The Copernicus Atmosphere Monitoring Service (CAMS): A digital revolution at the service of the environment

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Abstract:
After nearly ten years of exploratory research funded through European Commission programs, the Copernicus Atmosphere Monitoring Service (CAMS) became operational at the end of 2015. CAMS offers forecasts, maps and data about: the atmosphere's chemical composition on a global scale, ozone in the stratosphere, ultraviolet radiation and air quality in Europe. These services have come out of the work of approximately fifty research teams in Europe; all sorts of digital tools (models) or data (on location and via satellite) have been used to make analyses and forecasts on different scales of space and time. A new era has opened with the availability of products that, for free and of unprecedented quality and exhaustiveness, target users' needs and focus on topics as sensitive as the ecology of the atmosphere.

A short history

In 2015, the section grouping the services devoted to the atmosphere from Copernicus (the EU's Earth observation program financed by DG GROW: Directorate General of the Internal Market, Industry, Entrepreneurship and SMEs) was formed after more than ten years of preparatory work.[1] The Copernicus Atmosphere Monitoring Service (CAMS)[2] is one of the program's six components, alongside the EU services in charge of monitoring the sea and land environments and the climate, and managing emergencies and security (border surveillance).

The Copernicus program and its services rely on data from observation systems (on location and by satellite) and on models and simulations. Designed express for Copernicus, the space program Sentinel launched its first satellite, Sentinel-1A, in 2014 to monitor the land and oceans.[3] Approximately twenty satellites should be placed on orbit by 2030. Sentinel-4, -5 and -5p, also designed specifically for CAMS, will measure, from space, the concentrations of various chemicals in the atmosphere. Sentinel-4 will be placed on a geostationary orbit to monitor the European continent at the start of the coming decade. Sentinel-5p (Precursor), its launch planned for the autumn of 2017, should allow for testing new high-resolution instruments. Copernicus offers an unprecedented set of freely available data for use in developing services for localities or industries and thus stimulating green growth and boosting the market of environmental innovations.

[1] This article has been translated from French by Noal Mellott (Omaha Beach, France). The translation into English has, with the editor's approval, completed a few references.
[2] The Copernicus program (https://atmosphere.copernicus.eu/) was initially named Global Monitoring for Environment and Security (GMES).
[3] https://sentinels.copernicus.eu/web/sentinel/home

In November 2014, the European Commission has delegated the development and management of CAMS (and of Copernicus's climate services) to the European Center for Medium-Range Weather Forecasts (ECMWF, located in Reading, UK). This center coordinated all preparatory and pre-operational research projects (four funded by EU framework programs: the sixth, seventh and Horizon 2020). In 2015, operational systems were thus proposed for making forecasts, mapping and re-analyzing historical data related to: the atmosphere's chemical composition on a global scale, ozone in the stratosphere, ultraviolet radiation and the quality of air in Europe.

The services offered by CAMS

CAMS covers a broad range of activities that can be grouped under four headings:

— global: monitoring the atmosphere's chemical composition (of greenhouse and reactive gases, ozone and pollution-causing aerosols);

— European (or "regional"): air quality in Europe;

— support services for public authorities who manage air quality, evaluate the flow of greenhouse gases or monitor solar radiation; and

— services devoted to assessing chemical pollutants, whether of natural or of human origin, in the atmosphere.

The global and European services propose forecasts three days in advance, analyses of the atmosphere's chemical composition during the preceding days, and re-analyses for past years at the global and European scales. They rely on using the most advanced digital models, which are regularly subject to re-evaluation. Complex mathematical techniques serve to assimilate all types of data from observations into these, the purpose being to analyze as best possible pollution levels.

Some products are totally new and have been well received by users. For instance, forecasts about the movement of dust clouds from the Sahara (Figure 1) or about emissions from biomass fires (Figure 2) offer critical information for studying how natural sources add to the density of particulates in the atmosphere and thus to the population's exposure to them.[4] This information results from processing data collected by observations of our globe and integrating them in models of the chemistry of the atmosphere in order to make maps. The same procedures, using observations and complex models, have been applied to data about our planet from the past. Certain results (such as the analyses of radiative forcing from aerosols or of CO_2 emissions) are of interest to climatologists.

Dozens of teams, among the best in Europe in the chemistry of the atmosphere and air quality, have developed these services. The ECMWF selected them on the basis of competitive bids. All the data from the work conducted in CAMS can be downloaded from a website with a user-friendly interface. The ECMWF and its partners try to respond to specific requests from users and to follow up on how users process the data and put them to use. Besides providing forecasts and analyses to assist decision-making or improve the state of knowledge, the objective is also to boost innovative spin-offs by small and medium-sized businesses (SMEs).

[4] Available respectively at: http://www.copernicus.eu/news/poor-air-quality-over-western-europe and http://atmosphere.copernicus.eu/news-and-media/press-room/press-resources/press-photos.

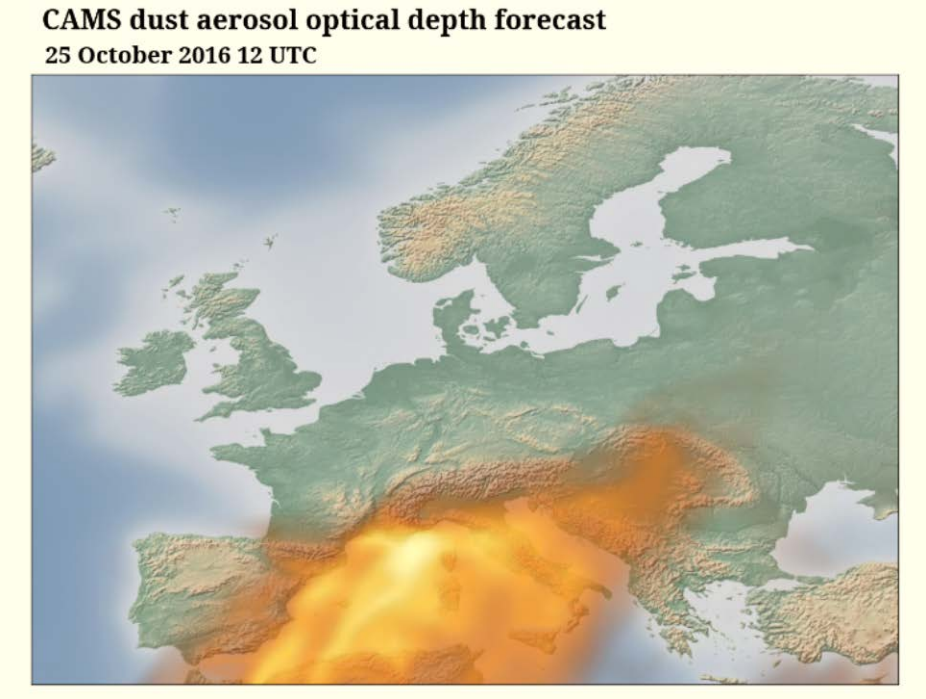

Figure 1: Plumes of desert dust covering much of southern Europe on 25 October 2016 (*Source*: CAMS).

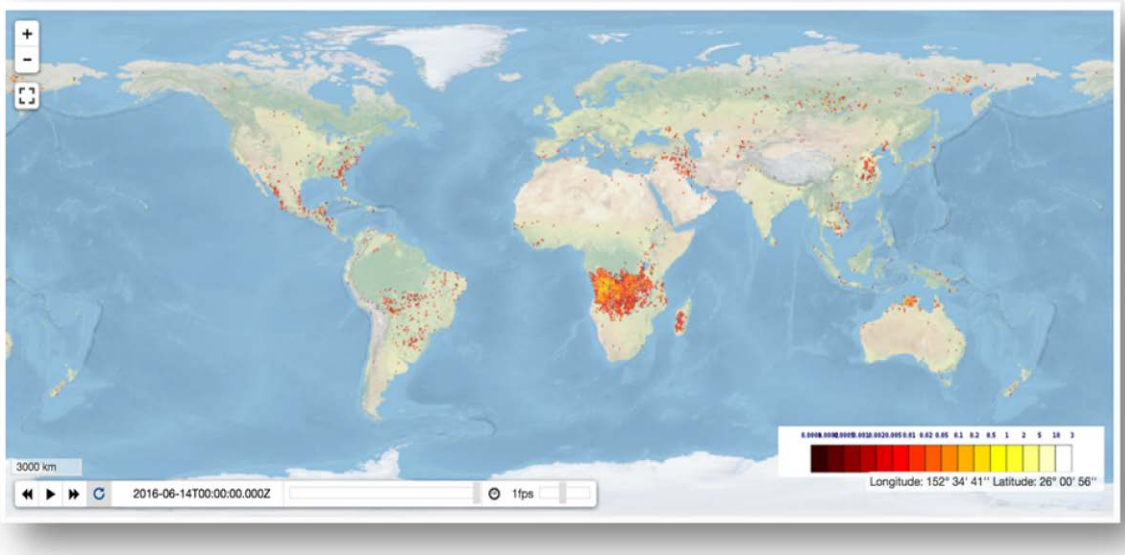

Figure 2: Fire activity detected on Earth on 14 June 2016 (*Source*: CAMS).

Air quality

The regional services of CAMS contribute to our knowledge of air quality in Europe and help manage spates of air pollution. This topic, related to health risks, receives much attention from the public and the media. It is sensitive, too, because air quality is regulated by international protocols and EU directives, which member states have transposed into national legislation.

French teams at INERIS (Institut National de l'Environnement Industriel et des Risques) and Météo France coordinate the work on air quality. These two institutions have earned legitimacy in the eyes of the ECMWF and its stakeholders owing to their experience acquired over the past fifteen years, in particular, when setting up PREV'AIR, a national platform for predicting air quality.[5]

The services for monitoring air quality in Europe describe changes in the concentrations of various atmospheric pollutants via:

— three-day forecasts of the concentrations of the major regulated pollutants in Europe (*e.g.*, ozone, NO_2, particulates of diameters less than 10 and less than 2.5 micrometers: PM_{10} and $PM_{2.5}$), and forecasts of pollen concentrations (including highly allergic birch pollen);

— nearly real-time analyses of the situation on the previous day; and

— annual re-analyses of changes in air quality in Europe for assessing the impact of policies for managing air quality and of strategies for reducing emissions of pollutants in the atmosphere.

These forecasts combine the seven chemistry-transport models (of the advection/convection of chemicals in the air) used by European teams, such as Météo France (Mocage), INERIS and the CNRS (Chimere).[6] Benefitting from the advantages of each model, this approach improves the continent's weather forecasts and maps (with a spatial resolution of 10 km). Analyses and re-analyses are made by assimilating the data that the observation systems set up in Europeans countries transfer to the European Environment Agency (EEA). Each model uses the same data as input: the ECMWF's meteorological forecasts and the data on emissions and limiting conditions from other services at CAMS.

The originality and force of the approach adopted by CAMS is that it uses all these models to produce a robust "whole" that, by combining their results, is of better quality than those of each model taken separately. CAMS applies very rigorous procedures for ensuring the quality of its findings and for making fully transparent evaluations of the performance of these models (as in Figure 3).

[5] http://www2.prevair.rg/

[6] Cf. respectively: https://donneespubliques.meteofrance.fr/?fond=produit&id_produit=200&id_rubrique=42 & for the CNRS (Centre National de la Recherche Scientifique) http://www.lmd.polytechnique.fr/chimere/.

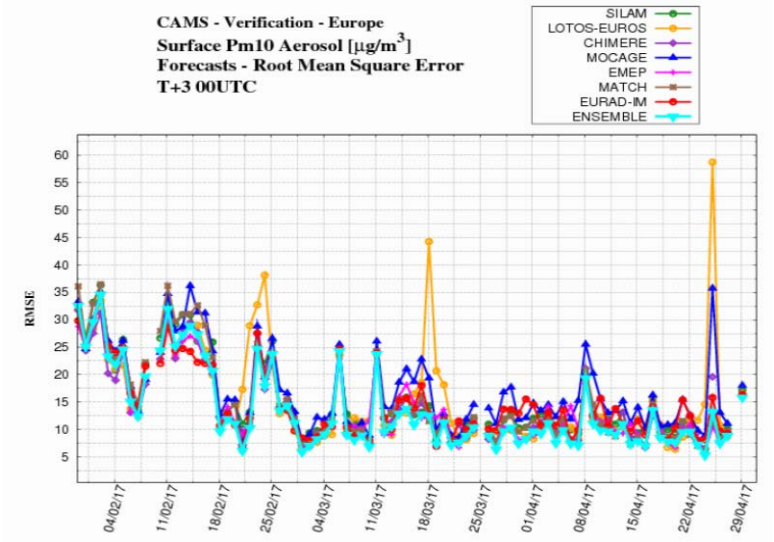

Figure 3: An example of the transparency of information on air quality produced by each of the seven models used and by all of them together: average RMS error for the concentrations of particulates (PM10) during the February-March-April period in 2017.
(*Source:* http://www.regional.atmosphere.copernicus.eu).

All these air quality services are available since June 2016 on the website.[7] This platform provides for-free access to a considerable quantity of data and to nearly 800 products.

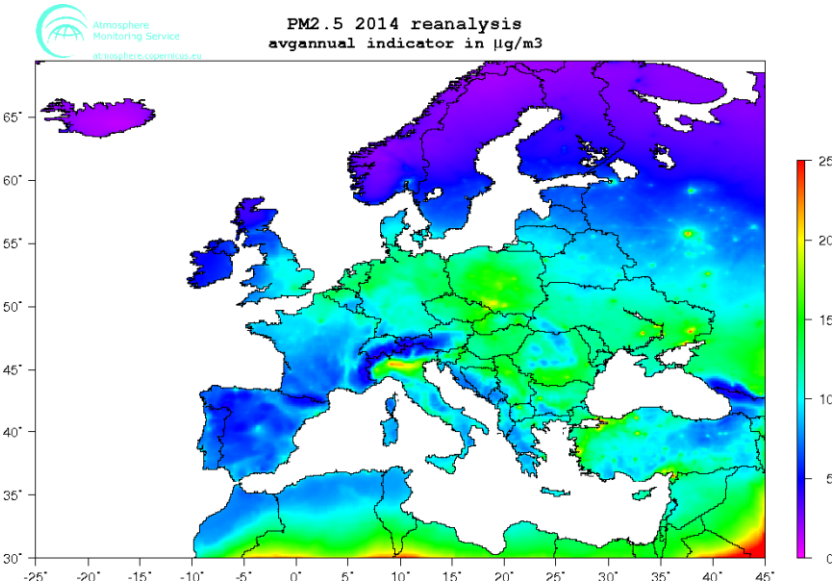

Figure 4: Annual average concentrations of particulates in the atmosphere over Europe in 2014.

[7] http://www.regional.atmosphere.copernicus.eu

Other services are offered to the parties involved in implementing policies for managing atmospheric pollution in Europe. These "policy support services" have three major orientations:[8]

— produce annual air quality reports, based on a re-analysis of air quality trends in Europe. These reports propose regulatory indicators along with indicators of the health effects of air pollution (as in Figure 4).

— make daily simulations of the impact that actions for reducing emissions in several sectors (industry, road traffic, residential heating, agriculture…) would have on the concentrations of various atmospheric pollutants. The analysis of these simulations (presented as maps) helps identify the decisive factors causing spates of pollution and settle on the most effective strategies ("green scenarios") for managing the situation. These results remind us that strategies for managing air pollution depend on the pollutant, the geographic area and the time period.

— make daily simulations, for European capitals, of the percentages of pollution due to local sources and to sources in neighboring lands. These "source allocation" simulations provide a qualitative analysis (in the form of pie charts and time series) of the long-distance transportation of atmospheric pollutants.

This information can help decision-makers eventually make more effective decisions. It informs them about the levers for national or local actions and about the consequences of certain actions on given economic activities. The resolution of the current models does not enable us to focus on very localized cases of pollution, for example in the vicinity of major highways or industrial plants. However it does prove useful for conducting actions for lowering the background levels of air pollutants and thus reducing the population's chronic exposure to them.

An original governance guided by users' needs

In conclusion, CAMS proposes a new generation of services and data that combines information from both digital models and observation systems on location and via satellite. The aim is to better describe and understand the factors affecting the atmosphere. This initiative is original owing to its scope and means: it marshals dozens of research teams in Europe. It is also original owing both to its requirements in terms of operability and quality, and to its policy of openness toward users.

To stimulate economic growth on the continent, an unprecedented mass of data and an unequaled number of sources of information on air quality in Europe (and also on the Earth) have been made available to all. CAMS now has more than 5.000 subscribers, who regularly download data and products for their own purposes or for developing and circulating new applications. These users are important for the governance of Copernicus, which depends very much on feedback and users' needs. At the level of Copernicus, a users' forum analyzes the available offer of services, makes recommendations for developing it and conducts surveys for this purpose. The same procedure is followed in each service. CAMS has a communications policy fully oriented toward users and plans for future developments, devoted as much to promoting and circulating existing products as to listening to the new needs that are voiced. A data base compiles requests and is augmented by user feedback (through surveys, workshops and training sessions). It will eventually help us steer a course toward the durability of our evolving services.

[8] Available at: http://policy.atmosphere.copernicus.eu/

CAMS has met the challenge and set up, in a period of a dozen years, fully operational services that produce, day after day, an unprecedented mass of information on the changing composition of the Earth's atmosphere and on air quality in Europe. This information relies on the most advanced, state-of-the-art, tools, models and data; it satisfies strict criteria for guaranteeing quality. These services, which draw on the findings of sophisticated research programs, are evidence of the tight linkage between academia, public institutions and business. In turn, these operational services and users' demands highlight points of uncertainty, questions calling for more research. In services for monitoring the atmosphere and in the other components of the Copernicus program, this new momentum will create a "little" revolution in the observation systems, digital simulations and forecasts that together serve to provide services fully turned toward citizens in general and toward economic agents, in particular.