Improved aerosol forecasting during extreme events by data assimilation

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1- Introduction

Aerosols play an important role in the atmospheric system of our planet. They have an important impact on the Earth's radiation budget by direct scattering and absorption of sunlight and by changing cloud properties. Therefore, they play a major role in the climate system. They also have an influence on the photochemistry of our atmosphere.

It is then very important to well simulate the tridimensional distribution of different type of aerosols within the chemistry and transport models (CTMs). Nevertheless, modelling of different type of aerosols is challenging and still subject of many uncertainties due to the complexity of their physical/chemical transformations and the approximations in the parameterizations of their sources/sinks. The improvements of the models can be achieved by means of i) improvements of the physical parameterizations of the aerosols (e.g., Sic et al., 2015, and ii) using data assimilation of aerosol products such as Aerosol Optical Depth (AOD) (e.g., Sic et al., 2016) and lidar backscatter/extinction profiles.

Desert dust or volcanic ash are important sources of aerosols in the troposphere and have a direct involvement in the tropospheric composition: Desert aerosols directly influence air quality while volcanic aerosols has a great impact on civil aviation. It is therefore important to better understand the evolution and long-range transport of these types of aerosols in order to assess their impact in the atmospheric system as well as in aviation safety. In this study, we assess the capacity of assimilation of different aerosol products in terms of AOD or lidar profiles to improve the three-dimensional concentration of aerosols during extreme events (desert aerosol transport or volcanic eruption). We also propose to study quantitatively the shape of the plumes and their impacts on French territory. The validation of assimilated products in terms of concentration of aerosols and AOD will be done in comparison with independent observations.

The assimilation system used in this study is MOCAGE- PALM (e.g. El Amraoui et al., 2008a) developed jointly between Météo-France and CERFACS (Centre Européen de Recherche et de Formation Avancées en Calcul Scientifique) in the framework of the ASSET European project (Lahoz et al., 2007). MOCAGE (MODELE de Chimie Atmospherique a Grande Echelle) (Peuch et al., 1999) is a 3-D-CTM which covers the planetary boundary layer, the free troposphere, and the stratosphere. It provides a number of optional configurations with varying domain geometries and resolutions, as well as chemical and physical parameterization packages. It has the flexibility to use several chemical schemes for stratospheric and tropospheric studies. MOCAGE is used for several applications: operational chemical weather forecasting in Météo France (Dufour et al., 2004), tropospheric as well as stratospheric research studies (e.g. Josse et al., 2004; Michou et al., 2005; Ricaud et al., 2009a,b), and data assimilation research (e.g., Semane et al., 2007; El Amraoui et al., 2008a,b; Semane et al., 2009). In this study, MOCAGE is forced dynamically by external wind and temperature fields from the ARPEGE.
model analyses, the global operational weather prediction model of Meteo-France (Courtier et al., 1991).

The assimilation of aerosols is a relatively new field compared to that of the reactive gases. Even if the number of unknowns relating to aerosol is larger than that of gases, the assimilation of aerosols nevertheless improves their distribution in the model. In CNRM-GAME, the assimilation of aerosols is implemented in the chemistry-transport model MOCAGE since 2014 and allows to assimilate two types of aerosol data: 1) integrated atmospheric column such as the Aerosol Optical Depth, 2) or aerosol profiles from lidar measurements with different configurations (from the ground, from satellite platforms or from aircraft measurements).

2- Assimilation of MODIS AOD observations

The MODIS (Moderate-resolution Imaging Spectroradiometer) instruments observe atmospheric aerosols on board Terra (since 2000) and Aqua (since 2002) from complementary sun-synchronous orbits. The Terra overpass time is around 10:30 local solar time at the Equator in its descending (daytime) node, and the Aqua overpass time is around 13:30 local solar time at the Equator in the ascending node. We use MODIS Aerosol Optical Depth Collection C051 retrievals at 550 nm from Terra and Aqua, the ocean product retrieved with the “best solution” and the reflectance-corrected land product. Over bright desert areas, we use the “Deep Blue” MODIS product (Hsu et al., 2006). For the assimilation, we only considered the best quality data, with the highest possible quality flag. MODIS L2 resolution of 10kmx10km is approximately 2 times finer than the model resolution of 0.2°x0.2° over the control MEDI02 domain in which the assimilation is performed.

Figure 1: The aerosol optical depth over Europe on 29 June 2012 at 12:00 UT, (top left) simulated in MOCAGE by the model direct run; (top right) simulated in MOCAGE by the MODIS assimilation model run; (bottom left) observed by MODIS (Aqua+Terra) and used for assimilation in MOCAGE (shown observations are collected during the whole day, and not only at 12:00); and (bottom right) observed by SEVIRI, which serves as an independent dataset. The colors from white to red represent AOD from low to high values.
Figure 2: Time series of aerosol optical depth at 550 nm of the AERONET data (black line), the direct model (blue line) and the assimilation model run (red line) for the period of the TRAQA campaign from 25 June until 13 July 2012. The presented AERONET data are from eight stations: Malaga (ESP), Tabernas (ESP), Avignon (FRA), Ersa (FRA), Frioul (FRA), Lampedusa (ITA), Limassol (CYP), Palma de Mallorca (ESP).

Time series plots for eight stations are presented in Fig. 2 which are chosen to representatively cover the basin. The time series of the stations in the western part of the Mediterranean basin and in Spain are marked by the strong desert dust event, which was already discussed earlier. Stations in Spain recorded the event before the stations in France, where it arrived a couple of days later. The duration of the event is well simulated by both the direct model run and the assimilation model run in all stations, but the intensity is underestimated in the direct model run (Fig. 1). However, the assimilation model run matches the outbreak intensity well. The second, smaller desert dust event is only observed at southern stations. Similarly, the assimilation model run corrects its intensity underestimated by the direct model run. The stations in the east, like in Lampedusa and Cyprus, were not influenced by these dust events. They are mostly influenced by sea salt aerosols, and the data assimilation also has a positive impact here. The assimilation model run, with only two MODIS overpasses per day, also shows improved hourly variations of AOD in these stations.
3- Assimilation of CALIOP lidar observations

The assimilation of lidar profiles of CALIOP measurements onboard the CALIPSO satellite during the summer 2012 was undertaken in terms of extinction coefficient. This period corresponds to the airborne campaign TRAQA-2012 and coincides with a desert dust transport event from Africa over the Mediterranean.

Figure 3 : (a) the aircraft trajectory with respect to its altitude corresponding to 29 June 2012 between 10:00 and 15:00. (b) Time-series of aerosol concentration given by the MOCAGE model, the CALIOP assimilated product and the in-situ aircraft measurements.

Figure 3-a shows the aircraft trajectory with respect to its altitude corresponding to 29 June 2012 between 10:00 and 15:00. Figure 3-b shows the aerosol concentration time-series of both model outputs and assimilated product compared to in-situ measurements made by the aircraft. Clearly the assimilation of CALIOP observations significantly improves the penny-underestimation of the aerosol concentration predicted by the model especially in high altitudes.

4- References:


