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Toward a forecast of aerosols with the ECMWF Integrated Forecast System

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Toward a forecast of aerosols with the ECMWF Integrated Forecast System

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A part of the EU-funded GEMS project (which concerns global environmental monitoring using satellite and in situ observations), a prognostic representation of aerosols is being developed in the ECMWF Integrated Forecast System (IFS) in both its analysis and forecast modules. In this short note, consideration is given to the forward modelling, outside of the analysis.

The forecast model

An experimental version of the forecast model now accounts for five tropospheric aerosol types (i.e. sea-salt, desert dust, organic matter, black carbon and a sulphate-related variable, SO2). Both the sea-salt and dust are each represented by three bins, whose limits are chosen as to have roughly 10%, 20% and 70% of the mass of each aerosol type in the various bins. The package of physical parametrizations dedicated to aerosol processes is standard. Sources of sea-salt and desert dust are interactive with surface and near-surface variables of the model. The surface flux of sea-salt aerosols is parametrized from the 10-m wind at the free ocean surface. For the production of desert dust, the source depends on the 10-m wind, soil moisture, the UV-visible component of the surface albedo, and the fraction of cover by vegetation when the surface is snow-free. Other aerosol sources are taken from monthly-mean climatologies or inventories (Global Fire Emission Database, Speciated Particulate Emission Wizard, Emission Database for Global Atmospheric Research) until more temporally-resolved data based on satellite observations are provided as part of the GEMS project.

All aerosols undergo sedimentation, and dry and wet deposition (this last one by large-scale and convective precipitation). For organic matter and black carbon, two components, hygrophobic and hygrophilic, are considered. SO2 is considered as one variable with no explicit chemistry included. Recent developments in the model dynamics and package of physical parametrizations allow the aerosols to be advected, and the vertical diffusion and the mass-flux convection schemes to account explicitly for tracers such as aerosols. The wet and dry deposition schemes are standard, whereas the sedimentation of aerosols follows closely the scheme recently introduced for the sedimentation of ice particles.

At present, the model prognostic aerosols are not interactive with the radiation scheme and are therefore passive tracers. However, their optical thickness is evaluated at different wavelengths as diagnostic quantities that can be compared to surface measurements such as those taken by AERONET (Aerosol Robotic Network) or derived from satellite measurements like those of MODIS (Moderate Resolution Imaging Spectro¬radio¬meter).

The analysis module has been developed and is currently running for GEMS's official reference study period, 2003–2004. The analysis ingests MODIS aerosol optical depth observations and uses the total aerosol mixing ratio as the control variable. Results so far are encouraging and show the capability of the analysis to draw to the observations.

For the results presented here, there is no assimilation of any data related to aerosols. The model is run from a given starting date in a series of 12-hour forecasts starting every 12 hours from the ECMWF operational analysis. The model aerosols are free-wheeling. They start from null concentrations of aerosols on the starting date. Then the various aerosols spin up for about 8–12 days (the time their contents establish themselves), with the aerosols produced from their surface emission fluxes, and going through the physical processes (dry deposition, sedimentation, wet deposition). After 12 hours of the forecast the aerosols are stored and passed as initial conditions for the next forecast starting 12 hours later. This is in essence not very different from what is done within a transport model, except that the aerosol processes are fully consistent with the dynamics and all physical parametrizations.

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Some results

Since 1 June 2007 this experimental version of the forecast model, which includes prognostic aerosols and runs at T159L91, produces near-real time aerosol forecasts that are available from the ECMWF web site at: www.ecmwf.int/products/forecasts/d/inspect/catalog/research/gems/aer/

Figure 1 illustrates the potential of the future aerosol forecasts. For an ascending orbit over Africa (Figure 1(a)), a classification of cloud and aerosol produced by the CALIPSO Science Team (Figure 1(c)) is compared with the corresponding model cloud and aerosol (Figure 1(d)). Even for this relatively low horizontal resolution (T159), the ECMWF model generally produces the cloud and aerosol in the proper location both horizontally and vertically. Over the same orbit, the total aerosol optical depth at 550 nm produced by the model is compared to the equivalent optical depth retrieved from MODIS observations over ocean and dark land surfaces in the absence of extended cloud cover (Figure 1(b)). For desert dust, the agreement is usually good reflecting the high quality of the initial conditions and of the atmospheric motions in the subsequent 12-hour forecast. Over Central Africa, the sources of sulphate, and organic and black carbon aerosols linked to biomass burning are well represented in the inventories, and the agreement on the optical depth of the plume moving towards the South Atlantic is also good.

As a further example, Figure 2 compares the model aerosol optical depth at 550 nm over Blida (Algeria) and Nes Ziona (Israel) to that derived from AERONET surface observations at those stations for July 2007. These results show that the model describes reasonably well the temporal variability of the aerosols. The model also captures the dominant aerosol type, dust in Blida and sulphate in Nes Ziona.

The quality of the results depends not only on the dynamics of the model and the adequacy of the aerosol physical parametrizations, but also on the representativeness of the sources. With the exact sources of aerosols (in particular, those of anthropogenic origin) not available in real time, the aerosol analysis, through the assimilation of aerosol-related observations, will provide initial conditions representative of the true aerosol burden in the atmosphere. The development of a successful aerosol analysis is therefore fundamental to the quality of the subsequent aerosol forecast. Here the forecast model including prognostic aerosols was shown to provide a reasonable basis for this analysis.

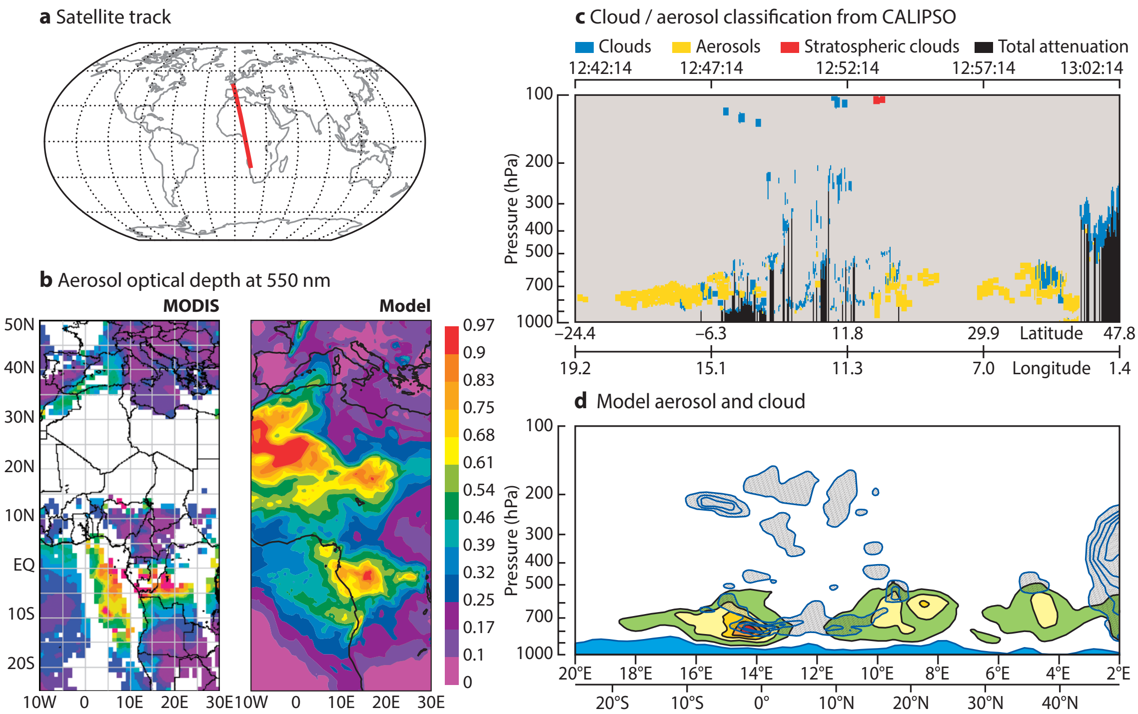

Figure 1 (a) The orbit of the A-train of satellites on 16 July 2007 between 1242 and 1302 UTC. (b) The aerosol optical depth at 550 nm derived from MODIS-Aqua observations (left) and produced by the ECMWF forecast model (right). (c) The cloud/aerosol classification derived from CALIPSO measurements along the orbit shown in panel (a). (d) The cross-section along the same orbit as used for (c) showing the aerosol (yellow) and cloud (blue) quantities produced by the ECMWF forecast model. The MODIS and CALIPSO data were downloaded from the NASA Giovanni server.

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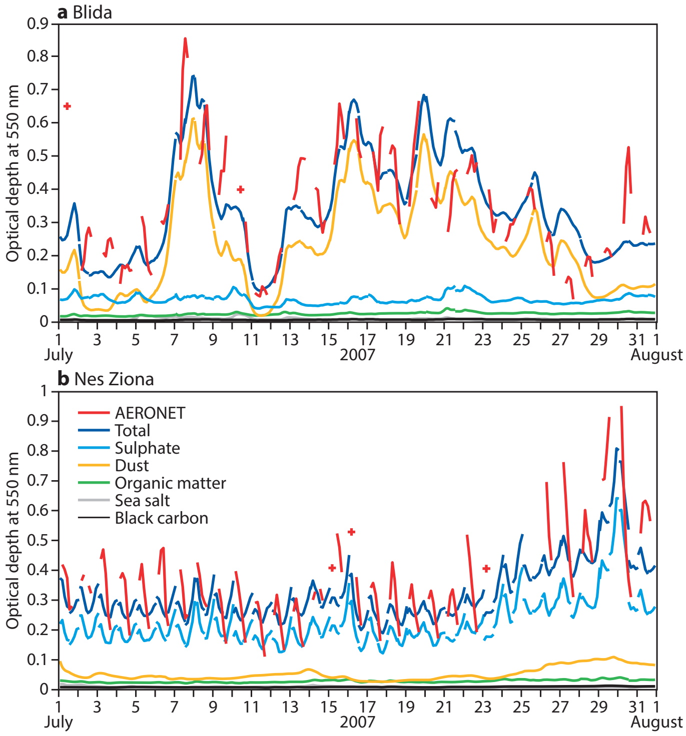

Figure 2 The observed optical depth at 550 nm from AERONET stations at (a) Blida and (b) Nes Ziona for July 2007 compared to the values from the model (total optical depth plus contributions from various aerosols). Dust aerosols dominates the optical depth at Blida, whereas sulphate aerosol dominates in Nes Ziona. Data for Blida and Nes Ziona were obtained from the AERONET web site. Thanks go to B. Holben, A. Karnieli and M. Boughedaoui for their efforts in establishing and maintaining the Blida and Nes Ziona AERONET sites.

Further Reading

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