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Forecasting Dust Storms using CARMA-Dust Model and MM5 Weather Data

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Introduction

Dust storms throughout Saharan Africa, Middle East and Asia are estimated to place more than 200 to 5000 million tons of mineral dust into the earth's atmosphere each year (Tegen and Fung 1994). Dust storms directly affect visibility and impact daily commercial and military operations in dust prone regions. The United States Air Force Weather Agency (AFWA) has supported the development of a dust forecast model with a 72 hour forecast capability. The dust model called CARMA (Community Aerosol Research Model from Ames) was developed by Professor Owen Toon and Dr. Pete Colarco at the University of Colorado, Boulder. The CARMA model has been modified by Johns Hopkins Applied Physics Laboratory to use daily Mesoscale Model 5th generation (MM5) weather forecasts run by the United States Air Force Weather Agency.

The latest version of the CARMA MM5 dust model can make 72 hour forecasts of surface and airborne dust concentrations in 3 different mesoscale theaters covering Saharan Africa and the Middle East, Southwest Asia and China. A new global dust source database developed by Dr. Paul Ginoux is used in the CARMA model. The dust source model is based on topographical features associated with dust sources and has been further supplemented with TOMS and AVHRR satellite data.

The forecast ability of the dust model was evaluated over a 3 month period for two of the AFWA MM5 forecast theaters; African Sahara and Middle East/Southwest Asia. The Middle East has been grouped with Southwest Asia for this evaluation. The model forecasts were compared with DMSP satellite imagery and ground observations. Each theater was broken into sub-regions for detailed evaluation of the short (6-12 hour), mid (30-36 hour) and long term (54-60 hour) forecast ability of the model. Results of the study show the dust model has good skill in forecasting dust conditions for short and medium range forecast periods.

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Forecasting Dust with CARMA

The CARMA model was written as a fully scalable aerosol model to study a variety of atmospheric processes, such as cloud formation, smoke and dust aerosols (Toon et al. 1988). The version of CARMA used for dust aerosol forecasting incorporates a global dust source database developed by Paul Ginoux at NASA Goddard Flight Center. The database uses dust sources associated with topographic depressions. The database was also developed using satellite data from the Total Ozone Mapping Spectrometer (TOMS) dust Aerosol Index (AI) (Ginoux et al. 2001). The CARMA model uses 10 particle size bins covering from 0.5 µm to 10.0 µm, which will have airborne residence times greater than several hours (Tegen and Fung, 1994).

The CARMA dust model uses 22 vertical sigma pressure levels and a 90 km horizontal latitude, longitude grid spacing. The model is run with lower resolution than the MM5 weather model, which uses 41 sigma levels and 45 km horizontal resolution. This grid scheme was chosen to have approximately the same spacing as the 1^{o} x 1^{o} (111 km) Ginoux global database model to save run time for daily forecasting.

The dust forecast is first initialized by running the model using a 2 day (48 hour) “spin-up”. The spin-up uses the first 24 hours of MM5 forecasts generated for each of the spin-up days. The data from the spin-up portion of the model is then used as the initial dust concentration condition at the beginning of the 72 hour forecast. The dust forecast then uses the MM5 72 hour forecast data for winds, pressure, temperature, rain, etc., for the concentration predictions. The dust model outputs a set of dust concentration maps for each 3 hour time period during the 72 hour forecast.

The dust source model first calculates the surface threshold wind velocity at each grid location for each particle bin size. Where there is measurable accumulated precipitation in a 24 hour period, the threshold wind velocity is set so that no dust flux is generated at the location. The surface dust flux is then calculated for each particle size bin and the MM5 forecast 10 meter wind speed using:

$$F_{ijr} = C*S_{ijr} * (w10m_{ij} - u_{t(ijr)})*w10m_{ij}^{3}.$$

Where C is a model constant, F_{ijr} is the surface dust flux in gm/m^{2}s, S_{ijr} is the Ginoux source strength for the particle class size, *w10m* is the wind speed at 10 meters, and $u_{t(ijr)}$ is the threshold wind velocity for each grid location and particle bin size (Ginoux et al. 2001, Chin et al. 2001).

The dust model forecasts are displayed as a set of color images showing total dust concentration at user selected altitudes, vertical profiles and total dust loading. The images are made for each 3 hour interval in the 72 hour forecast, an example is shown in figures 1 and 2. An example of the African and Middle Eastern mesoscale theater is shown in Figure 1.

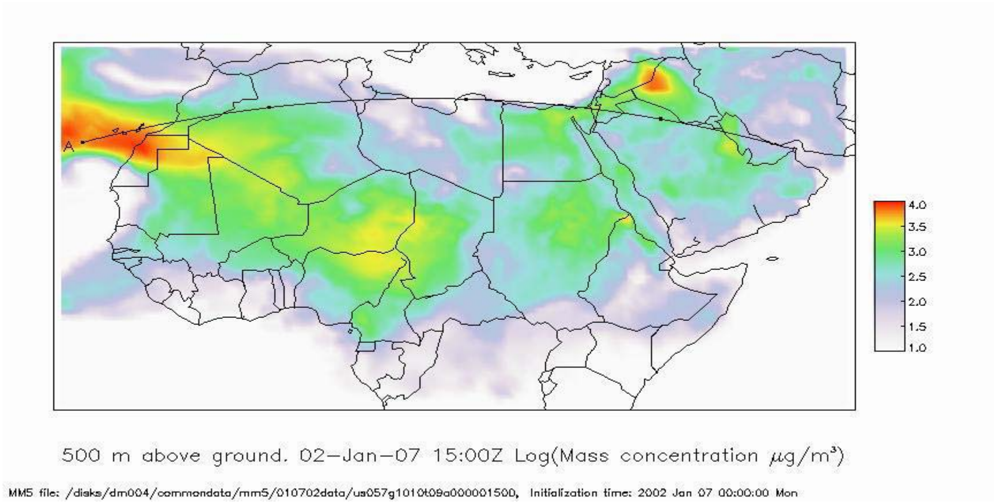

Figure 1 *Example of CARMA model output showing color map of dust concentration (log scale) over Saharan Africa and Middle East for the dust storm during January 7, 2002.*

Model Forecast Results

The dust model was installed and run daily at AFWA beginning February 2002. A qualitative evaluation of the model's dust storm forecast capability was made during February through April 2002. The evaluation covered the African Sahara and Middle East/Southwest Asian theaters. The study compared dust storms located using Defense Meteorological Satellite Program imagery (DMSP) data, and ground reported observations when available. Wherever model surface forecast concentrations exceeded 1800 $\mu gm/m^3$, dust storm or "dusty" conditions were considered to be present at the location. The model was scored using meteorological "skill scores" over short (6-12 hr), medium (30-36hr) and long (54-60hr) range forecasts. The skill scores used were Probability of Detection (POD), False Alarm Rate (FAR) and Critical Success Index (CSI). Each theater was divided in to sub regions for the study. The African Sahara was divided into 7 sub regions and the Middle East/Southwest Asian theater into 11 sub regions.

The average POD and FAR percentages for the two theaters are given in Table1. The lowest CSI scores occurred in the Yemen and Oman sub regions where the POD's were only 19, with a FAR of 0. This region of the Empty Quarter is a great sand desert, but is a relatively weak dust source in the Ginoux database. This desert region produces surface level sandstorms. Sandstorms typically have a lower TOMS AI, which is more sensitive to higher altitude dust concentrations.

MM5 theater: POD (FAR)	*Short (6-12 hr)*	*Medium (30-36 hr)*	*Long (54-60 hr)*
Sahara Africa	68 (16)	67 (15)	59 (18)
Middle East/Southwest Asia	61 (10)	62 (9)	52 (7)

Table 1: *CARMA model average Probability of Detection and False alarm rate for short, medium and long range MM5 forecasts during model evaluation (Jan.-April 2002).*

Results of the AFWA study show the dust model has good skill in forecasting dust conditions over short (12 hour) and medium (36 hour) forecast periods. In the Africa Sahara theater, the average POD for a 30-36 hour forecast was 67 percent with a FAR of only 15 percent. Long range forecasts of 54-60 hours had POD's of 59 percent with FAR's increasing to 18 percent, indicating decreasing forecast accuracy of the weather model by 60 hours

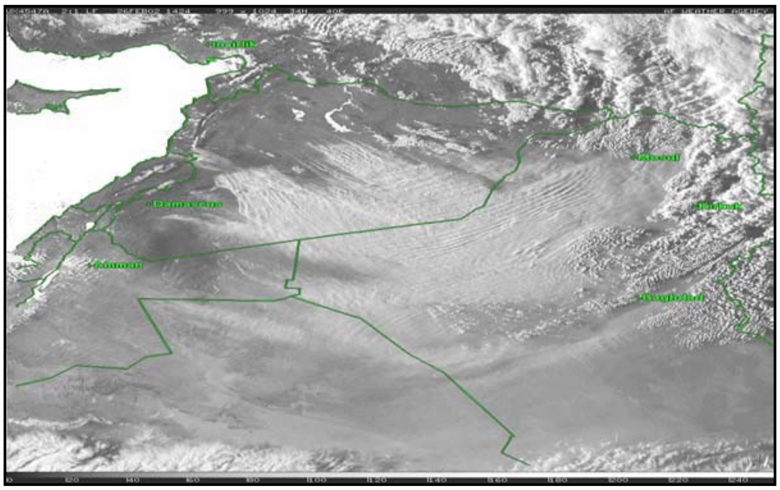

Figure 2: *Example of DMSP satellite imagery used to locate dust storms.*

Conclusion

The CARMA dust model has been successfully adapted to use MM5 weather forecast data for the operational prediction of dust storms. The global dust source database developed by Ginoux et al. has been especially accurate for forecasting in Saharan Africa. The next phase of the dust project will integrate the Continental United States and East Asia and China as operational dust forecast theaters. More studies are underway to evaluate model predicted dust concentrations with data from the Puerto Rican Dust Experiment (2000) and aerosol measurements at White Sands New Mexico.

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