PHAiRS – A Public Health Decision Support System: Initial Results

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Abstract - Respiratory diseases caused or aggravated by dust or smoke (PM_{10} and $PM_{2.5}$) are of concern to health officials in arid and semiarid regions where windblown dust constitutes a serious threat to public health. This paper presents early results of work on *Public Health Applications in Remote Sensing* (PHAiRS), a project that seeks to integrate NASA remote-sensing products into an existing public health decision-support system. With the goal of forecasting dust events, the project relies on outputs from the Dust Regional Atmospheric Model (DREAM). To characterize and establish baseline model behavior prior to the anticipated substitution of specified model parameters with NASA Earth Science data, a point-by-point comparison between *in-situ* observations and baseline DREAM model output is performed across reporting stations from north-central New Mexico to the Texas gulf coast for the two-day dust event of December 15-16, 2003.

1. INTRODUCTION

Respiratory diseases caused or aggravated by dust or smoke (PM 10 and PM 2.5) constitute a serious worldwide health risk, but are of particular concern to public health officials in arid and semiarid regions. This paper presents early results from work on *Public Health Applications in Remote Sensing* (PHAiRS), a project funded by NASA's Earth Science Application Division. PHAiRS aims to integrate NASA Earth Science satellite sensor data into RSVP (Rapid Syndrome Validation Project), a public health decision-support system, developed at Sandia National Laboratories, that will allow epidemiologists, public health officials, and other interested parties to forecast both epidemiologically-significant dust events, as well as potential increases in the occurrence of associated respiratory diseases. It is expected that the integration of NASA Earth Science data into dust modeling systems will enhance the temporal and spatial resolution of dust event forecasts.

To accurately forecast such dust events, the project relies on outputs from the Dust Regional Atmospheric Model (DREAM). This Eulerian model depends on input from two main sets of data. The first set is used in the dust concentration module, and consists of three static surface parameters: topography and vegetation cover at 30-second resolution (provided by USGS;) and soil types converted into texture classes at 2-minute resolution provided by the UN/FAO. The fairly course spatial resolution that characterizes these data, as well as the static representations of vegetation classes, obviously limits accurate modeling of temporal and spatial variation in friction velocity, and hence dust source potential for any specific locale on the landscape. The second set of data, used by the atmospheric modeling module of DREAM, includes a variety of outputs from the European Center for Medium Range Forecasts (ECMWF) deterministic model. These include, but are not limited to, humidity, atmospheric pressure, and wind patterns.

To assess the validity of DREAM outputs in forecasting epidemiologically-significant, atmospheric dust concentrations, and to baseline future improvements in said forecasting through the substitution of satellite sensor data as model inputs, the data cited above have been used to model a severe dust event that arose abruptly in Eastern New Mexico and West Texas. In this paper, a point-by-point comparison between *in-situ* observations and baseline model output is performed across reporting stations from Santa Fe in north-central New Mexico to South Padre Island on the Texas gulf coast for the two-day dust event of December 15-16, 2003. Three comparisons were made: (a) magnitude (highest 1-hour mean $PM_{2.5}$ μg/m^3); (b) peak hour (the UTC time that the 1-hour peak $PM_{2.5}$ occurred); and (c) duration (the length of exposure to $PM_{2.5} \geq 65$μg/m^3).

2. METHODS

2.1 Dust Regional Atmospheric Model (DREAM)

The DREAM model is a regional dust model developed over the last 15 years at the Euro-Mediterranean Centre on Insular Coastal Dynamics (IcoD), the University of Malta (Nickovic et al., 2001; Westphal et al., 1987; Westphal et al., 1998). As a plugable component of the NCEP/Eta model, DREAM comprises two modules. The first, an atmospheric modeling system, is the SKIRON forecasting system, which is itself based on the 1997 version of the NCEP/Eta model. As such, it is able to model other standard climatic phenomena, including precipitation, temperature, and wind. While The NCEP/Eta model has been used to drive the dust model in most applications, the current research project employed outputs from the European Center for Medium Range Forecasts (ECMWF). The DREAM model uses gridded analysis or forecasting fields from these various sources (ECMWF and NCEP/Eta) for initial and boundary conditions. For generating initial and boundary conditions in this research, the DREAM model ingests multi-level (15 vertical levels ranging from 10 to 1000 hPa) meteorological data from ECMWF. These include Specific Humidity (Q), Temperature (T), U-Velocity (U), and V-Velocity (V). Actual runs of the DREAM model in this research ingested boundary conditions at 6-hour intervals.

The second component of the DREAM system is a dust concentration module. The module simulates/predicts all major phases of the atmospheric dust cycle, including dust production, turbulent mixing, long-range transport and deposition. The dust production mechanism is based on viscous/turbulent mixing (Shao 1993; Janjic 1994), shear-free convection diffusion, and soil moisture (Fecan et al, 1998). The modeled dust particles are divided into four dust categories with representative radii of 0.73, 6.1, 18, and 38 μm, to more accurately simulate size-dependent processes. Most of the large particles will not travel long distances before they deposit to the ground. For modeling sources of dust on the landscape, a gridded array of land surface conditions is created using inputs from three static sources of data. These include, the United States Geological Survey (USGS) 30-second resolution terrain height data, the Olson World Ecosystem 10-minute resolution vegetation data, and FAO/UNESCO 2-minute soil texture data with 134 categories.

The DREAM system is easily configurable and transferable to any place on Earth, can cover domains on almost any size, and its horizontal resolution can vary from about 100 km up to approximately 4 km. In this application, the modeling domain covers the Southwest United States, focusing on an area in New Mexico and Texas. This area was selected as it provides atmospheric data where an historic dust storm event was observed. The modeling domain center is at (109°W, 35°N). The horizontal grid spacing is 1/3 degree, thus creating 41×65 horizontal grid points. Twenty-four vertical layers are generated that model conditions from 0 m up to about 15,000 m above sea level. The modeling period is 00:00 Z December 08 to 23:00 Z December 18, 2003, with the dust episode occurring on 15 and 16 December.

2.2 *In-Situ* Measurements

The primary goal of the current research is to develop a baseline of model performance against which improvements resulting from substitution of NASA-derived satellite data inputs to the DREAM model can be compared. To do this, DREAM model meteorological output fields are verified against *in-situ* measurements. In particular, surface and upper-air meteorological data, weather radar observations, and satellite images are used. Meteorological data are derived from 95 surface synoptic sites, 663 surface METAR (Meteorological Terminal Aviation Routine Weather Report) sites, and 77 upper-air sites. Second, DREAM model dust concentration fields are verified against surface *in-situ* particulate matter data measured at 40 $PM_{2.5}$ Air Quality System (AQS) sites in New Mexico and Texas. Graphical model verification measures include pattern comparison, surface time series and vertical profiles comparison.

3. RESULTS

3.1 Meteorological Fields

In general, meteorological fields modeled by DREAM, both at the surface and at the 500 hPa level, are in good agreement with *in-situ* observations. For example, Figure 1 shows DREAM output for geopotential height and temperature at 500 hPa at 12:00 Z Dec 16, as well as independent plots of these two variables from the Plymouth State Weather Center.

For wind speed, temperature, wind direction, and specific humidity, model outputs are extremely successful at modeling their *in-situ* measurements at altitudes below about 15,000 meters. In some cases, such as for wind speed, the model can be seen to closely track fine-grained changes in trends through the vertical profile. Figure 2 presents plots of DREAM model outputs of the vertical distribution of data points for wind speed at 12:00 Z on December 16. All values are recorded from a radiosonde over Tucson International Airport (32.12° N; -110.96° W).

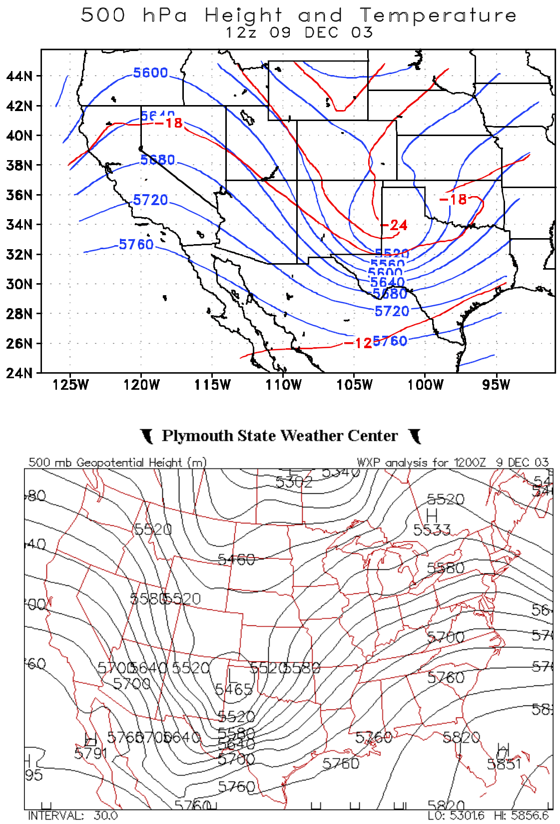

Figure 1. DREAM Model output and Plymouth State Weather Center plots for geopotential height and temperature at 500 hPa, 12:00 Z, Dec 16.

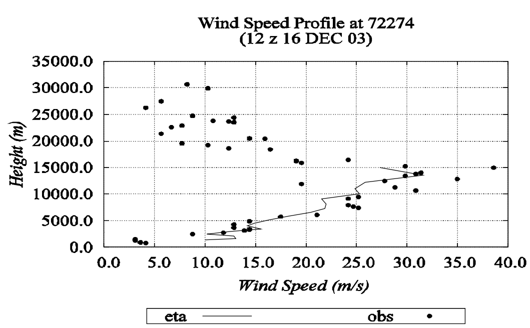

Figure 2. DREAM Model meteorological vertical profile for wind speed at 12:00 Z, Dec 16 (measured above Tucson International Airport).

In Figure 3, a time series plot for surface level meteorological data compare DREAM model outputs for temperature to data obtained at National Weather Service meteorological stations at Tucson (KTUS). As can be seen, variation of temperature is well-modeled, but underestimated at times by the DREAM model. In general, while DREAM model outputs may often predict general trends, they often seriously underestimate values recorded at meteorological stations.

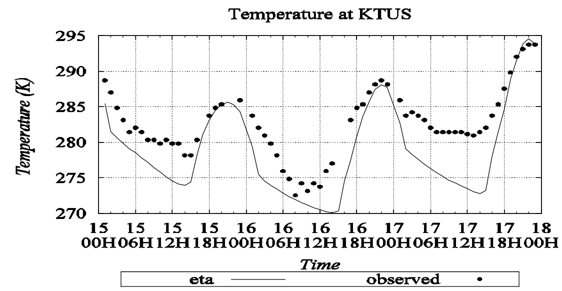

Figure 3. DREAM Model surface level time series for temperature between 00:00 Z Dec 16 and 00:00 Z Dec 19 (measured above Tucson International Airport).

In summary, the time series plots and site-wise comparisons of modeled and observed vertical profiles for such parameters as wind speed, wind direction, and temperature show they match well with each other.

3.2 Dust Concentration

During the 15-16 December, 2003 dust event, 40 air-monitoring stations in Texas and New Mexico continuously measured the fine fraction ($PM_{2.5}$) of aerosol dust. Three point-by-point comparisons were made between *in-situ* observations and baseline model output: (a) magnitude (highest 1-hour mean $PM_{2.5}$ μg/m^3); (b) peak hour (the UTC time that the 1-hour peak $PM_{2.5}$ occurred); and (c) duration (the length of exposure to $PM_{2.5} \geq 65$μg/m^3).

First addressing highest 1-hour means, as seen in Figure 4, it appears the model overestimated the magnitude of the highest 1-hour average $PM_{2.5}$ during the early stages of the episode, and underestimated the concentrations during the later stages, frequently by more than an order of magnitude. Scatter plots of maximum 1-hour values indicate no correlation ($r^2 = 0.04$, n=11 sites) on the first day and poor correlation ($r^2 = 0.42$, n=29 sites) on the second day. Modeled values had a larger range (1-1000μg/m^3) than *in-situ* values (14-168μg/m^3). As such, the model appears to underestimate background levels.

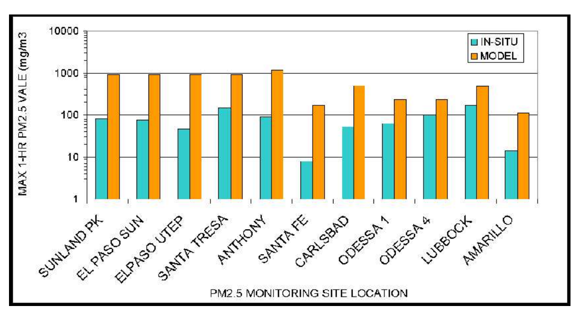

Figure 4. Magnitude of the highest 1-hour $PM_{2.5}$ for 11 stations in eastern New Mexico and West Texas.

Next, considering peak hour, the correlation coefficient for all data from 40 sites for the UTC Peak hour was $r^2 = 0.60$ (Figure 5), indicating that the model performed only moderately well forecasting the time of heaviest dust concentration. However, there is solid evidence that the model performed very well ($r^2 = 0.96$) for stations in central and east Texas, as the storm progressed southward toward the Gulf of Mexico.

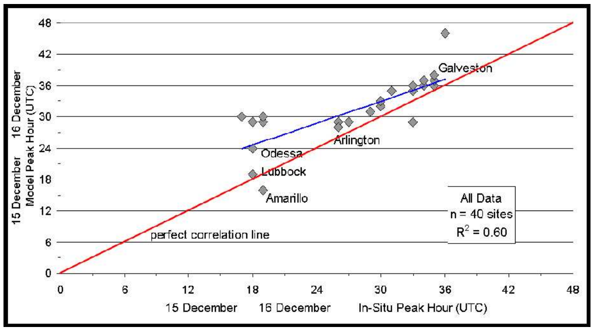

Figure 5. Correlation of occurrence of UTC peak hour.

Finally, the duration of peak $PM_{2.5}$ concentrations at all reporting stations lasted for only a few hours, and only one station exceeded the National Ambient Air Quality Standard of 65μg/m^3 (Lubbock, 76.7μg/m^3). As such, the model tends to over-estimate the duration at most sites.

4. CONCLUSIONS

While DREAM performs well with predicting meteorological patterns, it has mixed performance predicting the onset of dust events. It is anticipated that better land surface geographical data such as vegetation and soil texture will be used in the future to improve representation of the land surface features in the Southwest U.S., and eventually to improve the dust event modeling in this region. An initial list of remotely-sensed products that are being prepared for assimilation into the DREAM model include MODIS (MOD 12, 13, and 15) as possible replacements for land cover, coupled with finer resolution on soil texture derived from the U.S. Natural Resources Conservation Service (NRCS) STATSGO.

The team also hopes to improve model performance by deriving a better estimate of aerodynamic surface roughness length (z0) through remote sensing. The team has tried to derive this value from Shuttle Radar Topography Mission (SRTM) data and from digital elevation data, but are not yet satisfied with either result. Understanding and measuring this parameter is crucial for understanding surface friction and the ability of wind to lift dust from a surface.

5. REFERENCES

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6. ACKNOWLEDGMENTS

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