

# Air Quality (AQ) Atlases



<https://igacproject.org/activities/amigo>

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+ AQ-WATCH Team (<https://www.aq-watch.eu/>)

AMIGO Workshop  
19-20 June 2023  
Brussels, Belgium

# Overview

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- ⦿ Inputs for air quality atlases (focus on atmospheric reanalyses)
- ⦿ Examples of air quality atlases
- ⦿ The AQ-WATCH Atlas (AQWA)
- ⦿ CRANES AMIGO working group

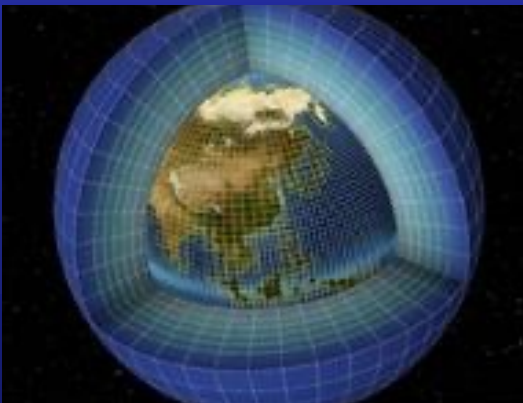
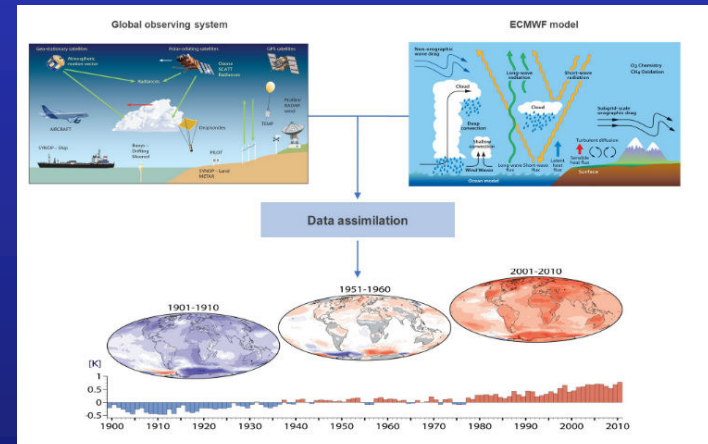
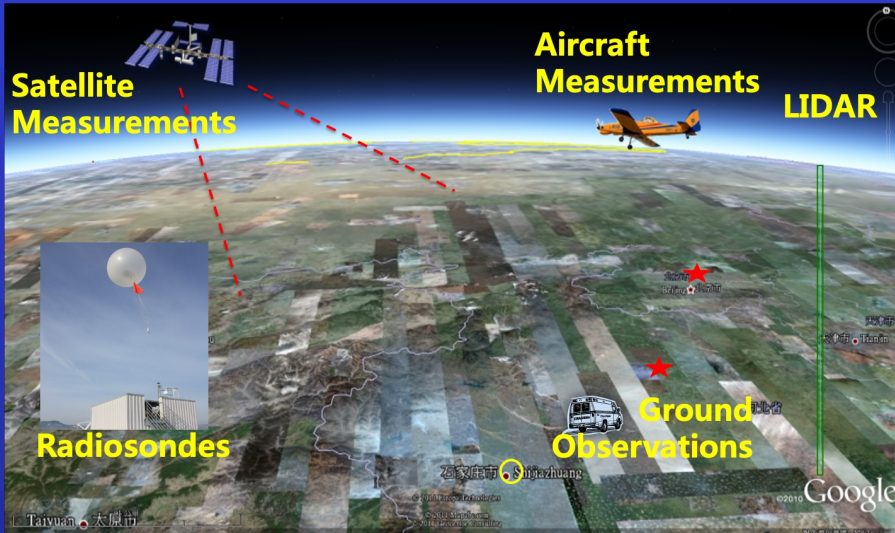
AQ-WATCH : Air Quality Worldwide Analysis and Forecasting of Atmospheric Composition for Health

CRANES : Chemical Reanalysis And flux iNvErsionS

# Inputs for Air Quality Atlases

Atlas = A collection of maps or charts

## Observations

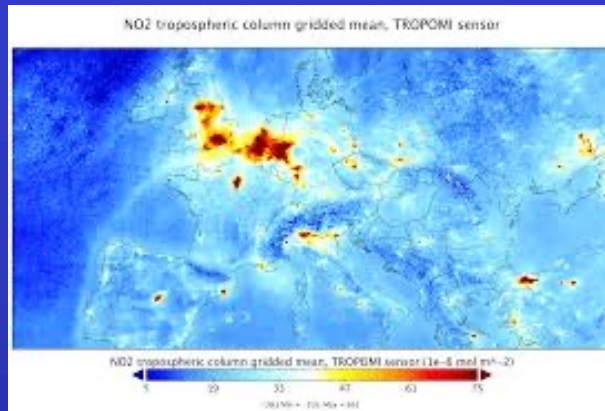


## Models

## Atmospheric Reanalysis

# Satellite Observations & Model Outputs

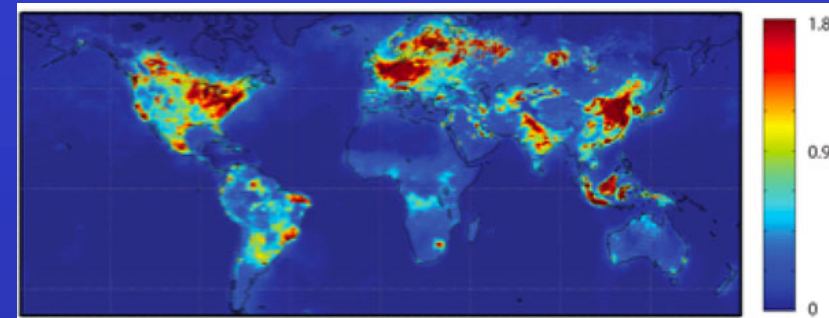
## TROPOMI on Sentinel-5P



**NO<sub>2</sub> trop. column**  
since 2017  
5.5km x 3.5km (7km  
x 3.5km before  
6/8/2019)

See Deborah's presentation

## OMI on AURA Platform

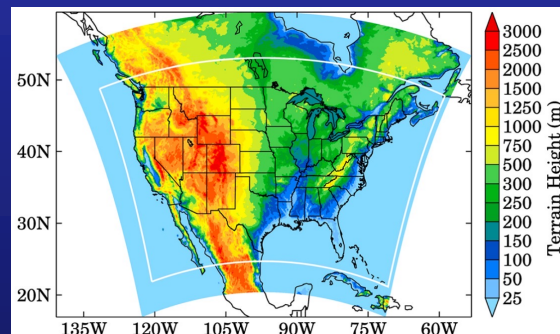


**NO<sub>2</sub>, O<sub>3</sub> trop. column**

since 2004

0.125 x 0.125° (approx. 12km)

## WRF-CMAQ (Contiguous US, CONUS, NCAR)



NCAR Reanalysis

12 km x 12 km

Period : 2005-2018

Parameters : PM<sub>1</sub>, PM<sub>2.5</sub>, PM<sub>10</sub>, O<sub>3</sub>,

NO<sub>2</sub>, SO<sub>2</sub>, CO, AQI

+ some meteorological fields

# Atmospheric Reanalysis



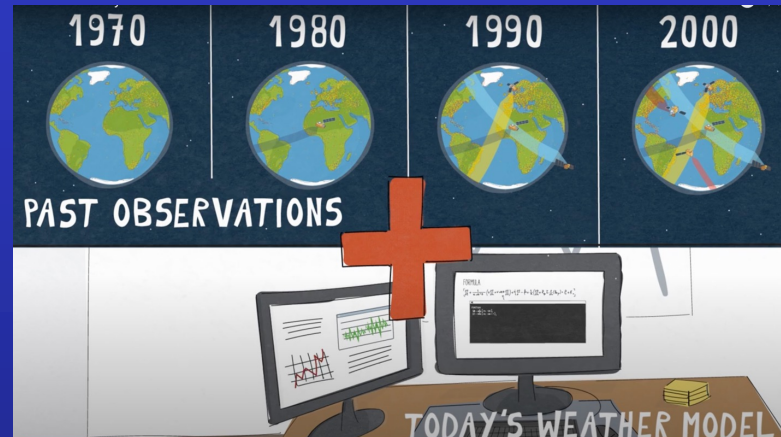
There are extensive and reliable historical records of the Earth's climate and atmospheric composition. However, observations are not distributed evenly around the globe.

# Atmospheric Reanalysis

There are extensive and reliable historical records of the Earth's climate and atmospheric composition. However, observations are not distributed evenly around the globe.



Atmospheric reanalysis combines observations made in the past with today's weather/atmospheric model through assimilation methods ...

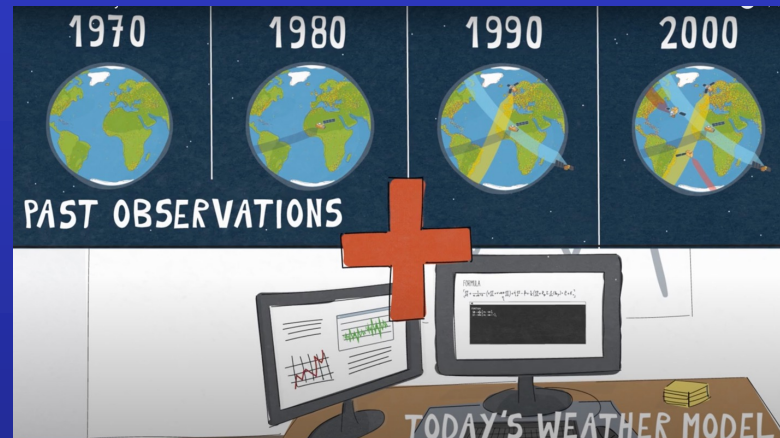


# Atmospheric Reanalysis

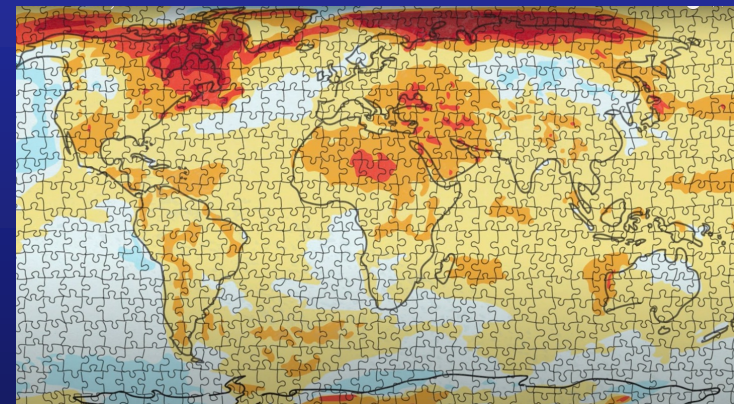


Atmospheric reanalysis combines observations made in the past with today's weather/atmospheric model through assimilation methods ...

There are extensive and reliable historical records of the Earth's climate and atmospheric composition. However, observations are not distributed evenly around the globe.



... to deliver a complete and consistent picture of the past weather/atmospheric composition.



# Example of a Reanalysis

## Copernicus Atmosphere Monitoring Service (CAMS, ECMWF)

**Time period** : 2003–2022

**Assimilated observations** :

- OMI, SCIAMACHY, GOME-2
- MOPITT, MIPAS, MLS, SBUV/2

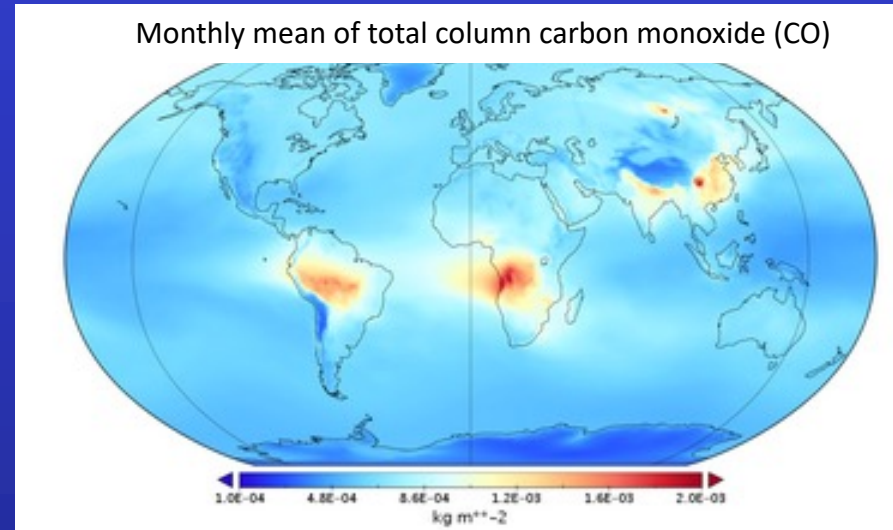
**Other assimilated observations** : Meteorology (as in ERA5)

**Vertical layers** : 25 pressure levels from 1000 to 1 hPa

**Variables** : +100 variables including  $PM_{10}$ ,  $PM_{2.5}$ ,  $PM_{1.0}$ ,  $O_3$ ,  $NO_2$ ,  $SO_2$ , CO, AOD

**Grid spacing** : T255 (80 km)

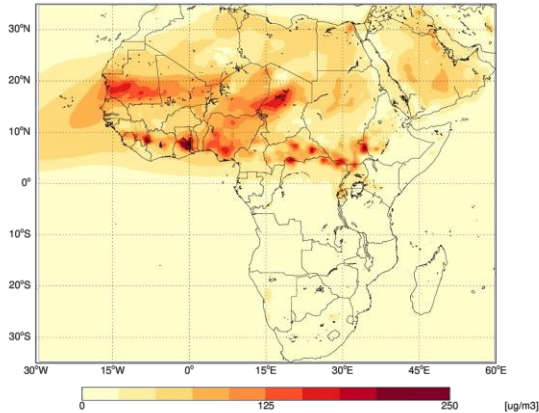
**Temporal resolution**: 3-hourly or monthly



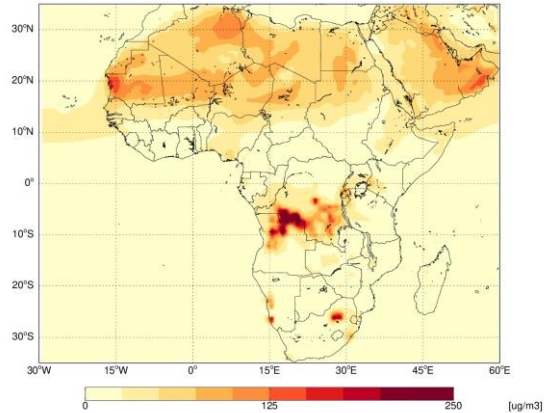


# PM<sub>2.5</sub> Concentrations (CAMS Reanalysis)

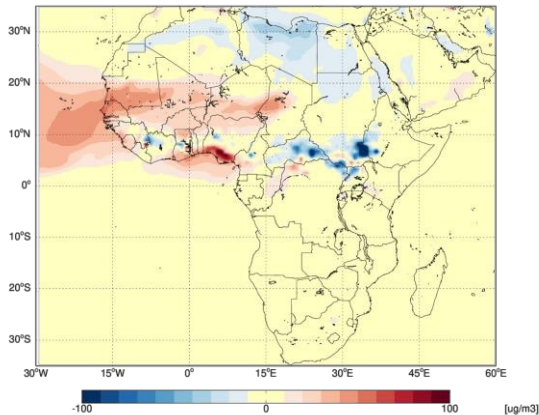
January 2003-2019



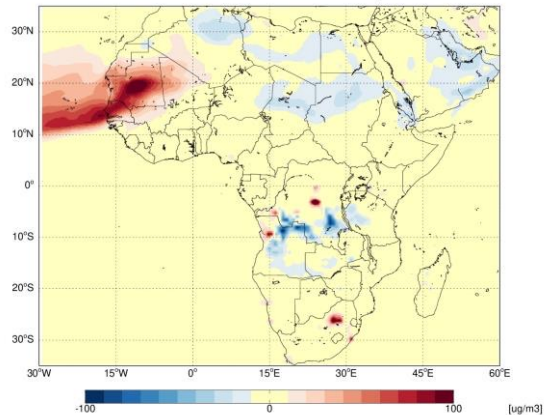
June 2003-2019



January 2020



June 2020



- This example shows January and June **monthly climatology** of surface PM<sub>2.5</sub> concentration calculated as the mean for the data from 2003-2019.
- Maps of **anomalies** for January and June 2020 highlight increased desert dust and decreased fire emissions.

# Access to CAMS Reanalysis

The Copernicus Atmosphere Data Store (ADS) is the primary data access portal of the CAMS products.

Launched June 2020

<https://atmosphere.copernicus.eu/data>

Home Search Datasets FAQ

Atmosphere Data Store

Welcome to the Atmosphere Data Store

Dive into this wealth of information about the Earth's past, present and future Atmosphere. It is freely available and functions as a one-stop shop to explore Atmosphere data. Register for free to obtain access to the ADS and its Toolbox.

We are constantly improving the services and adding new datasets. For more information, please consult the catalogue, our FAQ or the CAMS forum.

Enter search term(s)

Atmosphere Data Store API Access the CAMS Forum Access the CAMS website

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Log in

Log in Create new account Reset your password

To improve our service, we need to hear from you! Please complete this very short survey. Thank you.

Email

Password

Log in

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# Access to CAMS Reanalysis

There are two way to access data from the ADS

Terms of use

✓ Licence to use Copernicus Products [View terms](#)

Hide API request Not yet toolbox compatible **Submit Form**

Please go to [the documentation page](#) for information as to how to use the CDS API.

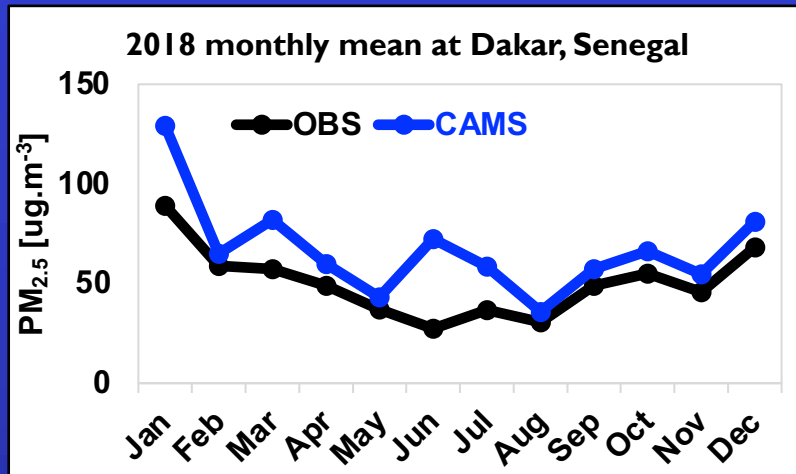
```
import cdsapi

c = cdsapi.Client()

c.retrieve(
    'cams-global-reanalysis-eac4',
    {
        'variable': 'particulate_matter_2.5um',
        'date': '2004-01-01/2021-12-31',
        'time': [
            '00:00', '03:00', '06:00',
            '09:00', '12:00', '15:00',
            '18:00', '21:00',
        ],
        'format': 'netcdf',
    },
    'download.nc')
```

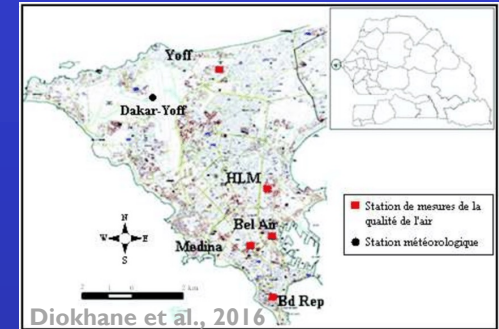
Download via web form...  
... or Python API

# Reanalysis evaluation in Dakar, Senegal

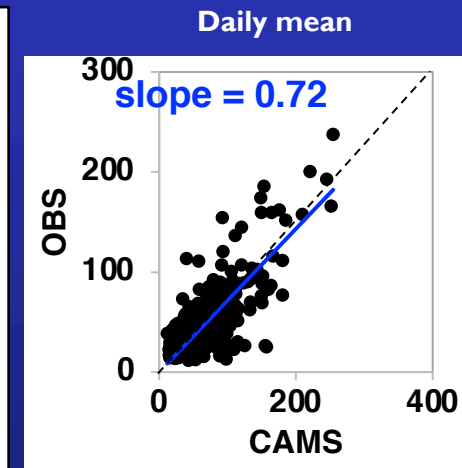
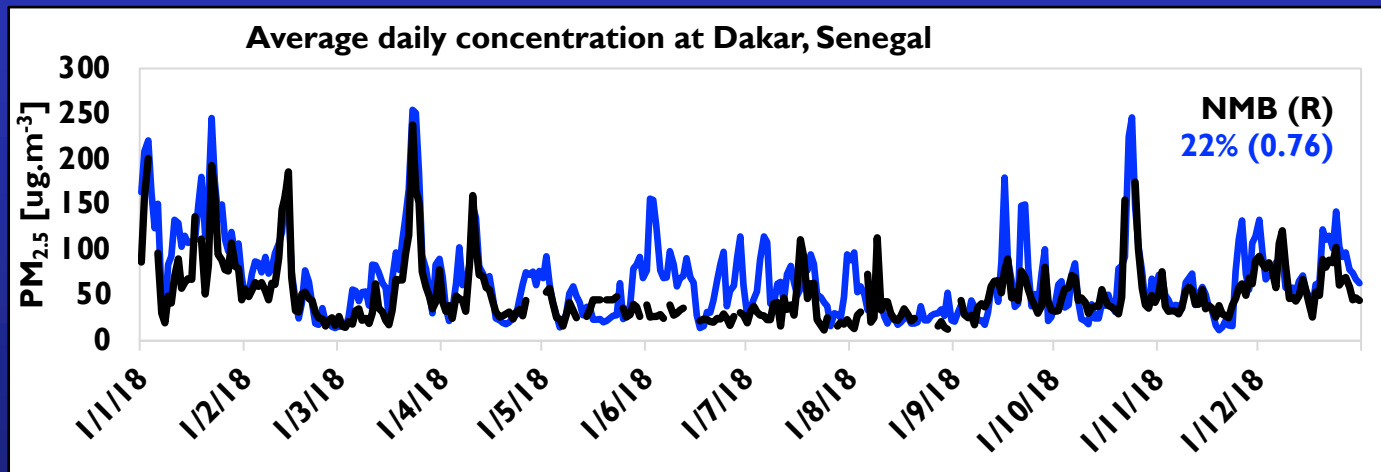


PM<sub>2.5</sub>

Centre de Gestion de la Qualité de l'Air, Dakar, Senegal (<https://www.denv.gouv.sn/stations-cgqa/>)



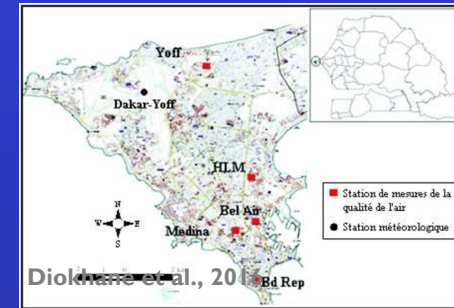
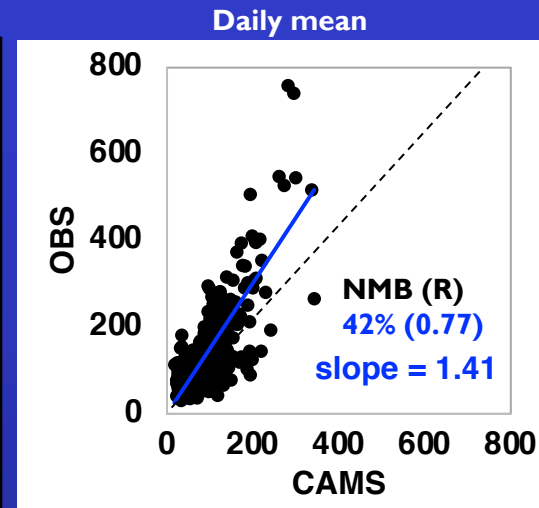
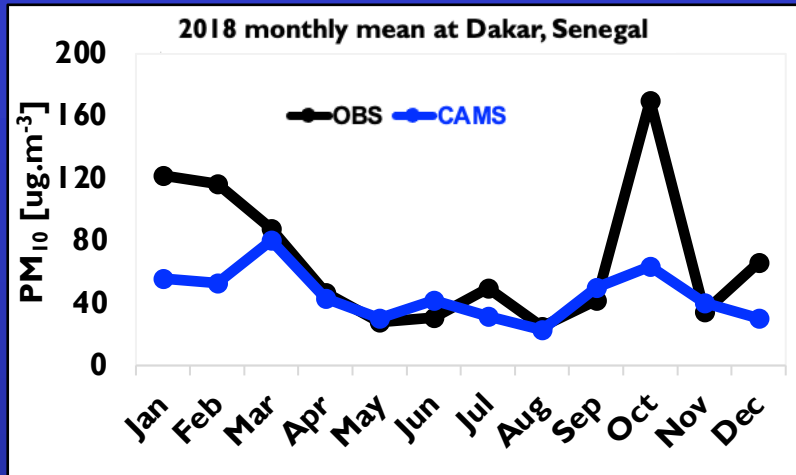
PM & Gases : Real time measurements



CAMS Reanalysis overestimates the magnitude of some daily peaks  
⇒ the coarse spatial resolution (80 km) or missing data in the in-situ measurements ?

# Reanalysis evaluation in Dakar, Senegal

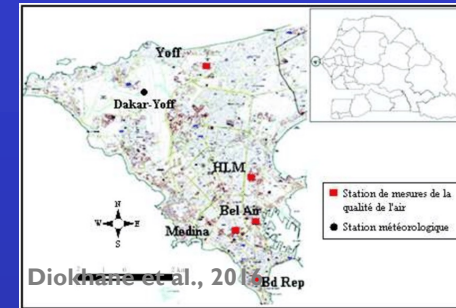
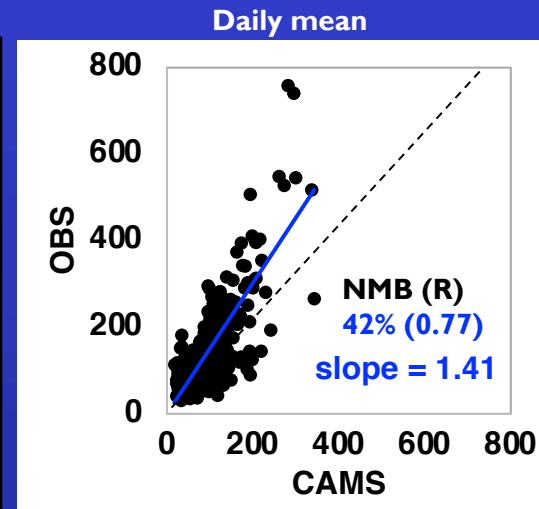
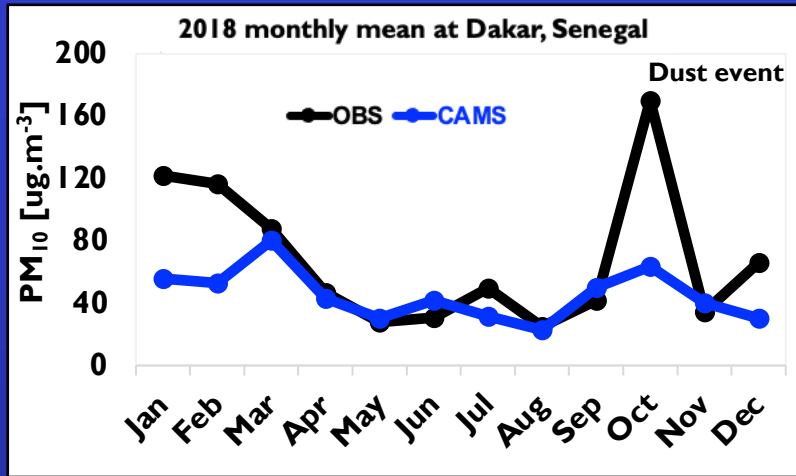
## PM<sub>10</sub>



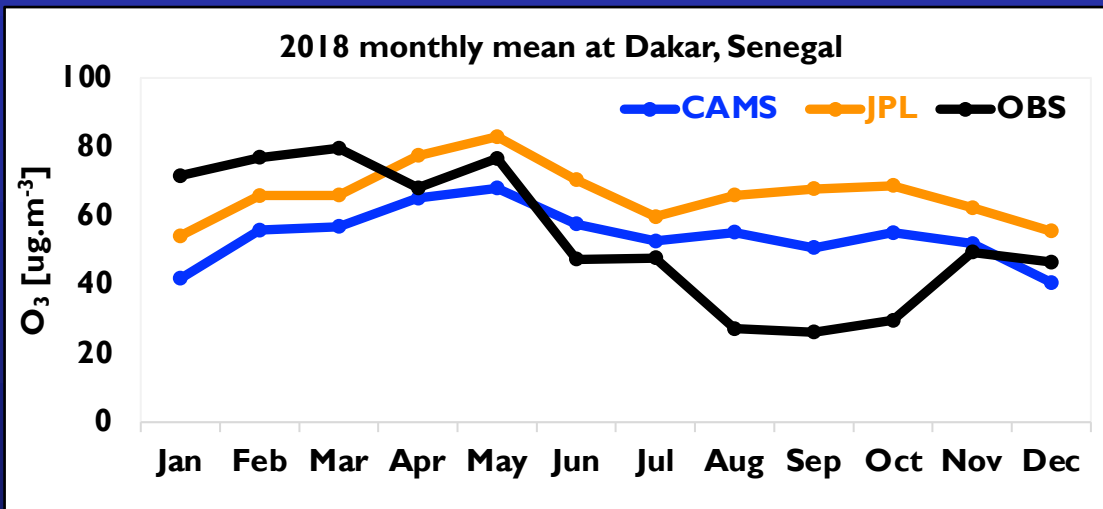
PM & Gases : Real time measurements

# Reanalysis evaluation in Dakar, Senegal

## PM<sub>10</sub>



PM & Gases : Real time measurements



## O<sub>3</sub>

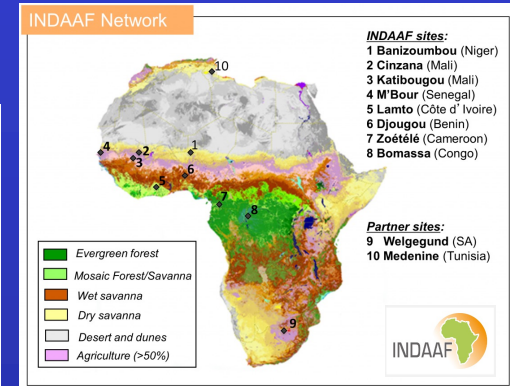
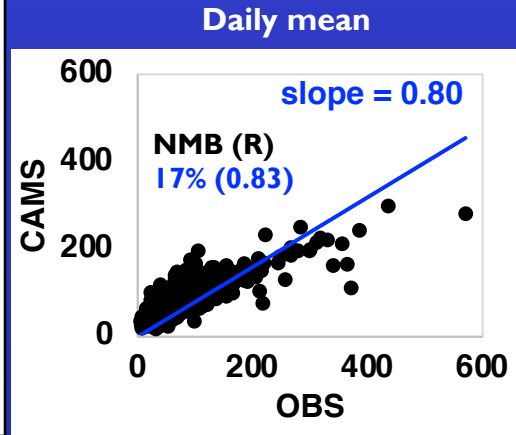
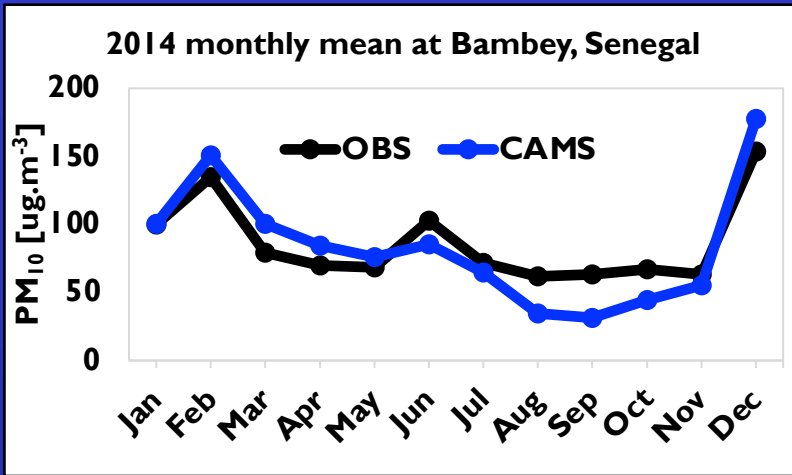
- Reanalyses underestimate concentrations in dry season and overestimate values in wet season.
- ⇒ Uncertainties in surface O<sub>3</sub> retrieval from satellites can explain observed differences, in addition to the spatial resolution issue.

# Reanalysis evaluation using INDAAF measurements

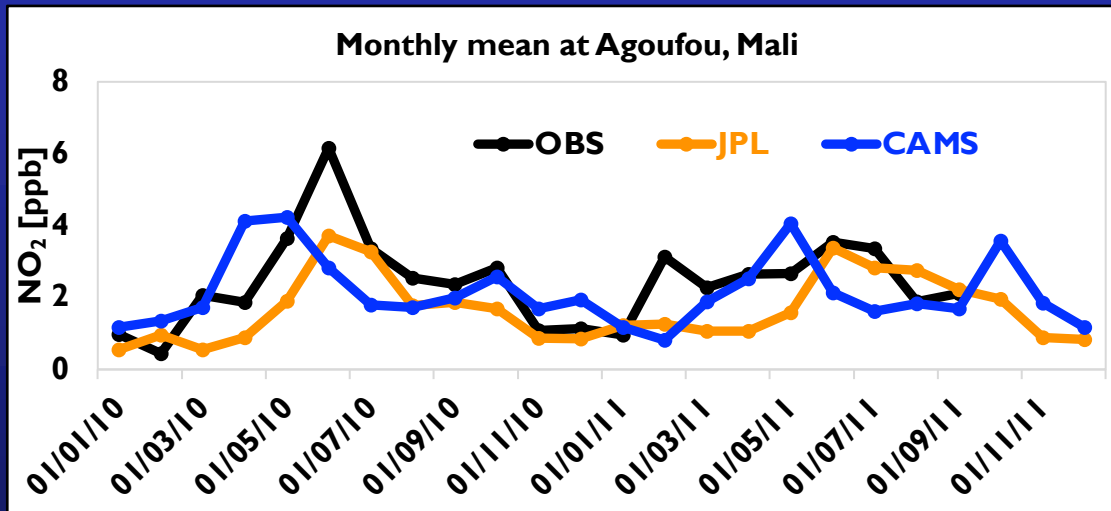
Better agreement for PM in the background/rural sites.

**PM<sub>10</sub>**

International Network to study Deposition and Atmospheric chemistry in Africa (<https://indaaf.obs-mip.fr/>)



- PM<sub>10</sub>: Real time measurements  
- Gases: Weekly samples



**NO<sub>2</sub>**

- Differences in peak concentrations.

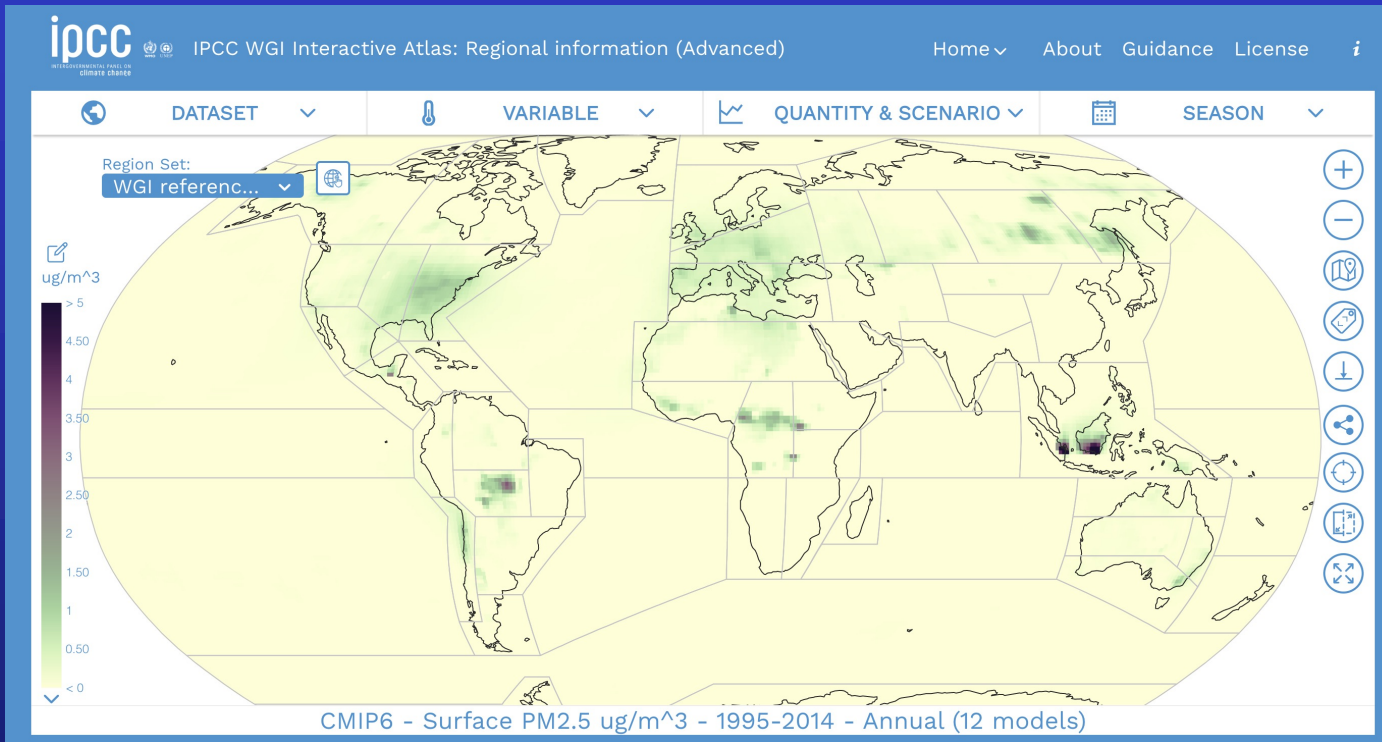
=> Uncertainties in emissions of O<sub>3</sub> precursors in reanalyses contribute to observed differences.



# Examples of Air Quality Atlas

IPCC interactive Atlas assesses changes in mean climate at regional scales, in particular observed trends and their attribution and projected future changes.

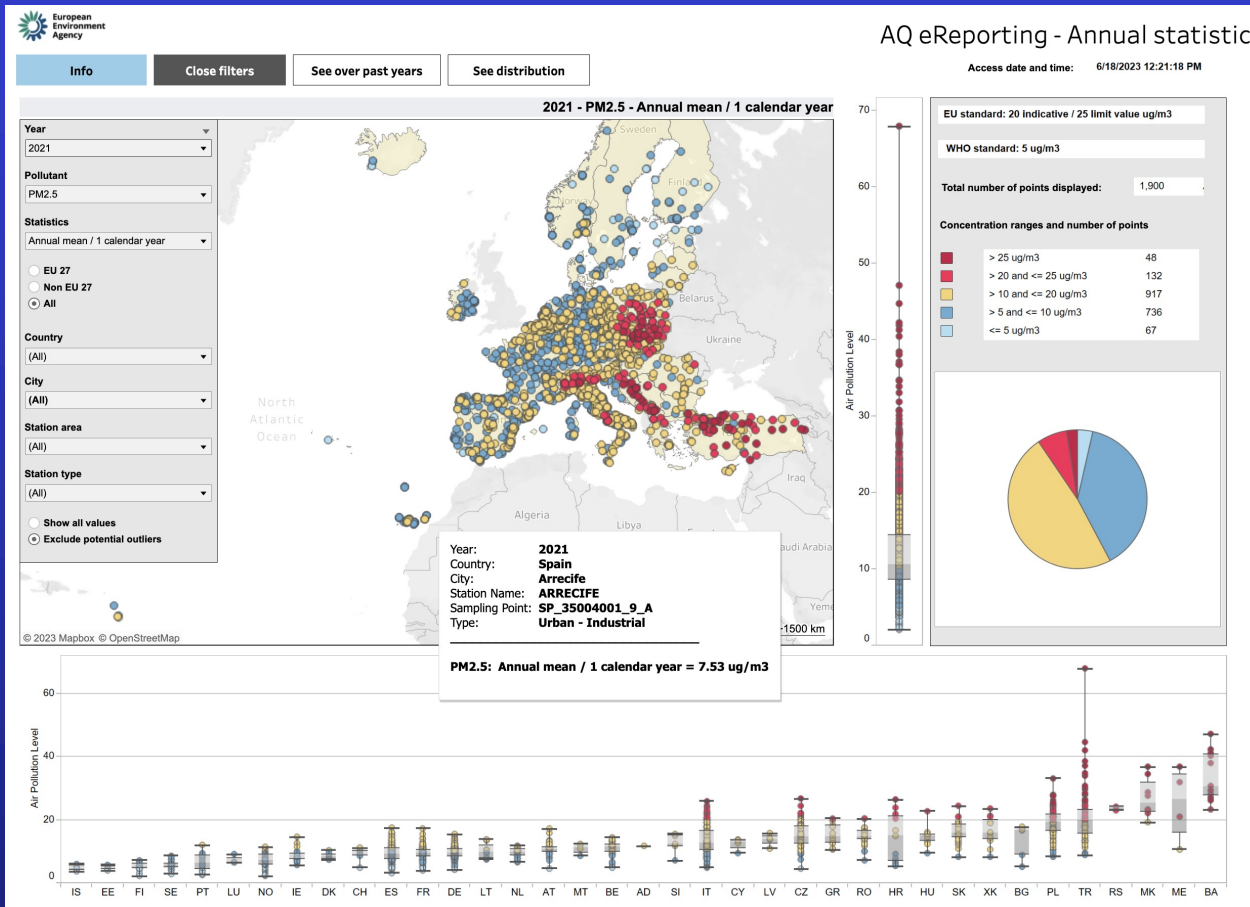
## CMIP6 PM<sub>2.5</sub> - 1995-2014 Annual (12 models)



The atlas includes climate variables (T, Precipitation), as well as PM<sub>2.5</sub> and O<sub>3</sub>.

# Examples of Air Quality Atlas

## Key air quality statistics for the main air pollutants



**Period : 2013-2021**

**List of species : NO<sub>2</sub>, CO, O<sub>3</sub>, PM<sub>2.5</sub>, PM<sub>10</sub>, SO<sub>2</sub>, and some metals**

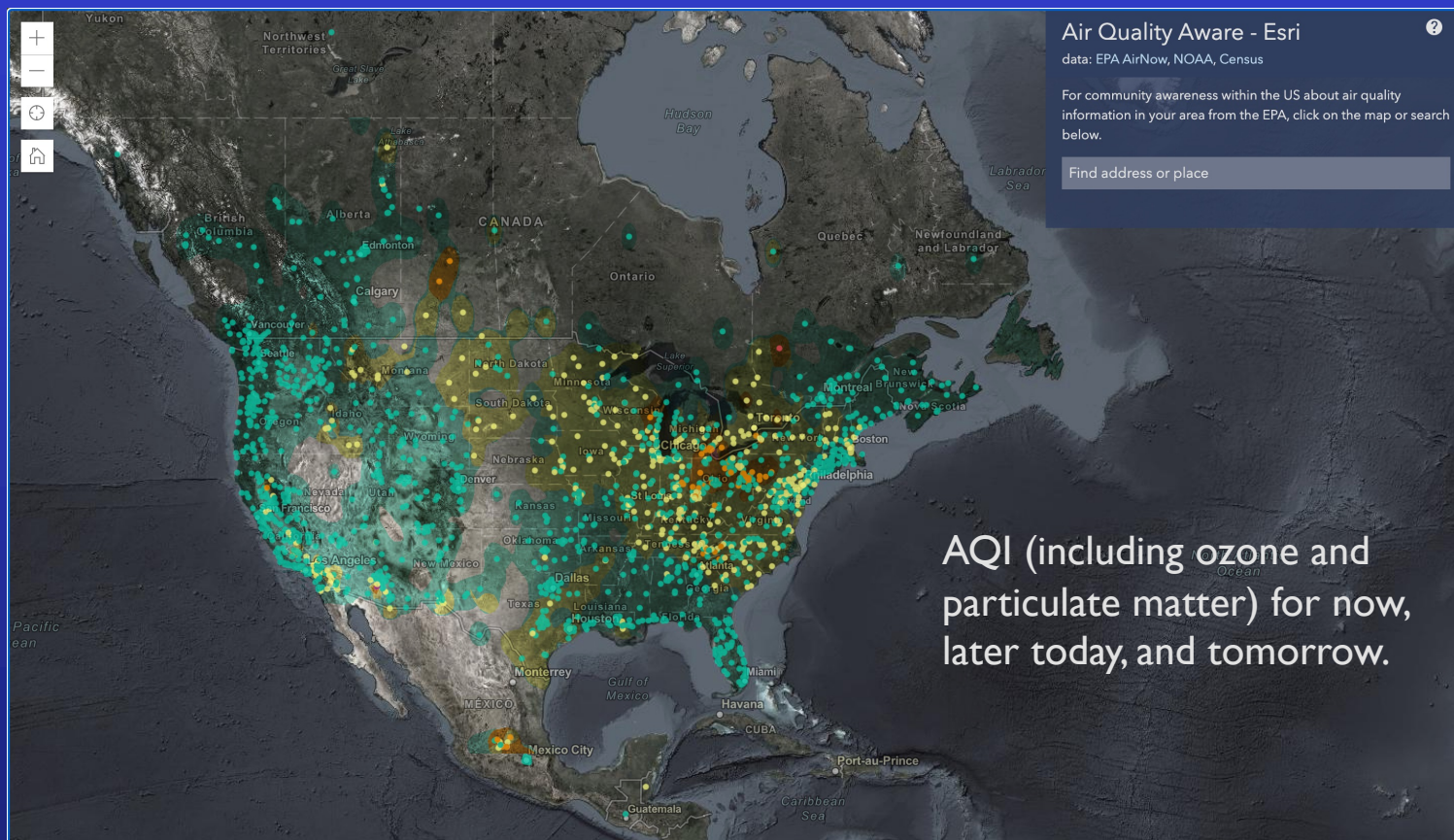
**Time resolution : hourly, daily, or annual**

**Spatial coverage : European countries**

<https://www.eea.europa.eu/data-and-maps/dashboards/air-quality-statistics>

# Examples of Air Quality Atlas

This atlas provides information about the current conditions of air quality in the US, along with the potential human health impacts.



<https://livingatlas.arcgis.com/airquality/>

data sources: EPA AirNow program, NOAA National Weather Service forecast and US Census

# AQWA (AQ-WATCH Atlas)



HOME

REANALYSIS ▾

SATELLITE

ACCOUNT

LOGOUT

CAMS

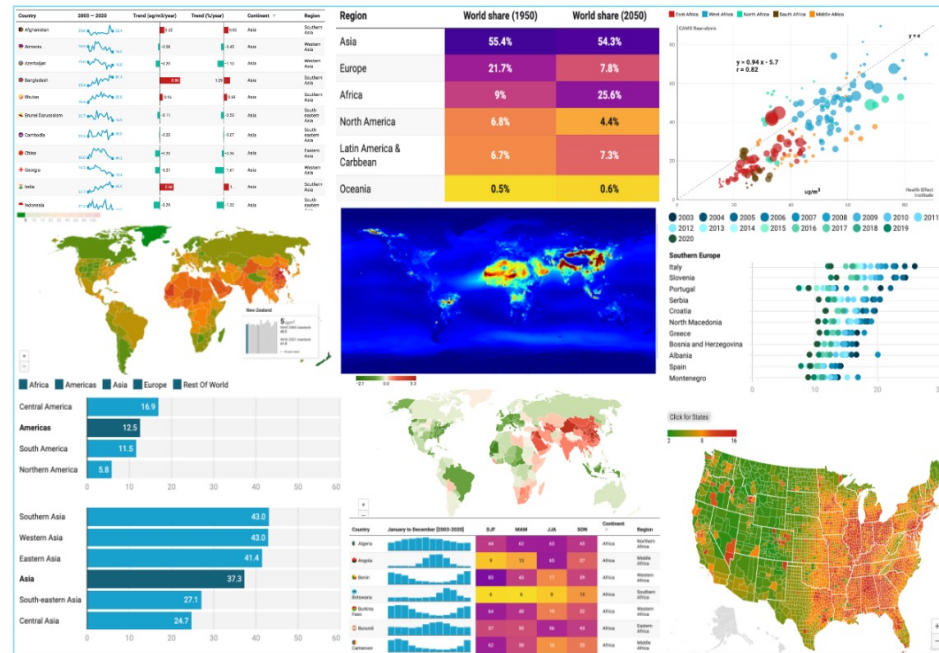
CMAQ

## Air Quality - Worldwide analysis and forecasting of ATmospheric Composition for Health

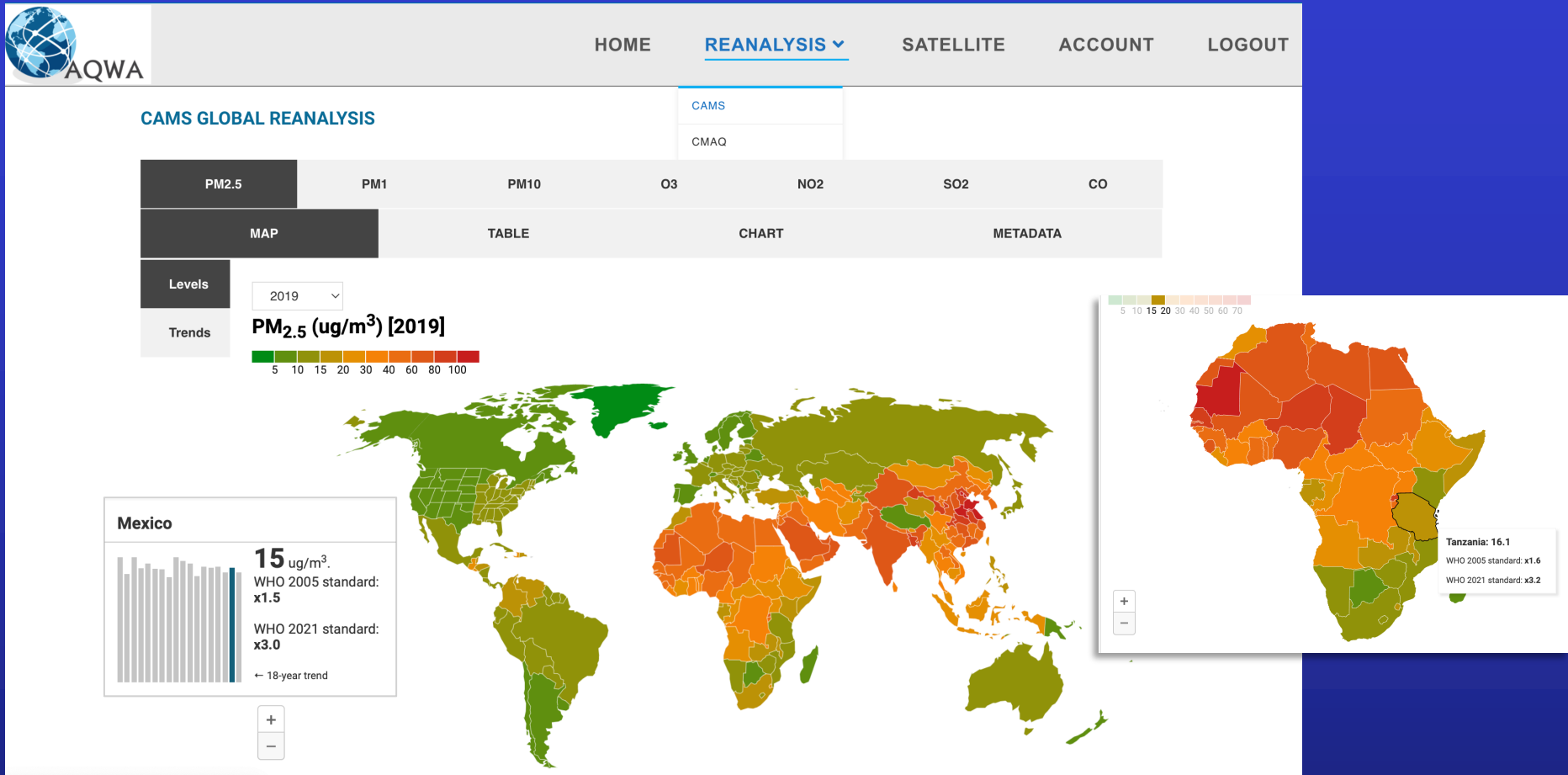
### AQ-WATCH Atlas (AQWA)

The goal of the **AQ-WATCH** atlas (AQWA) is to design and produce an air pollution atlas based on reanalysis data that includes the climatological distribution of chemical atmospheric compounds such as surface particulate matter (PM1, PM2.5, PM10), trace gases (O3, NO2, SO2, CO), black carbon, and organic aerosol optical depth, as well as air quality index (AQI) level.

Satellite observations of NO2 tropospheric columns are also included in the atlas. For each country on the planet, as well as each state and county in the United States, the atlas provides users with historical and current spatial distribution, as well as year-to-year and seasonal variations and long-term trends.



# Global Air Quality Atlas

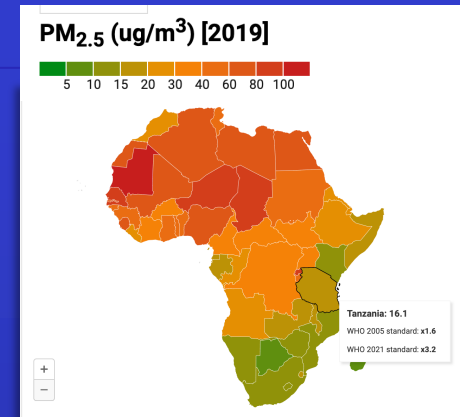


AQWA (AQ-WATCH Atlas) based on **CAMS** reanalyses and satellite observations for the Past Two Decades.

# Global Air Quality Atlas

The atlases can be used to :

- check if the recommended air quality guidelines by the WHO (World Health Organisation) are met.
- display the Air Quality Index at country, state, province, or city level.



## WHO 2021 Air Quality Guidelines

Table 0.1. Recommended AQG levels and interim targets

Pollutant	Averaging time	Interim target				AQG level
		1	2	3	4	
PM <sub>2.5</sub> , µg/m <sup>3</sup>	Annual	35	25	15	10	5
	24-hour <sup>a</sup>	75	50	37.5	25	15
PM <sub>10</sub> , µg/m <sup>3</sup>	Annual	70	50	30	20	15
	24-hour <sup>a</sup>	150	100	75	50	45
O <sub>3</sub> , µg/m <sup>3</sup>	Peak season <sup>b</sup>	100	70	–	–	60
	8-hour <sup>a</sup>	160	120	–	–	100
NO <sub>2</sub> , µg/m <sup>3</sup>	Annual	40	30	20	–	10
	24-hour <sup>a</sup>	120	50	–	–	25
SO <sub>2</sub> , µg/m <sup>3</sup>	24-hour <sup>a</sup>	125	50	–	–	40
CO, mg/m <sup>3</sup>	24-hour <sup>a</sup>	7	–	–	–	4

<sup>a</sup> 99th percentile (i.e. 3–4 exceedance days per year).

<sup>b</sup> Average of daily maximum 8-hour mean O<sub>3</sub> concentration in the six consecutive months with the highest six-month running-average O<sub>3</sub> concentration.

The AQI is defined as an overall scheme that transforms weighted values of individual air pollution related parameters (SO<sub>2</sub>, CO, NO<sub>2</sub>, etc.) into a single number or set of numbers.

# Global Air Quality Atlas



HOME

REANALYSIS ▾

SATELLITE

ACCOUNT

LOGOUT

## CAMS GLOBAL REANALYSIS

CAMS

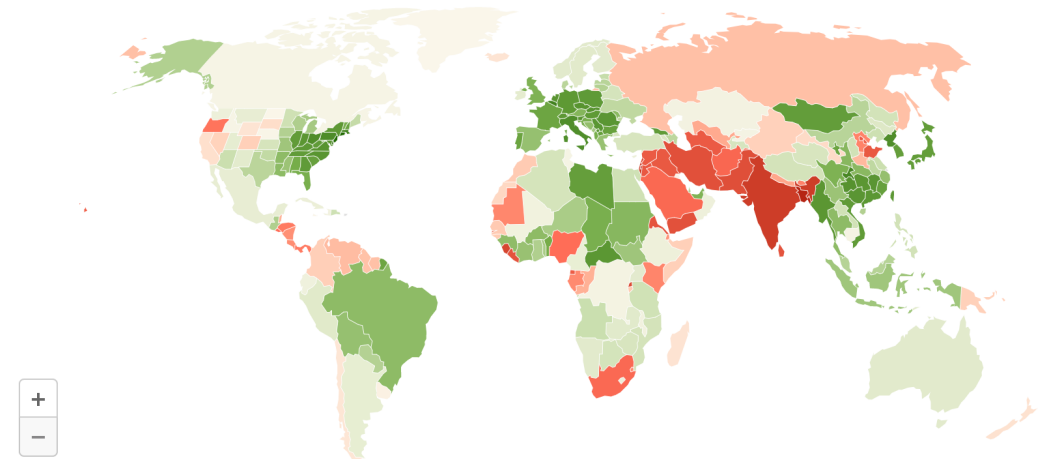
CMAQ

PM2.5	PM1	PM10	O3	NO2	SO2	CO
MAP	TABLE		CHART			METADATA

Levels

Trends

PM<sub>2.5</sub> Trend [ ug/m3/yr ] 2003-2020



2003-2010

2003-2015

2003-2020

2005-2010

2005-2015

2005-2020

2010-2015

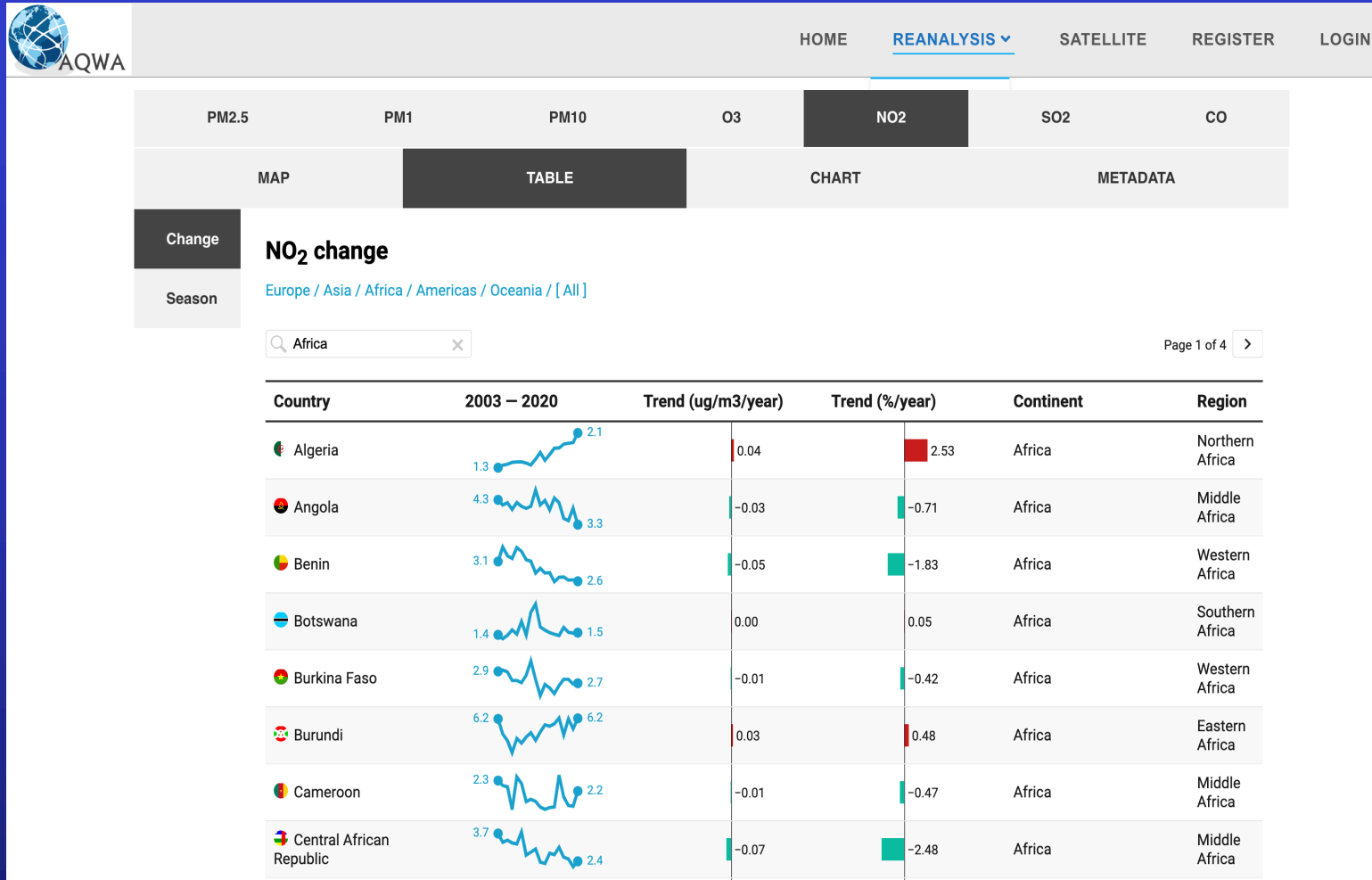
2010-2020

2015-2020

Figure shows change in PM<sub>2.5</sub> in each country, state in the United States and province in China from 2003 to 2020.

# Regional Air Quality Atlas

## Trends in African Countries

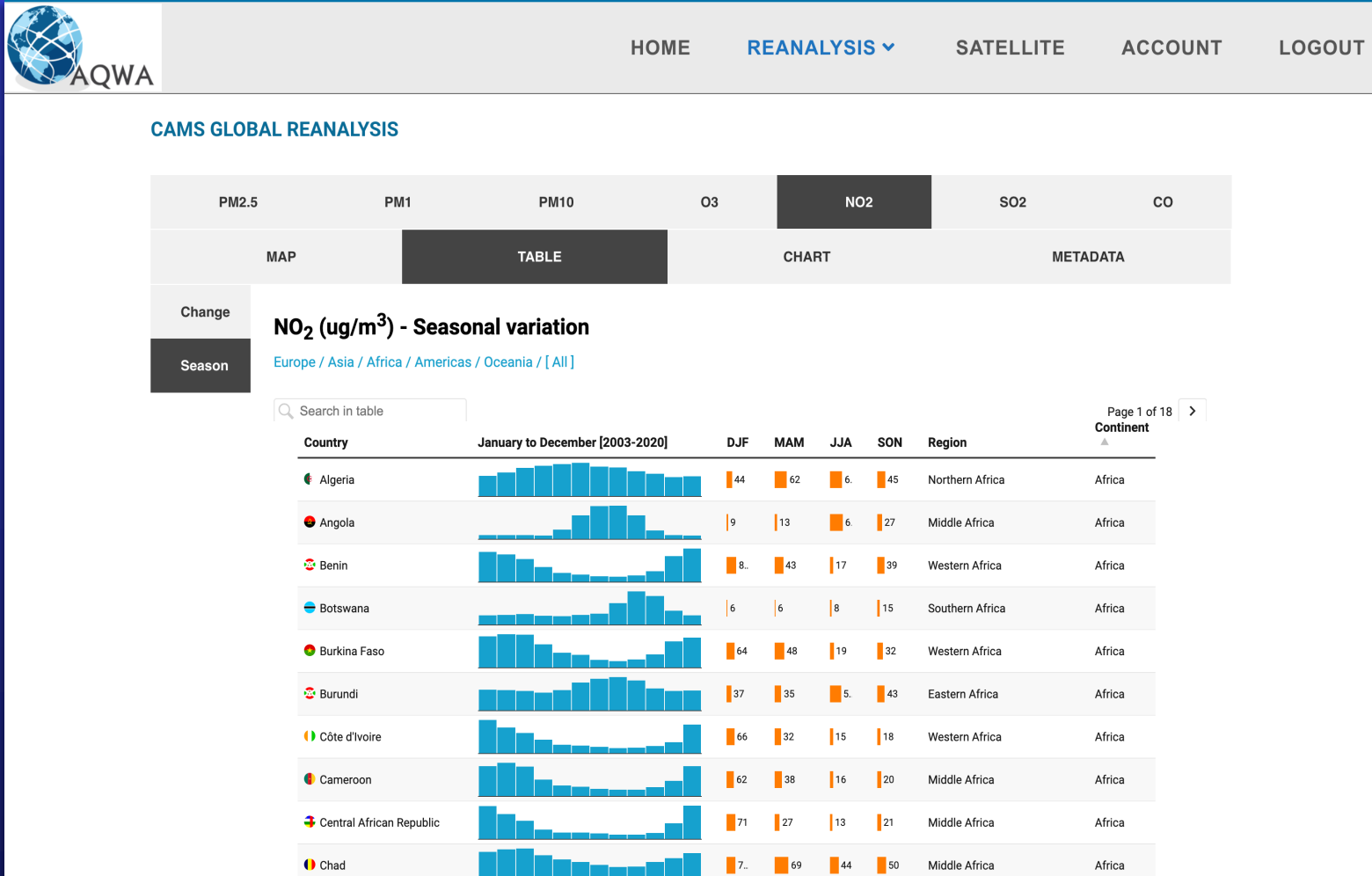


Aside from the trend maps, changes in air pollution can be displayed as a table with time evolution as a graph and absolute or percentage values.



# Regional Air Quality Atlas

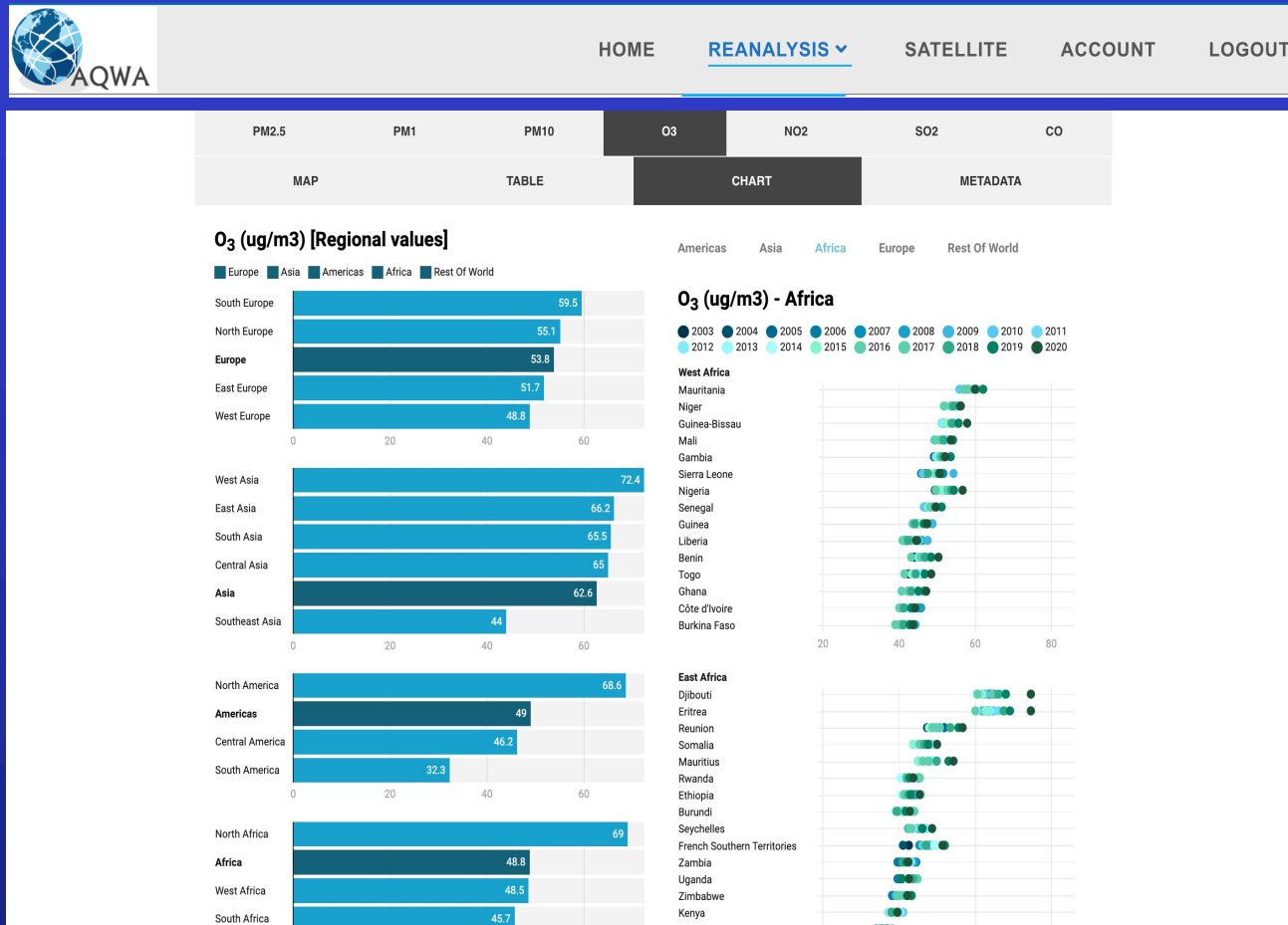
## Seasonal variations



Seasonal variations in climatological average NO<sub>2</sub> concentrations (2003-2020) in the different countries in Africa.

# Regional Air Quality Atlas

## Regional comparison



The atlas also provides regional values of air pollutants (left panel). In the right panel, annual O<sub>3</sub> levels in African countries are shown.

# Air Quality Index (AQI) Calculation

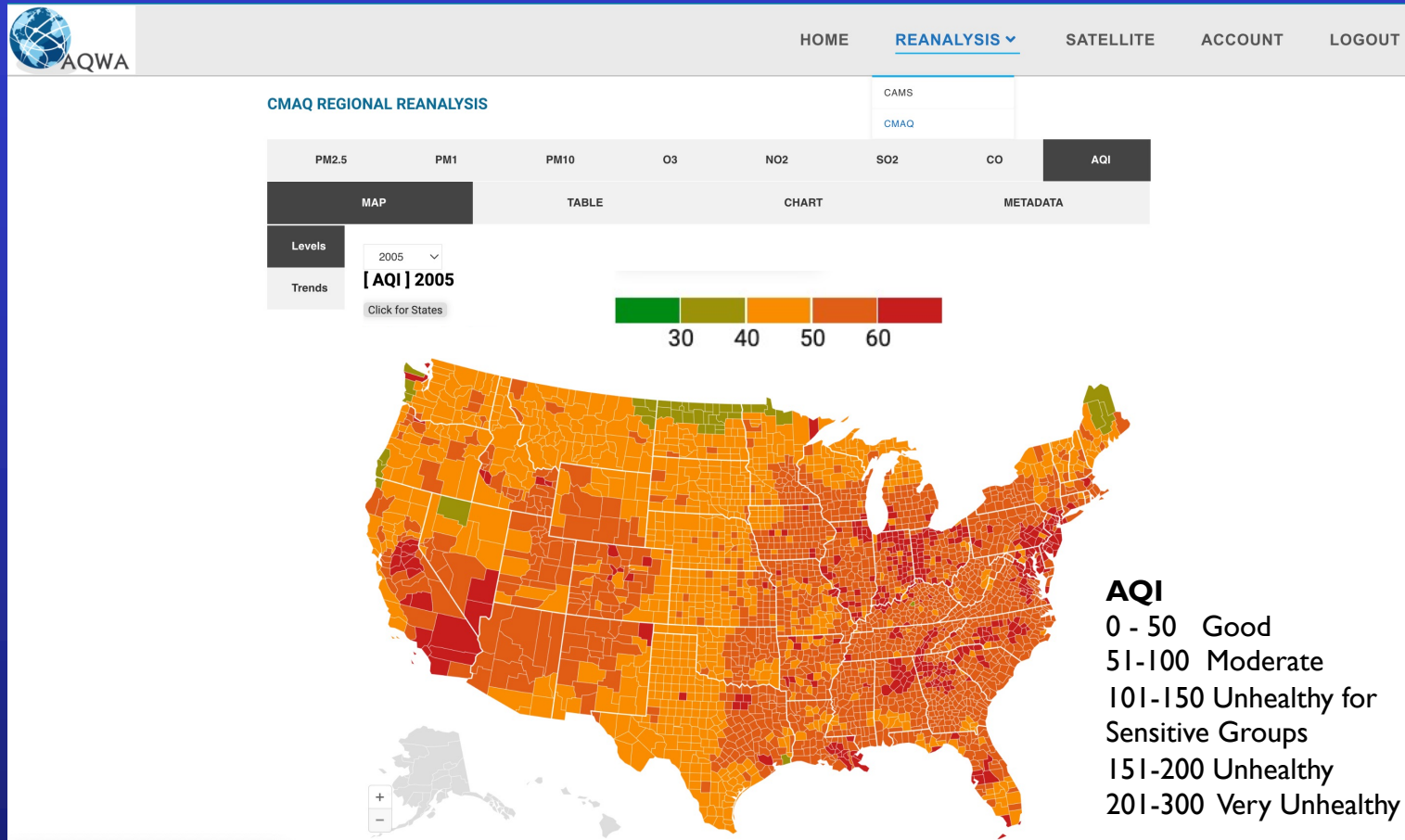
Index	Method	Definition	Pollutants & Avg. time
<b>EEA (AQI 1h/24h)</b>	Based on the breakpoint values* for up to key 5 pollutants. <b>*defined concentrations or sub-indices</b>	The AQI is defined as the sub-index that represents the worst quality among the key pollutants.	<b>PM</b> (24h) <b>NO<sub>2</sub>, SO<sub>2</sub>, O<sub>3</sub></b> (1h)
<b>US EPA (AQI 24h)</b>	$I_p = \frac{I_{Hi} - I_{Lo}}{BP_{Hi} - BP_{Lo}} (C_p - BP_{Lo}) + I_{Lo}$ <p><i>I<sub>p</sub></i> index for pollutant p <i>I<sub>Hi</sub></i> AQI corresponding to BP<sub>Hi</sub> <i>I<sub>Lo</sub></i> AQI corresponding to BP<sub>Lo</sub></p> <p><i>C<sub>p</sub></i> conc. Pollutant p BP<sub>Hi</sub> conc. Breakpoint ≥ <i>C<sub>p</sub></i> BP<sub>Lo</sub> conc. Breakpoint ≤ <i>C<sub>p</sub></i></p>	The AQI is the highest value calculated from the equation applied for each pollutant.	<b>PM</b> (24h) <b>NO<sub>2</sub>, SO<sub>2</sub></b> (max 1h) <b>O<sub>3</sub></b> (max 1h or 8h), <b>CO</b> (max 8h)
<b>UK (AQI 24h)</b>	The index is calculated from the highest concentration of the 5 pollutants.	The AQI is defined as the maximum value of the index.	<b>PM</b> (24h) <b>NO<sub>2</sub></b> (1h) <b>O<sub>3</sub></b> (8h), <b>SO<sub>2</sub></b> (15min)
<b>India (AQI 24h)</b>	Using sub-indices characterising 8 pollutants based on national standards.	The final AQI is equal to the worst sub-index.	<b>PM, NO<sub>2</sub>, SO<sub>2</sub>, NH<sub>3</sub>, Pb</b> (24h) <b>O<sub>3</sub>, CO</b> (8h)
<b>China (AQI 1h/24h)</b>	Based on the concentration of 6 pollutants, each of which is assigned a individual score.	The highest of the six scores.	<b>PM, NO<sub>2</sub>, SO<sub>2</sub>, CO &amp; O<sub>3</sub></b>

According to the CAMS reanalysis, it is possible to calculate AQI using any of these methods, however due to the time resolution (3-hourly), pollution peaks may be missed. That needs to be taken into account in the analysis of the results.

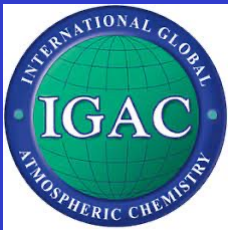
# Air Quality Index (AQI) Calculation

AQWA (AQ-WATCH Atlas) based on **WRF-CMAQ** simulations.

The high spatial resolution (12km x12km) allows calculating AQI at county level.



The spatial distribution of the AQI in the CONUS area in 2005.



# AMIGO Working Group: Chemical Reanalysis And flux iNvErsions (CRANES)

Co-chairs: Benjamin Gaubert<sup>1</sup>, Idir Bouarar<sup>2</sup>,  
Thierno Doumbia<sup>3</sup>

(1) National Center for Atmospheric Research, Boulder, USA

(2) Max Planck Institute for Meteorology, Hamburg, Germany

(3) Laboratoire d'Aérodynamique, Toulouse, France

## Goal of the CRANES WG

Promote the **use** and **availability** of chemical reanalysis and inversion datasets.





# Current activities and perspectives

- ⇒ Workshop / Training sessions on chemical reanalysis, inverse modelling, and assimilation data
- ⇒ Establishing a list of available **chemical reanalysis** and **inversion datasets** for a dedicated website

<https://www2.acom.ucar.edu/cranes>

- ✓ Copernicus Atmosphere Monitoring Service reanalysis (CAMSR)
- ✓ Tropospheric Chemistry Reanalysis version 2 (TCR-2)
- ✓ Jet Propulsion Lab (JPL) Reanalysis
- ✓ Global atmospheric carbon monoxide budget 2000–2017 inferred from multi-species atmospheric inversions
- ✓ NCAR/MOPITT Reanalysis
- ✓ BASCOE Reanalysis of Aura MLS version 2 (BRAM2)
- ✓ ...

The screenshot shows the NCAR Atmospheric Chemistry Observations & Modeling website. The page is titled "Overview of chemical reanalyses" and lists several reanalysis datasets. The first dataset is "Copernicus Atmosphere Monitoring Service reanalysis (CAMSR)" with a period from 2003 to the present. It lists assimilated observations from OMI, MOPITT, and SCIAMACHY. The second dataset is "Tropospheric Chemistry Reanalysis version 2 (TCR-2)" with a period from 2005 to 2018, updated to 2021. It lists assimilated observations from OMI, MOPITT, TES, and MLS.

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Home / Chemical Reanalyses

## Overview of chemical reanalyses

CHEMICAL REANALYSES

- CRANES
- Overview of chemical reanalyses

**Copernicus Atmosphere Monitoring Service reanalysis (CAMSR)**

Period: 2003–

**Assimilated observations:**

- OMI, SCIAMACHY, GOME-2 NO<sub>2</sub>
- MOPITT CO
- SCIAMACHY, MIPAS, MLS, OMI, GOME-2, SBUV/2

Assimilation system:

**Other assimilated observations:** Meteorology (as in ERA5)

**Online dynamic:** Yes

**Interactive chemistry:** Yes

**Grid spacing:** T255 (80 km)

**Assimilation window:** 3h

**Dataset location:** <https://ads.atmosphere.copernicus.eu/cdsapp#!/dataset/cams-global-reanalysis-eac4?tab=form>

**References:** Inness, A., Ades, M., Agustí-Panareda, A., Barré, J., Benedictow, A., Blechschmidt, A.-M., Dominguez, J. J., Engelen, R., Eskes, H., Flemming, J., Huijnen, V., Jones, L., Kipling, Z., Massart, S., Parrington, M., Peuch, V.-H., Razinger, M., Remy, S., Schulz, M., and Suttie, M.: The CAMS reanalysis of atmospheric composition, *Atmos. Chem. Phys.*, 19, 3515–3556, <https://doi.org/10.5194/acp-19-3515-2019>, 2019.

**Tropospheric Chemistry Reanalysis version 2 (TCR-2)**

Period: 2005–2018, updated to 2021.

**Assimilated observations:**

- OMI, SCIAMACHY, GOME-2 NO<sub>2</sub>
- MOPITT v7 CO
- TES, MLS O<sub>3</sub>
- MLS HNO<sub>3</sub>

# Current activities and perspectives



- Data collection is still ongoing
- Anyone interested in contributing to the CRANES working group is also welcome
- For more information visit <https://amigo.aeronomie.be/>

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# Conclusions

- ⦿ **Chemical reanalysis can provide relatively good information about the recent history of atmospheric composition in various parts of the world**
- ⦿ **Atlases can be used to :**
  - understand historical pollution level and how it changes over time
  - identify air pollution hotspots
  - compare concentration levels across countries, states, provinces, and cities
  - assess the impact of policy decisions on air quality.
- ⦿ **A new CAMS reanalysis will start in January 2024 and cover the period 2000-2025 at higher resolution than the current one.**

**Thank you for your  
attention**