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Sea-salt aerosol forecasts compared with daily measurements at the island of Lampedusa (Central Mediterranean)

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ABSTRACT

Operational regional sea-salt aerosol forecasts have been produced on a daily basis since February 2006 over the open sea in the Mediterranean, where sea-salt aerosol concentrations and their impact on the Mediterranean weather and climate could be significant under strong winds. In order to evaluate the model performance, the numerical simulations of sea-salt aerosol (SSA) were compared with sea-salt ground-based measurements taken at the tiny Mediterranean island of Lampedusa, Italy. Considerable effort was made in order to collect and analyze SSA measurements on a daily basis, during the two-year period from 2007 to 2008. In Lampedusa, the conditions of SSA measurements are considered similar to those in the open sea, given the small dimensions of the island. As estimated for all 380 days used in the analysis, model-vs.-measurement comparisons at Lampedusa show a relatively high correlation of 0.7 between model data and measurements; a rather low mean bias of $-0.5\ \mu g/m^3$; and a mean normalized bias less than 20%. Therefore, the model was capable of producing reasonable SSA concentrations and their day-to-day variations over the open sea.

1. Introduction

Sea salt aerosol (SSA) produced by surface winds, is an important component of atmospheric aerosols over the ocean. The reason for the current interest in sea-salt aerosols is their influence on climate (Lewis and Schwartz, 2004, and references therein): sea-salt could affect cloud formation by acting as cloud condensation nuclei (CCN) and contributing from 5% to 90% of CCN in the marine boundary layer (Clarke et al., 2006, Rosenfeld et al., 2002). Furthermore, SSA scatters solar radiation and thereby plays an important role in the atmospheric radiation budget (Haywood et al., 1999; Satheesh and Lubin, 2003). Some investigations have dealt with the possible effects of SSA on hurricane strength and development (Emanuel, 2003).

The Mediterranean Sea, being an almost-closed area surrounded by mountain ranges, has experienced elevated aerosol loading (Lelieveld et al., 2002; Papadimas et al., 2008). This region is of special importance because it is a crossroad where natural (Saharan dust and sea-salt) aerosols and anthropogenic aerosols from Africa, Europe, and Asia are superimposed. There are publications devoted to sea-salt aerosol studies in the Mediterranean region (Astitha et al., 2008; Athanasopoulou et al., 2008; Barnaba and Gobbi, 2004; Blot et al., 2008; Levin et al., 2005; Pace et al., 2006; Querol et al., 2004; Quinn et al., 2000; Viana et al., 2005, 2007; Zakey et al., 2008). In spite of the importance of SSA effects on the Mediterranean climate and weather, there are no regular sea-salt measurements in the open sea, where sea-salt aerosols are

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mainly produced, and where their concentration and impact on the Mediterranean climate could be significant. In order to partly fill the gap in our understanding of the SSA processes, our model-based daily forecasts of 3-D distribution of SSA over the Mediterranean could be helpful, providing valuable information about space and time distribution of this kind of aerosol.

In order to produce operational SSA forecasts over the open sea in the Mediterranean, the regional DREAM–Salt model with horizontal resolution 0.3° has been running daily at Tel-Aviv University, since February 2006. This study was aimed at evaluating the model performance in the open sea by comparing quantitatively daily model-predicted sea-salt aerosol concentrations with daily SSA measurements taken at the very small Mediterranean island of Lampedusa, located in the Central Mediterranean.

2. Sea-salt model

Numerical simulations of the sea-salt aerosols presented in this study were conducted using a version of the DREAM dust aerosol model (Nickovic et al., 2001; Kishcha et al., 2007, 2008) with embedded SSA component (DREAM–Salt) (Nickovic et al., 2007). The SSA component was embedded into the DREAM model, in order to produce simultaneously operational forecasts of both Saharan desert dust and sea-salt aerosols over the Mediterranean. The DREAM–Salt prediction system has been producing daily forecasts of 3-D distribution of sea-salt aerosol concentration over the Mediterranean model domain 20°W–45°E, 15°N–50°N (http://wind.tau.ac.il/salt-ina/salt.html). The model has 0.3° horizontal resolution and 24 vertical levels. Forecasts are made once every day, starting from the NCEP 12:00 UTC objective analyses and providing forecasts up to 72 h ahead.

The NCEP/Eta regional atmospheric model (Janjic, 1994, and references therein) drives the aerosol. The aerosol emission scheme is based on the viscous sub-layer model (Janjic, 1994), in which energy and mass transfers above the air–sea interface critically depend on turbulent conditions. The Janjic viscous sub-layer scheme is based on the following assumptions: (a) there are two distinct layers: a thin viscous sub-layer immediately above the surface and a turbulent layer above the viscous sub-layer; (b) at the top of the viscous sub-layer all fluxes are continuous. In the viscous sub-layer, it is assumed that (1) vertical transport is determined entirely by the molecular diffusion; and (2) vertical profiles of variables are linear since the viscous diffusivity is assumed to be constant. In the turbulent layer, the vertical transport is entirely defined by turbulent fluxes. Depending on the Reynolds roughness number, $\mathrm{Re} = z_0 \cdot u^*/\nu$, the viscous sub-layer scheme is assumed to operate in three different regimes: smooth and transitional; rough; and rough with sea spray. The parameters z_0, u^*, and ν are roughness height, friction velocity and air viscosity, respectively. When Re exceeds a prescribed critical value Re, the flow ceases to be smooth and enters the rough regime. The rough regime is characterized by combined viscous and turbulent mixing. In the rough regime with sea spray, the mixing becomes fully turbulent. Here, the breaking waves provide a mass exchange, which is more effective than that of the two previous regimes. The values of u^* at which the transitions between the different regimes occur are $u^* = 0.225$ m/s and $u^* = 0.7$ m/s.

Following Janjic (1994), the sea-salt fluxes are defined by the following expressions:

$$F_{C(VSC)} = \nu \cdot \frac{C_{INT} - C_S}{z_{INT}}; \text{ and } F_{C(TRB)} = K_C \cdot \frac{C_{LM} - C_{INT}}{z_{LM} - z_{INT}}$$

in the viscous and turbulent sub-layers, respectively. Here, K_C is the surface layer Monin–Obukhov bulk turbulent mixing coefficient; C_S, C_{INT}, and C_{LM} are sea salt concentrations at the sea surface, at the top of the viscous sub-layer and at the first computational model level, respectively; and z_{INT} and z_{LM} are the heights of the top of the viscous sub-layer and the first computational model layer, respectively. The depth of the viscous sub-layer is calculated as $z_{INT} = \frac{0.35 \cdot M \cdot \sqrt[4]{\mathrm{Re}} \cdot \sqrt[2]{S_c} \cdot \nu}{u_*}$ (Janjic, 1994). Here, S_C is the Schmidt number; the constant M has a value of 30 in the first regime and 10 in the second regime. The viscous sub-layer depth z_{INT} decreases as the turbulence increases. The viscous sub-layer vanishes in the last rough regime with sea spray. From the requirement for continuity of the viscous and turbulent fluxes at the viscous/turbulent interface, it follows that

$$C_{INT} = \frac{C_S + \omega \cdot C_{LM}}{1 + \omega}, \text{ where } \omega = \frac{K_C \cdot z_{INT}}{\nu \cdot (z_{LM} - z_{INT})}$$

where ω plays the role of a weighting factor. Note that ω vanishes with the disappearance of the viscous sublayer in the rough regime with spray. As a consequence, it follows that $C_{INT} = C_S$ at $z = z_0$. In the Janjic scheme, the interface value C_{INT} is considered as the lower boundary condition for the surface layer turbulence scheme in the NCEP/Eta model.

In our approach, the aerosol concentration at the top of the viscous sub-layer is used as the lower boundary condition. In this approach, the effects of the viscous sub-layer model are fully taken into account. The sea-salt emission scheme defines the lower boundary condition using the source function of Erickson et al. (1986):

$$C_S^j = \alpha^j \cdot \exp(0.16 \cdot U_{10} + 1.45) \quad \text{for } U_{10} \le 15 \text{ m/s}, \ j = 1, \text{N}$$

$$C_S^j = \alpha^j \cdot \exp(0.13 \cdot U_{10} + 1.89) \quad \text{for } U_{10} > 15 \text{ m/s}, \ j = 1, \text{N}$$

where C_S^j is sea-salt concentration in μg/m^3; and U_{10} is the 10m wind speed. In our model setup, we used N = 8 particle size bins (1.0–1.5, 1.5–2.5, 2.5–3.5, 3.5–4.5, 4.5–5.5, 5.5–6.5, 6.5–7.5, and 7.5–8.5 μm). α^j is an array describing the mass going into each of the eight particle size bins, which is in percentages 0.5, 1.5, 6.0, 11.0, 16.0, 19.0, 21.0, and 25.0 of the total source, respectively. The dependence of SSA productions and size distributions on relative humidity was not included in the model. Note that the source function of Erickson et al. (1986) was also used by Tegen et al. (1997) and Reader and McFarlane (2003) for sea-salt aerosol modeling.

In addition to the sea-salt emission, DREAM–Salt incorporates parameterizations of all other major phases of atmospheric sea-salt aerosol life such as diffusion, advection, gravitational settling, and wet removal of sea-salt aerosols (Nickovic et al., 2001).