Development of a Dust Assimilation System for NMM-DREAM Model Based on MSG-SEVIRI Satellite Observations

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Abstract Initial and boundary conditions of dust are still a missing component in atmospheric modeling. In this context, dust models are usually initialized based on their own previous forecasting cycle. As it is obvious, even at the idealized hypothesis of a perfect model run, this approach implies the propagation of numerical diffusion errors. However, recent improvements in remote sensing retrievals of dust optical depth allow the timely generation of dust fields that can be used for assimilation in forecasting atmospheric modeling systems. In this work we present the methodology and preliminary results for the application of MSG/SEVIRI dust retrievals in the atmospheric model NMME-DREAM. First results of the assimilation method are compared with ground photometers (AERONET) and LIDAR (PollyXT) systems during Charadmexp campaign (15 June–15 July 2014). Significant improvement is found mainly over dust sources in Africa and Arabia deserts. The introduction of satellite assimilation methods in dust models provides an additional tool for the improvement of our understanding on the dust-atmosphere interactions and on their possible implications for climate change.

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1 Introduction

Despite the recent improvements in numerical modeling of air-quality components and specifically of the atmospheric dust cycle (e.g. Baklanov et al. 2014) there is still significant unresolved uncertainty regarding the type of dust sources and the primary reasons that enable the mobilization of mineral dust particles from the desert and arid areas. Several factors that affect dust generation are not yet fully understood or resolved in atmospheric models. These may include the seasonal behavior of some sources such as the Aral Sea, the convectively driven dust-storms (e.g. Solomos et al. 2012) and local meteorological phenomena such as the breaking of nocturnal low level jets (e.g. Schepanski et al. 2015). Moreover, even at the hypothesis of a "perfect" dust source description in the model, the lack of initial conditions would result in an infinite recycling of modeled dust. This happens through the "warm start" configuration that is currently used to initialize all atmospheric dust models. The term "warm start" refers to the initialization of a prognostic cycle from the results of a previous prognostic cycle. As it is obvious, this procedure would propagate all forecasting errors into the next model run eventually leading to divergence of the model solution.

Until recently, the lack of atmospheric observations over the dust source areas (usually deserts and arid regions) did not allow the retrieval of sufficient data at spatial and temporal scales that could be useful for driving the modeling simulations. In-situ meteorological information is very sparse over these areas and air-quality information is even more difficult to obtain. This situation can be improved with the use of satellite data.

In this work we present for the first time the methodology and some preliminary results regarding the assimilation of satellite dust optical depth (DOD) from the Meteosat Second Generation—Spinning Enhanced Visible and Infrared Imager (MSG-SEVIRI) into the Dust Regional Atmospheric Model module of the Nonhydrostatic Mesoscale Model (NMM-DREAM). The methodology and the description of the numerical tools are described in Sect. 2. In Sect. 3 we present first results of the new model development obtained during the Characterization of Aerosol mixtures of Dust And Marine origin campaign (CHARADMexp) in Finokalia Crete (June–July 2014). Conclusions and future plans are included in Sect. 4.

2 Methodology

In this section we present the methodological tools and steps used in this study for the implementation of MSG-SEVIRI dust product in NMM-DREAM dust model. We describe the UK Met Office satellite retrieval algorithm that is used to obtain the dust optical depth (Brindley and Russell 2009), the atmospheric dust model NMME-DREAM (Nickovic et al. 2001) and the dust assimilation algorithm (Pejanovic et al. 2010).

2.1 MSG-SEVIRI Dust Optical Depth (DOD) Retrieval Algorithm

The UK Met Office MSG dust product provides an estimation of the dust optical depth (DOD) retrieved from empirical relationship between the changes in SEVIRI infrared (10.8 μm) brightness temperature and aerosol optical depth at 550 nm. A detailed description of this procedure and its accuracy is given in Brindley and Russell (2009). A moving time-window of 24 days is used to identify “clear sky” conditions for each pixel and thus derive the corresponding DOD. The current version of the algorithm is active only over land pixels. The high temporal resolution of the geostationary sensor (15 min) allows the real time observation of dust activity directly over the sources and provides valuable information for the diurnal variation of dust emissions (see for example Fig. 1).

2.2 The Atmospheric Model NMM-DREAM

We use the NMME-DREAM version of the well-established atmospheric dust module DREAM. The model solves the Euler-type partial differential nonlinear equation for dust mass continuity including dust concentration as a prognostic component. Soil texture is derived from the USDA 1 × 1 km global database and the effectiveness of dust sources is computed taking into account the vegetation type, soil moisture and atmospheric turbulence. Near surface Brownian motions are parameterized within a shallow viscous sub-layer and after injection into the free troposphere the particle motion is governed by the modeled winds and turbulence.

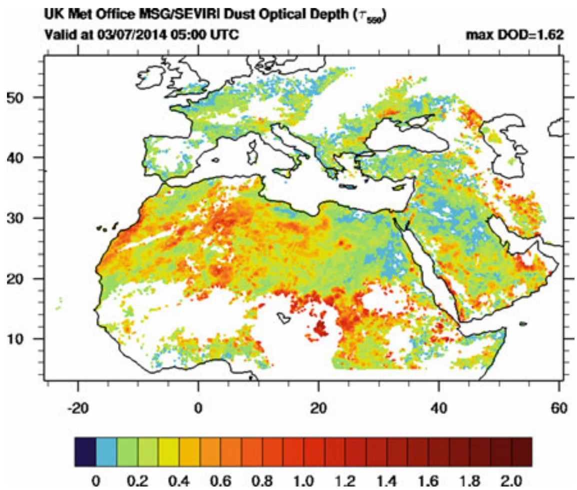

Fig. 1 DOD from the UK Met Office SEVIRI retrieval algorithm, 3 July 2014, 05:00 UTC

Removal processes include both dry and wet deposition of dust. The model includes eight size bins of dust and an online dust-interactive radiation scheme (Pérez et al. 2006).

2.3 Assimilation Algorithm

We adopt the Newtonian relaxation approach for assimilation of dust-related data (Nickovic et al. 2016) applied here for the assimilation of satellite DOD. This methodology has been previously developed and used at the Serbia Met Service (South East European Virtual Climate Change Center—SEEVCCC) for the assimilation of the ECMWF MODIS dust product in DREAM model (Pejanovic et al. 2012). Following this approach the prognostic field of dust concentration (C) is nudged towards the satellite observation field (C_T) basedon Eq. 1. The nudging strength in this equation is determined by the nudging coefficient (k).

$$\frac{\partial C}{\partial t} + k(C - C_T) = 0, \quad (1)$$

3 Results

In this section we present preliminary results from the application of the new model developments and examine the main contributions of satellite assimilation on the overall model performance. During the CHARADMexp experiment in Crete we performed two separate model runs, namely the NO-ASSIM run that is the standard model configuration without data assimilation and the MSG-ASSIM run that includes assimilation of satellite DOD. A comparison between the two different model configurations is shown in Fig. 2. As seen from the average plots of DOD (Fig. 2a, b) for the entire experimental period, the main difference between the two runs is found over the Arabian desert. The MSG-ASSIM run in general results in lower DOD values over Arabian Peninsula which is probably correct based on previous relevant literature (e.g. Basart et al. 2012). DOD values for the MSG-ASSIM run are also lower over the Saharan sources by almost 0.2 at some areas. The maximum DOD values (Fig. 2c, d) are accordingly lower for the MSG-ASSIM simulation and this reduction affects also several European areas. For example the maximum DOD in the NO-ASSIM run is over 0.5 at the Adriatic Sea and west Balkans (Fig. 2c) but it is lower than 0.5 in the MSG-ASSIM run (Fig. 2d). Comparison of the model vertical profiles of dust with lidar retrievals (not shown) and comparison of modeled DOD timeseries with the AERONET CIMEL photometer AOD at Finokalia (Fig. 3) confirm the successful implementation of the assimilation method in the model. An improvement in the correlation with the

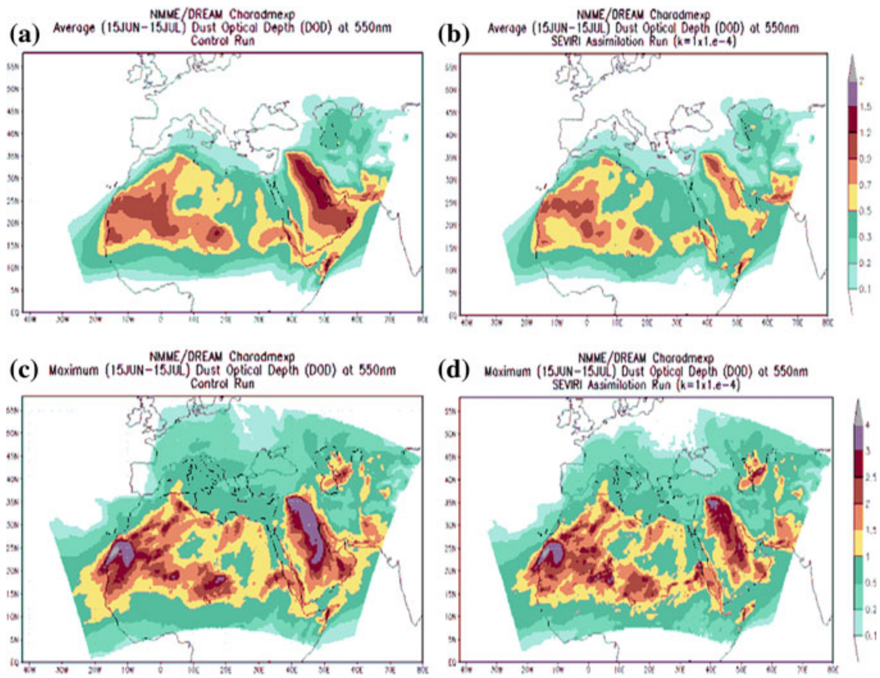

Fig. 2 Average DOD **a** NO-ASSIM, **b** MSG-ASSIM; Maximum DOD **c** NO-ASSIM, **d** MSG-ASSIM

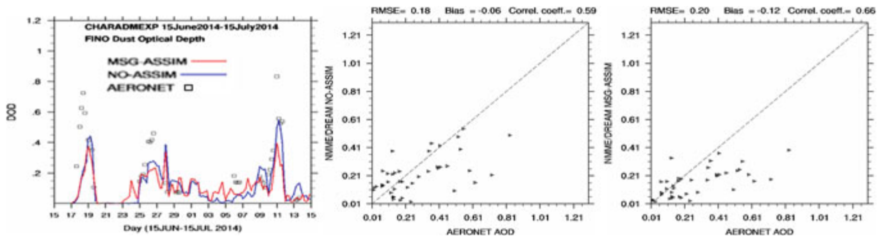

Fig. 3 Comparison of modeled DOD with the AERONET AOD at Finokalia (15 June–15 July 2014). (*left*): DOD timeseries, (*middle*): NO-ASSIM results, (*right*): MSG-ASSIM results

photometric measurements is also found ($R_{NO\text{-}ASSIM} = 0.59$, $R_{MSG\text{-}ASSIM} = 0.66$). However the bias and RMSE for the assimilation run are bigger ($BIAS_{NO\text{-}ASSIM} = -0.06$, $BIAS_{MSG\text{-}ASSIM} = -0.12$; $RMSE_{NO\text{-}ASSIM} = 0.18$, $RMSE_{MSG\text{-}ASSIM} = 0.20$). An ongoing detailed evaluation with ground-based sun-photometers (AERONET) and lidar measurements is expected to improve our understanding on the overall impact of satellite assimilation in model performance.

4 Conclusions—Future Plans

We present the assimilation of satellite dust retrievals from the geostationary MSG-SEVIRI sensor directly into NMME-DREAM model. First results indicate a reasonable response of the model to this additional forcing and some promising improvements. For example, Arabian dust seems to be more realistic in the assimilation run. This is also an indication of the natural variability between Saharan and Arabian sources that are currently treated in a similar way in numerical models. Eventually, a different dust-lift mechanism or a different description of the sources may be required for the Arabian deserts, but for the time being restricting the model with satellite observations could be adequate for improving the modeling of dust dispersion at this area. Development of an updated satellite retrieval algorithm to include also the DOD over the ocean could further improve the accuracy of our results. Ongoing research also includes the detailed evaluation of modeled fields against the AERONET sunphotometer network and the fine tuning of the assimilation method. Implementation of real time SEVIRI retrievals in long term simulations is expected to provide more statistically robust comparisons with the available measurements.

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