A GLOBAL ATLAS OF AIR QUALITY, BASED ON THE COPERNICUS ATMOSPHERE MONITORING SERVICE REANALYSIS

Thierno DOUMBIA[1], Claire GRANIER[1,2], Sabine DARRAS[3], Sekou KEITA[1], Cathy LIOUSSE[1], Antonin SOULIE[1], Rajesh KUMAR[4], Gabriele PFISTER[4]

[1]Laboratoire d'Aérologie, Université de Toulouse, CNRS/UPS, Toulouse, France
[2]NOAA Chemical Sciences Laboratory–CIRES/University of Colorado, Boulder, CO, USA
[3]Observatoire Midi-Pyrénées, Toulouse, France
[4]National Center for Atmospheric Research (NCAR), Boulder, CO, USA

Abstract : An atlas of air quality has been developed, as part of the AQ-WATCH (Air Quality – Worldwide Analysis and Forecasting of Atmospheric Composition for Health) European project. This atlas is primarily based on the reanalysis of the global atmospheric composition performed by the European Centre for Medium-Range Weather Forecasts (ECMWF) within the CAMS (Copernicus Atmosphere Monitoring Service) project and the regional chemical reanalysis from the Community Multiscale Air Quality (CMAQ) model. The atlas includes climatological distributions of the major particulate matter and gases, as well as their temporal variations and long-term trends. This tool can be used to assess the impact of policy decisions on air quality, identify hotspots of air pollution, and compare concentration levels across countries, states, provinces, and cities.

Keywords: Atlas, Air quality, Reanalysis

Résumé : Un atlas de la qualité de l'air a été développé dans le cadre du projet Européen AQ-WATCH (Air Quality-Worldwide Analysis and Forecasting of Atmospheric Composition for Health). Cet atlas est principalement basé sur la réanalyse de la composition atmosphérique globale effectuée par le Centre Européen pour les Prévisions Météorologiques à Moyen Terme (CEPMMT) dans le cadre du projet CAMS (Copernicus Atmospheric Monitoring Service) et sur la réanalyse régionale du modèle CMAQ (Community Multiscale Air Quality). L'atlas comprend des distributions climatologiques des principales particules et des gaz, ainsi que leurs variations temporelles, les tendances à long terme et les indices de santé associés. Cet outil peut être utilisé pour évaluer l'impact des décisions politiques sur la qualité de l'air, identifier les hotspots de la pollution atmosphérique et comparer les niveaux de concentration entre pays, états, provinces et villes.

Mots clés : Atlas, Qualité de l'air, Réanalyse

Introduction

As part of the AQ-WATCH (https://www.aq-watch.eu/) European project, an atlas of global and regional air quality has been developed at the Laboratoire d'Aerologie in Toulouse. This atlas is primarily based on a reanalysis of global atmospheric composition (PM_1, $PM_{2.5}$, PM_{10}, NO_2, O_3, CO and SO_2) performed by the European Centre for Medium-Range Weather Forecasts (ECMWF) as part of the CAMS (Copernicus Atmosphere Monitoring Service) project, as well as a chemical reanalysis developed by the National Center for Atmospheric Research (NCAR) using the coupled Weather Research Forecast and Community Multiscale Air Quality (WRF-CMAQ) model. The atlas also depicts the spatial and temporal distributions of NO_2 tropospheric columns from satellite instruments, as well as air quality indices at the county and state levels in the United States. This paper briefly describes the AQ-WATCH project and its goals, as well as the various types of datasets used in this work and the atlas' numerical and graphical contents.

1. The AQ-WATCH project

The AQ-WATCH project is funded under the European Union's Horizon 2020 Research and Innovation program. The goal of the project is to co-develop and co-produce tailored products and services that can be used by governmental institutions (at local, regional and national levels) and private companies in different sectors to help mitigate air pollution, and thus contribute to a better public health and optimized services from the energy sector. The different products developed in the project concern the design and development of global and regional air pollution atlases that include the climatological distributions of chemical pollutants complemented by quantities such as the diurnal and seasonal variations, air quality and related health indices, premature mortality exceedance frequency, long-term trends, etc. AQ-WATCH provides also daily forecasts of air pollution at the regional scale based on different predictive models and satellite and ground-based information: the tools are initially designed for three regions such as Chile, the Contiguous United States and China, but they could be expanded to cover additional geographical areas. Predictions of the degradation of air quality and reduction in visibility caused by the occurrence of wildfires and the development of a related regional alert system are another AQ-WATCH product, as well as the predictions of the degradation of air quality and reduction in visibility caused by dust mobilization and impact on solar energy systems. Model predictions of the potential impact on regional air quality (e.g., ozone levels) due to fracking operations and determination of the exposure of the local population to related emissions of hydrocarbons represent another product of the project. Finally, the development of a demonstration model to allow future customers to assess the efficiency of alternative actions to mitigate air pollution has been achieved, which helps the development of strategy options for air pollution abatement and support of air quality policy.

2. The input data for the atlas

The AQ-WATCH global air quality atlas is using the results of the simulations from the most recent version of the global reanalysis developed within the Copernicus Atmosphere Monitoring Service (CAMS: https://atmosphere.copernicus.eu/). The CAMS reanalysis combines model data with observations from across the world into a globally complete and consistent dataset using the atmospheric model (IFS: Integrated Forecasting System) of the ECMWF and data assimilation (Inness et al., 2019). For the CAMS reanalysis, satellite retrievals of carbon monoxide total column, nitrogen dioxide tropospheric column, aerosol optical depth, and ozone total column, partial column and profile retrievals are assimilated. The reanalysis has a horizontal resolution of about 80 km (0.75°x0.75°) and provides the distribution of chemical species at a sub-daily (3 hourly frequency) and monthly temporal resolution. The most recent global reanalysis spans January 2003 to June 2021, but only data up to December 2020 are included in the atlas.

The global atlas also includes an access to the NO_2 tropospheric columns from the satellite-based Ozone Monitoring Instrument (OMI) sensor (Boersma et al., 2011). The NO_2 tropospheric columns data observed by the OMI sensor are obtained from the temis website at: https://www.temis.nl/airpollution/no2.php. The data used in this project were generated as part of the QA4ECV (Quality Assurance for Essential Climate Variables) European project and are available as daily and monthly means since October 2004. We downloaded the monthly average values from version 1.1, which has a spatial resolution of 0.125°x0.125° (about 13x13 km^2), for the period 2005-2020. We first converted the monthly mean ascii files to netcdf before regridding them to the same resolution as the CAMS reanalysis.

The regional atlas, which focuses on the contiguous United States, is based on atmospheric composition simulations performed by the NCAR's Research Application Laboratory (RAL) using a regional air quality model (CMAQ; Community Multiscale Air Quality) (Kumar et al., 2019). The CMAQ model uses meteorological fields derived from the Weather Research and Forecast (WRF) model, and assimilated MODIS aerosol optical depth (AOD) retrievals and other in-situ observations. The model domain is defined on a Lambert Conformal map projection centered at (40°N, 97°W) and a horizontal grid spacing of 12 km in both the longitudinal and latitudinal directions. The CMAQ outputs are available at a daily basis for the period 2005-2018 and include air quality indices, as well as some meteorological parameters (temperature, cloud fraction, solar radiation, etc.). As for satellite data, the model simulations are regridded to 0.75°x0.75° for the comparison with CAMS reanalysis.

3. The AQ-WATCH atlas of air quality

The home page of the atlas is shown in Figure 1. The final version of the atlas has not yet been made available to the public. Discussions are currently taking place with possible hosts for this website.

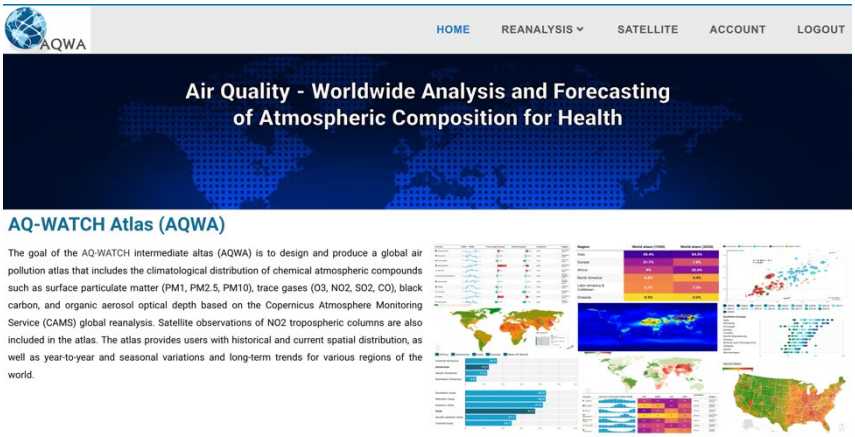

figure 1. Homepage of the AQ-WATCH atlas.

The data in the atlas are derived from sub-daily and monthly CAMS reanalysis, as well as daily average CMAQ model outputs and monthly average OMI NO_2 tropospheric columns. For each of the dataset, data are averaged seasonally and yearly. All of these statistics are also calculated for every country in the world, as well as for every state and county in the United States and every province in China. The system developed for this atlas allows an interactive visualization of the different statistics for the surface concentrations of the following species: PM_1, $PM_{2.5}$, PM_{10}, O_3, daily maximum 8h average ozone (MDA8), CO, NO_2 and SO_2. More species could be added in the future at the request of users. After choosing the species, maps of the average concentrations and trends for the dates chosen by the users can be obtained. Figure 2 depicts an example of such a map, which shows the concentration of $PM_{2.5}$ in 2019 (top panel) and the absolute change in $PM_{2.5}$ from 2003 to 2020 (bottom panel) at the country, state, and province levels. The user can, for example, display the PM concentration level on the map in comparison to WHO (World Health Organization) standards, as well as the trend and its significance or not for different time periods.

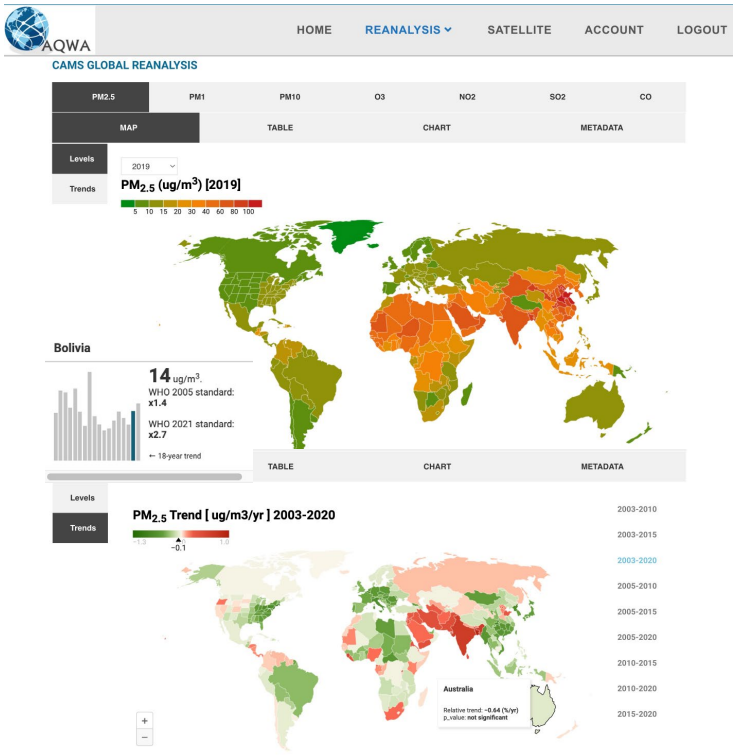

figure 2. Average $PM_{2.5}$ concentration in 2019 (top panel) and trend in $PM_{2.5}$ from 2003 to 2020 (bottom panel).

In addition to plots of species global distribution, data are presented as tables providing the user with a more effective way to visualize the data. For example, Figure 3 (top panel) shows change in atmospheric composition for each country in the world, with the user able to obtain trends as graphs, as well as trends in absolute values and percentages over time. The atlas also allows users to vizualize seasonal variations in atmospheric pollutant levels (bottom panel).

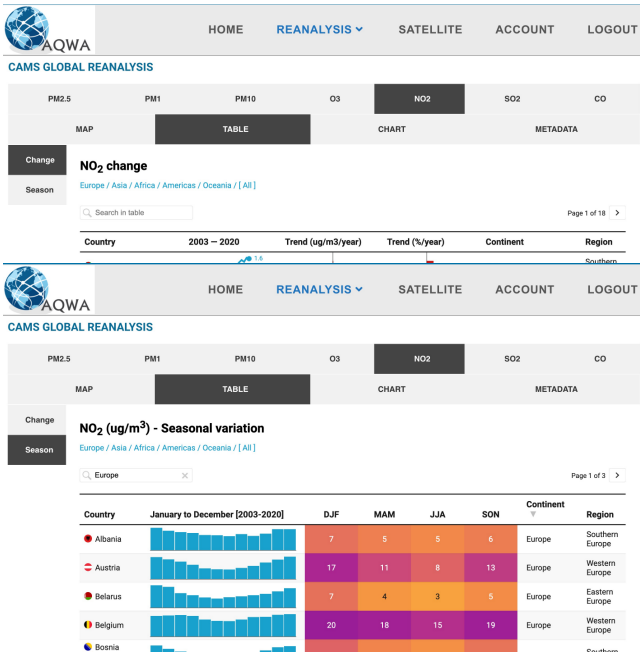

figure 3. Change in NO_2 surface concentration (top panel) and seasonal variation (bottom panel).

The atlas also contains additional statistics. For example, the ranking of surface pollutant concentrations per continent, as well as the evolution of these concentrations in all countries in classified regions over the selected period, can be visualized. Figure 4 displays the average concentration levels in various European countries as well as the changes in average ozone mixing ratio from 2003 to 2020.

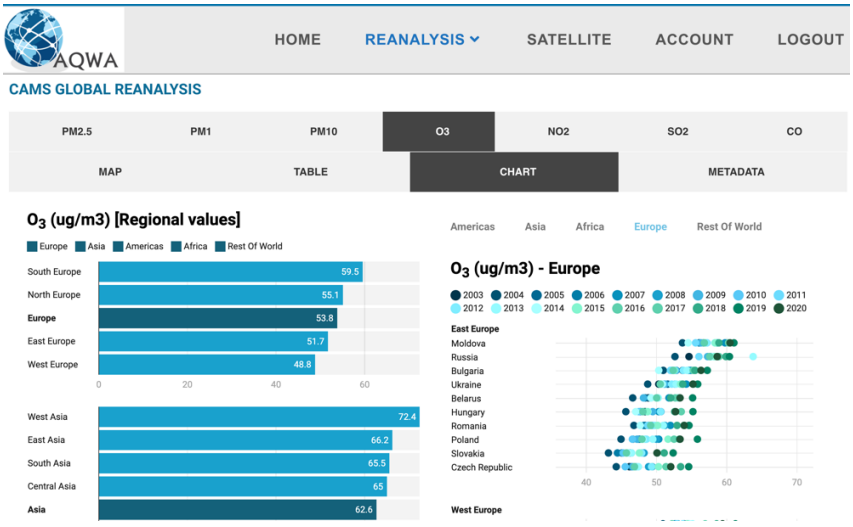

figure 4. Annual average ozone surface concentrations in European countries from 2003 to 2020.

Figure 5 depicts a spatial distribution of air quality index (AQI) derived from the CMAQ model result in 2005 for various counties in the United States as an example of the regional atlas. Users can also switch from county to state and vice versa by clicking on the button at the top of the map. It should be noted that the AQI values from the regional CMAQ model will be used in the evaluation of the global AQI calculation method.

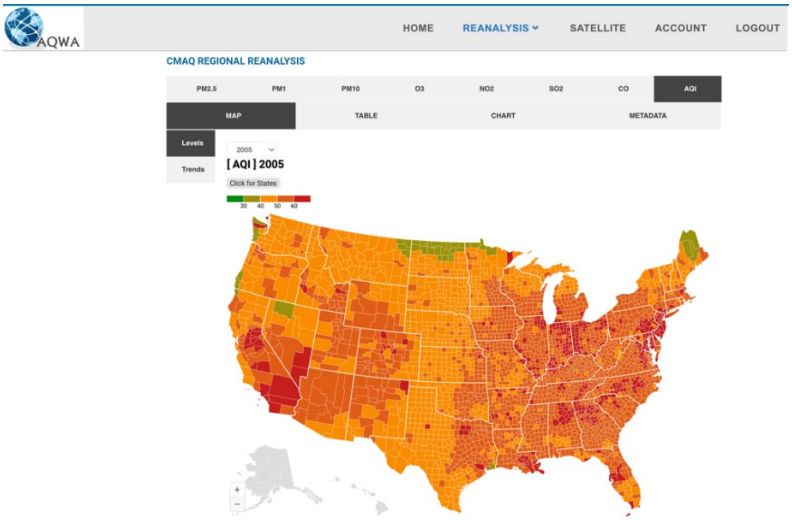

figure 5. Map of air quality indices (AQI) at the county level in the United States in 2005.

Conclusion

An atlas of air quality at the global and regional scales has been developed at the Laboratoire d'Aerologie in Toulouse as part of the AQ-WATCH European project. This atlas is based on the CAMS reanalysis of global atmospheric composition, as well as CMAQ model simulations and satellite observations of NO_2 tropospheric columns.

This paper describes the AQ-WATCH project and the various datasets (particularly reanalysis and satellite data) that were used to create our atlas of air quality. The AQ-WATCH atlas allows us to promote reanalysis data, which are still underutilized due to a lack of information available to people who are unfamiliar with their application. Our tool allows users to better understand the chemical composition of the atmosphere in the different parts of the world, as well as their concentration levels, spatial distributions, and historical trends. This atlas may also be useful as a decision-making tool for assessing the impact of air quality policies on human health and the environment.

The atlas is for now developed in a local website: discussions are taking place with institutions interested in hosting the website.

Bibliography

Boersma, K.F., Eskes, H.J., Dirksen, R. J., van der A, R. J., Veefkind, J. P., Stammes, P., Huijnen, V., Kleipool, Q. L., Sneep, M., Claas, J., Leitao, J., Richter, A., Zhou, Y., and Brunner, D., 2011 : An improved retrieval of tropospheric NO_2 columns from the Ozone Monitoring Instrument, *Atmos. Meas. Tech.* 4, 1905-1928, doi:10.5194/amt-4-1905-2011.

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., 2019 : The CAMS reanalysis of atmospheric composition, *Atmos. Chem. Phys.*, 19, 3515–3556, https://doi.org/10.5194/acp-19-3515-2019.

Kumar, R., Delle Monache, L., Bresch,J., Saide, P. E., Tang, Y., Liu, Z., da Silva, A., Alessandrini, S., Pfister, G., Edwards, D., Lee, P. and Djalalova, I., 2019 : Toward improving short-term predictions of fine particulate matter over the United States via assimilation of satellite aerosol optical depth retrievals. *Journal of Geophysical Research: Atmospheres*, 124, 2753–2773. https://doi.org/10.1029/2018JD029009.