Air Quality (AQ) Atlases

https://igacproject.org/activities/amigo

Thierno DOUMBIA*

&

Claire Granier (Laboratoire d'Aerologie, Toulouse, France* & NCAR, Boulder, USA)

Benjamin Gaubert (National Center for Atmospheric Research, Boulder, USA)

Idir Bouarar (Max Planck Institute for Meteorology, Hamburg, Germany)

Paulette Middleton (Panorama Pathways, Boulder, USA)

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

AMIGO Workshop
19-20 June 2023
Brussels, Belgium

Overview

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

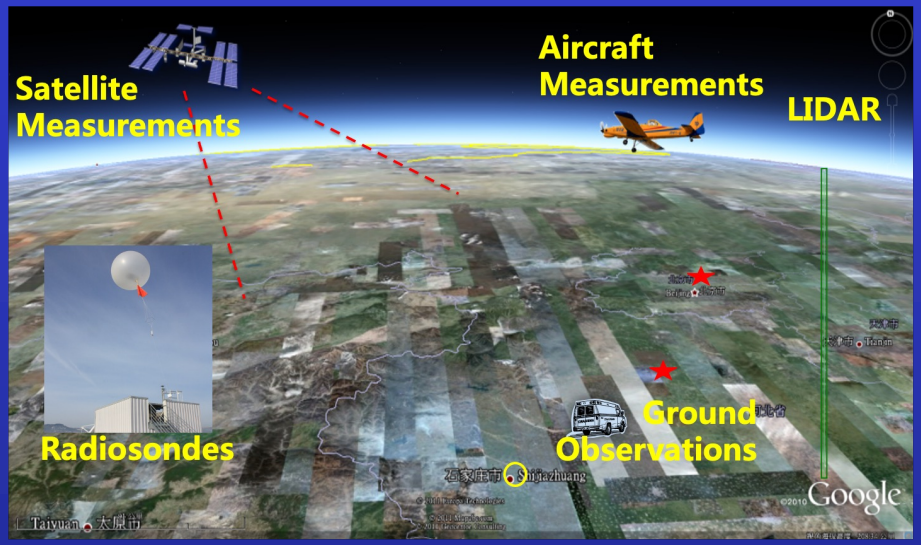
AQ-WATCH : Air Quality Worldwide Analysis and Forecasting of Atmospheric Composition for Health

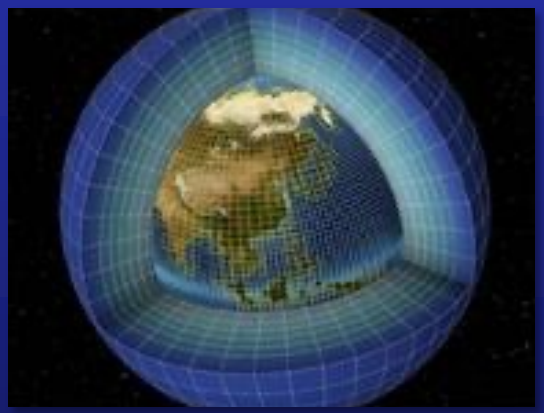
CRANES : Chemical Reanalysis And flux iNvErsionS

Inputs for Air Quality Atlases

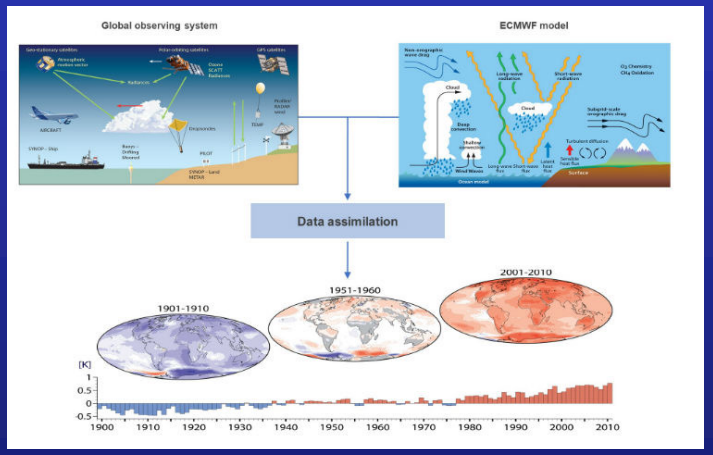
Atlas = A collection of maps or charts

Observations





Models

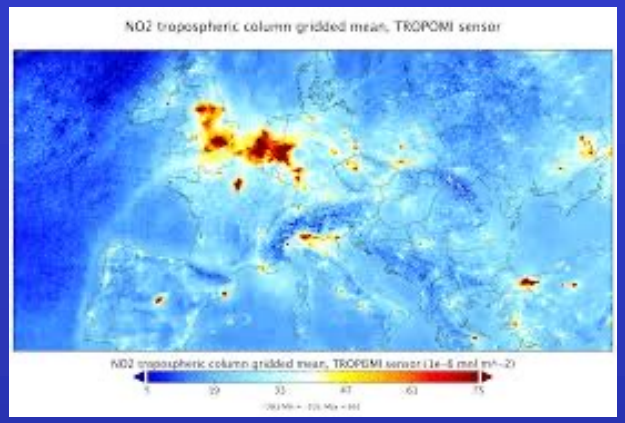


Atmospheric Reanalysis

Satellite Observations & Model Outputs

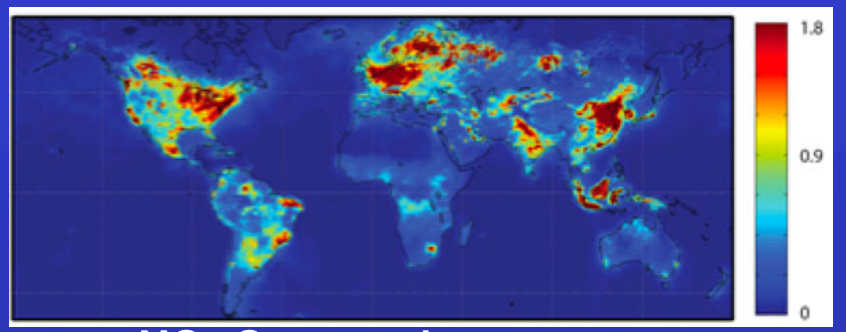
TROPOMI on Sentinel-5P

NO_2 trop. column
since 2017
5.5km x 3.5km (7km x 3.5km before 6/8/2019)



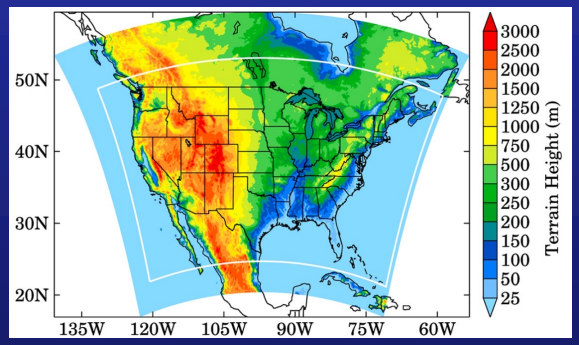
See Deborah's presentation

OMI on AURA Platform



NO_2, O_3 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_1, $PM_{2.5}$, PM_{10}, O_3, NO_2, SO_2, CO, AQI
+ some meteorological fields

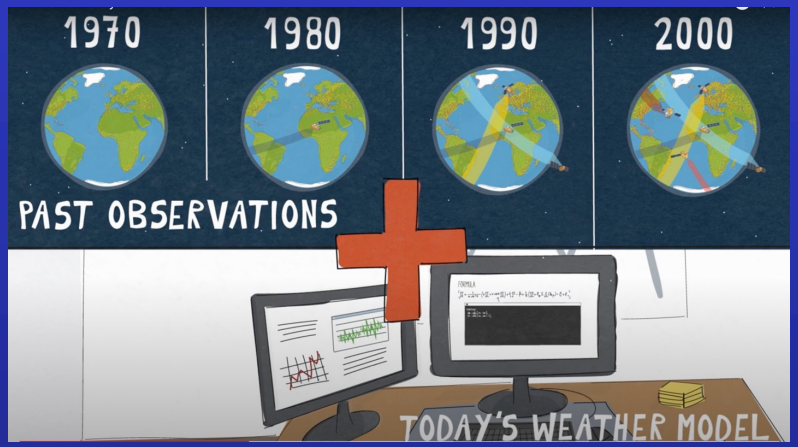
Atmospheric Reanalysis

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.

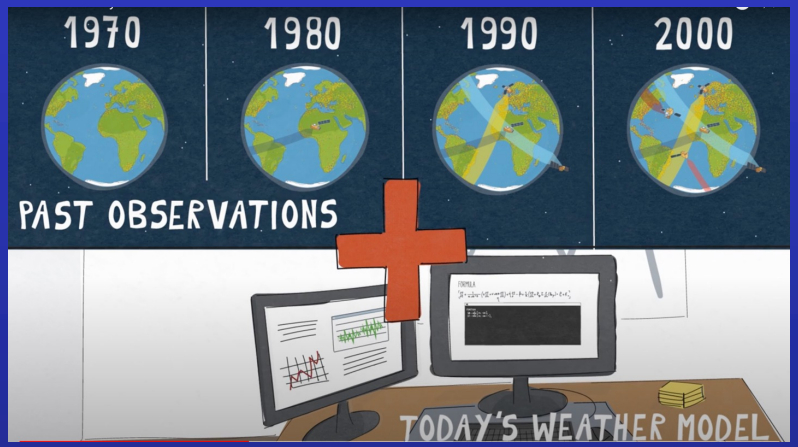
Atmospheric reanalysis combines observations made in the past with today's weather/atmospheric model through assimilation methods …



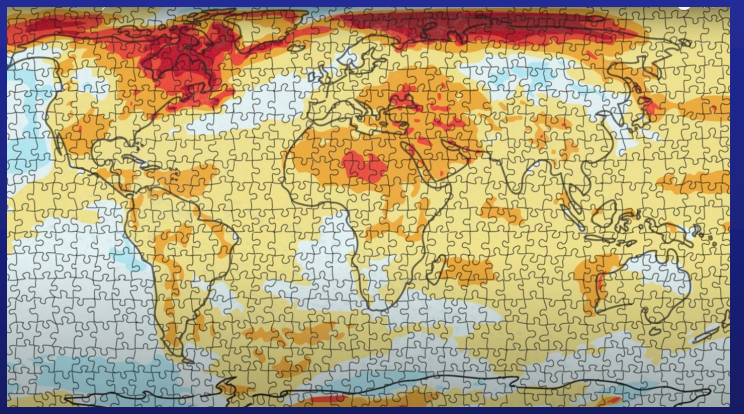
Atmospheric Reanalysis

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 …

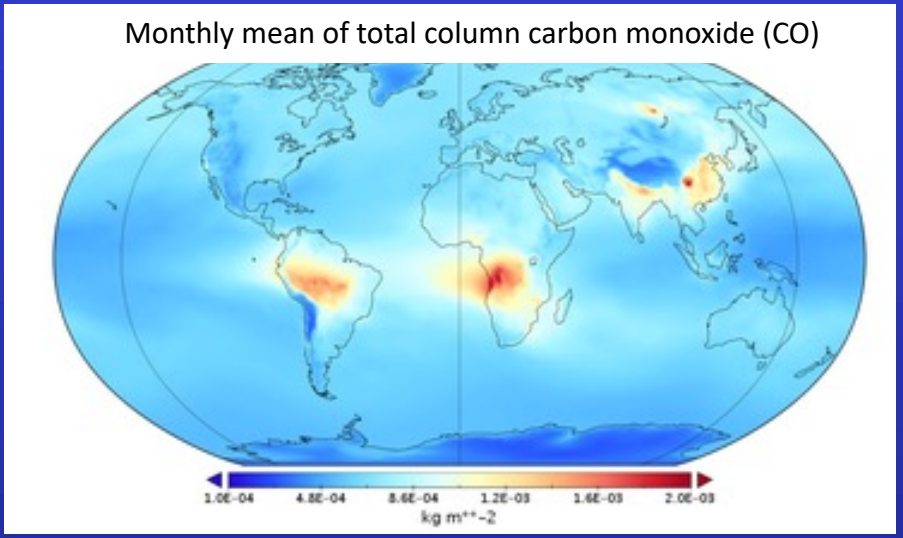


… to deliver a complete and consistent picture of the past weather/atmospheric composition.



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)

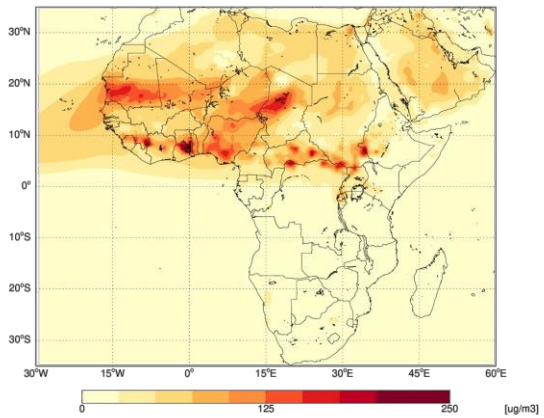
Vertical layers : 25 pressure levels from 1000 to 1 hPa

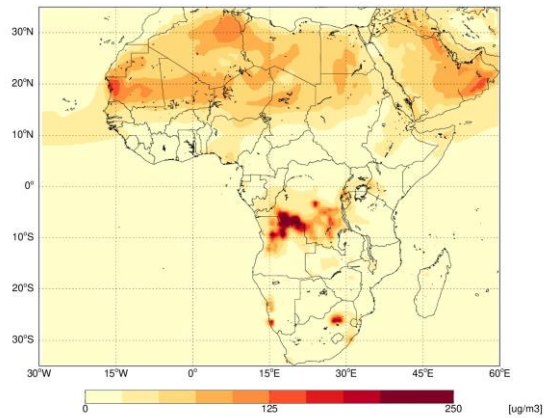
Variables : +100 variables including PM_1, $PM_{2.5}$, PM_{10}, O_3, NO_2, SO_2, CO, AOD

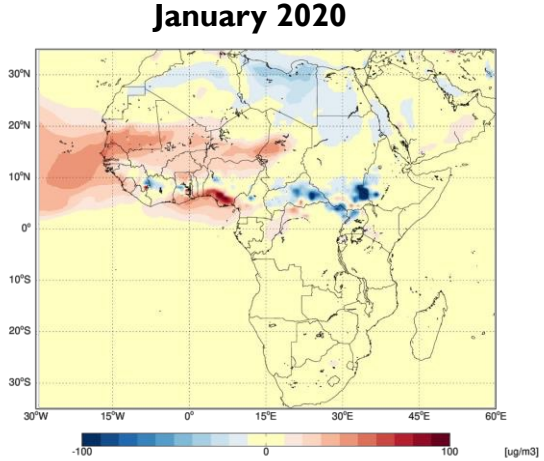
Grid spacing : T255 (80 km)

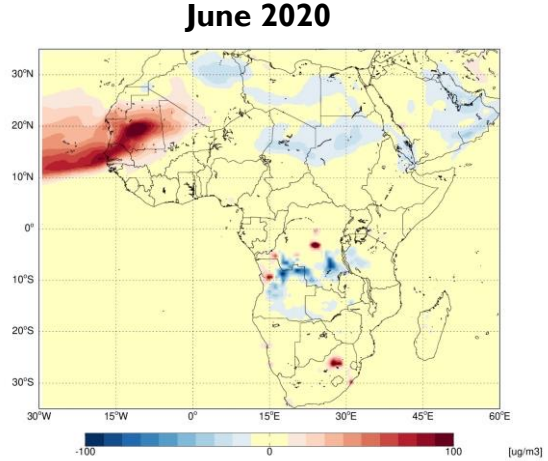
Temporal resolution: 3-hourly or monthly

$PM_{2.5}$ Concentrations (CAMS Reanalysis)









- This example shows January and June **monthly climatology** of surface $PM_{2.5}$ concentration calculated as the mean for the data from 2003-2019.

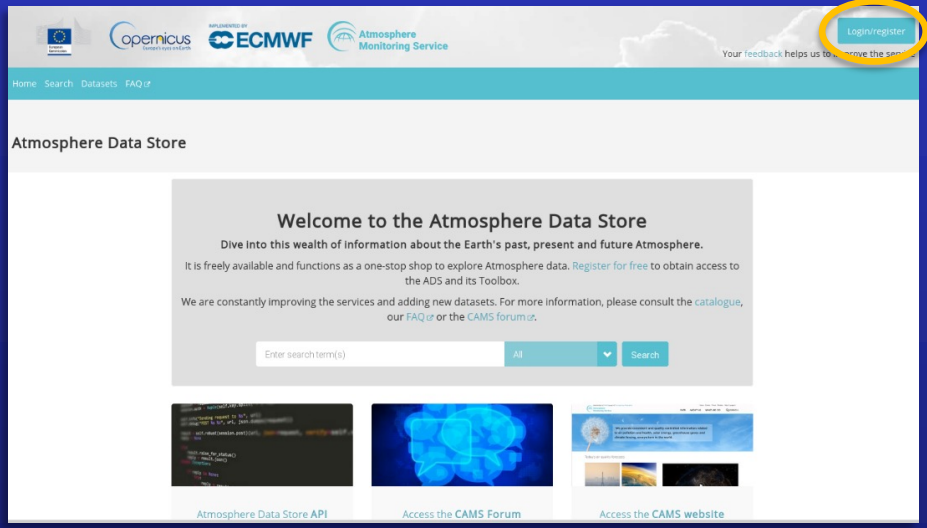
- Maps of **anomalies** for January and June 2020 highlight increased desert dust and decreased fire emissions.

Access to CAMS Reanalysis

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

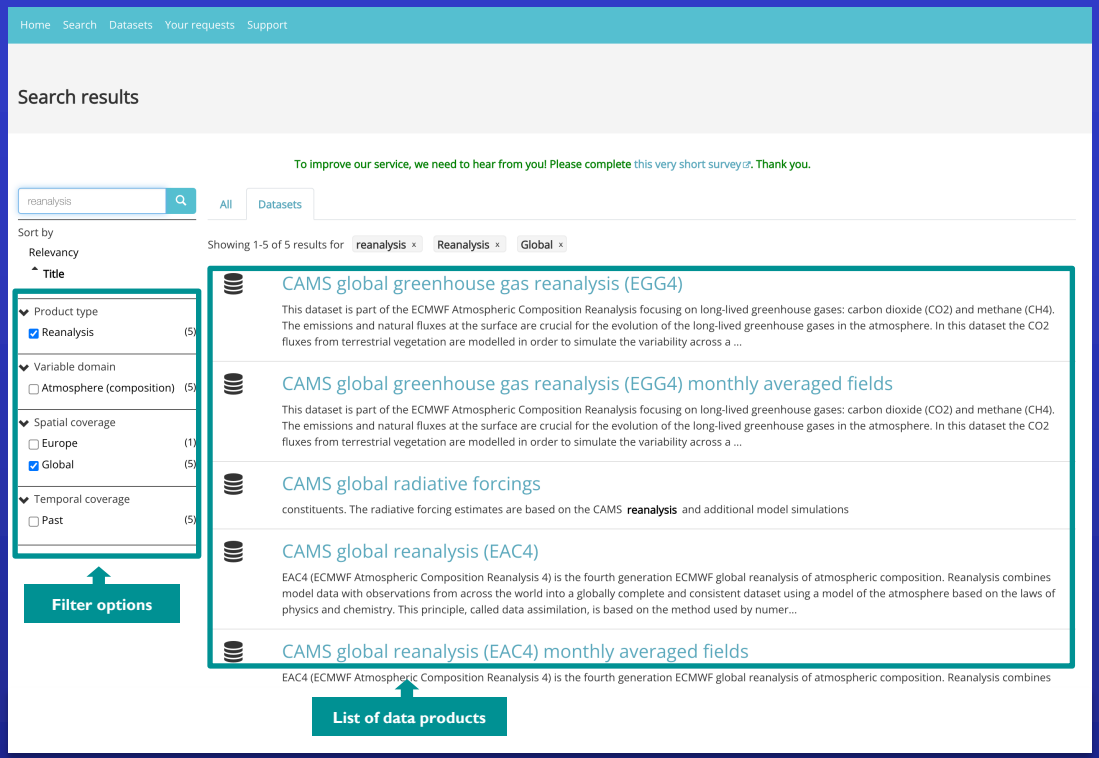
Launched June 2020

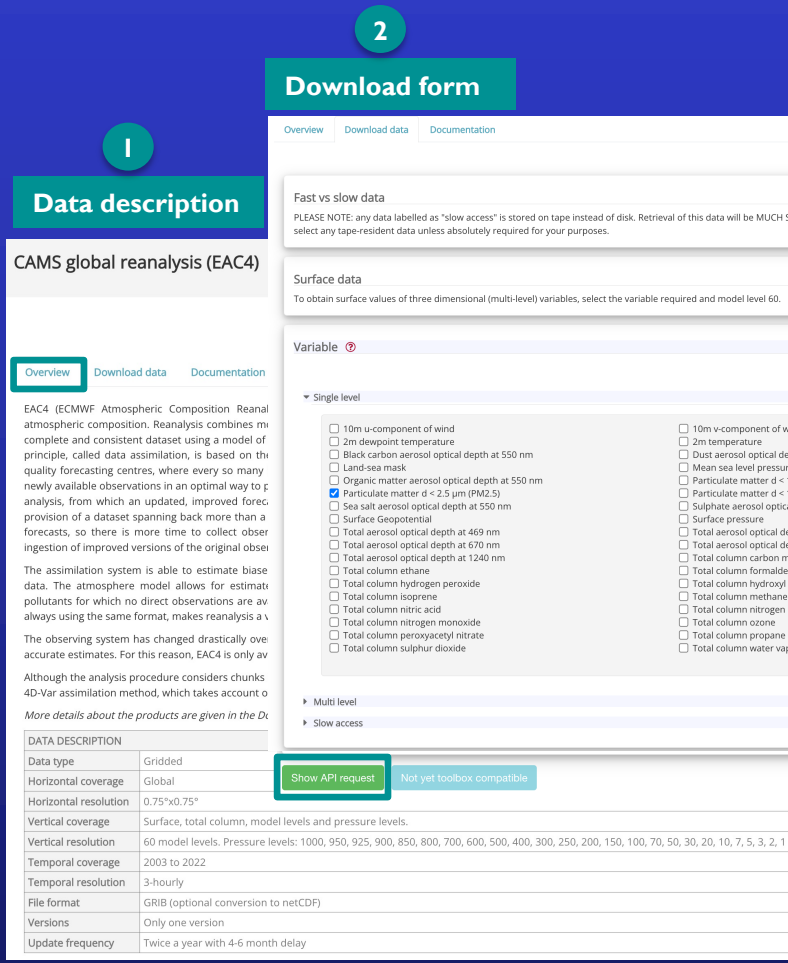
https://atmosphere.copernicus.eu/data



Access to CAMS Reanalysis

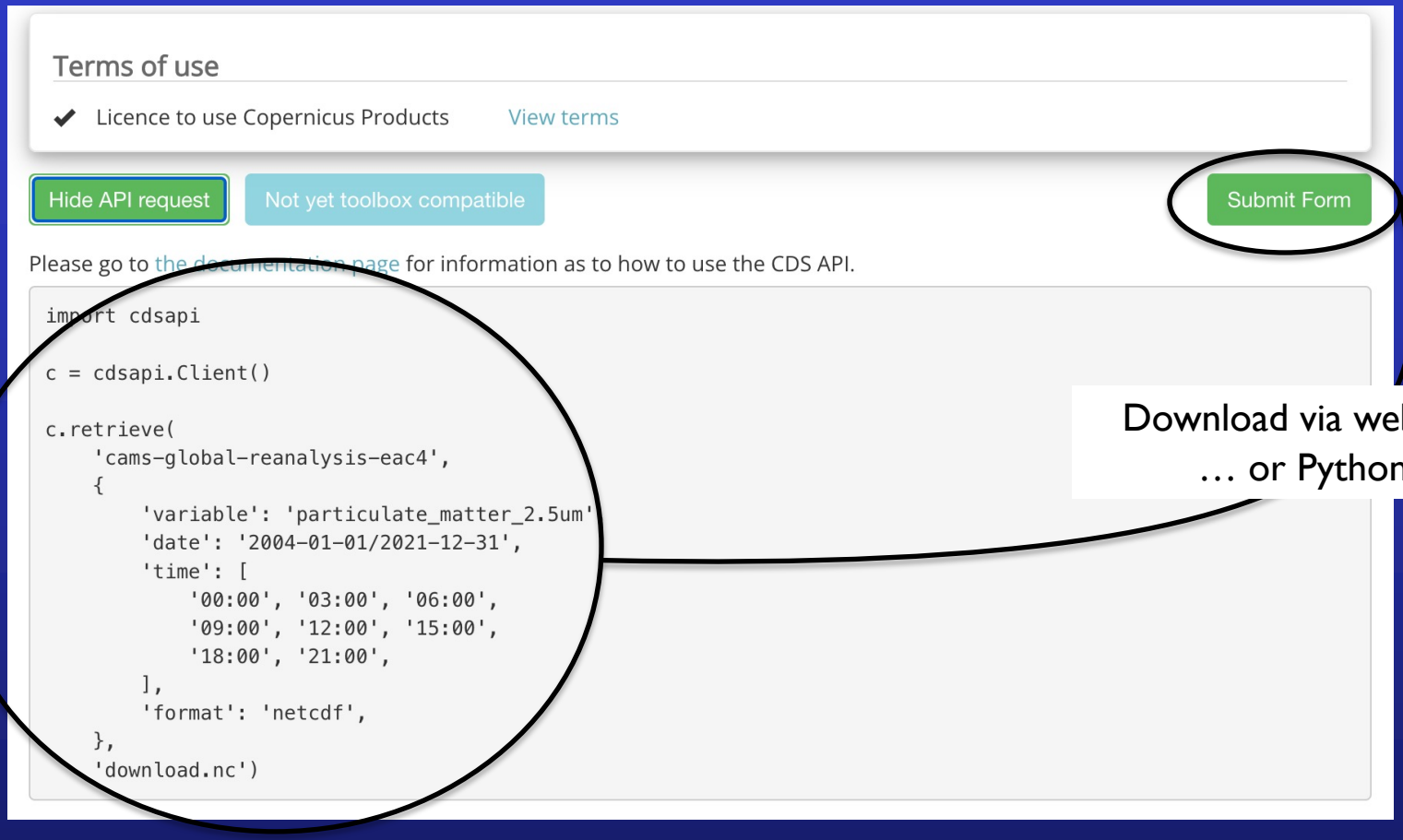
Browse and filter the dataset you are interested in.



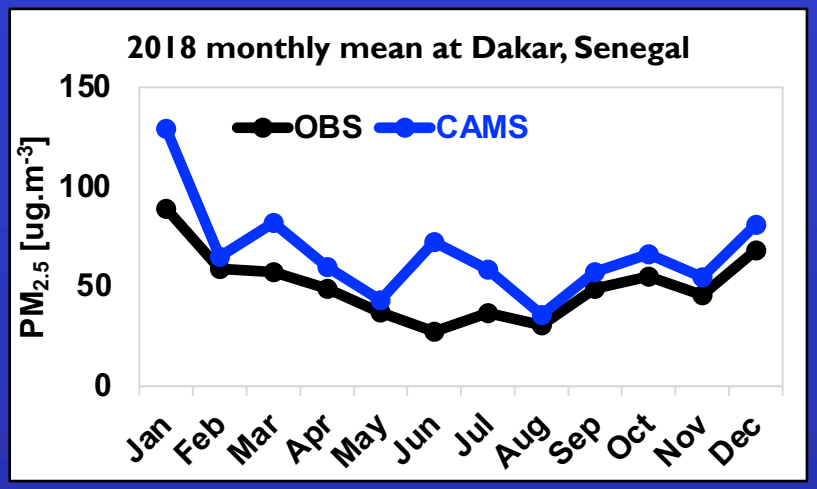


Access to CAMS Reanalysis

There are two way to access data from the ADS

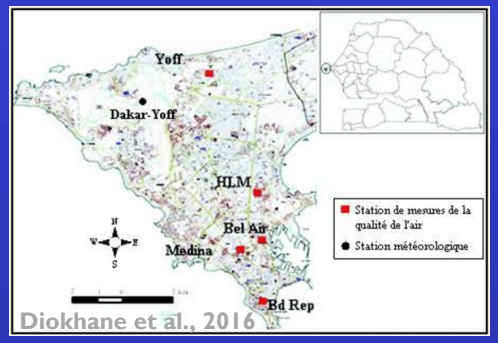


Reanalysis evaluation in Dakar, Senegal

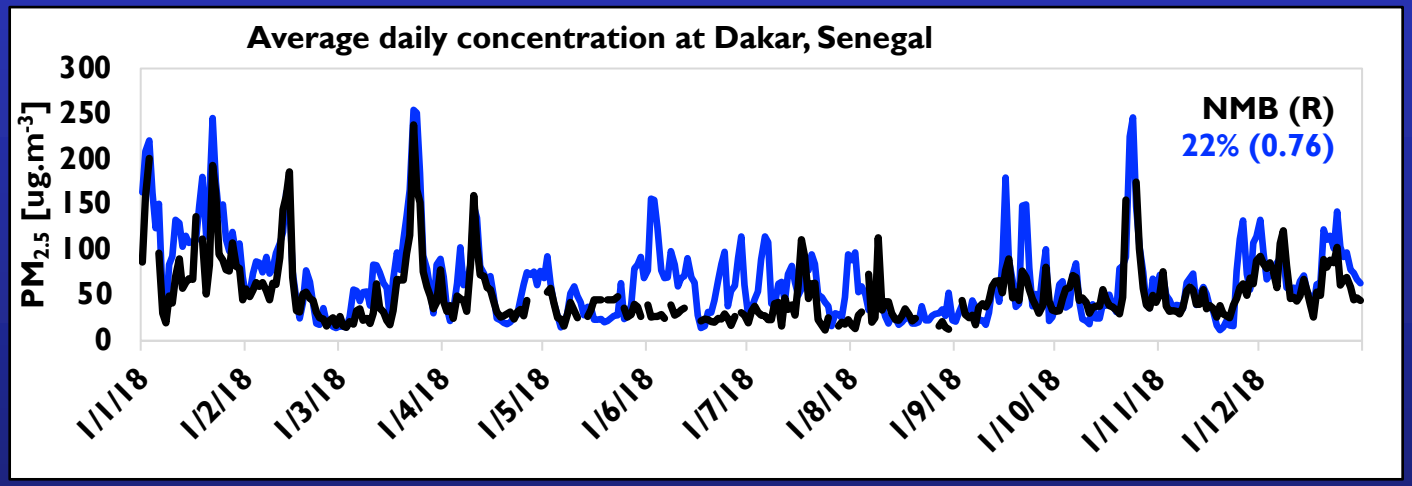


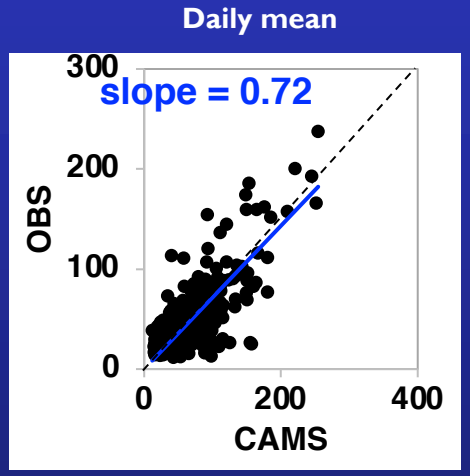
$PM_{2.5}$

Centre de **G**estion de la **Q**ualité de l'**A**ir, Dakar, Senegal (https://www.denv.gouv.sn/stations-cgqa/)



PM & Gases : Real time measurements



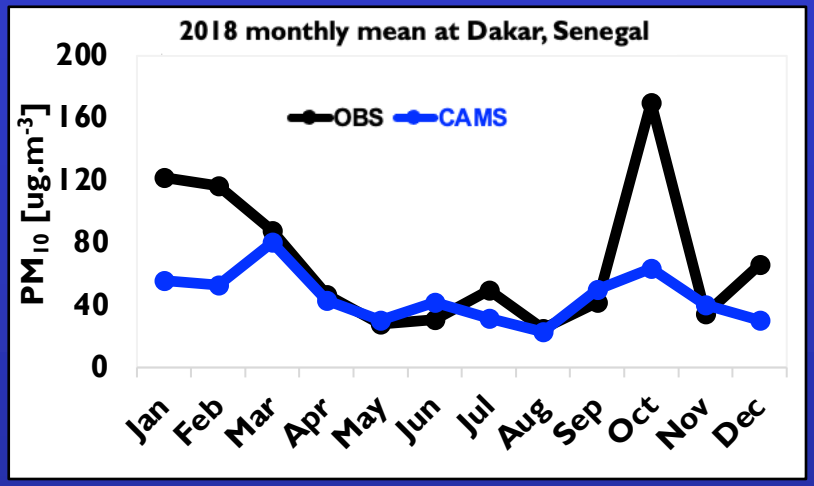


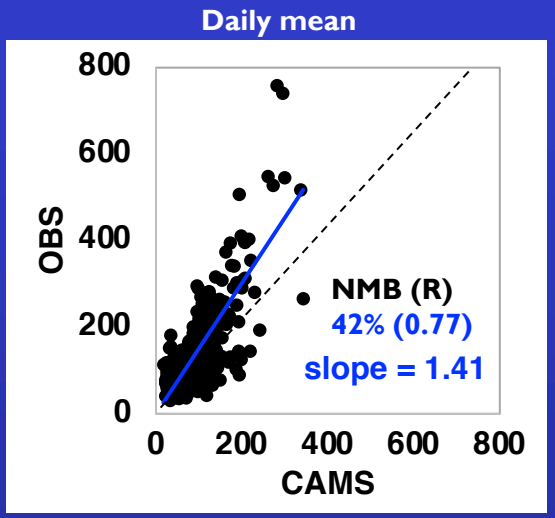
CAMS Reanalysis overestimates the magnitude of some daily peaks

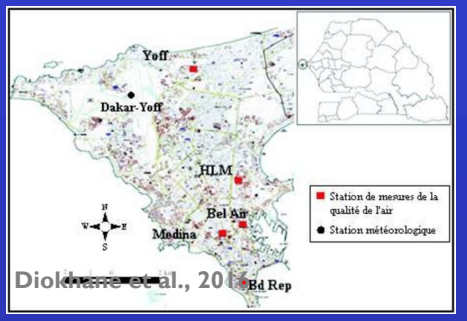
⇒ the coarse spatial resolution (80 km) or missing data in the in-situ measurements ?

Reanalysis evaluation in Dakar, Senegal

PM_{10}



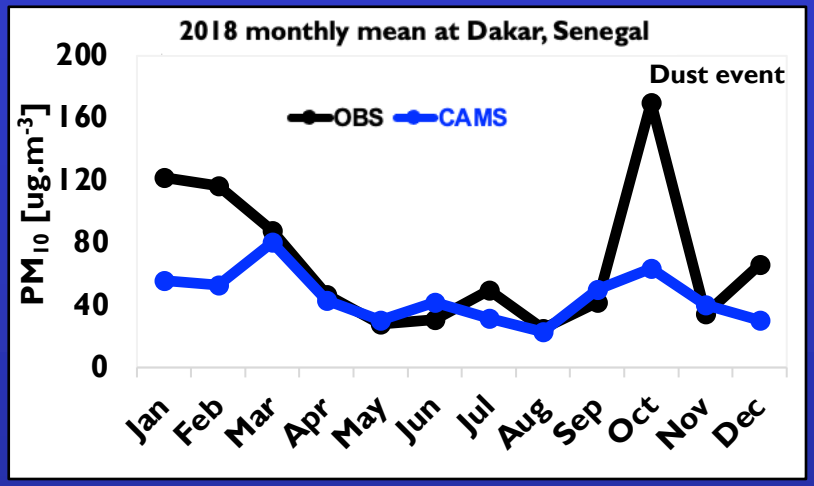


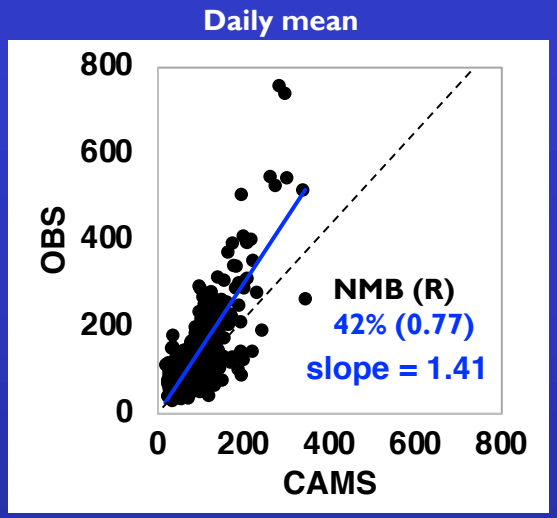


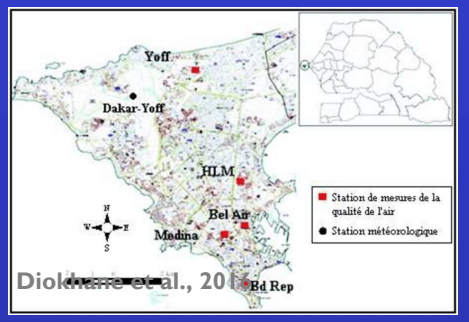
PM & Gases : Real time measurements

Reanalysis evaluation in Dakar, Senegal

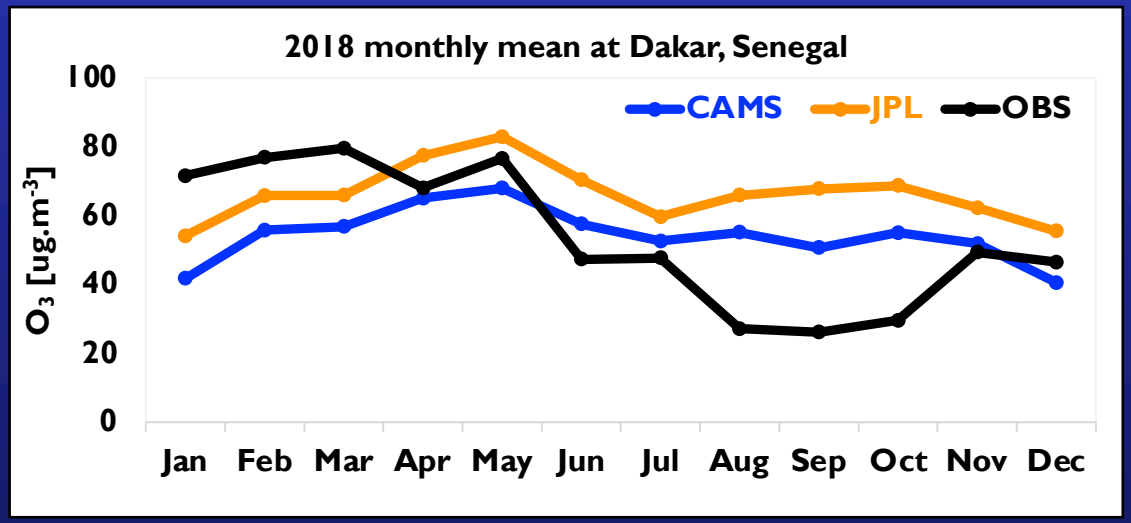
PM_{10}







PM & Gases : Real time measurements



O_3

- Reanalyses understimate concentrations in dry season and overestimate values in wet season.

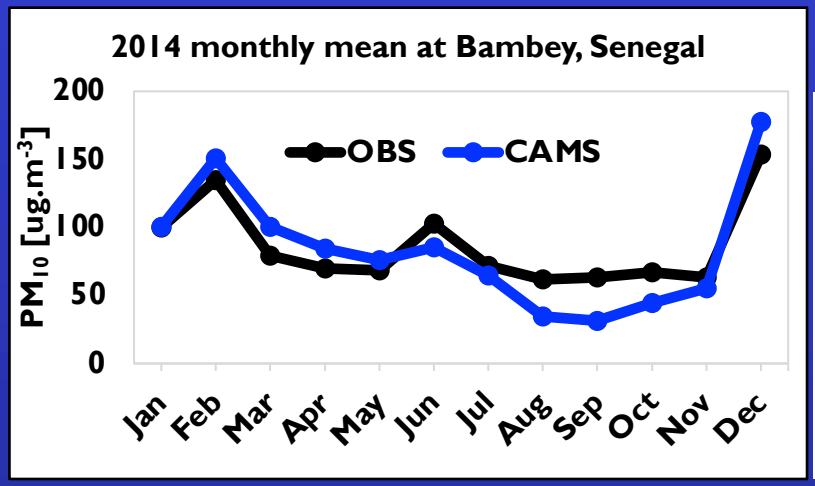
=> Uncertainties in surface O_3 retrieval from satellites can explain observed differences, in addition to the spatial resolution issue.

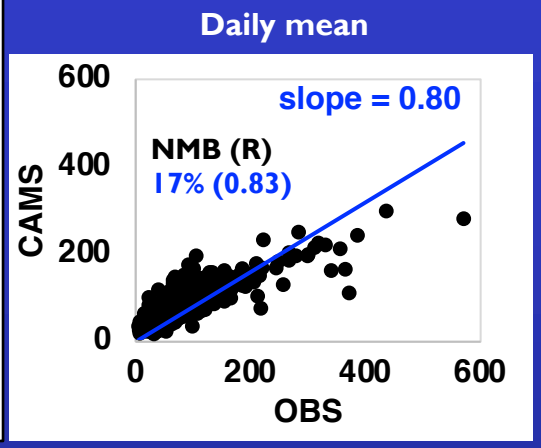
Reanalysis evaluation using INDAAF measurements

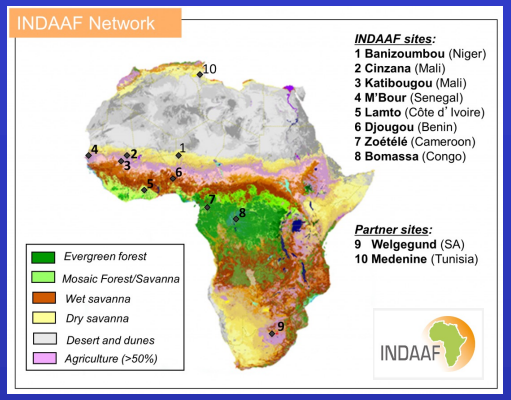
Better agreement for PM in the background/rural sites.

PM_{10}

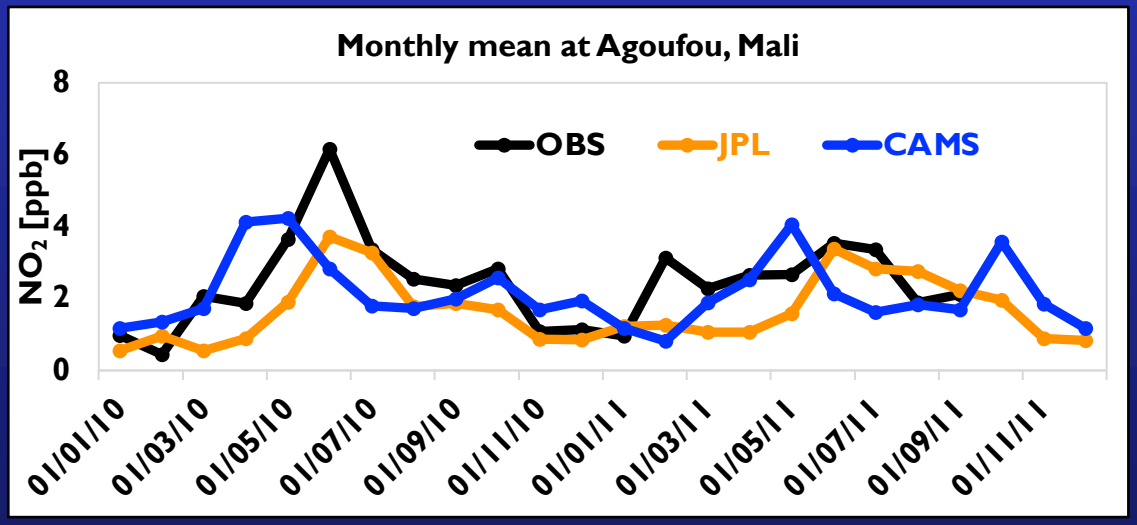
International **N**etwork to study **D**eposition and **A**tmospheric chemistry in **AF**rica (https://indaaf.obs-mip.fr/)







- PM_{10} : Real time measurements
- Gases : Weekly samples



NO_2

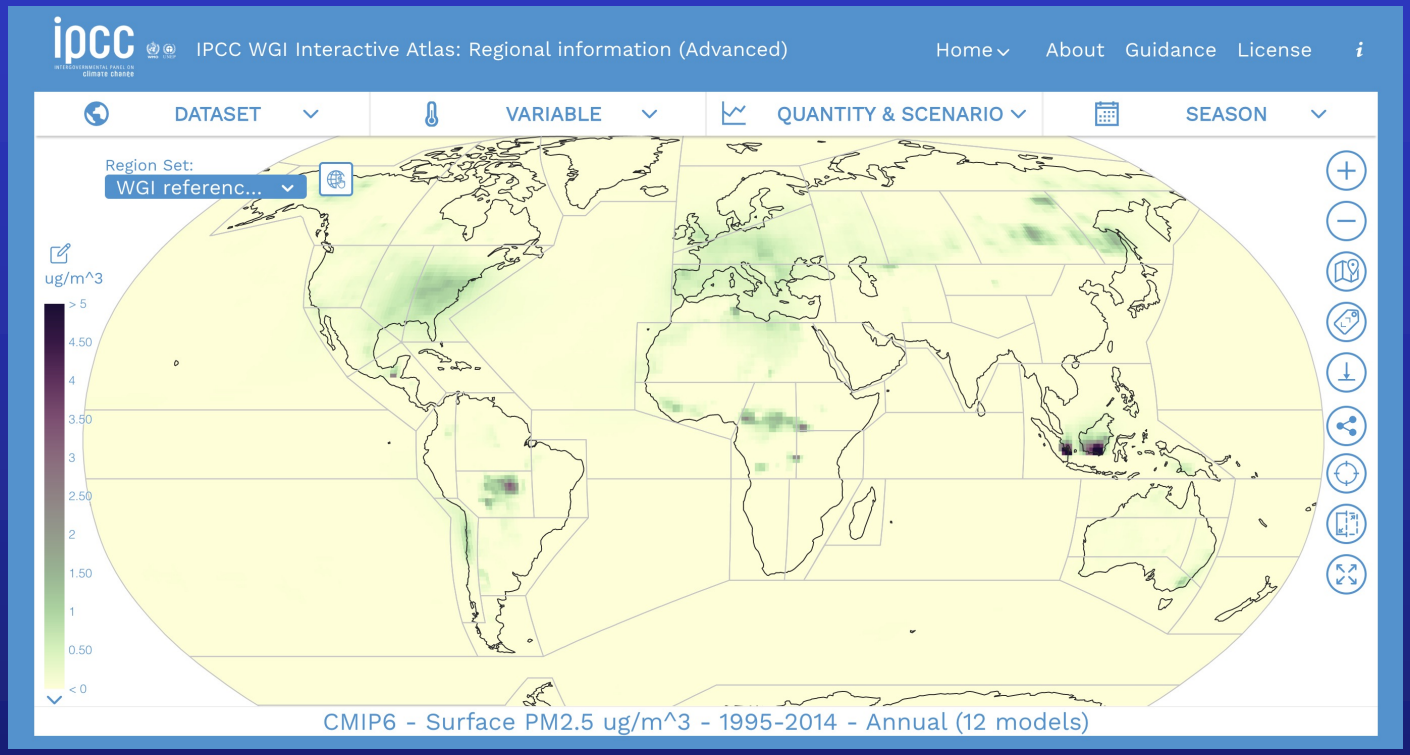
- Differences in peak concentrations.

=> Uncertainties in emissions of O_3 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 $PM_{2.5}$ - 1995-2014 Annual (12 models)



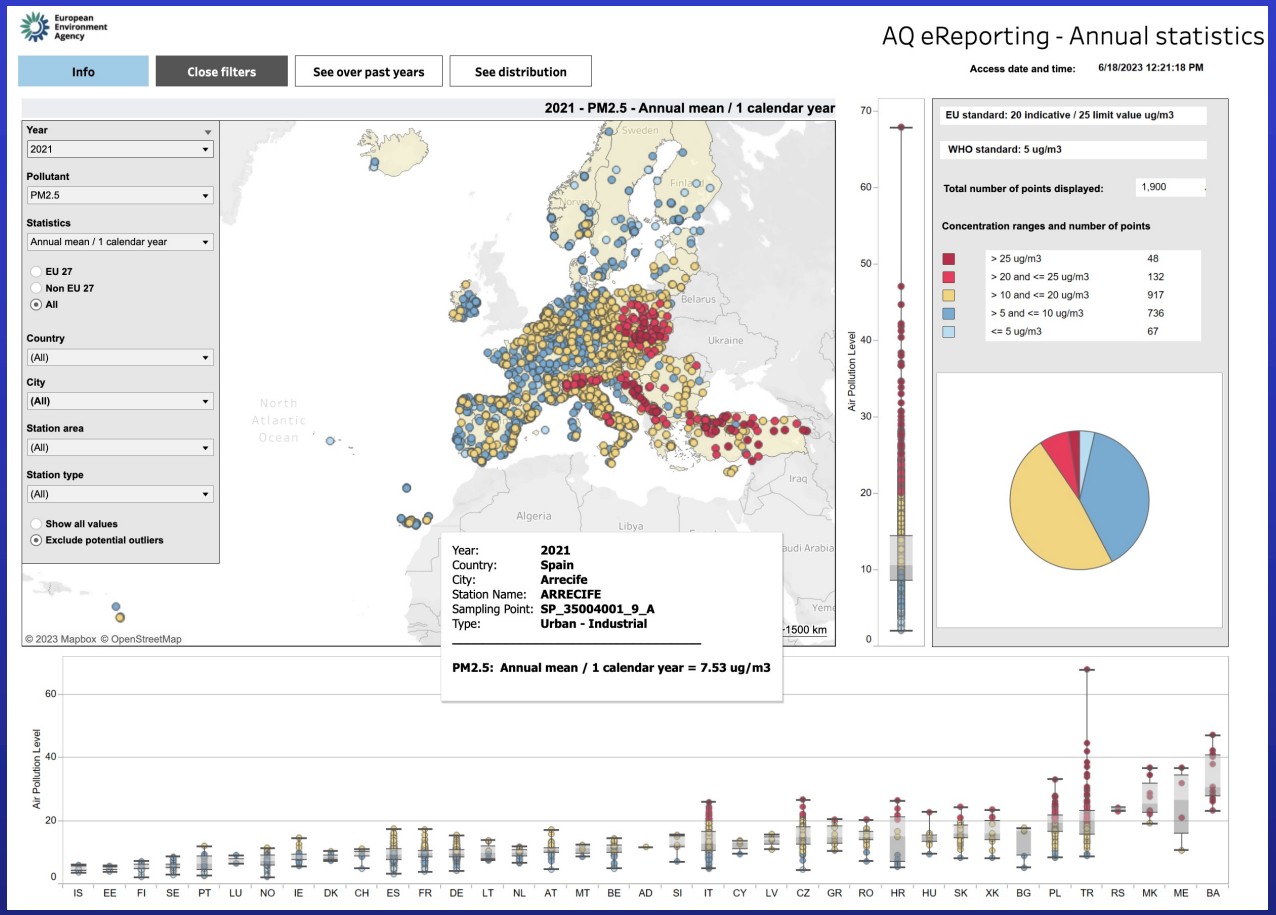
The atlas includes climate variables (T, Precipitation), as well as $PM_{2.5}$ and O_3.

https://interactive-atlas.ipcc.ch/

IPCC : Intergovernemental Panel on Climate Change

Examples of Air Quality Atlas

Key air quality statistics for the main air pollutants



Period : 2013-2021

List of species : NO_2, CO, O_3, $PM_{2.5}$, PM_{10}, SO_2, and some metals

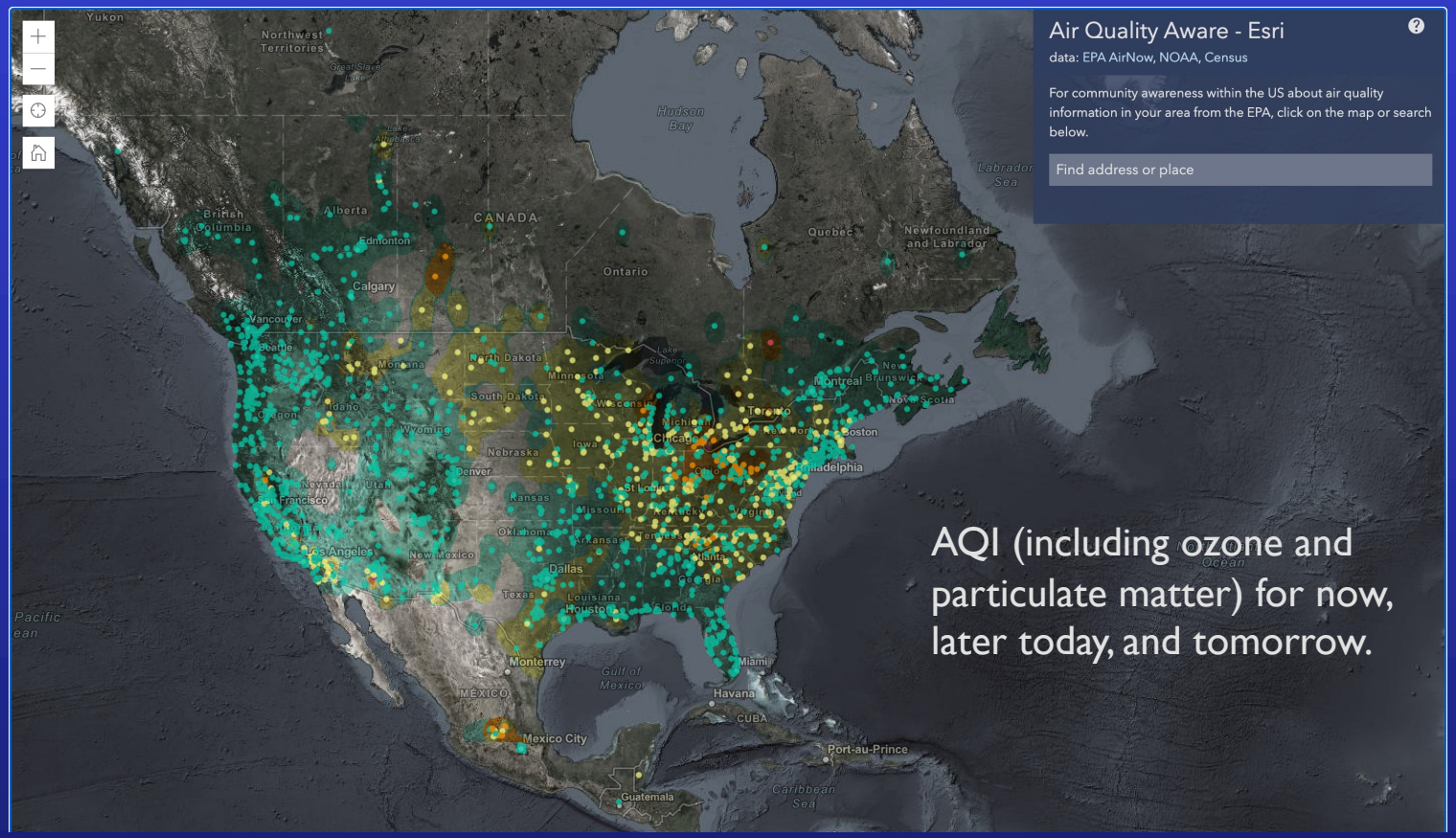
Time resolution : hourly, daily, or annual

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)

AQWA

HOME | REANALYSIS | SATELLITE | ACCOUNT | LOGOUT

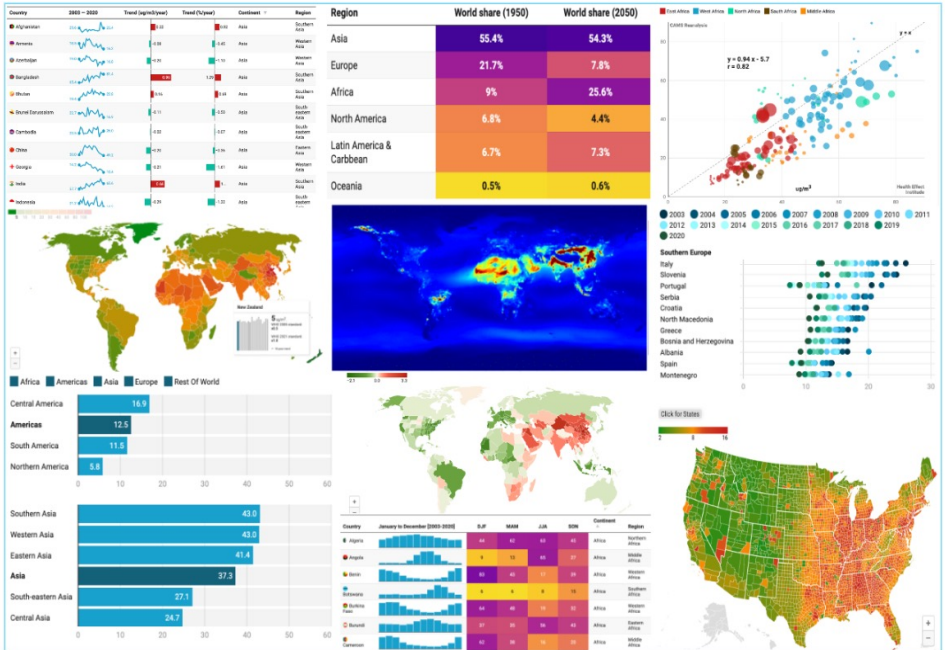
- CAMS
- CMAQ

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

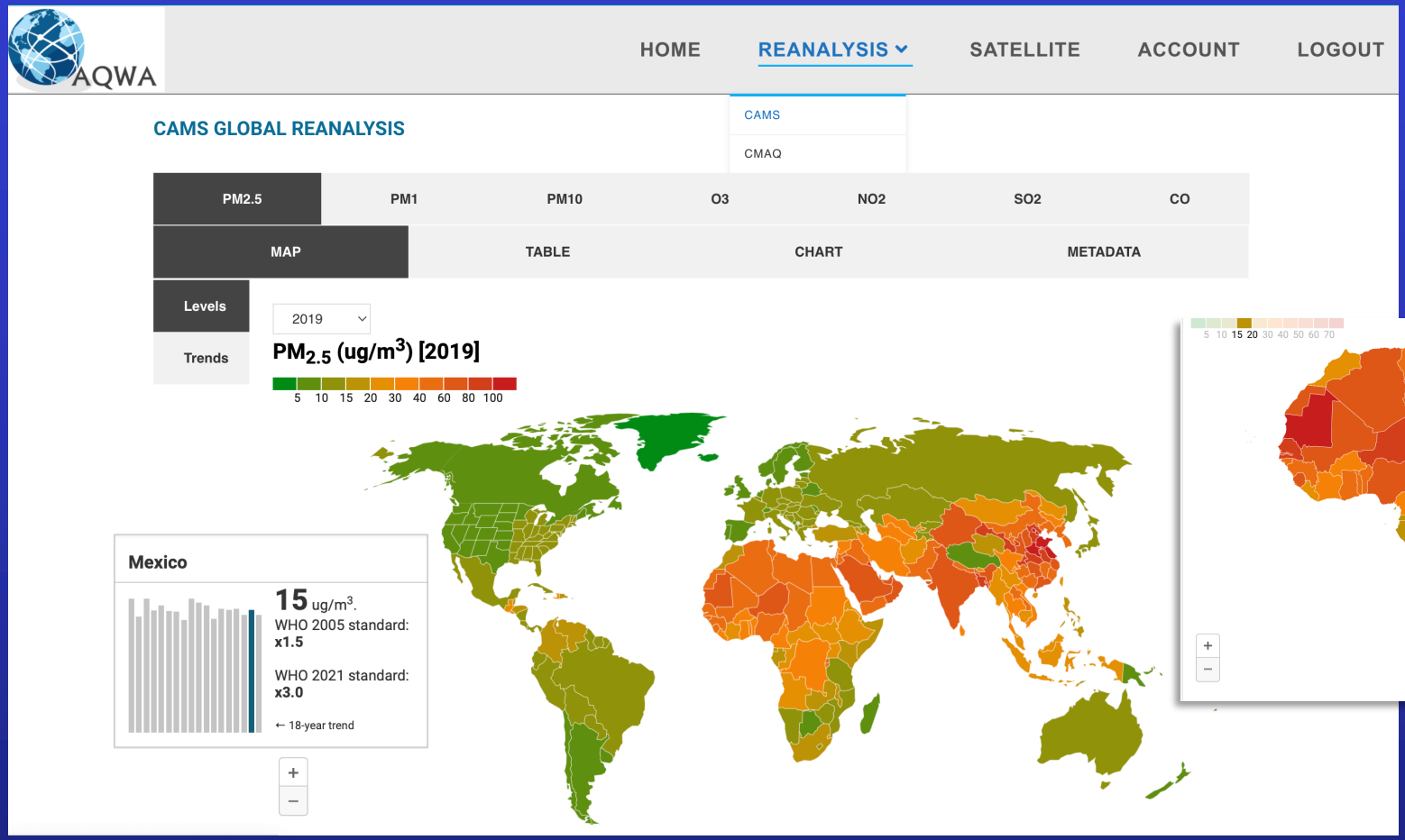
AQ-WATCH Atlas (AQWA)

The goal of the **AQ-WATCH** altas (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.

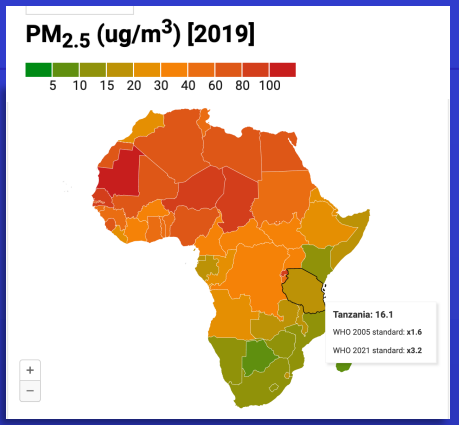


Global Air Quality Atlas



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.

The AQI is defined as an overall scheme that transforms weighted values of individual air pollution related parameters (SO_2, CO, NO_2, etc.) into a single number or set of numbers.

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	
$PM_{2.5}$, µg/m³	Annual	35	25	15	10	5
	24-hour[a]	75	50	37.5	25	15
PM_{10}, µg/m³	Annual	70	50	30	20	15
	24-hour[a]	150	100	75	50	45
O_3, µg/m³	Peak season[b]	100	70	–	–	60
	8-hour[a]	160	120	–	–	100
NO_2, µg/m³	Annual	40	30	20	–	10
	24-hour[a]	120	50	–	–	25
SO_2, µg/m³	24-hour[a]	125	50	–	–	40
CO, mg/m³	24-hour[a]	7	–	–	–	4

[a] 99th percentile (i.e. 3–4 exceedance days per year).
[b] Average of daily maximum 8-hour mean O_3 concentration in the six consecutive months with the highest six-month running-average O_3 concentration.

Global Air Quality Atlas

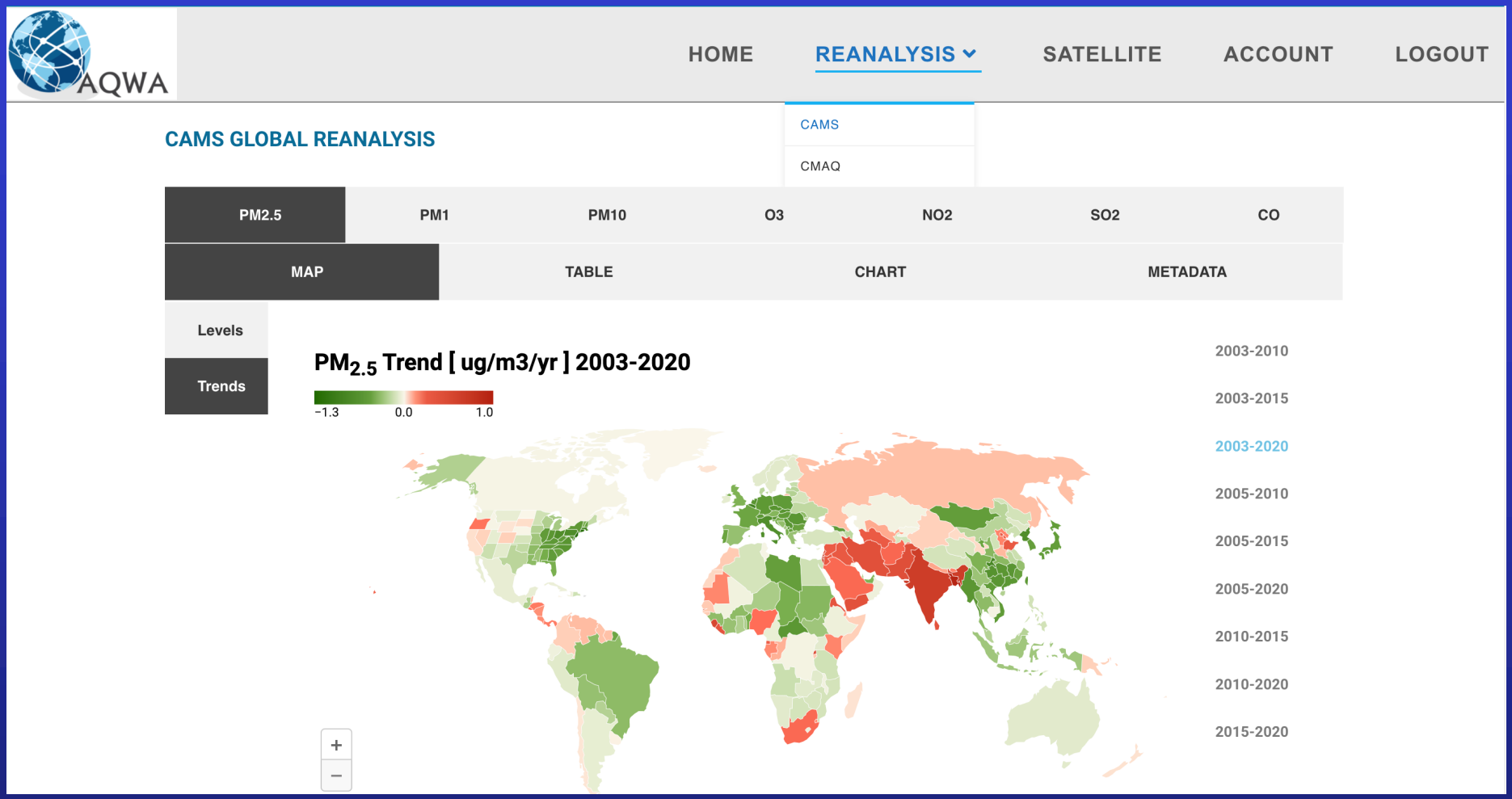
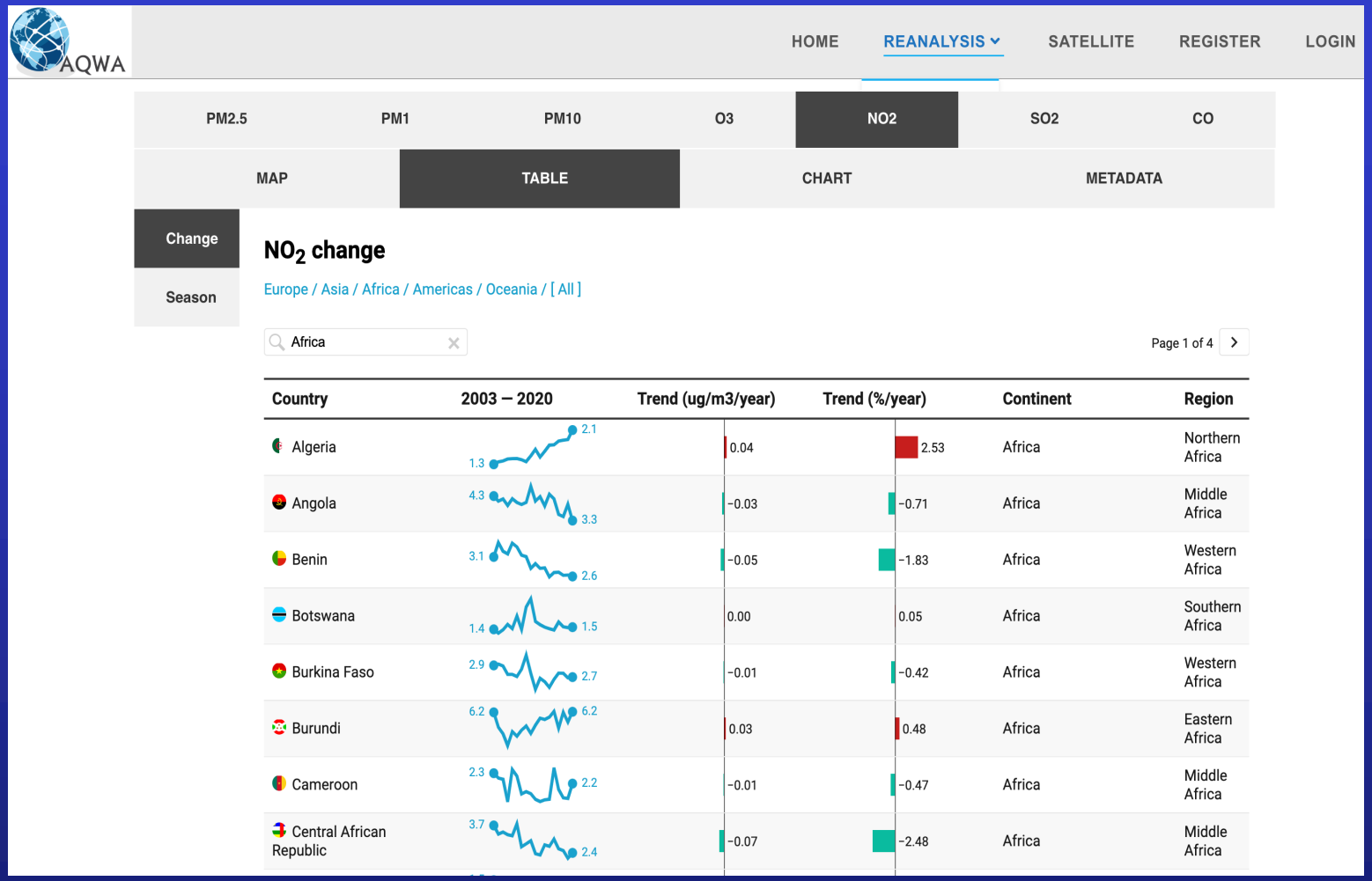


Figure shows change in $PM_{2.5}$ in each country, state in the United States and province in China from 2003 to 2020.

Regional Air Quality Atlas

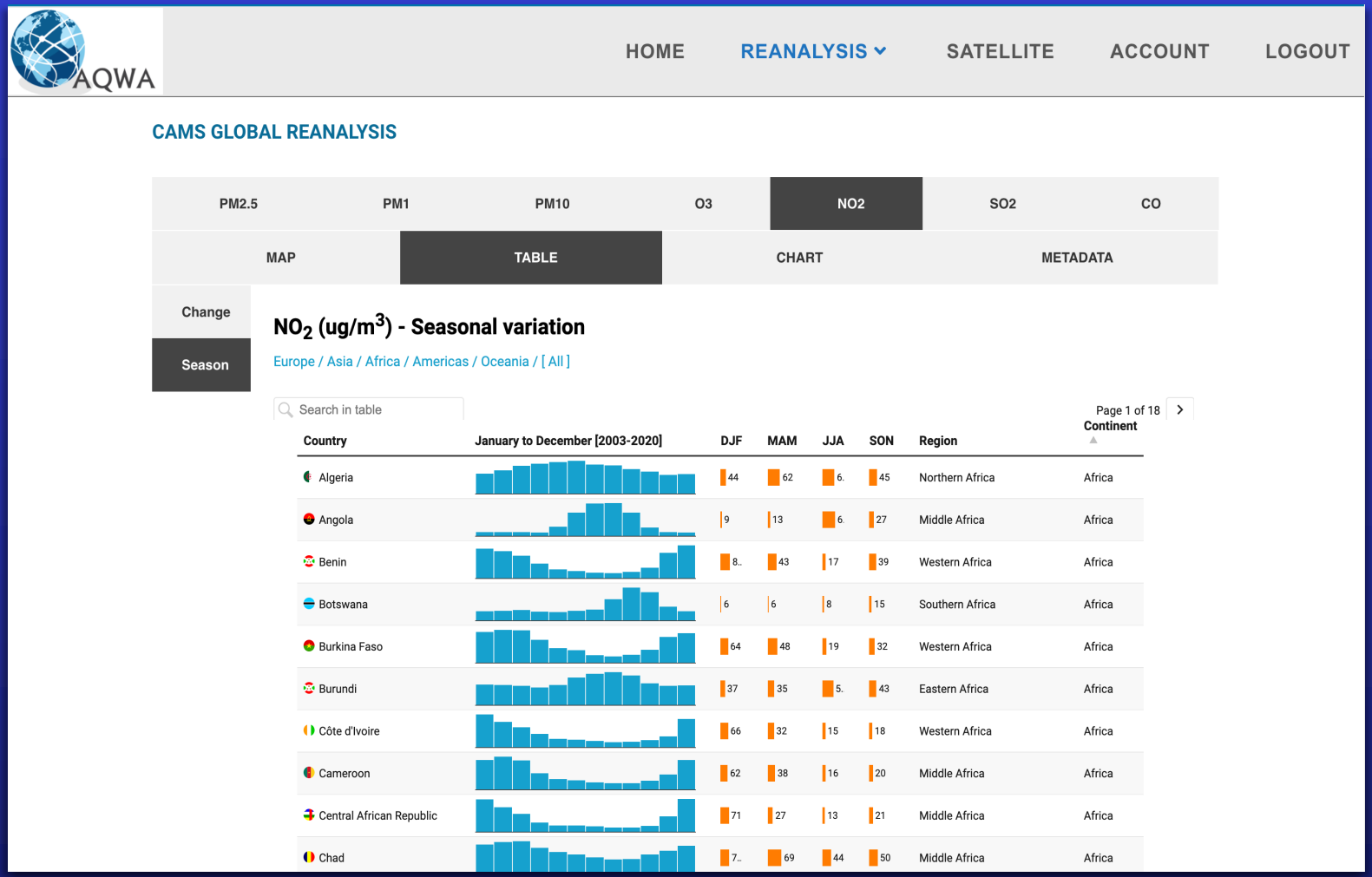
Trends in African Countries



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

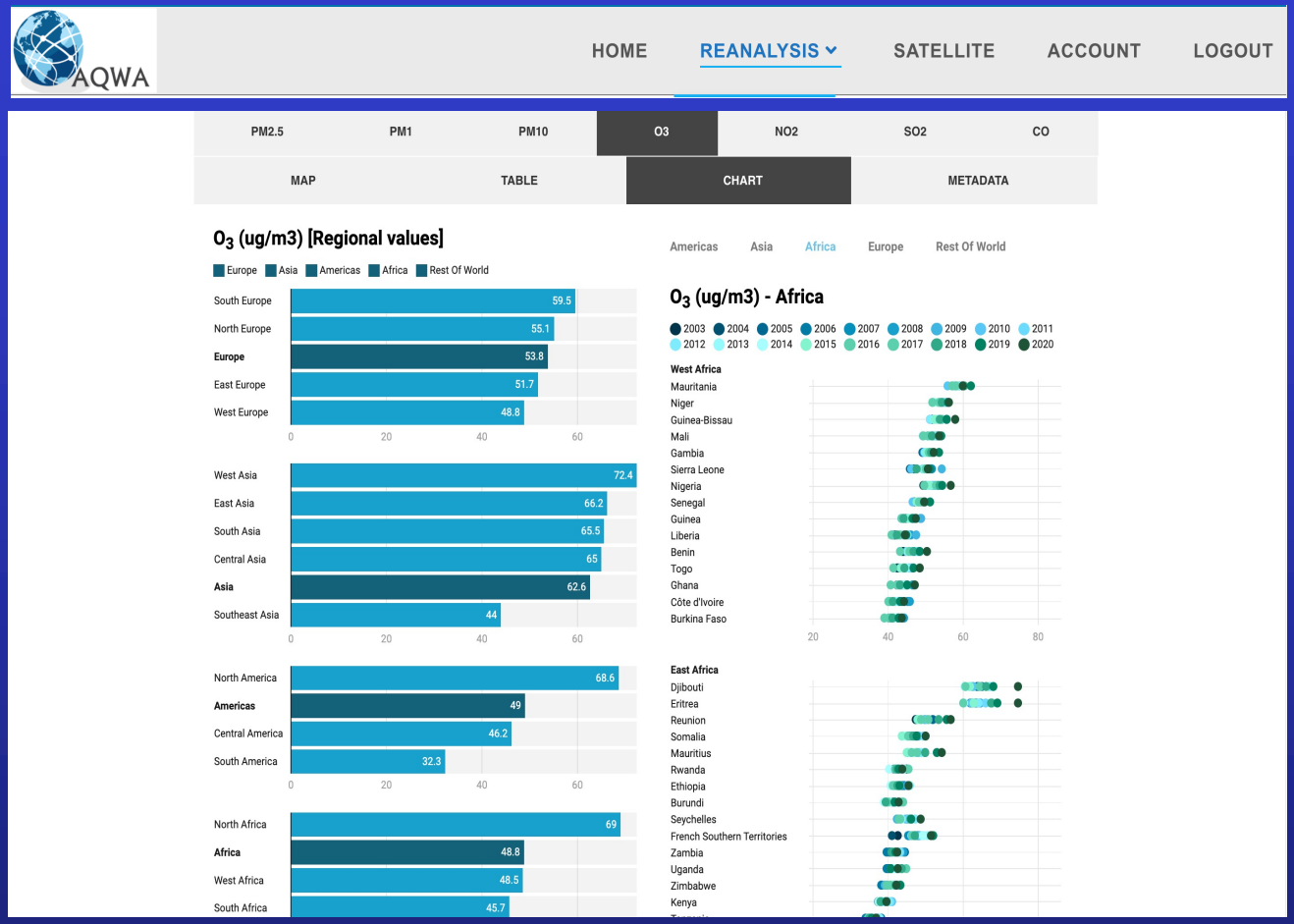
Seasonal variations



Seasonal variations in climatological average NO_2 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_3 levels in African countries are shown.

Air Quality Index (AQI) Calculation

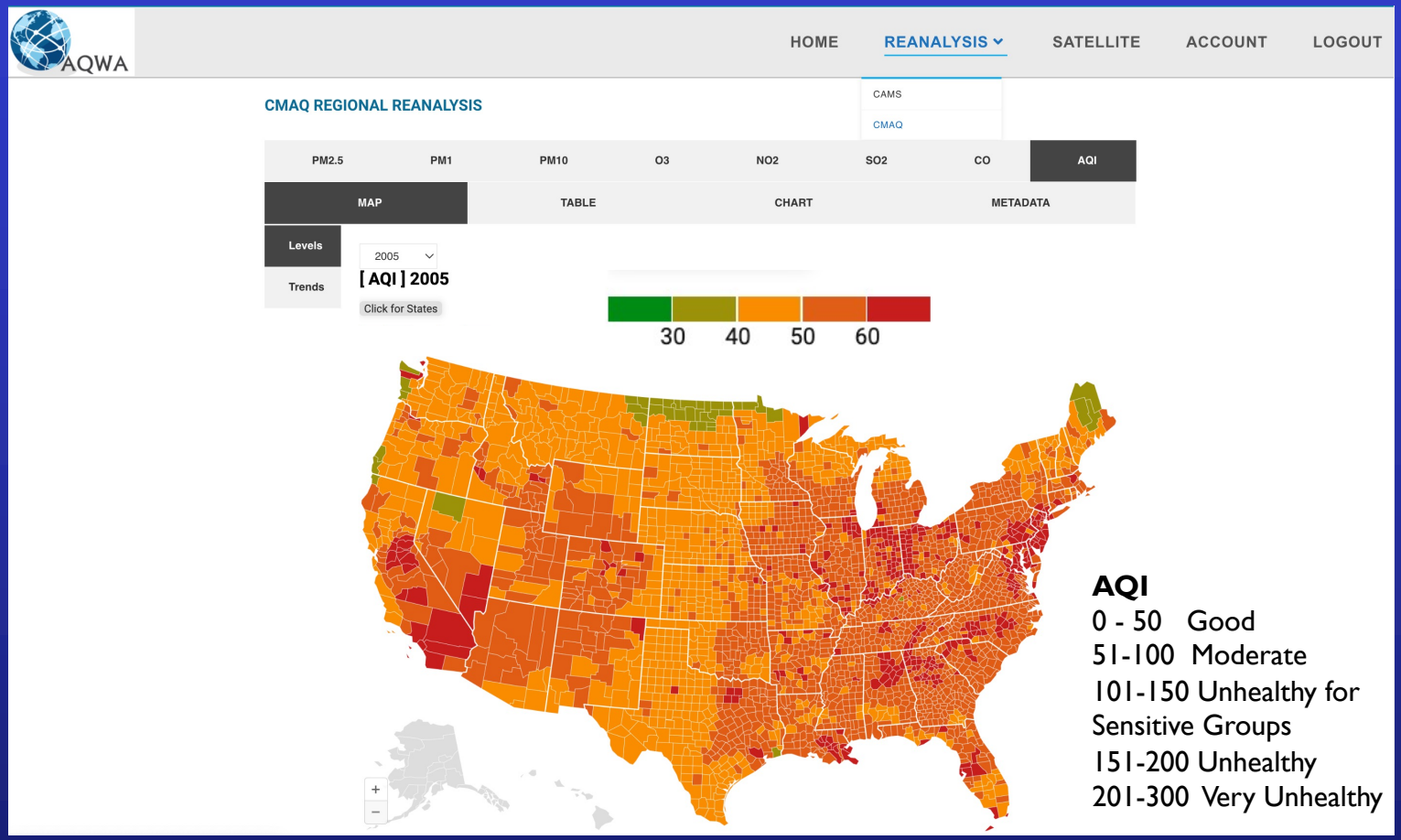
Index	Method	Definition	Pollutants & Avg. time
EEA (AQI 1h/24h)	Based on the breakpoint values* for up to key 5 pollutants. ***defined concentrations or sub-indices**	The AQI is defined as the sub-index that represents the worst quality among the key pollutants.	**PM** (24h) **NO_2, SO_2, O_3** (1h)
US EPA (AQI 24h)	$I_p = \frac{I_{Hi} - I_{Lo}}{BP_{HI} - BP_{Lo}}(C_p - BP_{Lo}) + I_{Lo}$ I_p index for pollutant p I_{Hi} AQI corresponding to BP_{HI} I_{Lo} AQI corresponding to BP_{Lo} C_p conc. Pollutant p BP_{Hi} conc. Breakpoint $\geq C_p$ BP_{Lo} conc. Breakpoint $\leq C_p$	The AQI is the highest value calculated from the equation applied for each pollutant.	**PM** (24h) **NO_2, SO_2** (max 1h) **O_3** (max 1h or 8h), **CO** (max 8h)
UK (AQI 24h)	The index is calculated from the highest concentration of the 5 pollutants.	The AQI is defined as the maximum value of the index.	**PM** (24h) **NO_2** (1h) **O_3** (8h), **SO_2** (15min)
India (AQI 24h)	Using sub-indices characterising 8 pollutants based on national standards.	The final AQI is equal to the worst sub-index.	**PM, NO_2, SO_2, NH_3, Pb** (24h) **O_3, CO** (8h)
China (AQI 1h/24h)	Based on the concentration of 6 pollutants, each of which is assigned a individual score.	The highest of the six scores.	**PM, NO_2, SO_2, CO** & **O_3**

According the 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 take 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[1], Idir Bouarar[2], Thierno Doumbia[3]

(1) National Center for Atmospheric Research, Boulder, USA
(2) Max Planck Institute for Meteorology, Hamburg, Germany
(3) Laboratoire d'Aérologie, Toulouse, France

Goal of the CRANES WG

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

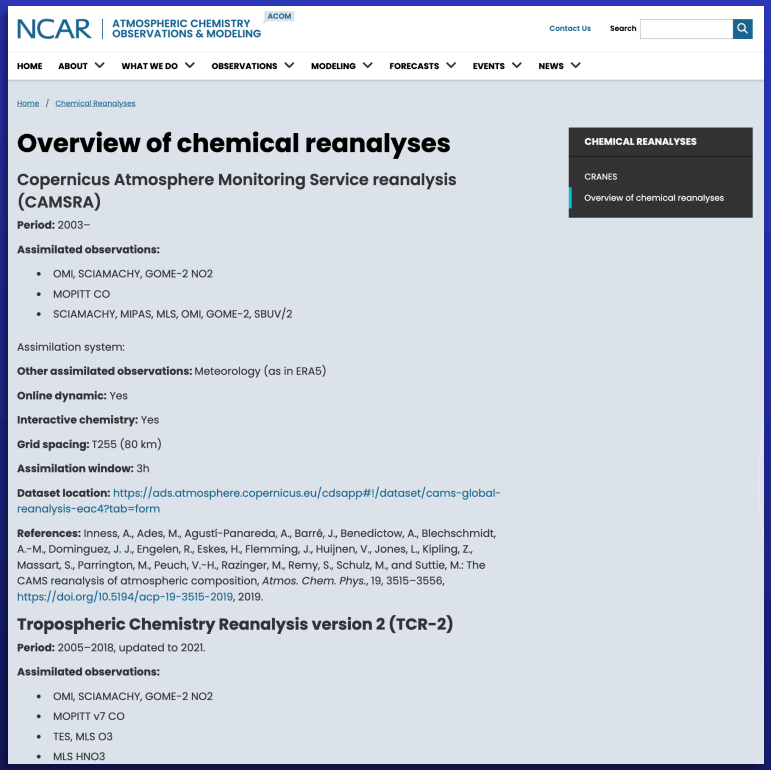
Current activities and perspectives

⇒ 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 (CAMSRA)
- ✓ 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)
- ✓ …



Current activities and perspectives

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

Contact : thierno.doumbia@aero.obs-mip.fr

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 then the current one.**

Thank you for your attention