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SEA-SALT AEROSOL FORECASTS COMPARED WITH WAVE AND SEA-SALT MEASUREMENTS IN THE OPEN MEDITERRANEAN SEA

P. Kishcha [(1)], B. Starobinets [(2)], R. Bozzano [(3)], S. Pensieri [(4)], E. Canepa [(5)], S. Nickovic [(6)], A. di Sarra [(7)], R. Udisti [(8)], S. Becagli [(9)], P. Alpert [(10)]

[(1)] *Dept. of Geophysics and Planetary Sciences, Tel-Aviv University, 69978 Tel-Aviv, Israel,* pavel@cyclone.tau.ac.il
[(2)] *Dept. of Geophysics and Planetary Sciences, Tel-Aviv University, 69978 Tel-Aviv, Israel,* starob@post.tau.ac.il
[(3)] *National Research Council (CNR-ISSIA), Via de Marini 6, 16149 Genoa, Italy,* roberto.bozzano@cnr.it
[(4)] *National Research Council (CNR-ISSIA), Via de Marini 6, 16149 Genoa, Italy,* sara.pensieri@ge.issia.cnr.it
[(5)] *National Research Council (CNR-ISMAR), Via de Marini 6, 16149 Genoa, Italy,* elisa.canepa@ge.ismar.cnr.it
[(6)] *World Meteorological Organization, Avenue de la Paix 7bis, 1211 Geneva, Switzerland,* snickovic@wmo.int
[(7)] *UTMEA-TER, ENEA, Via Anguillarese, 301, 00123 S. Maria di Galeria, Italy,* alcide.disarra@enea.it
[(8)] *Dept. of Chemistry, University of Florence, Via della Lastruccia 3, 50019 Florence, Italy,* roberto.udisti@unifi.it
[(9)] *Dept. of Chemistry, University of Florence, Via della Lastruccia 3, 50019 Florence, Italy,* silvia.becagli@unifi.it
[(10)] *Dept. of Geophysics and Planetary Sciences, Tel-Aviv University, 69978 Tel-Aviv, Israel,* pinhas@post.tau.ac.il

ABSTRACT

Sea-salt aerosol (SSA) could influence the Earth's climate acting as cloud condensation nuclei. However, there were no regular measurements of SSA in the open sea. At Tel-Aviv University, the DREAM-Salt prediction system has been producing daily forecasts of 3-D distribution of sea-salt aerosol concentrations over the Mediterranean Sea (http://wind.tau.ac.il/salt-ina/salt.html). In order to evaluate the model performance in the open sea, daily modeled concentrations were compared directly with SSA measurements taken at the tiny island of Lampedusa, in the Central Mediterranean. In order to further test the robustness of the model, the model performance over the open sea was indirectly verified by comparing modeled SSA concentrations with wave height measurements collected by the ODAS Italia 1 buoy and the Llobregat buoy. Model-vs.-measurement comparisons show that the model is capable of producing realistic SSA concentrations and their day-to-day variations over the open sea, in accordance with observed wave height and wind speed.

1. INTRODUCTION

Marine aerosol is mechanically produced by the interaction between wind and waves resulting in the direct injection of sea-salt aerosol (SSA) into the atmosphere through breaking waves during whitecap formation [1].

As soon as SSA is introduced by wind into the boundary layer, SSA can contribute to the intensity of Mediterranean storms by changes in the energy balance, as it does in intensifying tropical hurricanes. Marine aerosol also supplies a significant amount of energy for generating and maintaining tropical hurricanes [2][3]. SSA can exchange its heat and moisture with the air above the sea [4][5]. Recent laboratory and theoretical studies show that, indeed, SSA can redistribute enthalpy between the temperature and humidity fields in the marine boundary layer [3]. SSA contributes significantly to the atmospheric radiation budget, the impact on marine ecosystems, and even to regional air quality. Moreover, acting as efficient cloud condensation nuclei (CCN), sea-salt aerosol affects cloud formation and atmospheric dynamics. Its impact on clouds is accompanied by a release of latent heat [1].

In the Mediterranean Sea, marine aerosol may create conditions for the intensification of Mediterranean storms resulting in changes in strong winds, high sea-waves, and heavy rainfall. This can cause damage to coastal processes, resulting in erosion of the coastal line, landslides, and changes in the marine ecosystems. As sea-salt particles are very efficient CCN, the characterization of their surface production is of major importance for aerosol impacts on clouds [6]. Estimates of the total sea-salt flux from ocean to atmosphere vary over a wide range. The most recent estimates [7] are 2690 Tg a^{-1} in a mode centered at 2 μm diameter, plus 17,100 Tg a^{-1} in a mode centered at 11 μm diameter.

In spite of the importance of SSA variations for the Mediterranean weather and climate, there are no regular measurements in the open sea, where SSA concentrations and their impact on weather and climate are significant under strong winds.

Due to lack of sea-salt aerosol measurements, model-

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based daily forecasts of 3-D distribution of SSA over the Mediterranean could partly fill the gap in our understanding of SSA processes, providing us with valuable information about space and time distribution of these types of aerosols. This study was aimed at evaluating daily forecasts of 3-D distribution of sea-salt aerosol concentrations over the open Mediterranean Sea using available measurements of SSA and wave height.

2. METHODOLOGY

In order to analyze space-time distribution of SSA aerosols over the Mediterranean Sea, operational SSA forecasts have been produced at Tel-Aviv University during the six-year period, from February 2006 until the present, using the DREAM dust aerosol model [8][9] with embedded sea-salt-aerosols component (DREAM-Salt) [10][11] (http://wind.tau.ac.il/salt-ina/salt.html). The DREAM-Salt model produces daily forecasts of 3-D distribution of sea-salt aerosol concentrations over the Mediterranean model domain 20^{o}W – 45^{o}E, 15^{o}N – 50^{o}N (Figure 1).

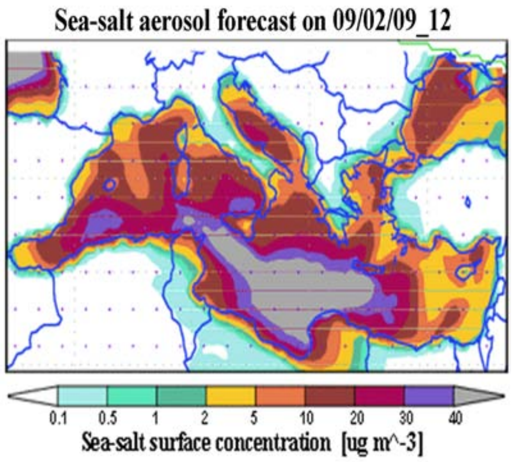

Figure 1. Example of sea-salt aerosol *forecast on February 9, 2009 12:00Z.*

The model has 0.3 degrees horizontal resolution, 24 vertical levels, and eight particle size bins ranging from 1 - 8 µm. Forecasts are made once every day, starting from the 12:00 UTC objective analyses and providing forecasts up to 72 hours ahead. The NCEP/Eta regional atmospheric model drives the aerosol. The sea-salt emission scheme defines the lower boundary condition using the source function of Erickson [12]. DREAM-Salt incorporates parameterizations of all major processes of atmospheric sea-salt aerosol life such as: generation, transport, gravitational settling, and wet removal of sea-salt aerosols.
In order to evaluate the model performance over the open sea, numerical simulations of sea-salt aerosol were compared directly with sea-salt ground-based measurements, taken at the tiny Mediterranean island of Lampedusa, and also indirectly with the data collected by the W1-M3A open-ocean observing system, moored in the center on the Ligurian Sea. W1-M3A consists of the ODAS Italia 1 buoy and a close-by subsurface mooring. In addition, a comparison between model SSA forecasts and sea-wave height data, acquired by the Llobregat buoy, located in the vicinity of Barcelona, has been performed (Figure 2)

Figure 2. Map of the measurement sites: Lampedusa island and ODAS Italia 1 buoy in the Ligurian Sea, and Llobregat buoy.

3. RESULTS AND DISCUSSION

3.1 Direct comparison between sea-salt-aerosol forecasts and in-situ data in Lampedusa

Lampedusa is a tiny island in the central Mediterranean which measures several kilometers across, far from the continental areas and large islands. Lampedusa is characterized by clean air without local industrial pollution. One can assume that sea-salt aerosol measurement conditions on this tiny island are similar to those in the open sea. Sea-salt aerosol concentrations were collected by means of chemical composition determination of PM10 aerosol measurements. Considerable efforts have been made in order to collect and analyze sea-salt aerosol measurements on a daily basis, during the two year period, January 2007 – December 2008. A comparison between model data and measurements has been performed for a total of 380 days. The comparison showed a relatively high correlation of 0.7, a rather low mean bias of -0.5 µg/m^3, and a mean normalized bias less than 20% [11].
Figure 3 shows examples of the comparison between modeled and measured daily sea-salt aerosol concentrations in different months at the Lampedusa site. The comparison evidenced a good agreement between model data and in-situ measurements.
As estimated, for different months during the two-year period under consideration, the majority of correlation coefficients between modeled SSA concentrations and measurements were mainly above 0.6, which demonstrates the ability of the model to reproduce measured SSA concentrations. The obtained correlation coefficients were found to be statistically significant at the 0.05 level [11].
Our analysis for different months showed that the mean

bias could be both negative and positive. This indicates that the model could sometimes underestimate or overestimate measurements. The averaged simulated aerosol concentrations ranged mainly within the same intervals as the measurements did [11]. The relatively high standard deviation indicates strong variability of sea-salt aerosol concentrations due to the strong variability of wind speed.

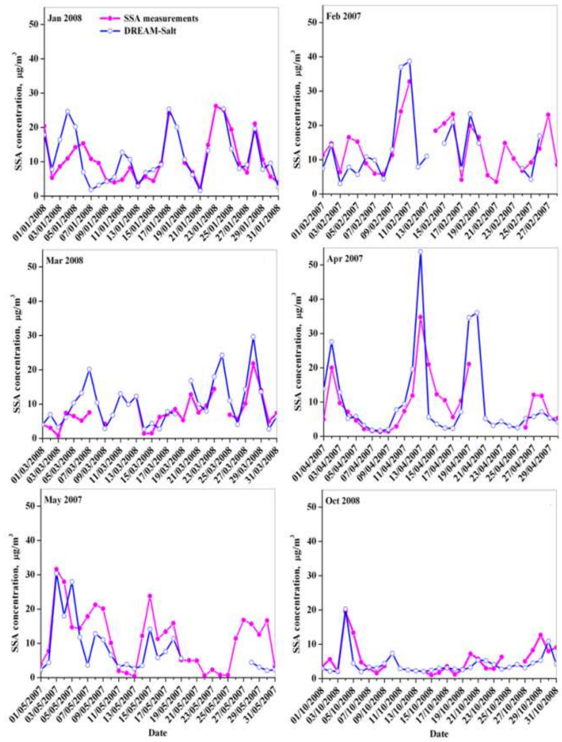

Figure. 3. Examples of the comparison between modeled sea-salt concentrations and measurements in the Lampedusa island.

Although there is general agreement between modeled and measured SSA concentrations, for some short periods the discrepancies were quite large. In order to understand the cause of the discrepancies between modeled and measured SSA concentrations, we analyzed the relationship between measured SSA concentrations and observed wind speed at the monitoring site. We found that, during the aforementioned periods with discrepancies, there was no correlation between observed winds and SSA measurements. Our forecast model uses wind speed as a key parameter for sea-salt aerosol production. Therefore, the model cannot predict SSA concentrations when there is no correspondence between measured SSA concentrations and wind speed. A possible reason for the discrepancies between measured SSA concentrations and wind speed could be the fact that the measured conditions in Lampedusa only approximately correspond to those in the open sea

2.2 Indirect comparison between sea-salt-aerosol forecasts and in-situ wind/wave data collected by the ODAS Italia 1 buoy.

In order to further test the robustness of the model, the model performance over the open sea was indirectly verified by comparing modeled SSA concentrations with observed wave height, given that the main factors for SSA production in the open sea are sea waves and associated winds. For the comparison, wind and wave height data collected by the W1-M3A off-shore oceanographic observing system were used. The W1-M3A observing system is moored in the Ligurian Sea, in the North-Western Mediterranean basin, at approximately 75 km far from the coast on a deep-sea bed (1200m). The observatory consists of the ODAS Italia 1 surface spar buoy and a subsurface mooring close to the main platform. Since the buoy is positioned off-shore, it is exposed to winds and waves without any shield by the surrounding orography [13]. The buoy collects measurements of deferent meteorological and oceanographic parameters, including wave height and sea-surface wind [14].

In this study, modeled surface SSA concentrations were compared with wind/ wave height buoy measurements on a daily basis for the periods July 2006 – August 2007, August 2008 – December 2008, and March 2009 – September 2009. We found that, for all 540 days used in the analysis, the model performance was characterized by a relatively high correlation of 0.78 between modeled sea-salt-aerosol concentrations and wave height. This indicates that, over the open sea, the DREAM-Salt model produces day-to-day time variations of SSA concentrations in line with observed day-to-day variations of wave height (Figure 4).

In order to investigate if waves at the ODAS site were effectively wind driven, a comparison between wave height estimates and wind speed observations has been carried out (Figure5). It was found that the correlation between observed wind speed and wave height was equal to 0.82, indicating that most sea-waves are created by observed strong winds.

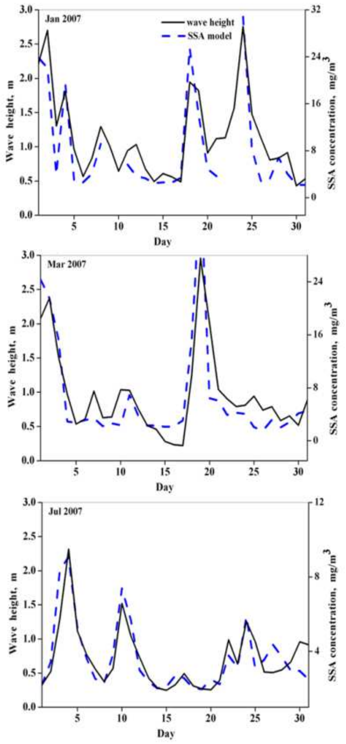

Figure 4. Examples of the comparison between modeled sea-salt concentrations and wave height for January, March and July 2007.

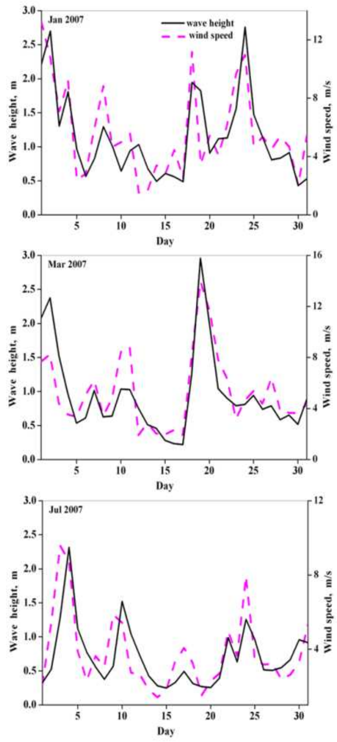

Figure 5. Examples of the comparison between wave height estimates and wind speed observations for January, March and July 2007.

2.3 Comparisons between sea-salt-aerosol forecasts and in-situ wave data provided by the Llobregat buoy

In order to further evaluate the model performance, wave-height measurements, collected by the Llobregat buoy, as well as SSA measurements, taken at the coastal site in Barcelona, have been compared with model outputs.

The Llobregat platform is a wave-meter buoy, moored in front of the Barcelona coast, providing wave height data. Figure 6 represents a comparison between model outputs and observations in July 2006 and July 2007. One can see that wave height measured in July 2007 was approximately twice than wave height collected in July 2006. This is despite the fact that wave heights in both July 2006 and July 2007 were observed under approximately the same winds (Figure 6). One can suggest that high waves in July 2007 were not created by local winds, but, probably, they were originated from remote storms, far from the Barcelona coast, and successively transferred across larger distances.

Note that modeled and measured wind speed and wind direction showed a good agreement for both July 2006 and July 2007 (Figure 6). Modeled SSA concentrations, which are based only on sea-winds and do not take into account actual wave heights, underestimated SSA measurements.

Furthermore, in November – December 2006, strong winds, blowing along the Barcelona coast, produced high SSA concentrations over the sea. Low measured concentrations over the land are evidence that sea-salt aerosols, produced over the sea, could not be transported inland, due to the absence of sea-breezes in the winter months (Figure 7).

4. CONCLUSIONS

Sea-salt aerosol is mainly produced in the open sea and its concentration and impact on the Mediterranean climate and weather could be significant under strong winds. The current study deals with sea-salt aerosol forecasts over the Mediterranean Sea produced by the regional prediction system DREAM–Salt.

The model performance has been evaluated by comparing model outputs directly with in-situ sea-salt aerosol measurements, taken at the island of Lampedusa (Central Mediterranean), and indirectly with wave height measurements, taken at the two offshore platforms: the first one in the Ligurian Sea and the second one in front of Barcelona.

The obtained results demonstrate that, over the open sea, the model is able to reproduce realistic day-to-day time variations of SSA concentrations, in line with observed day-to-day changes of wind speed and wave height.

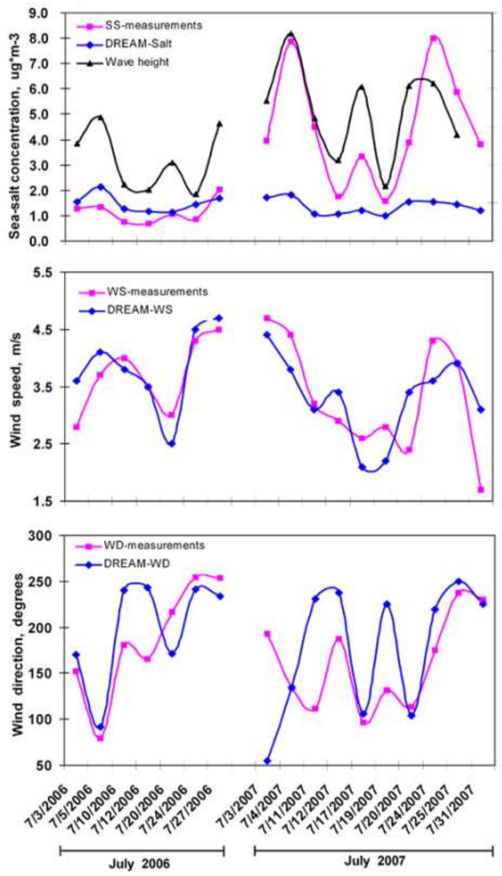

Figure 6. Comparison between model outputs and in-situ measurements near Barcelona in July 2006 and July 2007: (top) sea-salt concentration; (middle) wind speed; (bottom) wind direction.

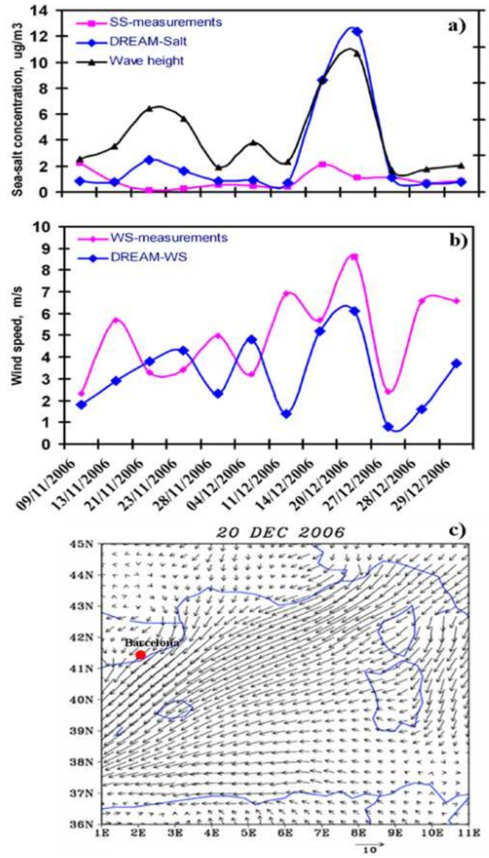

Figure 7. (top) Comparison between model outputs and in-situ measurements near Barcelona in November and December 2006; (bottom) wind field for 20th of December 2006.

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