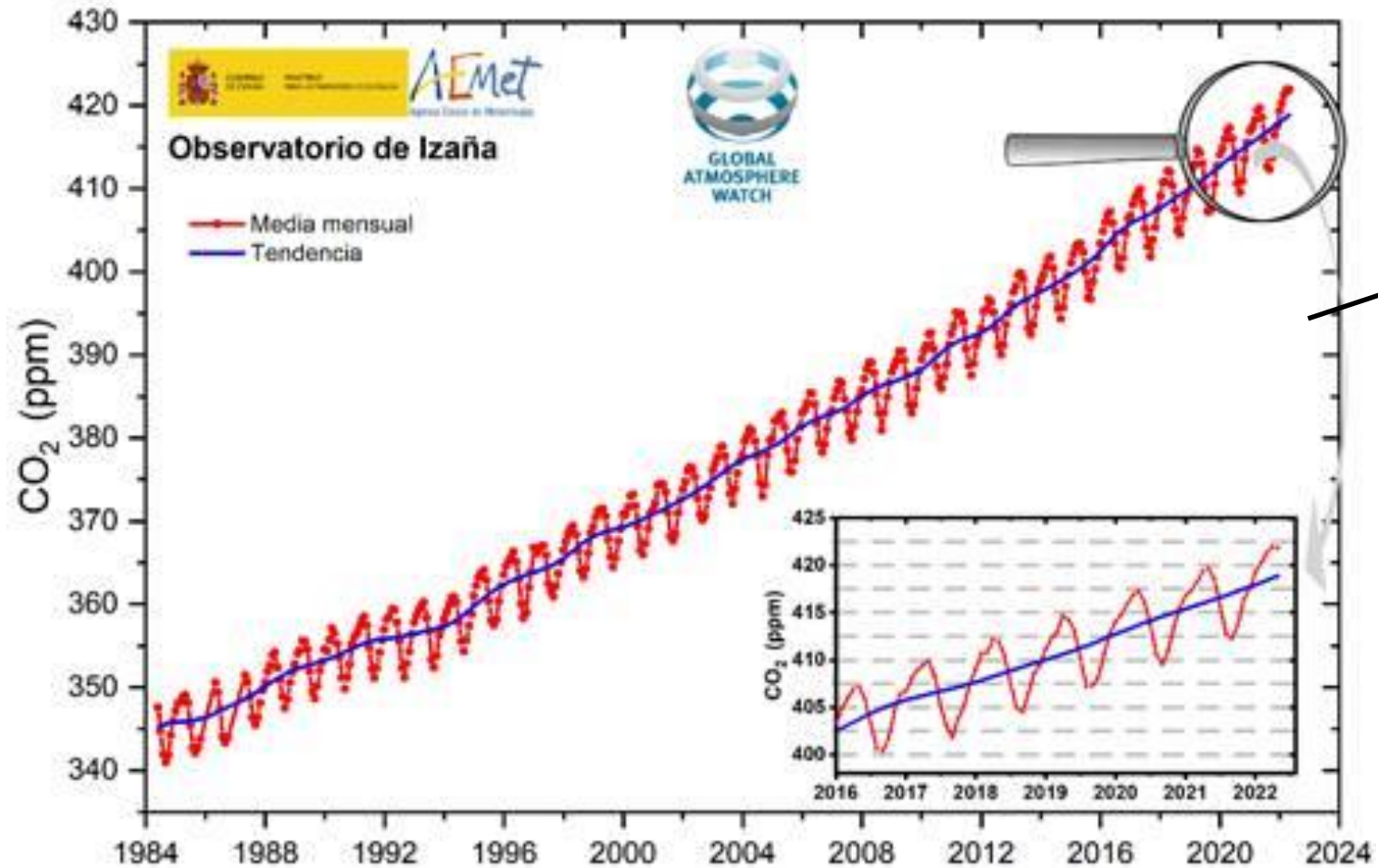
Satellites measure several aspects of Earth's weather as well as provide essential data over decades to monitor how our climate is changing



For more information, visit [space for our climate: www.esa.int/climate](http://spaceforourclimate.com)

GAW Research Infrastructure

Research Enabling Atmospheric Composition Services



mapbox © Mapbox

GAW Research Infrastructure



WMO Integrated Global Observing System (WIGOS)

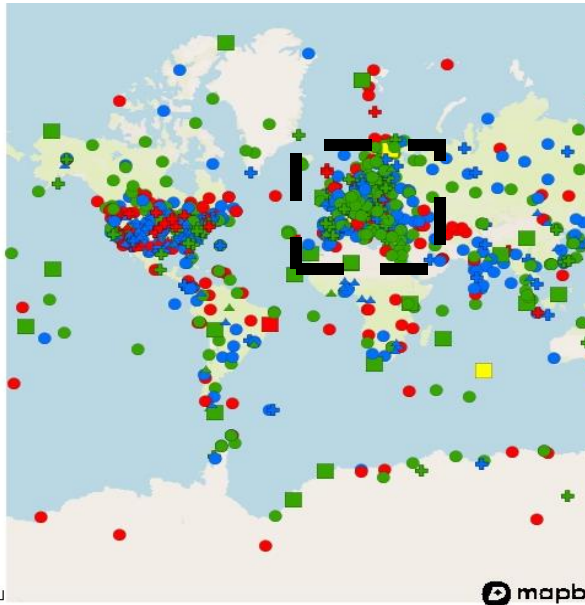
- Global Observing System (GOS)
- Global Atmosphere Watch (GAW)**
- Global Cryosphere Watch (GCW)
- WMO Hydrological Observing System (WHOS)
- Global Basic Observing Network (GBON)
- Regional Basic Observing Network (RBON)



<https://community.wmo.int/en/activity-areas/WIGOS>

GAW Research Infrastructure

European Cluster: ACTRIS



ACTRIS Data Centre

Home Data Services About Documentation VRE item(s)

Help Large Data Extract

Data Search

Number of data objects matching your search: 222079

Variable matrix *i*

Search or select one or more items

Facility types *i*

Search or select one or more items

Variables *i*

Search or select one or more items

Object of interest *i*

Search or select one or more items

Facilities (741)

ACTRIS National Facility - In Progress *i*

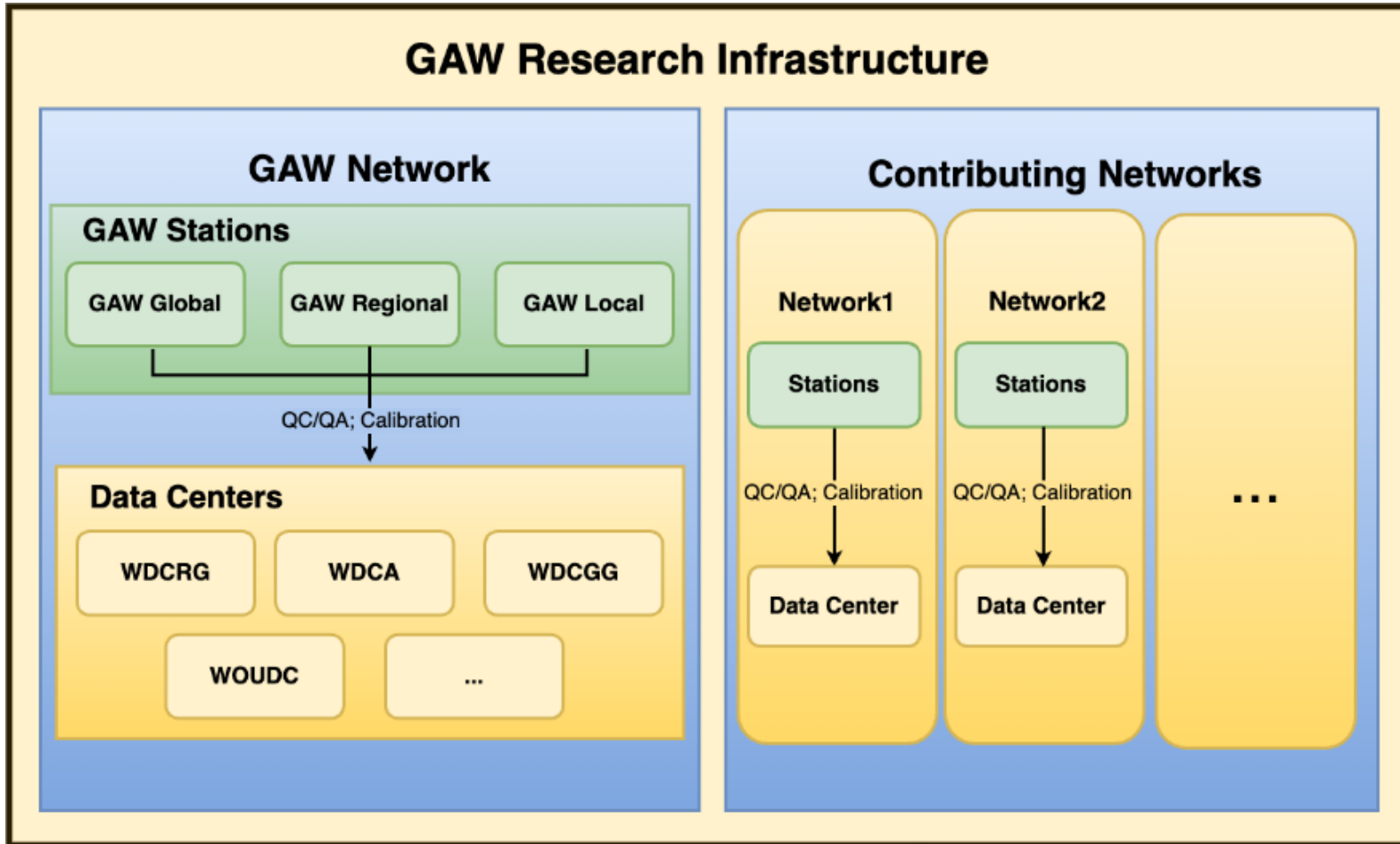
Select options

Privacy Policy Data Policy Feedback Statistics

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<https://www.actris.eu/>

GAW Research Infrastructure



Contributing Networks

[CASTNET \(Clean Air Status and Trends Network\)](#)

[IMPROVE \(IMPROVE Optical Aerosol\)](#)

[INDAAF \(International Network to study Deposition and Atmospheric chemistry in Africa\)](#)

[NADP \(National Atmospheric Deposition Program\)](#)

[TCCON \(Total Carbon Column Observing Network\)](#)

Other relevant data archives

[EMEP \(EMEP\)](#)

[NDACC \(NDACC Data Center\)](#)

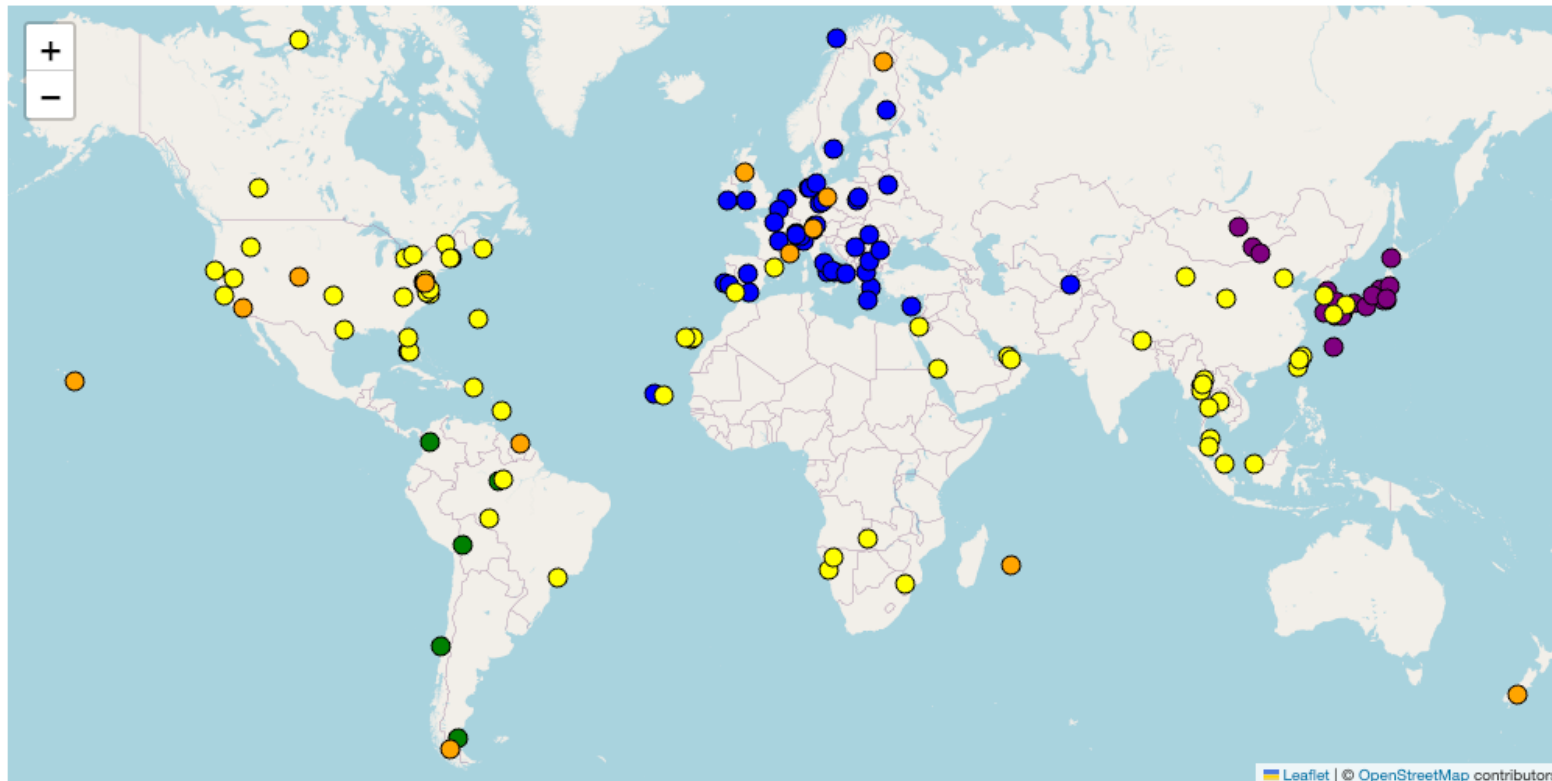
GAW Research Infrastructure



 WORLD METEOROLOGICAL ORGANIZATION

GALION The GAW Aerosol Lidar Observation Network

- Home
- Sites
- Applications
- GALION Networks
- Other Networks
- About
- Login



<https://galion.world/>



GAW: Observational (research) Infrastructure



Integrating other sources of Air Quality information: Low-Cost Sensor Systems

An update on low-cost sensors for the measurement of atmospheric composition

December 2020 Edited by Richard E. Peltier

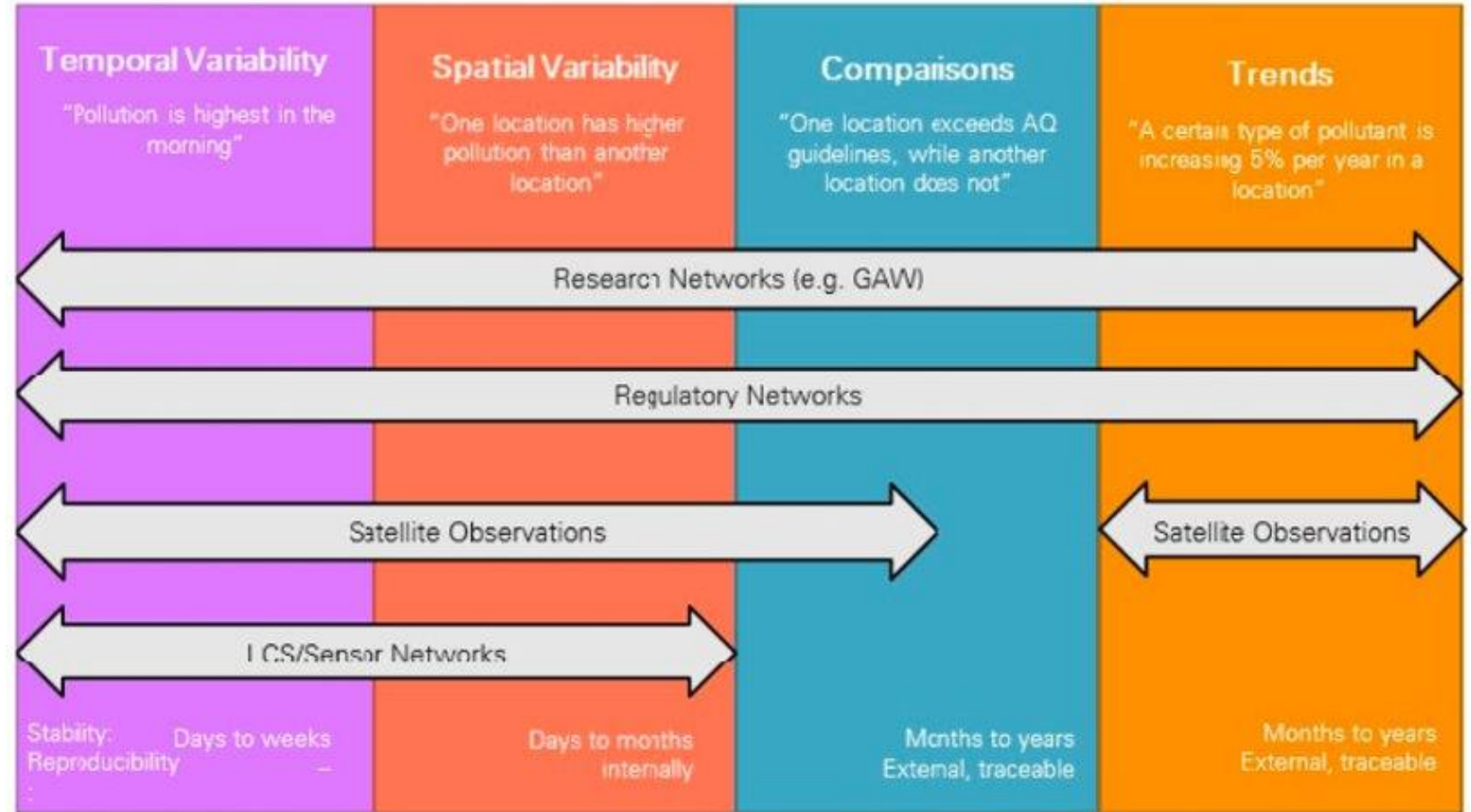
Benefits and Limitations of Low-cost Sensors

Benefits

- Low cost production
- Portable and small
- Uses low amounts of power
- Rapidly advancing technology
- Low power consumption

Limitations

- High cost for their maintenance
- Low measurement precision
- Prone to large measurement errors
- Difficult to calibrate
- Limited lifetime

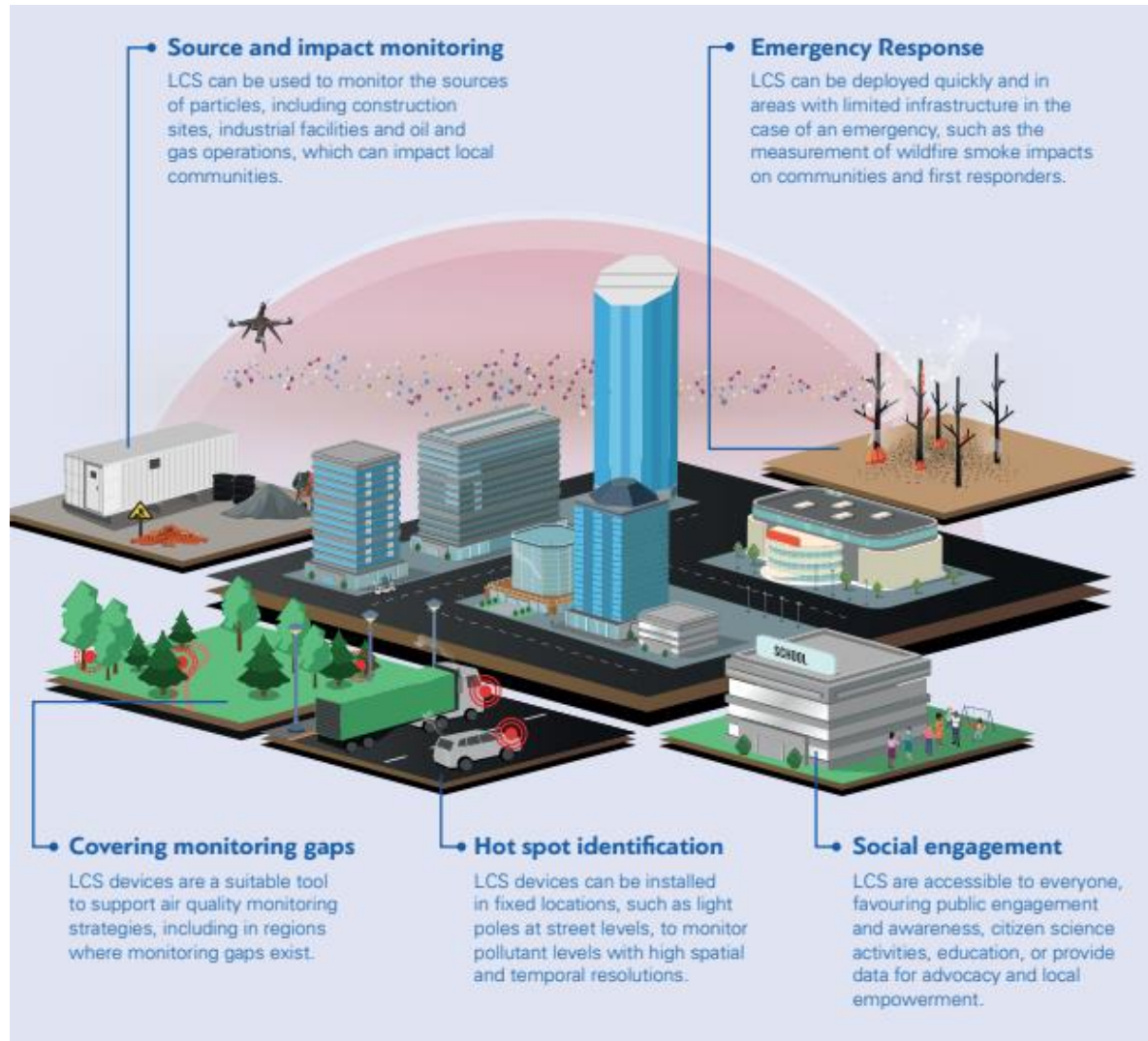


Extracted from (WMO, 2020)

GAW: Observational (research) Infrastructure



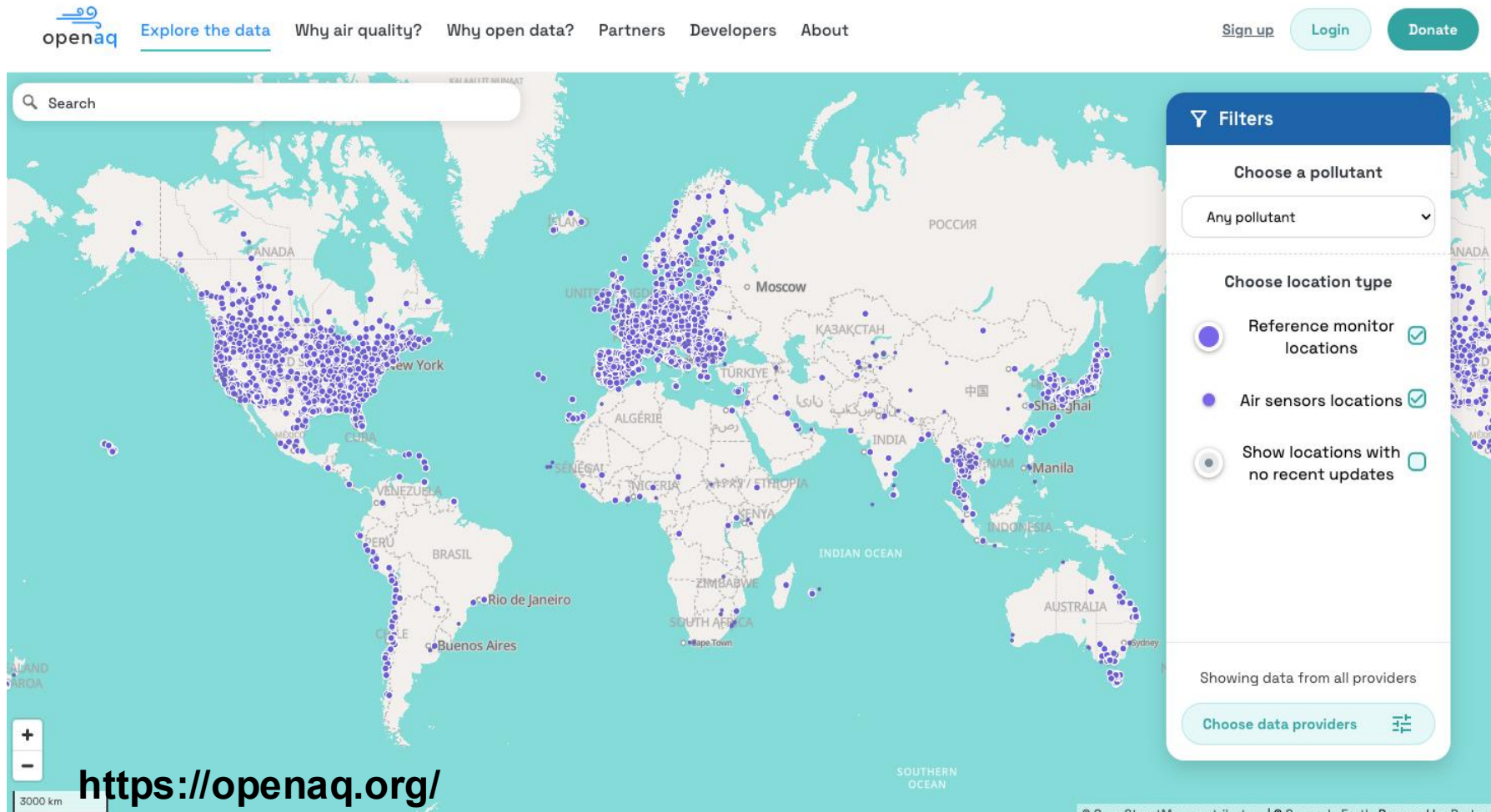
Integrating other sources of Air Quality information: Low-Cost Sensor Systems Application



(WMO, 2024)

Integrating other sources of information

Low-Cost Sensor Systems *Networks* – Spatial distribution



- Low-cost sensors can fill gaps in existing networks
- Low- and middle-income countries can benefit
- Latency, quality (i.e., accuracy and uncertainty) and spatial representativity of the data are key factors for their application

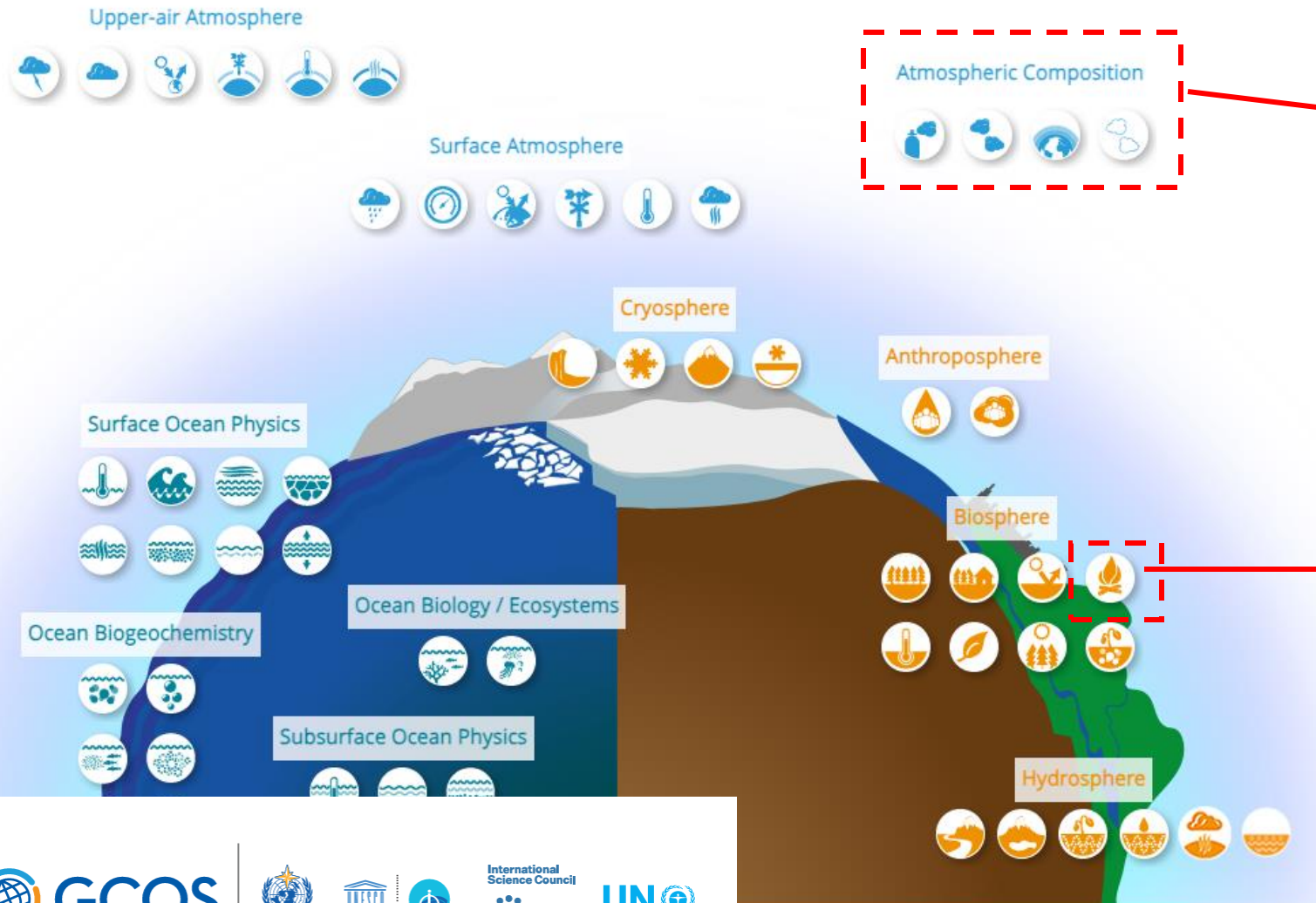
GCOS – Global Climate Observing System

- GCOS regularly assesses the status of global climate observations and produces guidance for its improvement. GCOS works towards a world where climate observations are accurate and sustained, and access to climate data is free and open.
 - GCOS expert panels maintain definitions of **Essential Climate Variables (ECVs)**.
 - It is GCOS' task to make sure, that the totality of all climate observation networks **is more than the sum of the individual networks**, forming together the one Global Climate Observing System, providing the full picture of our climate.



GCOS – Global Climate observing System

Essential Climate Variables (ECV)



Atmospheric composition Focal Areas

- **Aerosols (chemical and physical properties, AOD)**
- Carbon Dioxide, Methane & Other Greenhouse Gases
- Ozone and vertical ozone distribution
- Precursors for Aerosols and Ozone (CO, SO₂, NO₂)

GAW Research Infrastructure and satellites

Fire

- Burned Area
- Active Fires
- Fire Radiative Power (FRP)

Satellites

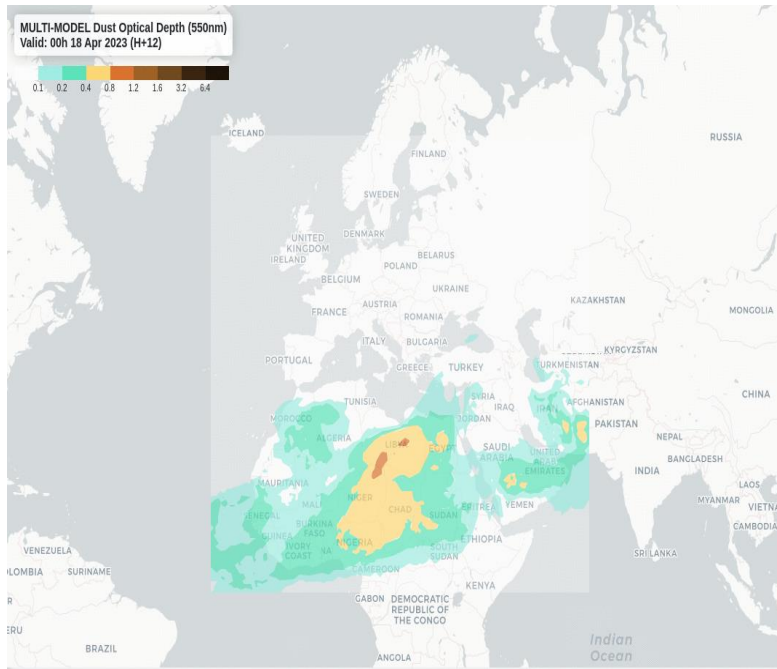
Is this enough for tracking climate change?

Science for Services

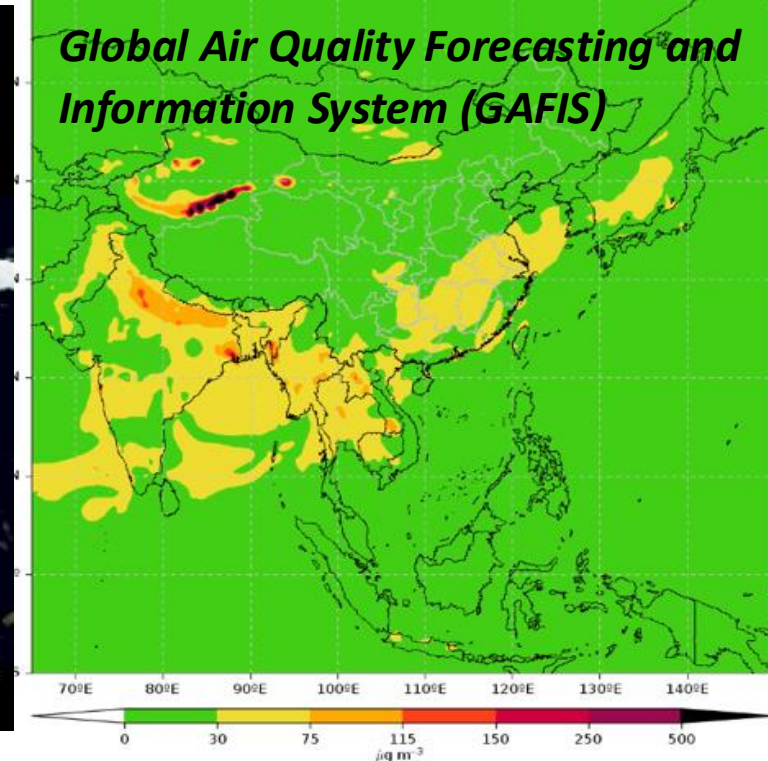
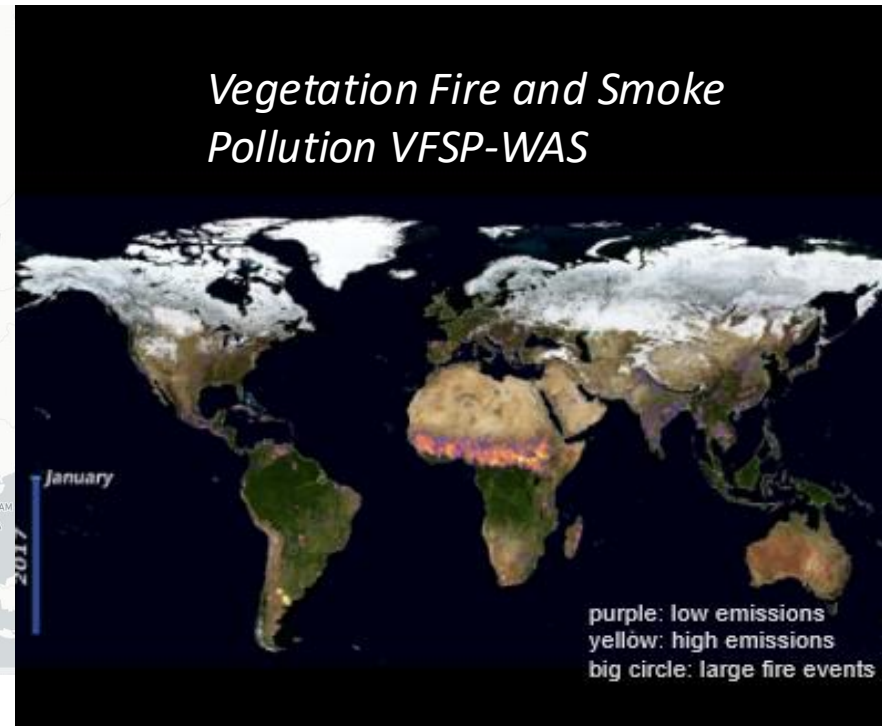


*Advance the application of atmospheric composition information in support of policies and conventions, and expand **societal services** related to air quality, human and ecosystem health, climate change and food production.*

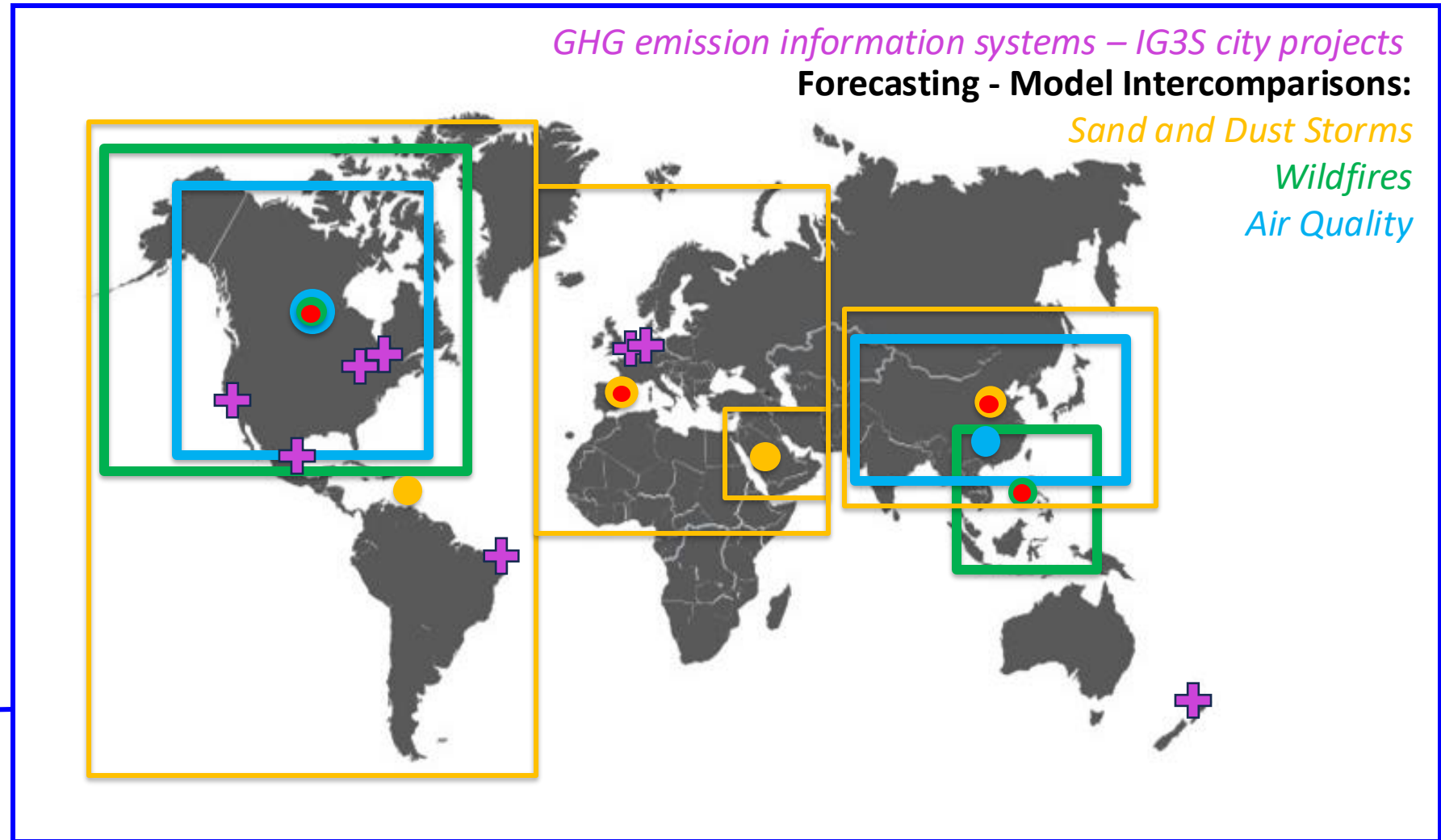
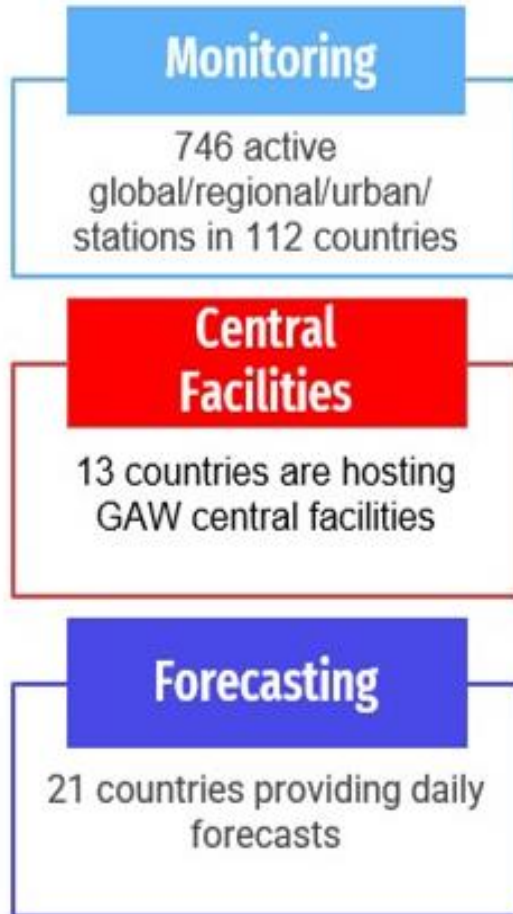
Warnings and Forecasting Services Model intercomparisons



Sand and Dust Storm SDS-WAS



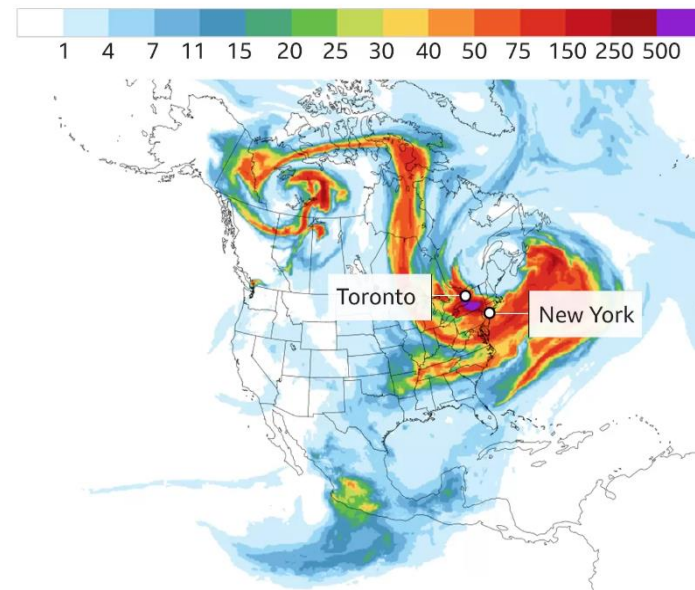
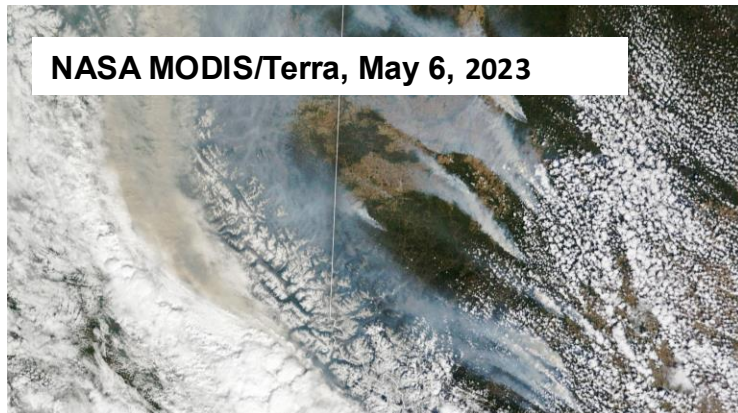
Infrasctructure for the provision of Services



WMO-GAW Warning Advisory and Assessment Systems (SDS-WAS and VFSP-WAS)



The World Meteorological Organization spearheads a Sand and Dust Storm Warning Advisory and Assessment System.



International coordination of research for weather and climate

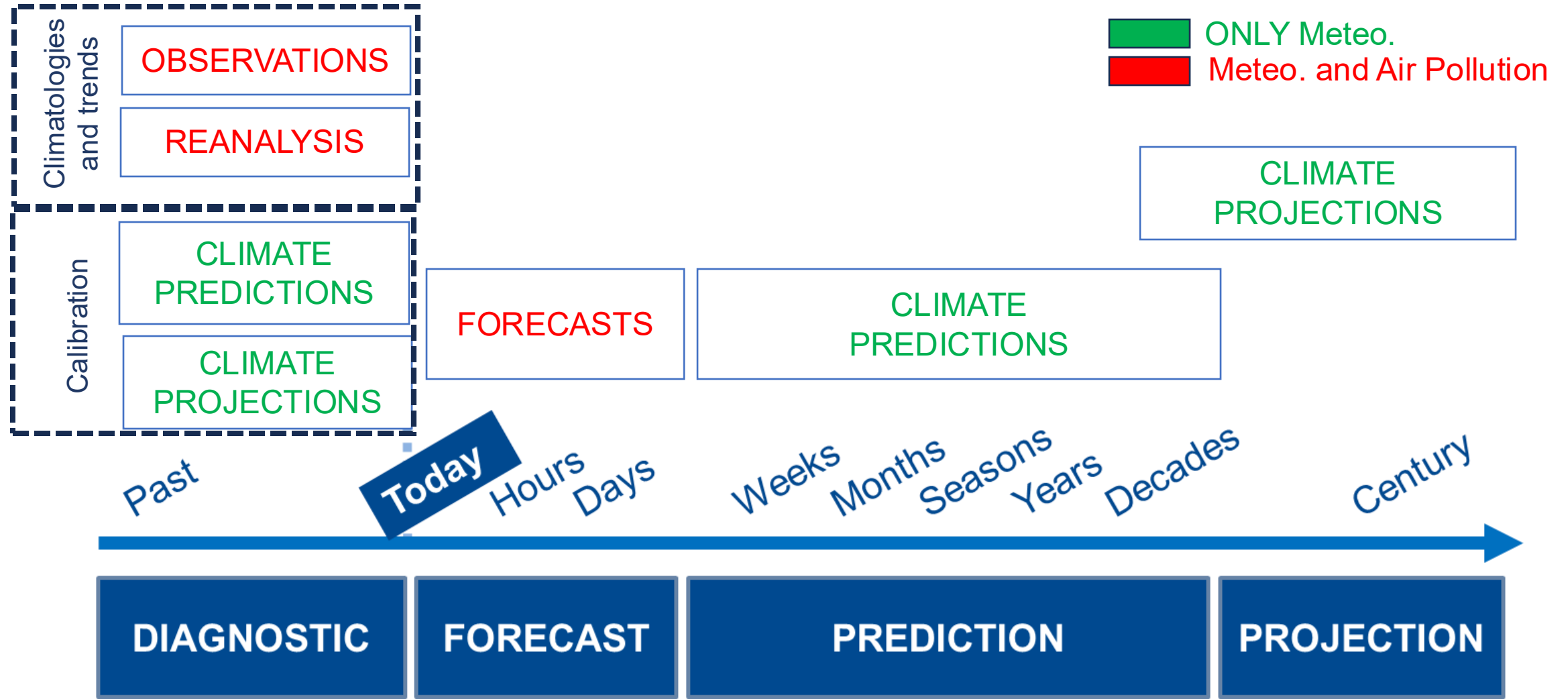
Identification and assessment of SDS and VFSP impacts

Promoting the use of current available products (observations and monitoring)

Building capacity and facilitate access to the available services

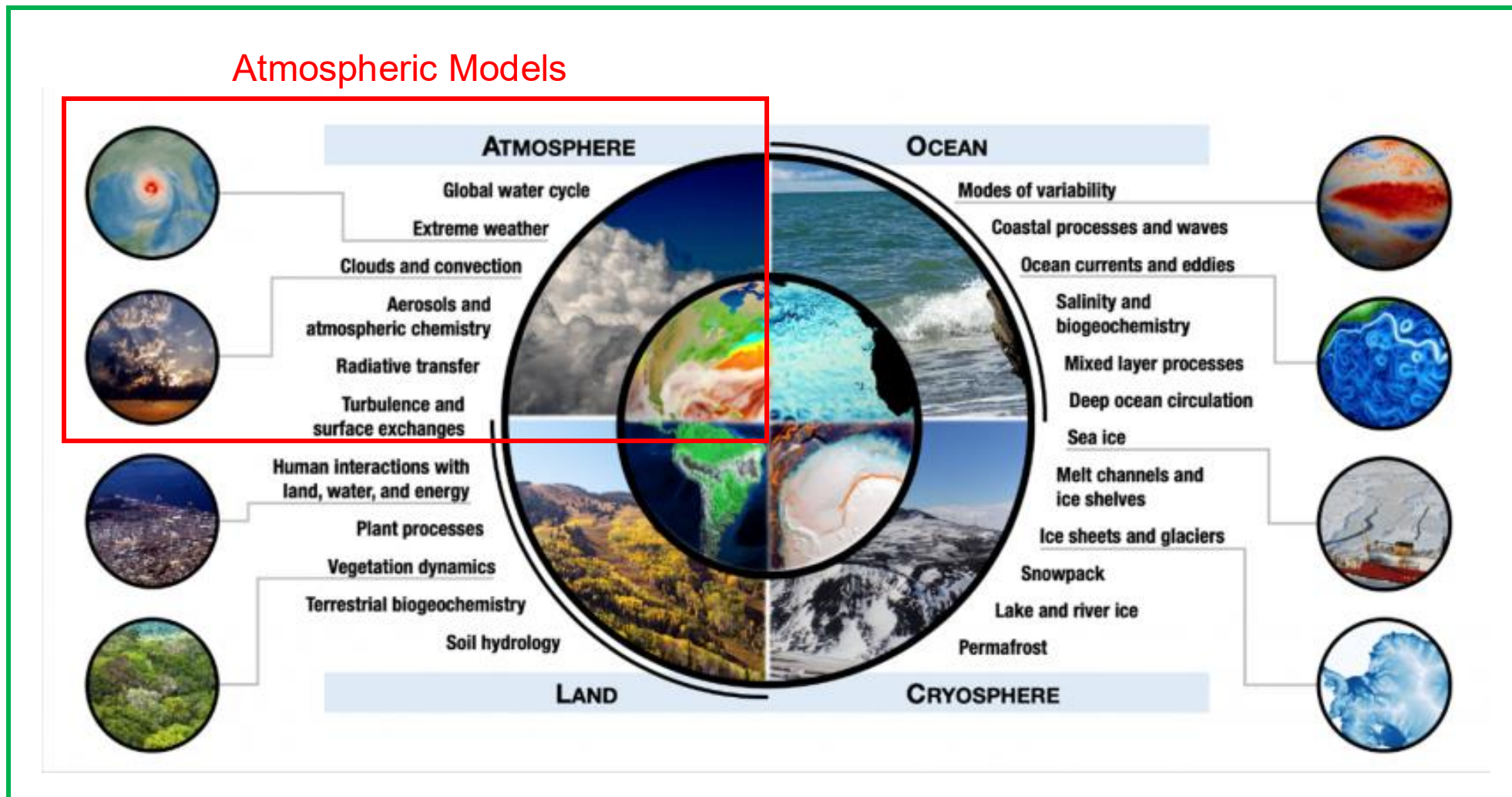
Dissemination and awareness

Integrating time scales

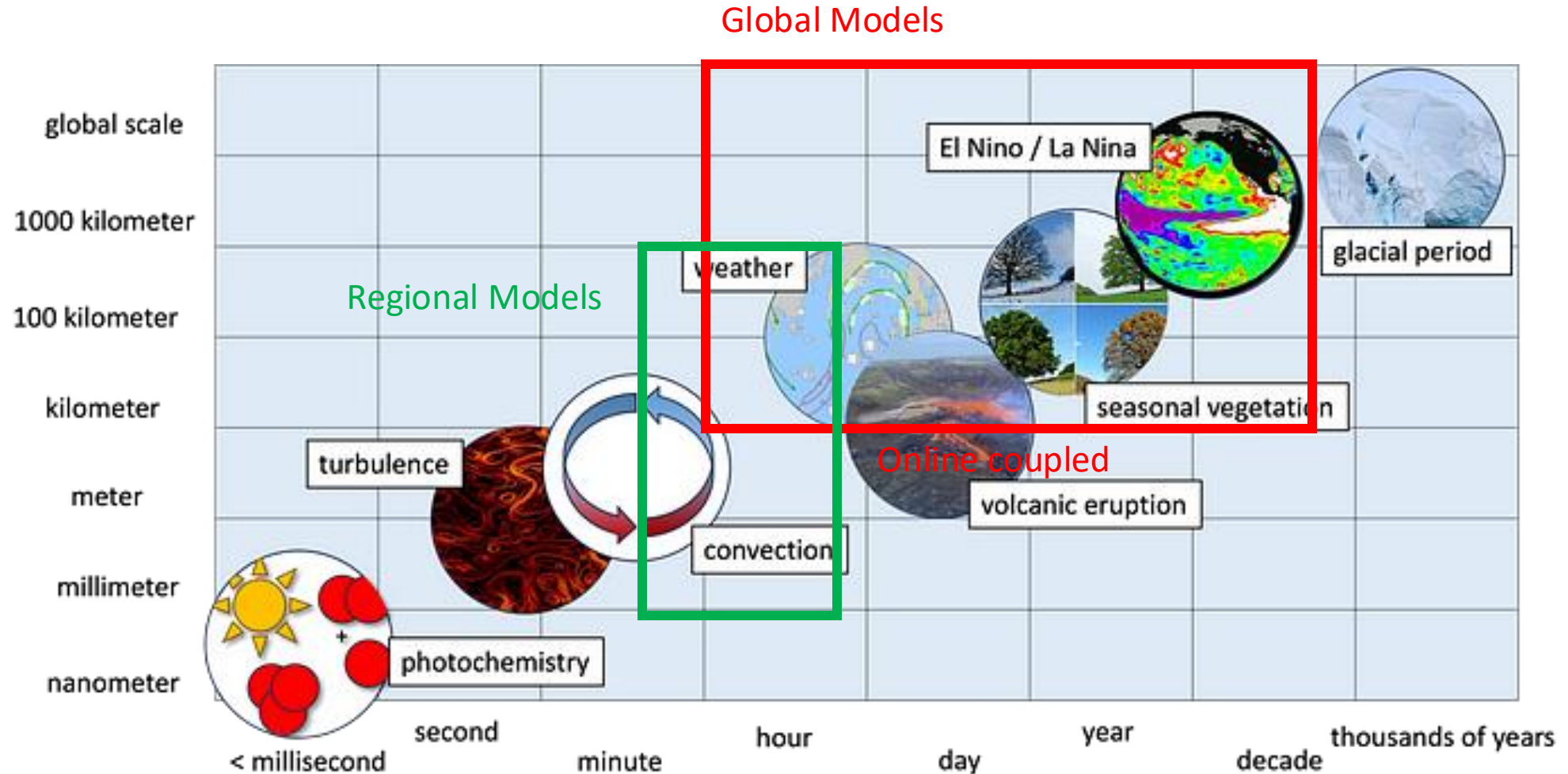


Model types

Climate Models



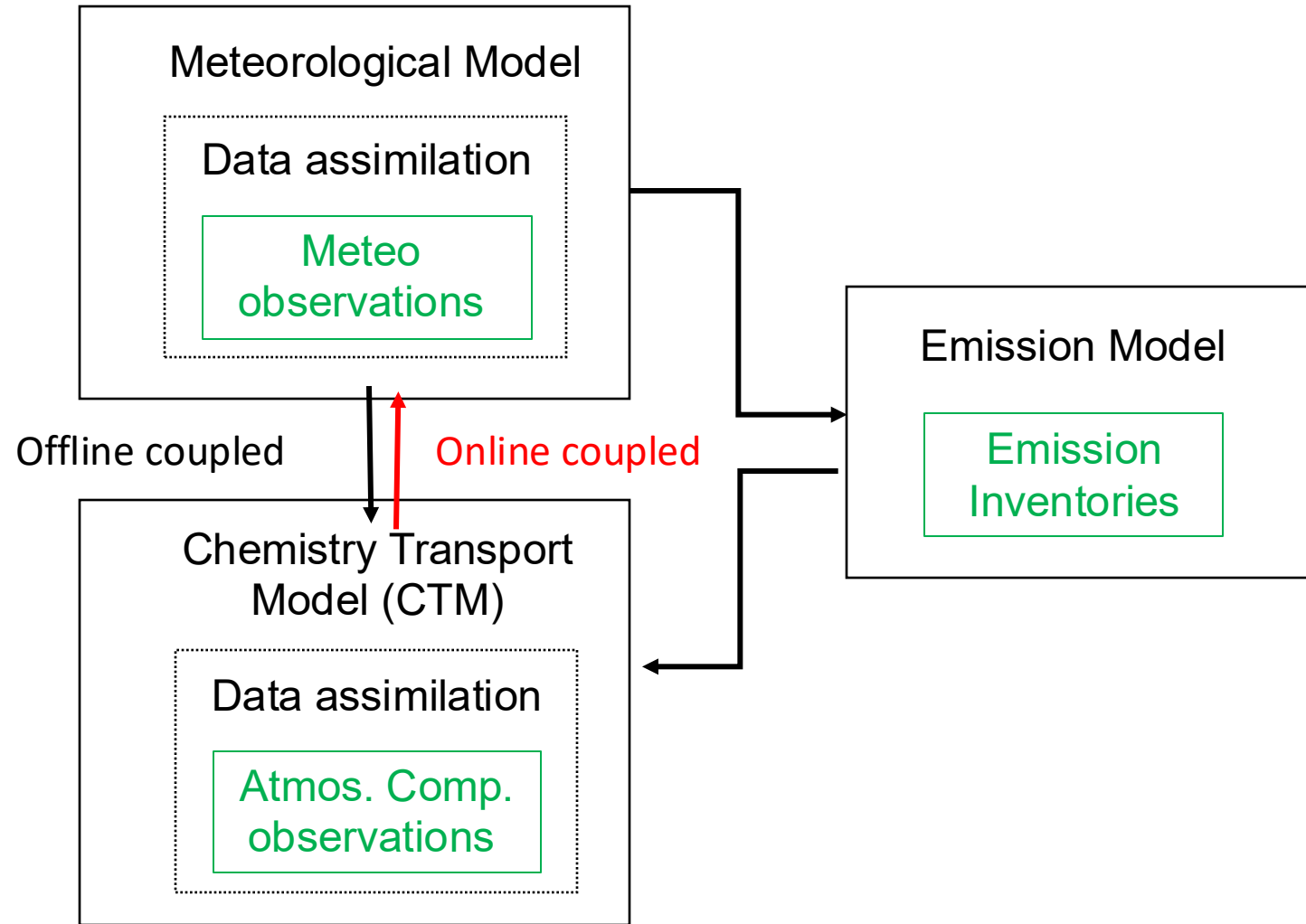
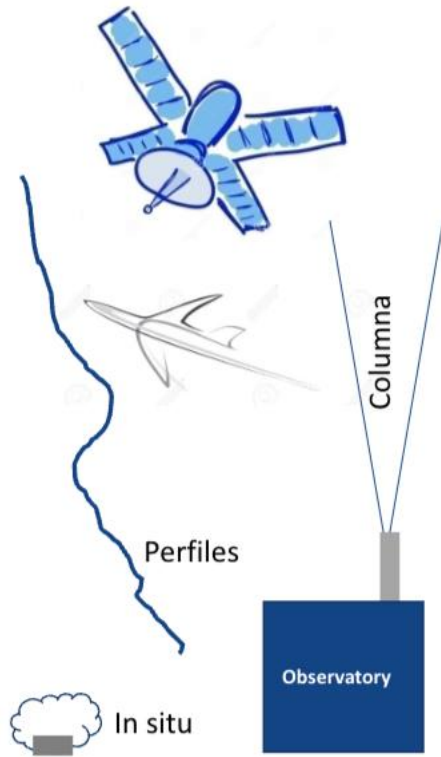
Atmospheric Composition models: Scales



G. Inchingolo CC-BY-SA 4.0 / Aviation Weather Center Public Domain / Government of Iceland / J. Hagelüken CC-BY-SA 3.0 / G. Boz CC-BY-SA 3.0 | All Wikimedia Commons

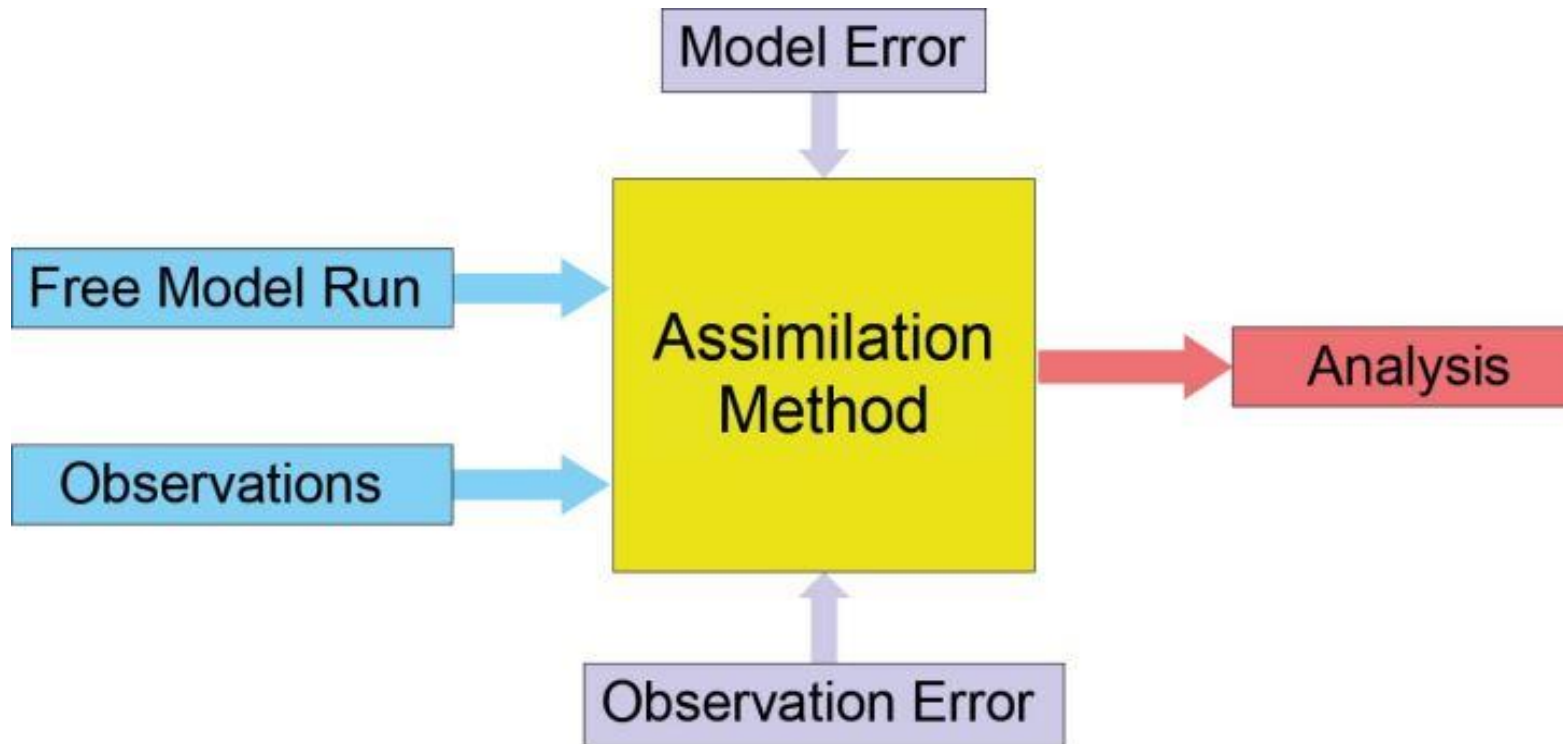
Atmospheric Composition models: (Re)analysis

Observations



Scheme courtesy of L. Mona

Atmospheric Composition models: (Re)analysis



Analysis: Obtaining the "best" estimate of current atmospheric dust conditions

Reanalysis: Creation of data sets describing the recent history of dust in the atmosphere

Modelling framework: PRACE

HPC (high-performance computers) are fundamental for executing numerical models. The **size of each cell in the grid and the length of the simulation** is determined by the power of the computer running the model.



PRACE Hosting Members



The MareNostrum 5 supercomputer, Spain
It is a pre-exascale EuroHPC supercomputer

<https://www.bsc.es/ca/marenostrum/marenostrum-5>



PARTNERSHIP FOR ADVANCED
COMPUTING IN EUROPE

<https://prace-ri.eu/>

Designated WIPPS Centres Web portal for the WMO Integrated Processing and Prediction System

Filter by Region

- I
- II
- III
- IV
- V
- VI

Filter by WIPPS Activities

Buscar...

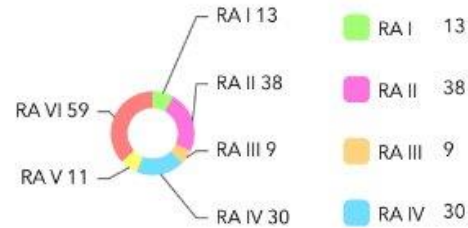
- World Meteorological Centre
- Global deterministic numerical weather prediction
- Limited-area deterministic numerical weather prediction
- Global ensemble numerical weather prediction
- Limited-area ensemble numerical weather prediction
- Global sub-seasonal prediction
- Global seasonal prediction
- Annual to decadal climate prediction
- Global climate reanalysis

159

centres/networks

28

activities



WMC Beijing
World Meteorological Centre

WMC ECMWF
World Meteorological Centre

WMC Exeter
World Meteorological Centre

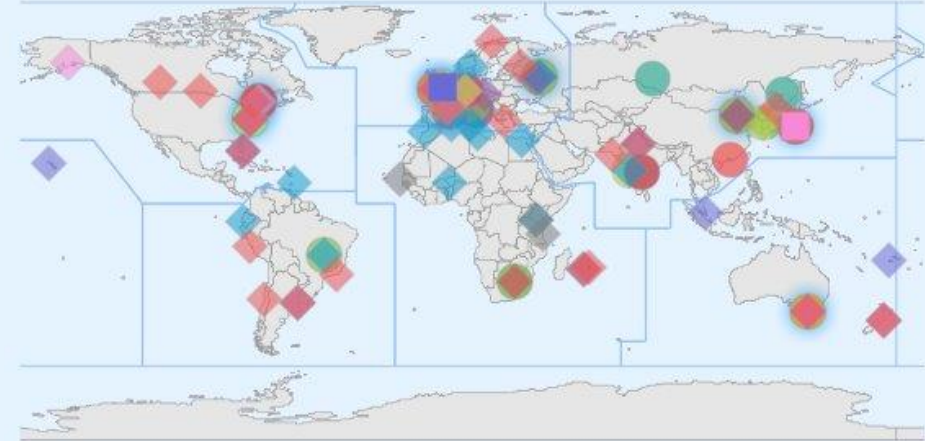
WMC Melbourne
World Meteorological Centre

WMC Montreal
World Meteorological Centre

WMC Moscow
World Meteorological Centre

WMC Offenbach
World Meteorological Centre

WMC Tokyo



10.000 km
5000 mi

©WMO 2018 - Disclaimer: The designations employed in this map are in conformity with United Nations practice. The pres... Powered by Esri

Selección requerida en uno o más elementos

Please select a centre to view its information.

♥ indicates mandatory products.

Useful links

- A full list of designated WIPPS centres (Part III of Manual on the WMO Integrated Processing and Prediction System)



CLIMATE CHANGE



MARINE MONITORING



ATMOSPHERE MONITORING



LAND MONITORING



SECURITY



EMERGENCY MANAGEMENT



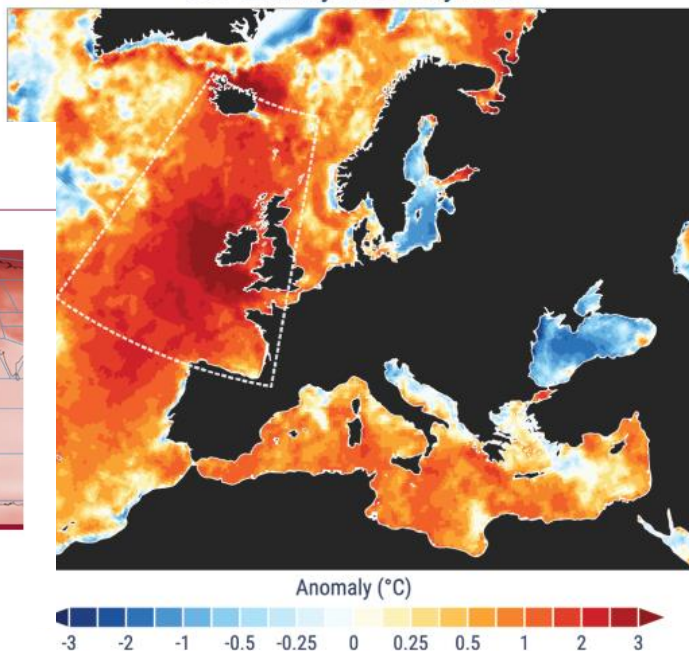
Climate Change Service

climate.copernicus.eu

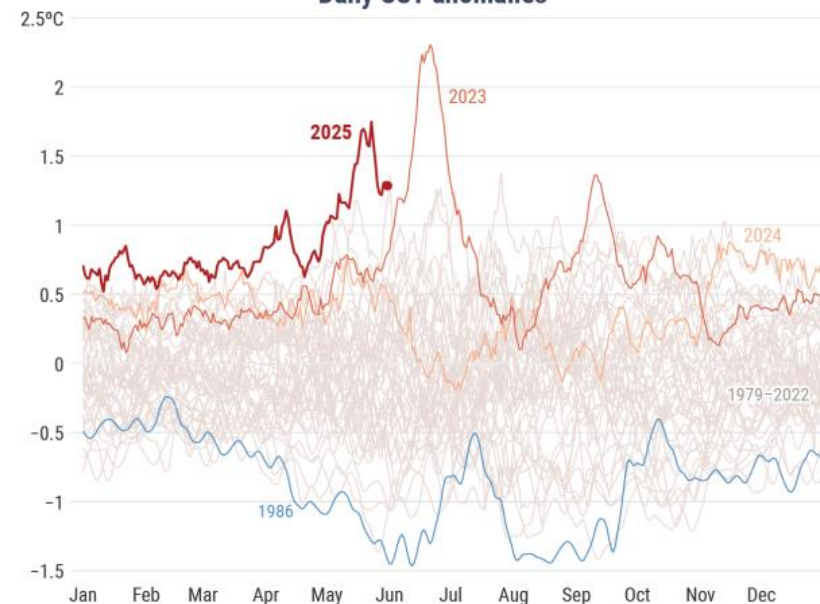
Sea surface temperature (SST) anomalies in northeastern North Atlantic

Data: ERA5 • Reference period: 1991–2020 • Credit: C3S/ECMWF

SST anomaly on 23 May 2025

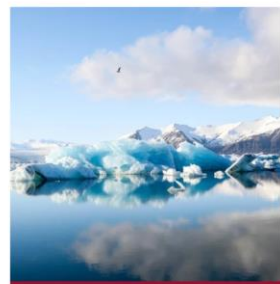


Daily SST anomalies

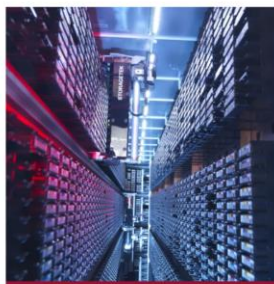


Northeastern North Atlantic defined as 25W–0E, 43N–66N

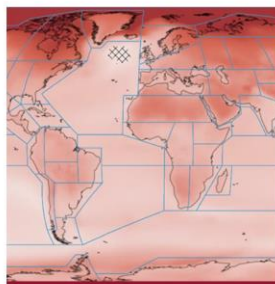
Key products and services



Climate Intelligence



Climate Data Store



C3S Atlas



PROGRAMME OF THE EUROPEAN UNION



IMPLEMENTED BY ECMWF

More details in Carlo Buontempo's talk



Copernicus
Europe's eyes on Earth

IMPLEMENTED BY





Atmosphere
Monitoring

COPERNICUS ATMOSPHERE MONITORING SERVICE - THEMES

CAMS delivers consistent and quality-controlled information related to air pollution and health, solar energy, greenhouse gases and climate forcing, everywhere in the world.



Air quality



Policy tools



Solar energy



Ozone layer and UV radiation



Emissions and surface fluxes



Climate forcing



PROGRAMME OF
THE EUROPEAN UNION

Europe's eyes on Earth

IMPLEMENTED BY



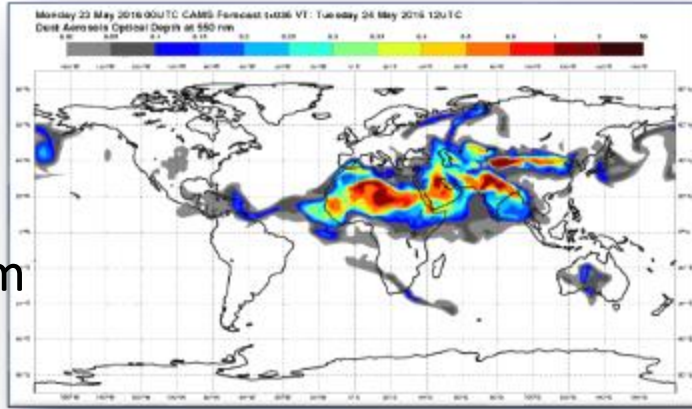


Atmosphere
Monitoring

Global and Regional CAMS systems

Global
CAMS
Emissions

ECMWF
IFS
global,
40x40 km

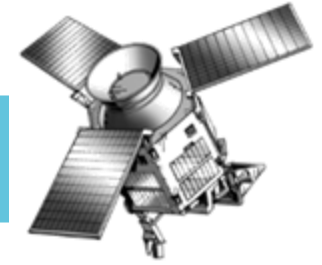
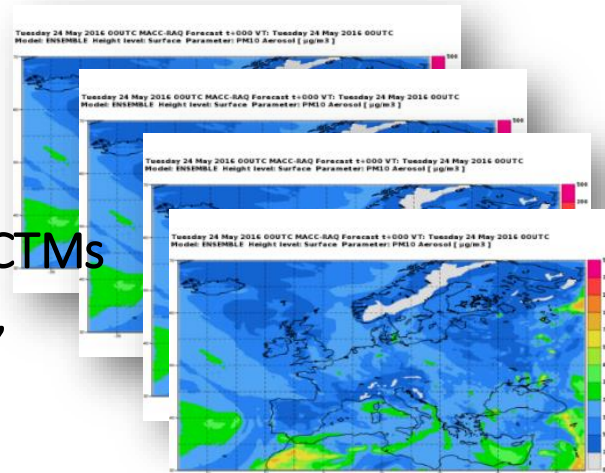


GFAS
wildfire
emissions

Boundary Conditions

European
CAMS
Emissions

11 regional CTMs
over Europe,
10x10 km



Data assimilation

Satellite Observations
(AOD, O₃, CO, NO₂, SO₂)



Surface AQ observations

Data assimilation



PROGRAMME OF
THE EUROPEAN UNION

Europe's eyes on Earth

IMPLEMENTED BY

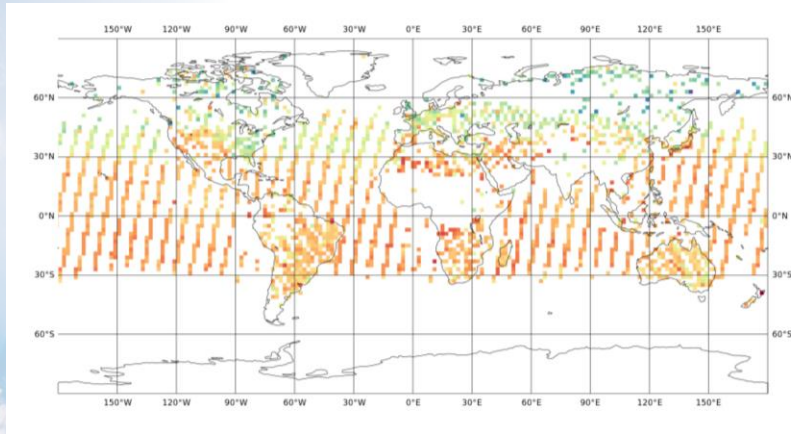




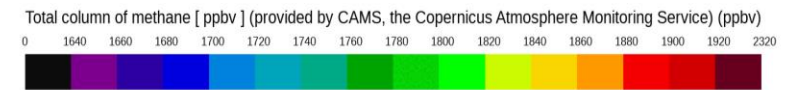
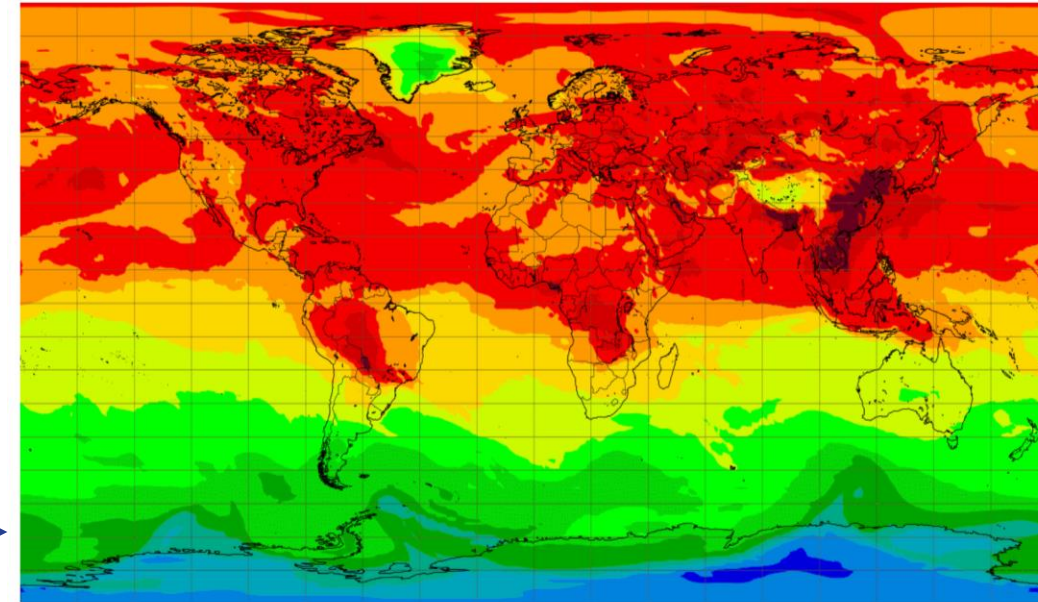
Atmosphere
Monitoring

CAMS Global Forecasts – CO₂ as example

Satellite observations (GOSAT & IASI)



Base time: Sat 31 Dec 2022 00 UTC Valid time: Sat 31 Dec 2022 03 UTC (+3h) Area : Global Level : Total column



Medium-range forecast

Forecast

Analysis

Forecast

Analysis

Yesterday's forecast is adjusted by today's observations to produce the outlook for tomorrow. Every day.



PROGRAMME OF
THE EUROPEAN UNION

Europe's eyes on Earth

IMPLEMENTED BY

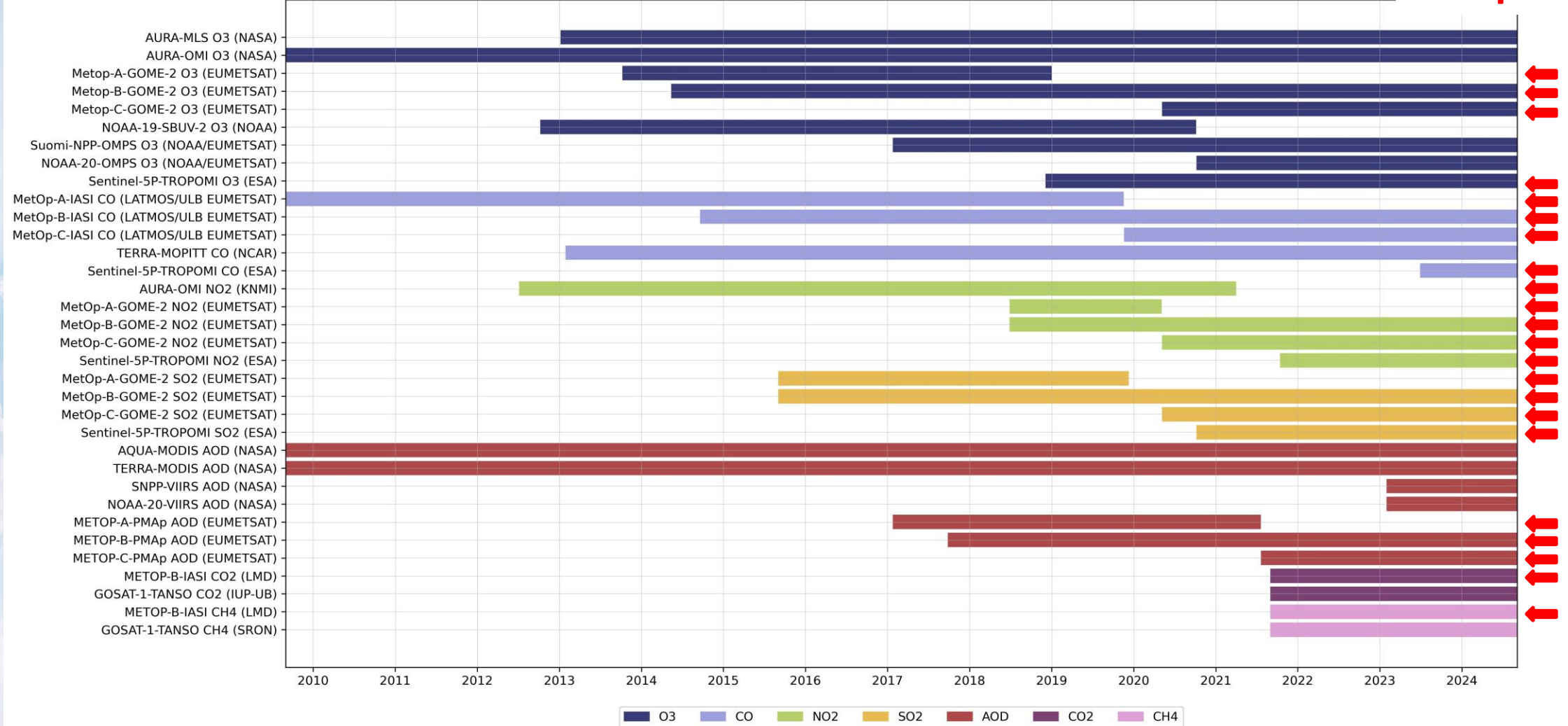




Satellite data usage in CAMS global forecast system

Satellite retrievals of reactive, greenhouse gases and aerosol optical depth that are actively assimilated in the IFS-COMPO and IFS-GHG o-suites u
[Reference: IFS DOCUMENTATION - Cy48r1, PART VIII: ATMOSPHERIC COMPOSITION, Table 6.1]

European





Atmosphere
Monitoring

Evaluation of CAMS global products with independent observations



Balloons



Airplane



Satellites

About 65 observational datasets for evaluation of the CAMS real-time analyses/forecasts

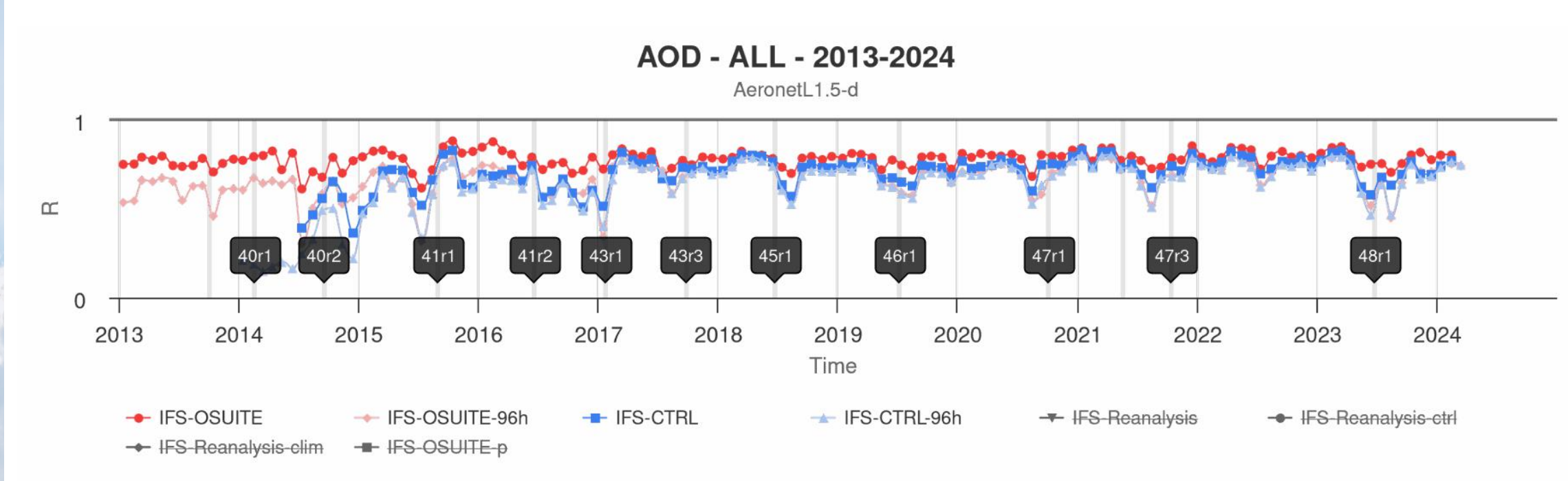


Ground-based stations; in-situ, remote sensing



Ships





FORECASTS can NOT be used for trend analysis - **Forecast systems are upgraded regularly**

REANALYSIS is the alternative for long-term analysis – CAMSRA IS based on the same CAMS system but it is run consistently since 2003 to now





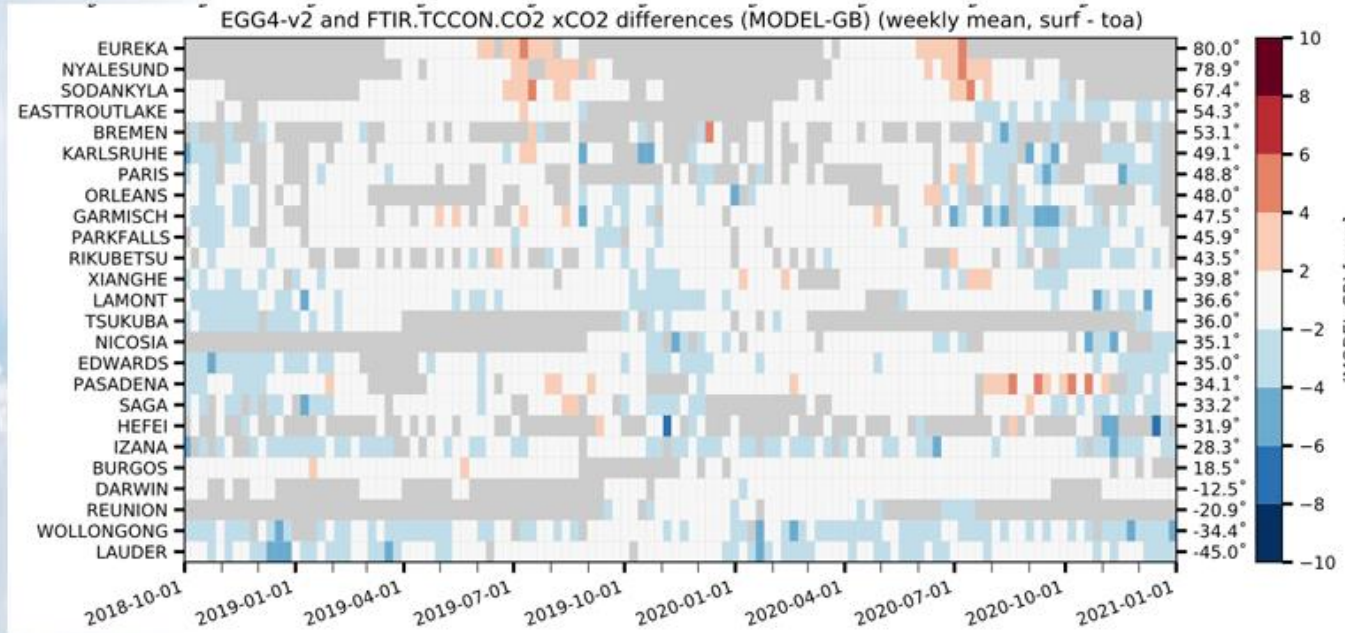
Satellite data usage in CAMS global reanalysis system





CAMS greenhouse gas reanalysis, 2003-2023

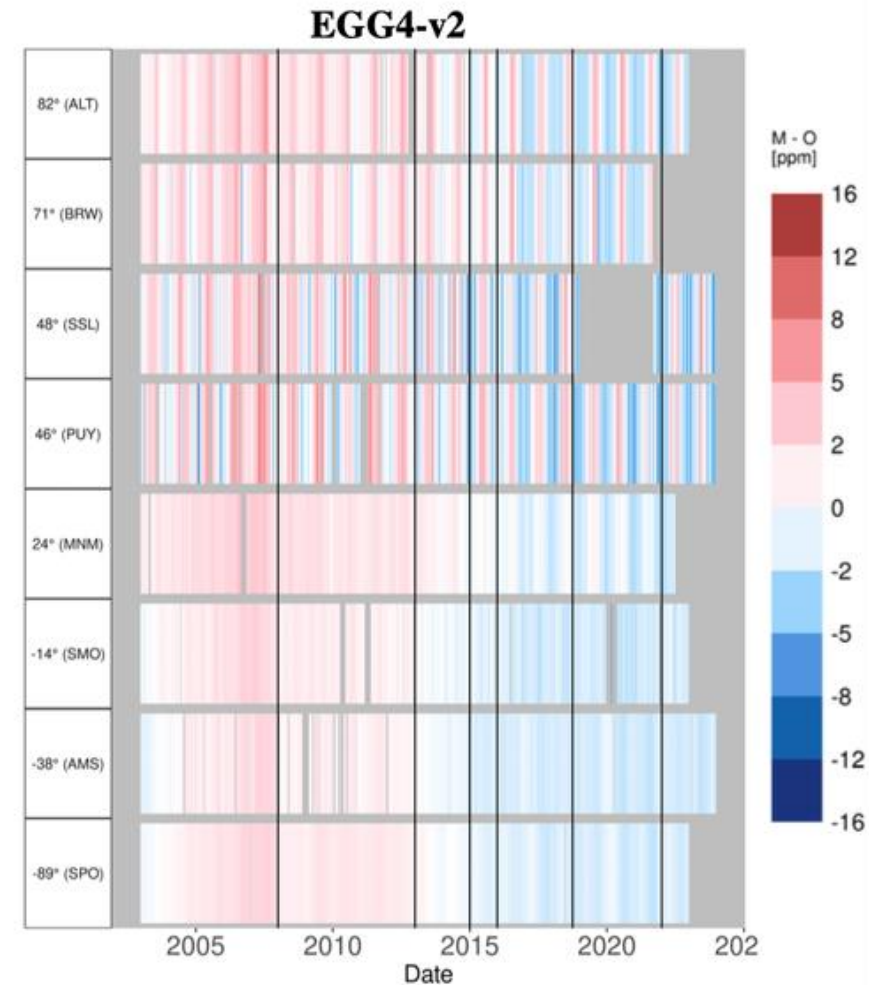
CO₂ column amount (TCCON)



Quantification of seasonal biases and trend to negative bias

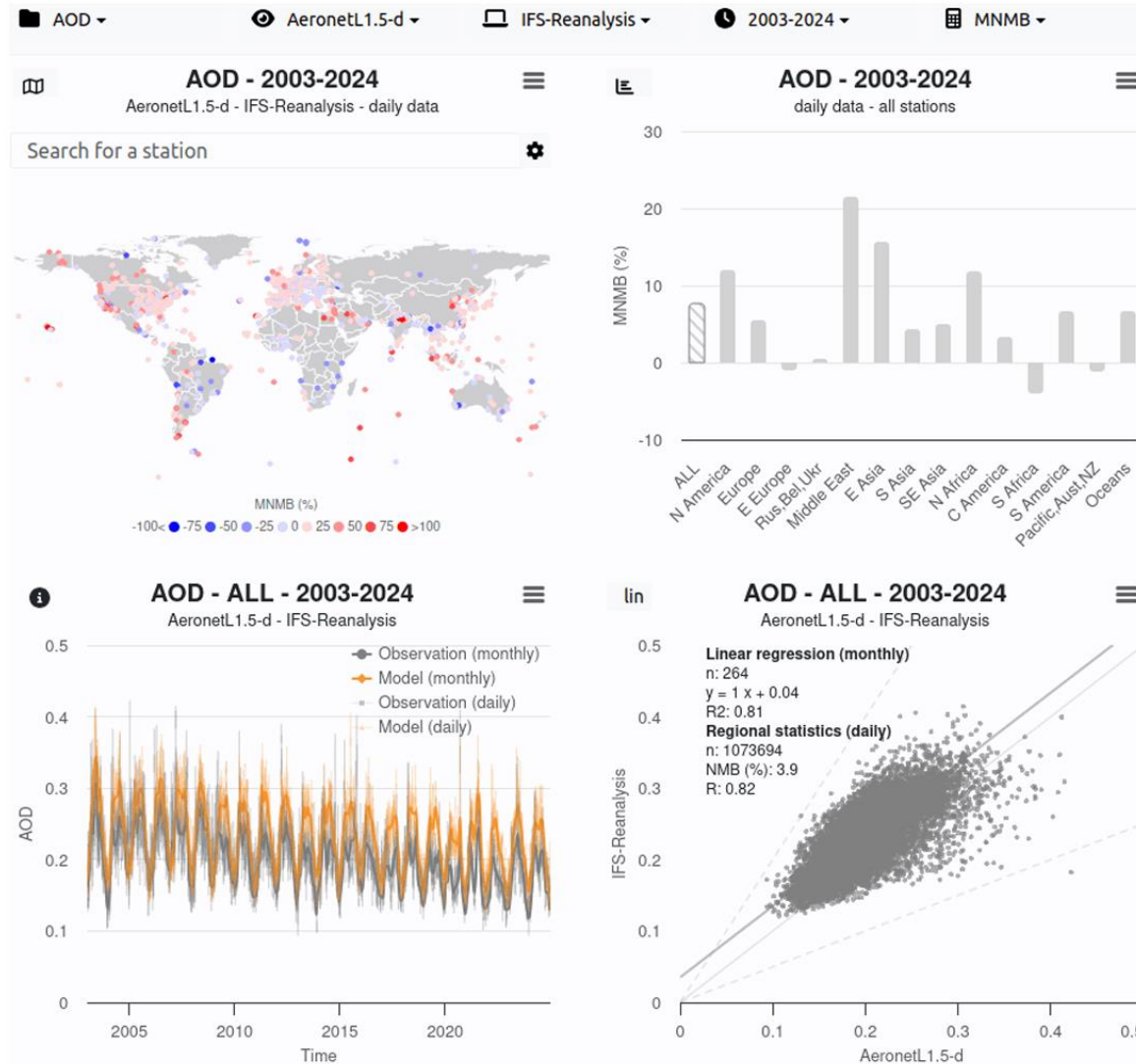
CAMS EGG4 GHG reanalysis reference:
Agustí-Panareda et al. (2023)

CO₂ surface concentrations





Global CAMS reanalysis validation



GAW Scientific Assessments

WMO Bulletins in 2024

WMO AIR QUALITY AND CLIMATE BULLETIN
No. 4 - SEPTEMBER 2024

Introduction

Ongoing climate change, caused by the accumulation of greenhouse gases in the atmosphere, is happening on a timescale of decades to centuries and is driving environmental changes worldwide. In contrast, the air pollution that occurs near the Earth's surface happens on a timescale of days to weeks, and across spatial scales that range from local (for example, urban centres) to regional (such as the eastern United States of America, northern India or the Amazon).

Despite these wide-ranging differences, air quality and climate change are strongly interconnected, with some pollutants affecting climate change. For example, short-lived reactive gases such as methane and nitrous oxide, and their precursors, are both common greenhouse gases that warm the planet. They also affect pollution, changing winds, increasing with new precipitation patterns and dispersion of air pollution, climate via ecosystem health, deposition the process by which particles and gases are removed from the atmosphere and sulfur and ozone can negatively impact natural ecosystem biodiversity and carbon storage yields in agricultural systems.

Many of the sources of air pollution are the same. For example, those that emit carbon dioxide (CO₂) and methane (CH₄) also emit nitrogen oxides (NO_x) and volatile organic compounds (VOCs), which can lead to the formation of ozone. Similarly, some agricultural activities emit methane and nitrous oxide, which are also greenhouse gases.

WMO OZONE AND UV BULLETIN
No. 2 - SEPTEMBER 2024

Introduction

Over the past few decades, the ozone layer has been found to be thinning in many parts of the world. This is due to the release of ozone-depleting substances (ODS) into the atmosphere. The Montreal Protocol, signed in 1987, is the only international environmental agreement that has been fully implemented. It aims to phase out the production and consumption of ODS. The success of the Montreal Protocol is a testament to international cooperation and the effectiveness of a global treaty.

WMO AIRBORNE DUST BULLETIN
No. 6 - JULY 2024

Overview of global airborne dust in 2023

The global average of annual mean surface dust concentration in 2023 (32.7 µg m⁻³; see Figure 1a) was slightly lower than that in 2022 (33.8 µg m⁻³; see WMO Airborne Dust Bulletin, No. 7). This decrease in 2023 is mainly attributed to reduced dust emissions from several dust-affected regions around the world, such as North Africa, the Arabian Peninsula, the Indian subcontinent, northern India, central Australia and north-eastern China. But annual mean surface dust concentrations were higher in western Central Asia, north-central China and southern Mongolia in 2023 were higher than those in 2022. Sporadically, the estimated peak annual mean surface dust concentration (>600-1 100 µg m⁻³) in 2023 occurred in some areas.

that are most vulnerable to long-range transport of dust are the northern tropical Atlantic Ocean between West Africa and the Caribbean, South America, the Mediterranean Sea, the Arabian Sea, the Bay of Bengal and central-eastern China. In 2023, the transatlantic transport of African dust involved parts of the Caribbean Sea region, and East Asian dust emissions from the Gobi Desert also continued to reach the Bohai and Yellow Seas.

In the most affected areas, the annual mean surface dust concentration in 2023 was higher than the climatological mean. Exceptions to this were most of West and southern Mongolia in 2023 were higher than those in 2022. Sporadically, the estimated peak annual mean surface dust concentration (>600-1 100 µg m⁻³) in 2023 occurred in some areas.

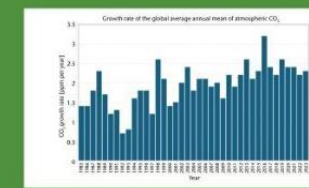
WMO GREENHOUSE GAS BULLETIN
No. 20 (28 October 2024)

The State of Greenhouse Gases in the Atmosphere
Based on Global Observations through 2023

The WMO Global Atmosphere Watch (GAW) Greenhouse Gas (GHG) Bulletin has been informing policy and the public on the composition of GHGs in the global atmosphere since 2006. The first bulletin reported that in 2004, the carbon dioxide (CO₂) level was 377.1 parts per million (ppm)¹. In 2023, the level was 420.2 ppm. This is an increase of 42.8 ppm, or 11.4%, in just 20 years.

Atmospheric carbon dioxide (CO₂) is the most prominent anthropogenic greenhouse gas driving climate change. From 2020 to 2023, the mean surface CO₂ level in the global surface atmosphere increased by 2.3 ppm (Figure 1). This increase is the steepest in the annual increase greater than 2 ppm, continuing an already significant trend of CO₂ increasing in the atmosphere faster than at any time during human existence. The current atmospheric CO₂ level is already 50 ppm above the pre-industrial (before 1750) era.

A detailed analysis (Figure 2) of atmospheric monthly atmospheric greenhouse gas (methane change) from 2020 to 2023, the mean surface CO₂ level in the global surface atmosphere increased by 2.3 ppm (Figure 1). This increase is the steepest in the annual increase greater than 2 ppm, continuing an already significant trend of CO₂ increasing in the atmosphere faster than at any time during human existence. The current atmospheric CO₂ level is already 50 ppm above the pre-industrial (before 1750) era.



WMO-GAW Newsletter



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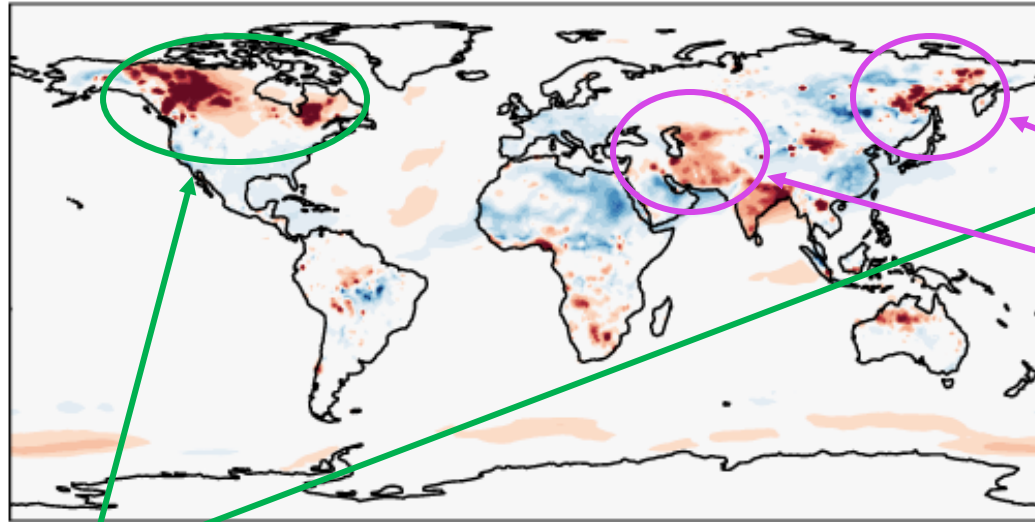
Available at: <https://library.wmo.int/>



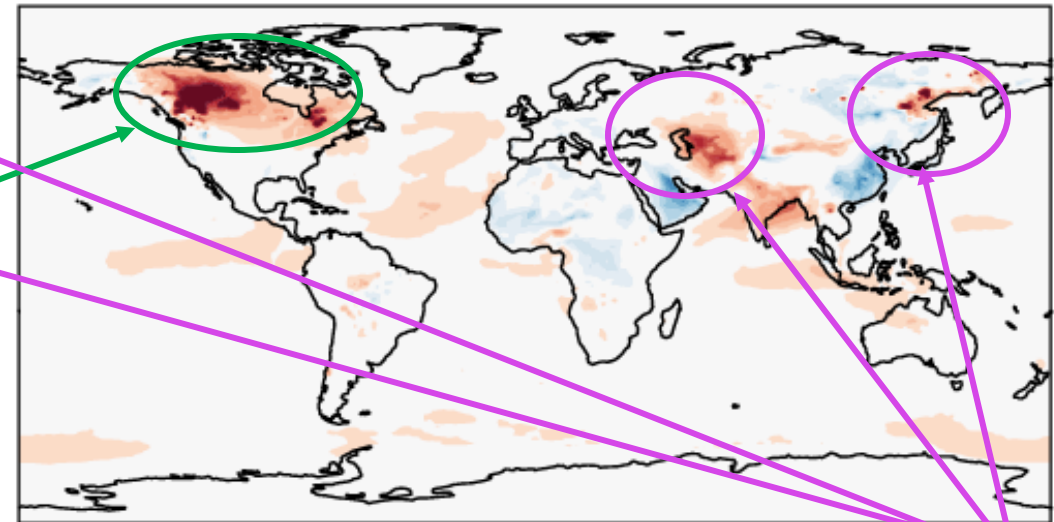
What did it happen in 2023?

PM2.5 anomaly for 2023 with respect 2003-2023

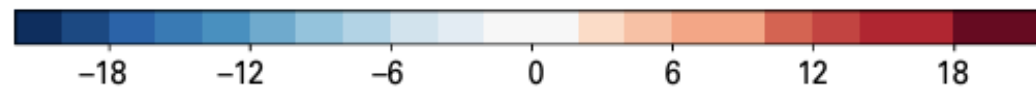
Source: MERRA-II Reanalysis



Source: CAMS Reanalysis



Wildfires



PM2.5 ($\mu\text{g m}^{-3}$)

Sand and Dust



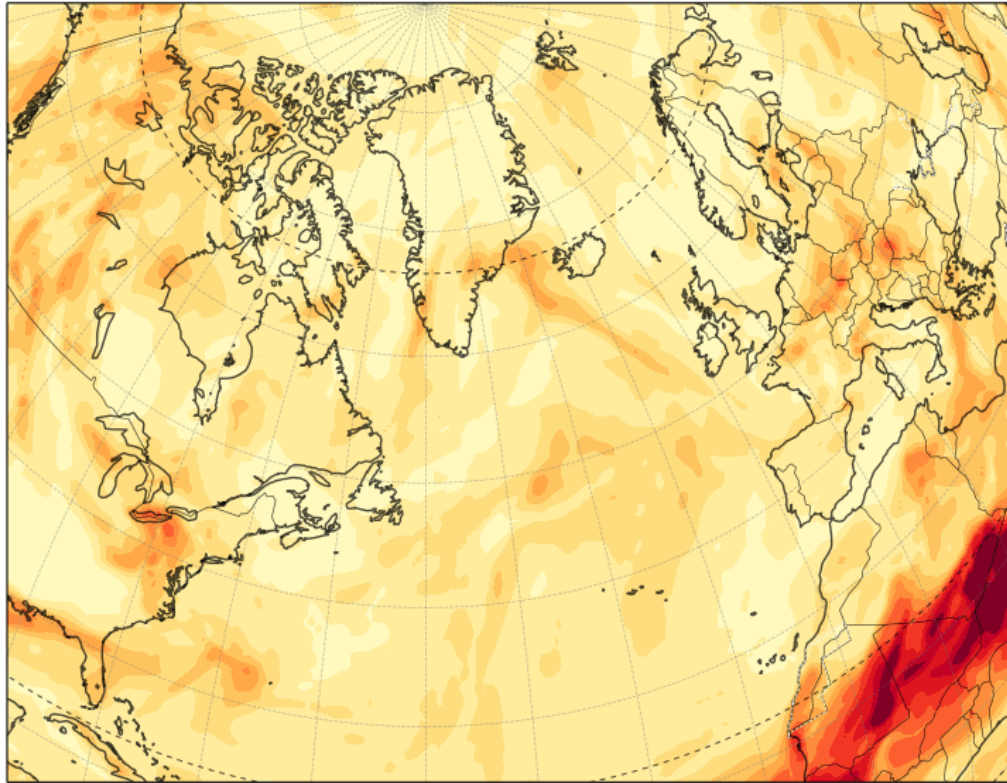
WMO Air Quality and Climate Bulletin 2024 Edition – Released on 6th Sep 2024
<https://library.wmo.int/records/item/69006-no-4-september-2024>

Transboundary Smoke Pollution June 2025

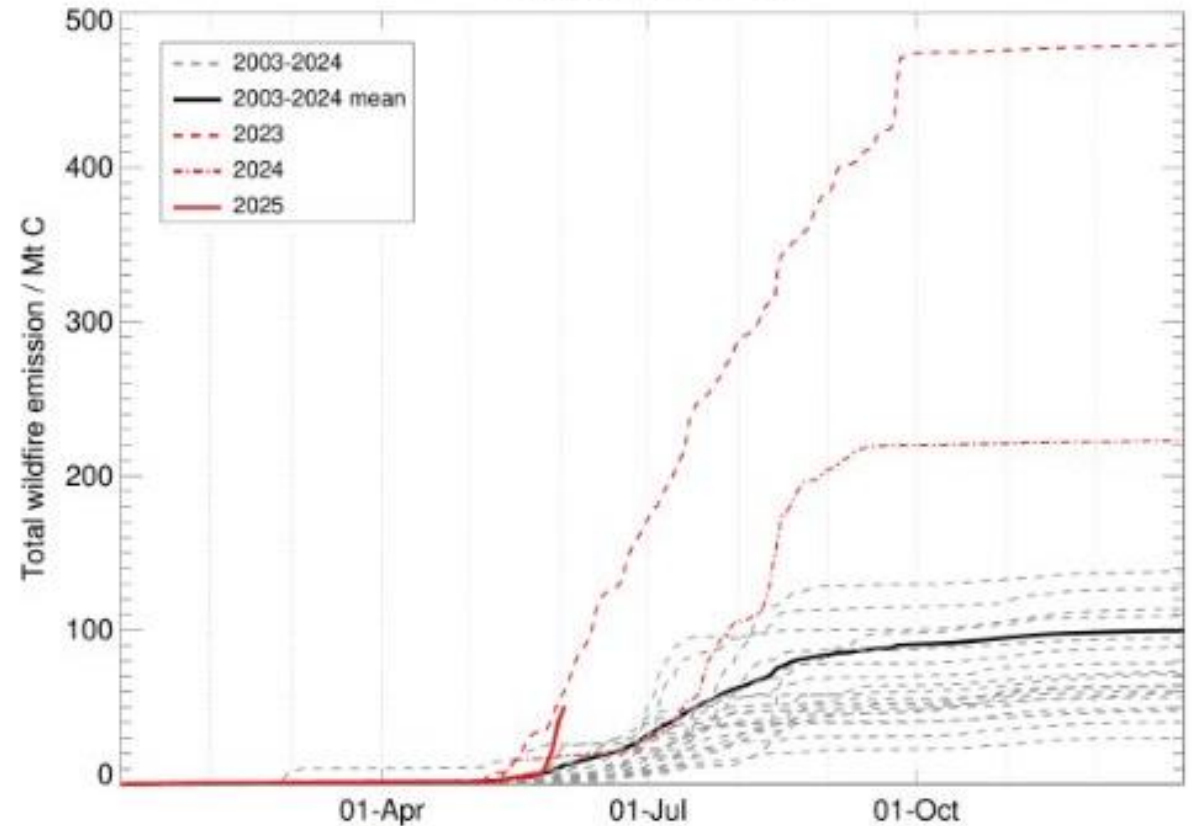
CAMS Analysis Total Aerosol Optical Depth at 550nm

2025-05-22 T00

Data: CAMS global atmospheric composition forecast • Credit: CAMS/ECMWF



Cumulative total



CAMS GFASv1.2 daily total fire radiative power. Source: CAMS

Courtesy of Mark Parrington (ECMWF)

Key Messages

- RIs are essential for enabling frontier research, supporting international collaboration, fostering innovation in both academia and industry, and providing long-term data and experimental capabilities.
- Understanding, managing and mitigating air pollution risks and effects (at weather and climate scales) requires fundamental and cross-disciplinary knowledge.
- WMO is key to coordinate the international research community and to provide guidance on how to monitor, model, and mitigate air pollution at global scale and at different time scales (weather to climate).



THANKS!

IR0000032 – ITINERIS, Italian Integrated Environmental Research Infrastructures System
(D.D. n. 130/2022 - CUP B53C22002150006) Funded by EU - Next Generation EU PNRR-
Mission 4 "Education and Research" - Component 2: "From research to business" - Investment
3.1: "Fund for the realisation of an integrated system of research and innovation infrastructures"

